The PFPNet Roadmap Document

A Guide to Developing a PFP Scheme for a Hydrocarbon Facility

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Executive Summary

This Guidance Document is designed to lead the reader through the process of developing a Passive Fire Protection (PFP) (also often referred to as “fireproofing”) scheme, starting from the actual fire risk and associated scenarios up to the point where a PFP scheme or PFP system is specified. The document aims to guide readers in their choice of selecting appropriate methodologies for developing their scheme for their specific project.

Identification of credible release of hydrocarbons in an accident event leads to many risks to the survivability of structural steel and equipment. Some of these risks are not related to the fire case but may impact the integrity and insulation effectiveness of PFP when fire occurs. This document only deals in detail with mitigating the effects of fire where the integrity of the PFP is equivalent to that used in third party fire tests and certification.

It is intended that Other PFP Net documents will deal with guidance in relation to environmental and mechanical stresses, cryogenic exposure, blast considerations and use of other fire mitigation in combination with PFP.

This document may be applied to PFP schemes for onshore and offshore facilities, and for new construction or brownfield sites. Schemes describing the application of PFP to structure, refuges, other buildings, piping items, vessels, key equipment, and associated structural supports are also discussed.

This document recognizes that there is already much detailed technical information already available on PFP schemes, along with codes and standards, which cover many of the key elements within the overall process, and which represent good or common practice. It is not the intention of this document to develop and present new technical methods, but to reference existing methods and standards which are good practice, place them in a structured decision-making process, describe to the user the benefits or otherwise of different approaches, and where necessary clarify language.

A check list is provided towards the end of this document to help the reader address appropriate aspects for specification development. Key learning points are also included to ensure that all the necessary information is clearly understood. The ultimate objective is to ensure PFP schemes are appropriately selected for specific project needs meeting client, certification body or regulatory requirements through development of a robust specification.

This guidance document is known by its shortened form as “The PFP Roadmap Document”.

About PFPNet

PFPNet is an independent, not-for-profit organization funded by member subscriptions and dedicated to raising standards in the use of PFP in industries where hydrocarbon-fueled fires pose a threat to the safety of critical structures and equipment. It aims to achieve this through a focus on education, training, capturing and retaining existing knowledge, researching key topics, clarifying points of confusion and disseminating this to the membership, and to the industry at large – all with the aim of improving quality.

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Definitions and Abbreviations

Definitions and Abbreviations	
Terminology	Role
AFP	Active Fire Protection. Fire protection methods using water and/or foam and including sprinklers, deluge systems. fire water monitors, firefighting, etc.
AIChE	American Institute of Chemical Engineers
ALARP	As Low As Reasonably Practicable
API	American Petroleum Institute
Approval	In the offshore oil and gas industry ‘approval’ generally refers to ‘Type Approval’ (from e.g. ABS, DNVGL, Lloyd’s Register, etc.). The TAC guide generally considers certification and approval to be similar and the same in some cases. Other terms are also used. For example, when a product has been accepted by UL, it is said to have ‘UL listing’. Essentially such products are ‘UL approved’ or ‘certified by UL’.
ASTM	American Society for Testing and Materials
ATS	Allowable Tensile Strength
Blowdown	Also known as Emergency Depressurization (EDP). Safety function whereby pressure and inventory in an isolated process segment are reduced as quickly as possible in an emergency event, to reduce the opportunity for escalation.
BS	British Standards
CCPS	Center for Chemical Process Safety
Certification	The written assurance by a third-party of the conformity of a product to specified requirements. This would be issued by a competent body. An approval can also be a third-party endorsement that a particular product meets specified requirements – a certificate may or may not be issued.
CFD	Computational Fluid Dynamics
CMPT	Center for Marine and Petroleum Technology
Consequence	The undesirable result of the occurrence of a hazardous event such as a fire or explosion. For example, people killed due to a fire.
DAL	Design Accident Load.

Definitions and Abbreviations	
Terminology	Role
Design Assessment or Design Verification	Different names for the same thing. They are generally issued by one of the Class Organizations when Type Approval cannot be issued. They constitute an assessment of available test data applicable to a specific project scenario followed by the issuance of a document that details the scope and limitations of the design. They are a form of third-party approval or assurance.
EER	Escape, Evacuation and Rescue
EDP	See Blowdown
ESD(V)	Emergency Shut Down (Valve)
FABIG	Fire and Blast Information Group
F&E	Fire & Explosion (Guidance document from O&G UK)
FEA	Finite Element Analysis
Fire Area	Similar to fire zone
Fireproofing	The term 'fireproofing' is widely used where it generally refers to fire protection that is applied to insulate steelwork. Fireproofing is a misnomer as no PFP system is 'fire proof' rather they provide protection by delaying the adverse thermal effects of fire on protected items. In this guide the term 'fireproofing' is avoided wherever possible and the acronym PFP used instead to include the wide range of Passive Fire Protection materials and systems that are available.
Fire Scenario	The fire event describing the fire type (pool fire, jet fire, etc.), the fire duration and for some scenarios the background and maximum heat flux values anticipated from the design fire
FPZ (or FZ)	Fire Protection Zone (FPZ), or just Fire Zone (FZ). An area on a facility where a fire is an anticipated possible fire event may occur. It covers the source of the potential fire and a defined area, vertically and horizontally where equipment and structures may be affected by the fire.
FRA	Fire Risk Analysis
Hazard	UK HSE defines Major Accident Hazards as: "An intrinsic property of a dangerous substance or physical situation, with a potential for creating damage to human health or the environment
HAZID	Hazard Identification
The UK HSE	UK Health and Safety Executive
ISO	International Standards Organization
LPG	Liquefied Petroleum Gas

Definitions and Abbreviations	
Terminology	Role
LTB	Lateral Torsional Buckling
LQ	Living Quarters
MCE	Maximum Credible Event. The worst-case fire event that can potentially occur considering the hazards, quantities, leak frequencies, ignition probabilities, etc., along with the control measures in place such as isolation, EDP, etc. Similar approach can be used to define the MCE explosion event.
O&G UK	Oil & Gas UK
Performance Standard	The standard of performance that is required from a safety critical item, be that a structure, barrier or equipment item.
PFP	Passive Fire Protection (PFP) is any passive protection material or system that is used to protect specific items of structure, equipment or control systems against the effects of fire.
QRA	Quantitative Risk Analysis
Risk	The combination of the hazard and the frequency
SECE	Safety and Environmentally Critical Element (SECE) is a term used in the UK and Norwegian offshore industries as an effective way to identify those items that are critical to the safety of people and the environment. The definition of SECE given in Energy Institute (EI) document, "Guidelines for the management of safety critical elements", is: "Any part of the installation… whose failure will either cause or contribute to a major accident, or the purpose of which is to prevent or limit the effect of a major accident". Thus, if an SECE fails before it has fulfilled its safety (or environmentally) critical function, it can lead to undesirable consequences. One potential cause of failure of SECE is the exposure to the thermal effects of fire. Thus, SECEs may need to be protected against fire and PFP is one way of achieving this. Although currently used in the offshore sector, the concept of SECEs is also useful onshore as a means of identifying those items that are critical to safety and environmental protection
SCE	Safety Critical Elements (SCE) was used prior to the inclusion of environmental impacts within the UK Offshore Safety Case Regulations] in 2015. After this, the term SECE was used to include the fact that these items may be both 'safety' critical and 'environmentally' critical.

Definitions and Abbreviations	
Terminology	Role
Temporary Refuge (TR)	A location on an offshore platform, usually a protected building, where personnel muster whilst they await evacuation during hazardous events. The TR is often the same building as the accommodation module but other smaller 'safe haven' shelters may be provided close to alternative evaluation points.
UL	Underwriters Laboratory
UTS	Ultimate Tensile Strength

1 Purpose and Scope of this Document

Passive Fire Protection (PFP) has been used extensively within the hydrocarbon industry for many years to mitigate the effects of fire, saving lives and assets. However, despite this track record it is a technology that is not broadly understood and is often neglected by some project stakeholders during the engineering phase. Recognizing these shortfalls, the PFPNet Steering Committee has commissioned the development of a PFP Roadmap aimed at providing guidance on the process of developing a PFP scheme and considerations for specification.

PFP in relation to this document relates to materials designed to delay the structure or equipment from reaching a limiting temperature. Other PFP types (e.g. guards, deflectors) are not considered within the scope of this document.

Identification of credible release of hydrocarbons in an accident event leads to many risks to the survivability of structural steel and equipment. Some of these risks are not related to the fire case but may impact the integrity and insulation effectiveness of PFP when fire occurs. This document only deals in detail with mitigating the effects of fire where the integrity of the PFP is equivalent to that used in third party fire tests and certification.

It is intended that other PFP Net documents will deal with guidance in relation to environmental and mechanical stresses, cryogenic exposure, blast considerations and use of other fire mitigation in combination with PFP. This document touches on a few key points in relation to these topics for information

The purpose of this document is to provide guidance on the development of PFP schemes to protect vulnerable process plant from the effects of hydrocarbon-fueled fires. The document, referred to as the “PFP Roadmap” is structured to inform stakeholders on the various steps required to develop a robust protection scheme, whilst also informing on the various options available to engineering teams developing the protection scheme and writing specifications from which PFP systems are selected. The information should be beneficial to stakeholders including client, engineering teams, certification and regulatory bodies and providers of PFP systems.

This guidance will not develop and present new technical methods but will reference existing methods and standards that are considered good practice, place them in a structured decision-making process, describe to the user the benefits and limitations of different approaches, and where necessary clarify language.

The guidance presented in the PFP Roadmap applies to onshore and offshore facilities where new PFP is to be applied; to new construction (greenfield) and to existing (brownfield) facilities where PFP needs to be retrofitted or updated to reflect changing risk analysis. This document also provides some guidance where PFP needs to be repaired by replacement however consideration of the condition of PFP on aging assets is not included in this document. The information in this document may be applied to PFP schemes for the protection of structures, partitions, refuges, vessels, key equipment items and their associated structural supports.

2 Overview of the PFP Roadmap

The PFP roadmap can be represented by a simple flow chart illustrated in figure 1, each step of which is explained in this document but can be summarized as follows:

Step 1: Development of the fire protection philosophy and strategy

This requires an understanding of the potential fire hazards present on a facility. It also requires the definition of the principle drivers for PFP; safety, environment and property loss/business interruption, along with the identification of appropriate codes, standards and guidelines for the PFP design. Development of the fire protection philosophy and strategy is presented in Section 4.

Step 2: Determination of fire protection coverage and fire performance

Once the fire hazards are understood it is possible to set about defining the extent of PFP coverage and the fire performance requirements; integrity, insulation and resistance requirements. Guidance on two distinct options are presented in the Roadmap:

- Prescriptive design approach (see Section 5).
- Performance-based design approach (see Section 6).

Depending on the defined philosophy/strategy, it may then be necessary to optimize the PFP design (see Step 3) or progress to Step 4 to develop the specification.

Step 3: PFP Optimization

PFP optimization is a method where fire load response analysis is undertaken to better understand the thermo-mechanical and thermo-structural response of critical equipment and structure that are identified as requiring to survive a fire event to safeguard safety, the environment or business. It is typically undertaken for critical structure and pressurized systems. Section 7 presents some approaches for PFP optimization.

Step 4: Development of the PFP specification

The PFP specification requires definition of the key design and fire performance requirements for the PFP systems to be installed. This includes testing and certification requirements as well as non-fire related aspects of system performance. Section 7 presents insights on the non-fire related requirements of PFP system design, and Section 9 presents an overview of what a PFP specification should cover.

Editorial Notes:

1. There is a box at the start of each section that contains a summary of the key points and lessons from that section.

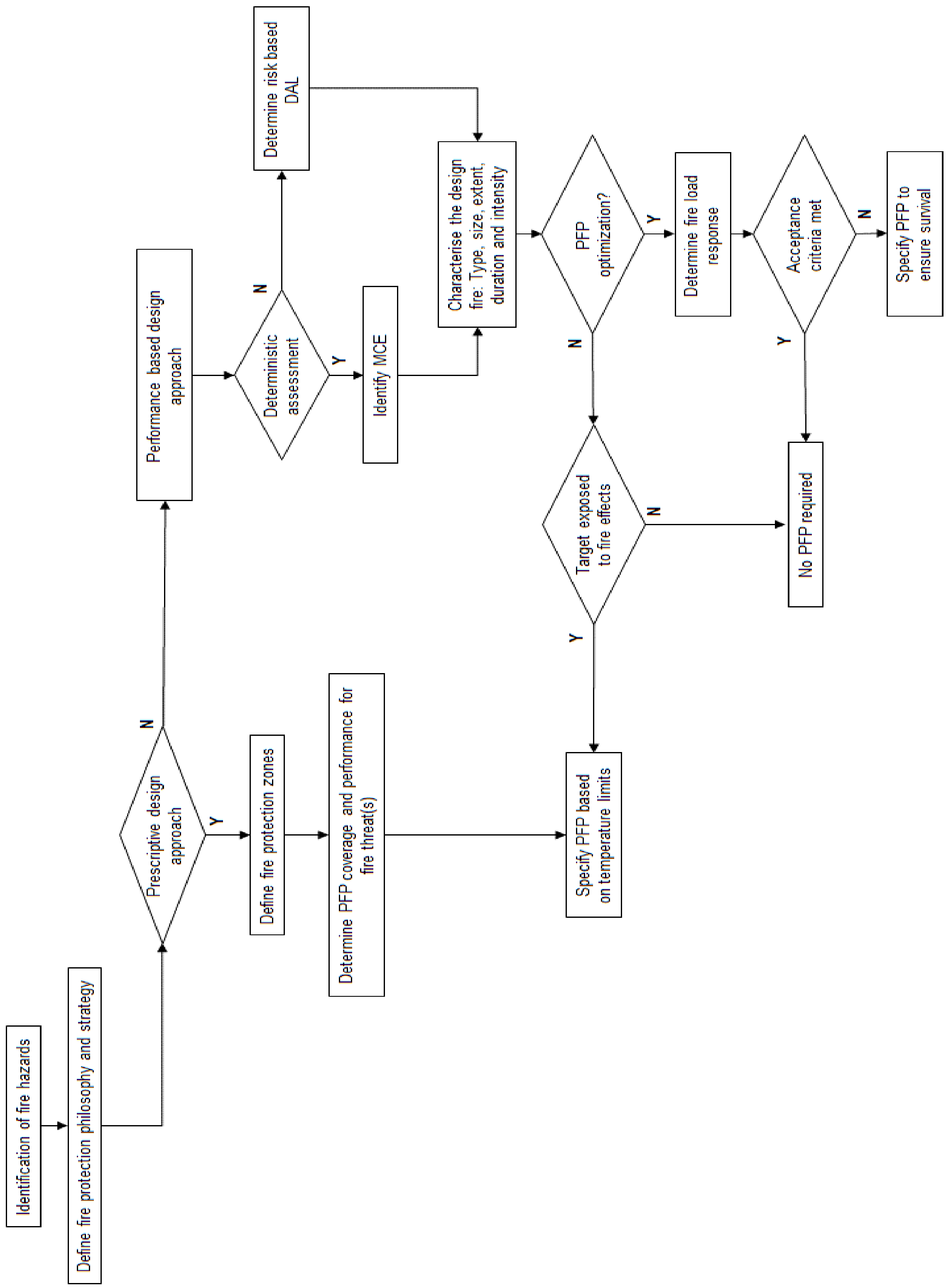


Figure 1 PFP Roadmap – document flow diagram for fire only considerations

3 Codes, Standards and Guidelines

3.1 Codes and Standards

Table 1 Codes and Standards referenced within this document

Codes and Standards	
Reference document	Title
ASTM E119-16a	Standard Methods of Fire Tests of Building Construction and Materials.
ASTM D5894	Standard Practice for Cyclic Salt Fog/UV Exposure of Painted Metal.
BS/EN/ISO 23521	Petroleum, petrochemical and natural gas industries — Pressure-relieving and depressuring systems. Equivalent to API 251 (revision 6).
BS 476-20	Fire tests on building materials and structures. Method for determination of the fire resistance of elements of construction (general principles). This standard defines the ‘cellulosic’ fire test curve and Appendix D defines the hydrocarbon fire test curve.
BS 476-21	Fire tests on building materials and structures. Methods for determination of the fire resistance of loadbearing elements of construction.
Eurocode 3 Part 1-2	EN 1993-1-2 Eurocode 3: Design of steel structures - Part 1-2: General rules Structural fire design.
IEC 60331-21	International Electrotechnical Commission (IEC), Tests for electric cables under fire conditions - Circuit Integrity - Part 21.
IMO FTP 2010	International Convention for the Safety of Life at Sea (SOLAS), Chapter II-2 SOLAS Chapter II-2 International Code for Application of Fire Test Procedures (2010 FTP): International Maritime Organization.
ISO 834-1	Fire-resistance tests -- Elements of building construction - Part 1: General requirements. This standard defines the ‘cellulosic’ fire test curve.
ISO TR834-3 (1994)	Fire-resistance tests — Elements of building construction — Part 3: Commentary on test method and test data application. This standard refers to hydrocarbon fire test curve cross referenced with BS476 part 20, Appendix D.
ISO 12944-1	Paints and varnishes — Corrosion protection of steel structures by protective paint systems — Part 9: Protective paint systems and laboratory performance test methods for offshore and related structures.
ISO 20340	Paints and varnishes — Performance requirements for protective paint systems for offshore and related structures.

Codes and Standards	
Reference document	Title
ISO 20902-1	Fire test procedures for divisional elements that are typically used in oil, gas and petrochemical industries - Part 1: General requirements.
ISO 21843 / BS 8619 (2020)	Determination of the resistance to hydrocarbon pool fires of fire protection materials and systems for pressure vessels.
ISO 22899-1	Determination of the resistance to jet fires of passive fire protection materials, Part 1: General requirements.
ISO/TR 22899-2	Determination of the resistance to jet fires of passive fire protection, Part 2: Guidance on classification and implementation methods.
ISO 20088-1,2,3	Determination of the resistance to cryogenic spill of insulation materials —Part 1 Liquid phase, Part 2 Vapour exposure, Part 3 Jet release.
ISO 10497	Testing of valves - Fire type-testing requirements.
Norsok S-001	NORSOK S-001: Technical Safety.
Norsok M501	Surface Preparation and Protective Coatings.
TRB801	LPG Pressure Vessel Test for German Federal Standard TRB 801 Nr. 25 (Technical Regulations for Pressure Vessels Pressure Vessels for non-corrosive gases and gas mixtures), 1991
UL 263	Standard for Fire Tests of Building Construction and Materials, Edition 14, 2011. This defines a cellulosic fire test curve and is generally not applicable for the hydrocarbon process industries.
UL1709	Standard for Rapid Rise Fire Tests of Protection Materials for Structural Steel. Defines the hydrocarbon and environmental testing required for hydrocarbon process industries.
UL2431	Standard for Safety for Durability of Fire Resistive Coatings and Materials.
Note: Issue dates and edition number of standards, codes and guidance have been intentionally omitted. Users of this guide must identify and use the most recent and valid issue of the standard concerned.	

3.2 Guidelines and Additional Reading

Table 2 Guidelines referenced in this document or for background reading.

Guidelines and additional reading	
Author	Document Title
API 520 Part 1	Sizing, Selection, and Installation of Pressure-relieving Devices, Part I-Sizing and Selection.
API 520 Part 2	Sizing, Selection, and Installation of Pressure-relieving Devices, Part II-Installation.
API 607	Fire test for Quarter-turn Valves Equipped with Non-metallic Seats.
API 2218	Fireproofing Practices in Petroleum and Petrochemical Processing Plants.
Centre for Marine and Petroleum Technology (CMPT)	Guide to Quantitative Risk Assessment for Offshore Installations.
FABIG TN 8	Fire and Blast Information Group (FABIG): Technical Note 8: Protection of Piping Systems subject to Fires and Explosions.
FABIG TN 13	Fire and Blast Information Group (FABIG): Technical Note 13, Design Guidance for Hydrocarbon Fires.
Fire and Blast Information Group	A range of guidance for fire and explosion engineering, including FABIG TN-13 "Design Guidance for Hydrocarbon Fires".
Oil & Gas UK	Fire and Explosion Guidance.
PFPNet	General Guidance on Testing, Assessment and Certification of PFP – Part 1.
Scandpower (now Lloyd's Register Consulting)	Guidelines for the Protection of Pressurised Systems Exposed to Fire.
The Energy Institute	Guidelines for the management of safety critical elements.
The Energy Institute	Guidance on passive fire protection for process and storage plant and equipment.
The Institute of Petroleum (now The Energy Institute)	Guidelines for the design and protection of pressure systems to withstand severe fires.

Guidelines and additional reading	
Author	Document Title
UK Department of Energy	The Hydrocarbon Fire Resistance Test for Elements of Construction for Offshore Installations, Test procedure. Note this has been superseded by BS, ISO and EN standards that define the same curve.
UK HSE 12/2007	UK HSE, Offshore Information Sheet Number 12/2007: Advice on acceptance criteria for damaged Passive Fire Protection (PFP) Coatings.
UK Health and Safety Executive	Guidance on Risk Assessment for Offshore Installations, 3/2006
Note: Issue dates and edition number of guidance have been intentionally omitted. Users of this guide must identify and use the most recent and valid issue of the standard concerned.	

4 Developing the Protection Strategy

Key points

The protection strategy should present the key project drivers for installing PFP:

- *Life safety, environment and asset protection drivers;*
- *Emergency response philosophy; and*
- *Regulatory and other stakeholder requirements.*
- *Be appropriate for the potential fire hazards present on the facility.*
- *Address how escalation is to be managed.*
- *Identification of equipment and structures requiring protection.*

4.1 Overview

The designs of fire protection systems vary considerably due to the nature of the hazards and the wide choice of system options available. It is important that appropriate system(s) designs are selected that:

- Offer effective protection against the presented fire hazards (i.e. fit for purpose).
- Are practicable to implement.

4.2 Fire Hazard Identification

Fire hazard identification is a systematic process that seeks to define the range of fire threats that exist on a hazardous facility with the aim of:

- Defining the fire type and size (the credible release scenarios based on available fuels and process and/or storage conditions); and
- The physical location, typically defined in terms of a Fire Zone (or Fire Protection Zone), a plant area or a module.

The process should identify both process and non-process fire hazards and often forms part of a more general hazard identification exercise (i.e. HAZID) as part of a formal safety assessment.

The range of fire hazards involved with handling flammable substances are typically described as:

- Pressurized jet/spray fires.
- Liquid pool fires.
- Oil mist fires.

- Flash fires.
- Non-process fires (e.g. mineral oils, cellulosic fires, electrical fires).

In identifying fire hazards, consideration should also be given to inventories of pressurized liquid hydrocarbons (e.g. LPG) where the containment envelope (vessel or pipe) is vulnerable to fire induced pressurized rupture, as these are major escalation events.

4.3 Defining the Fire Protection Philosophy and Strategy

The fire protection philosophy provides the overall aims and goals of how fire hazards are to be managed on a facility. The philosophy should define:

- The key drivers for protection; these typically include consideration of life safety and asset protection (and may extend to the avoidance of further environmental damage), and may factor in emergency response philosophies;
- Applicable regulatory requirements.
- Applicable engineering standards and guidelines.
- Assessment criteria that should apply to the design process.

The Fire Protection Strategy describes how the fire protection philosophy requirements are to be achieved by providing definition of:

- Separation and segregation strategies to manage fire hazards (i.e. fire zoning).
- The application of firefighting (fixed or mobile), active and passive fire protection technologies to fire zones and their functional performance requirements.
- The interfaces with other systems and processes.
- Emergency response strategies.

With respect to PFP, the strategy should typically extend to the functional requirements to account for:

- Reduction in the heat transfer to critical equipment, structures, and enclosures to:
    - Prevent or limit escalation.
    - Maintain the performance/functionality of critical systems.
    - Facilitate emergency response actions.
- Prevent the spread of fire by preserving segregation of plant and protecting means of escape, muster and evacuation.
- Limit or prevent fire induced failures of process equipment containing flammable/combustible material.

A well thought out strategy may identify PFP requirements for:

- Fire separation barriers or divisions; bulkheads (walls), and decks (floors, roofs) of rooms/buildings such as living quarters (LQ), muster stations, control rooms, temporary refuges (TR), safe havens, etc.; or fire walls and decks intended to separate process areas from non-process areas to mitigate escalation.

- Critical Structures – the main structure on offshore facilities, or process unit structures onshore. Also, the structures supporting the Temporary Refuge (TR), Escape, Evacuation and Rescue (EER) facilities, fire barriers, process equipment, piping and critical control lines.

- Process vessels, tanks and pipework (and their supports), including risers offshore.

- Valves, actuators, flanges and other equipment that form part of the containment or emergency response systems such as Emergency Shutdown Valves (ESDV), blow-down valves, flare and vent headers, critical control lines, etc.

5 Prescriptive Design Approach

Key points

Relies on the definition of fire scenario envelopes (otherwise known as fire protection zones).

Focuses on pool fire threats and is typically implemented in accordance with the envelope dimensions defined in API 2218 (or similar); simple and quick to apply once fire threats are identified.

Credit taken for liquid spill containment and drainage systems.

Survivability of structure / equipment is typically based upon a predefined limiting temperature rise.

Lack of risk assessment can result in an overly specified coverage of PFP through the protection of equipment and structures that are not exposed to a significant fire risk.

In general, the approach assumes pool fire as the dominant threat and therefore jet and spray hazards are not taken into consideration.

5.1 Overview

Prescriptive approaches to defining the coverage of PFP rely on the identification of fire threats and the definition of Fire Scenario Envelopes, also referred to as Fire Protection Zones (FPZ). Such an approach relies on the characterization of fire scenarios for each of the areas of the facility defined in the Fire Hazard Identification.

Industry recommended practice documents, such as API 2218 and API 2510, offer insights into the sizing of Fire Scenario Envelopes and define the extent of coverage within such envelopes, as well as fire resistance ratings for selected equipment. Although such guidance is stated as being 'risk based', its implementation typically adopts the defined Fire Scenario Envelope dimensions and the guidance provided on 'what to protect' – effectively it is used as prescriptive guidance, or even as a 'code'.

Such approaches are commonly adopted onshore (API 2218 explicitly states the guidance is for asset protection for onshore plant) and for pool fire hazards and has been adopted by some onshore facility owners/operators in their internal engineering standards.

The approach is not recommended for facilities where there is a significant jet/spray fire hazard and/or the facility is offshore.

5.2 Fire Characterization

Fire characterization is an extension of the Fire Hazard Identification (also Fire Hazard Analysis) (see section 4.2) and considers the following factors that affect the size, duration and intensity of pool fire hazards:

- Location of release sources within areas of the plant identified in the Fire Hazard Analysis as posing a pool fire hazard;
- Size of flammable inventory, composition and process operating conditions;

- Performance of isolation systems and the ability to depressurize the process affected by the leak (and the process impinged by the release);
- Extent of pool formation from release source accounting for area drainage systems and bund/kerb structures aimed at containing a release; and
- Presence and effectiveness of active fire protection systems.

Fire consequence modelling may be undertaken to characterize the extent of heat exposed plant from the edge of the pool fire, or empirical heat exposure charts may be used if available.

5.3 Defining Fire Scenario Envelopes

Guidance provided in API 2218 (or similar) defines the extent of the fire protection envelop in three-dimensions. Envelopes are typically defined from the edge of the pool fire (or containment structure) in the horizontal plane (typically 6 m to 12 m), and a vertical height from the horizontal plane were the pool is defined (typically 6 m to 12 m). Such an approach therefore caters for elevated release sources that are above plated/solid deck structures.

5.4 Extent of Coverage

The extent of PFP coverage within a Fire Scenario Envelope (or FPZ) is targeted at the critical equipment, which is typically defined in the Fire Protection Strategy and factors in the availability and efficacy of active fire protection systems. API 2218 provides guidance for equipment types.

The extent of PFP coverage may be relaxed where it can be demonstrated that the equipment will not fail before the fuel source is consumed and the fire has been extinguished. However, typical practice is to provide fire protection to all critical structures within the envelope for the duration defined in the fire protection philosophy and/or strategy or is based on guidance presented in API 2218.

The evolved PFP specification should state the FPZ and the item types within that zone that require protection, the fire threat that needs to be protected against (e.g. a pool fire), and the limiting temperature the item must not exceed over the defined fire duration. From this information PFP manufacturer's certified data can then be used to identify the required PFP product/system, system parameters (e.g. thickness of coating, dimensions of jackets, etc.) and the installation/application method.

5.5 Considerations

Guidance such as that defined in API 2218 (and some company engineering standards) is based on years of experience of refinery fires and offers a simple and quick means of specifying the extent of a PFP scheme. However, there are limitations:

- The current version of API 2218 (3rd Edition 2013) is not appropriate for mitigating jet/spray fire hazards;
- The method should not be applied to offshore facilities;
- Any accompanying risk assessment tends to be high level and qualitative;
- The implementation of the method and strict adherence to the fire envelope dimensions can lead to an under-protection for the fire threats presented (e.g. un-

protected top flanges on elevated structural beams); and

- The lack of a detailed risk assessment can result in a tendency to over-protect plant.

Historically, API 2218 is often used for structural steel fire protection based on UL1709 testing, where for many years it was implied that determination of PFP thickness for a W10 x 49 column was suitable and sufficient. This led to the requirement of a single thickness of PFP for all steel sizes (and shapes) within the FPZ. However, PFP thickness is a function of steel size and shape (I sections and hollow sections for example). The most recent version of UL1709 (Edition 5, 2017) addresses this by requiring testing on a range of steel sizes and shapes. The standard also provides methodology to ensure that the thickness of PFP applied will function on beams through an additional testing to the column package.

The thickness of PFP required from UL1709 testing on steel sections has been used to protect process vessel walls. Pressure development, shape and steel wall thickness are not considered, and other test methodologies should be utilized.

Section 9.3 describes how the information generated from a prescriptive design approach is used to develop a PFP specification and how that specification is translated into the selection of appropriate PFP products and systems. This is supplemented by descriptions in Appendix A.

6 Performance-Based Design Approach

Key points

Considers the characteristics of the process and the fire hazard inventory and takes account of other fire escalation mitigation measures.

Considers all fire threats, is specific to the plant and the plant fire threats and can factor in the frequency with which events are likely to occur.

Identifies the fire Design Accidental Load (DAL).

Credit taken for liquid spill containment and drainage systems, and for other mitigation measures such as isolation and EDP systems.

The use of risk assessment can result in a targeted coverage of PFP protecting only those items of equipment and structure that are safety and/or environmentally critical. It can also be used for loss prevention where there is a desire to examine whether a prescriptive scheme can be optimized.

This approach typical involves more engineering effort and so may impact design schedules and cost. Needs to be considered at the early stages of design. Leads to a reduction in application installation schedule in most instances.

Recommended for offshore facilities or where there is a significant jet/spray fire hazard and/or the onshore facilities where there is a desire to examine whether a prescriptive PFP scheme can be optimized.

6.1 Overview

Performance based design approaches to specifying the extent of coverage and performance of PFP require the definition of risk-based fire loads (referred to as the design accident load or "DAL") and the performance requirements of critical structure and equipment when subjected to such loads.

There are a several ways in which the DAL can be determined that vary in terms of rigor, and with that the degree of resolution in the spatial and temporal variations of the fire loads:

- Fully quantitative fire risk assessment methods whereby risk acceptance criteria are defined, and a probabilistic assessment of fire scenarios is undertaken using exceedance-based approaches. Such approaches provide a thorough assessment of the fire threats accounting for a range of parameters to capture variations in release sizes, action of safety systems, directionality and ignition probability.

- Deterministic fire risk assessment whereby a maximum credible event (MCE) is defined based on experience and engineering judgement. Such an approach typically necessitates a degree of conservatism to be adopted in the assessment, to offset the inherent uncertainty associated with the selection of the MCE and ensure margins of safety are preserved.

Following definition of the DAL, the response of critical structure and equipment are assessed to determine whether failure is likely to occur and, where it is, PFP is specified to safeguard performance.

6.2 Design Accident Load

The size, duration and type of a release of flammable substance is dependent on several factors including:

- The composition of the material as a function of time; this will in part govern whether there is a liquid, gaseous or spray (gas with liquid droplets) release.
- The pressure and temperature under which it is stored; this will govern the length of the initial release, the release rate and can influence the conditions of the initial release, which could be gas, liquid or spray.
- The hole size; the larger the hole size the greater the release rate although the fire duration is likely to be shorter than for a small hole size as the inventory is released more quickly.
- The size (e.g. volume) of the inventory; this will in part govern the duration of the release.
- The effectiveness of safety features and systems such as bund structures, hazardous open drains, ESD and EDP in controlling the fire.

Design accident loads are determined using risk-based approaches. Here a fire risk assessment (FRA) is undertaken and a fire load is calculated that satisfies the predefined risk-based criteria. DALs are typically defined for each fire zone and for each type of fire; with separate DALs defined for jet/spray fires and pool fires.

6.3 Methods for Determining a DAL

When deciding on the best method to define the DALs for a given facility it is necessary to take into consideration the resolution of the input data required to develop an understanding of the design loads, the level of uncertainty in the assessment and the hence the necessary conservatism required to offset the uncertainty. Methods are usually based on a deterministic approach or a probabilistic approach:

6.3.1 Deterministic Approach

The MCE is a representative fire scenario that has a reasonable likelihood of occurrence. It is selected based on experience and typically captures the effects of isolation and EDP (where appropriate) and seeks to maximize both fire size and duration that results in the most damaging fire scenario. As these are competing characteristics the MCE tends to be characterized by medium size releases.

The MCE is the simplest approach and one that can be quickly defined, and whose physical effects can be characterized using the various modelling techniques available.

6.3.2 Probabilistic Approach

A probabilistic approach to developing the DAL for a given fire zone requires a comprehensive assessment of the range of fire hazards presented on a facility, both in terms of its physical effects and its likelihood of occurring.

Guidance on the application of such approaches are presented in industry guidance material, and examples are described in the following section.

FABIG TN-13 Approach

FABIG document TN-13 offers an FRA methodology whereby exceedance curves based on heat dose are developed and then, using risk acceptance criteria that are in use for the project, dimensioning fire loads are calculated. The dimensioning fire load is then used to define the DAL. Depending on the level of uncertainty inherent in the FRA a margin of safety may be adopted between the dimensioning fire load and the DAL. The DAL is then defined in terms of a characteristic fire scenario such as, for example, “60 minutes exposure to jet fire loading with a received heat flux of 275 kW/m^2”.

A fully implemented FABIG TN-13 approach (summarized in figure 2) combines phenomenological modelling tools with CFD fire modelling to understand how the fire loads are influenced and can be an extensive assessment when compared to other approaches. The use of the fire modelling tools allows for explicit calculation of heat flux values.

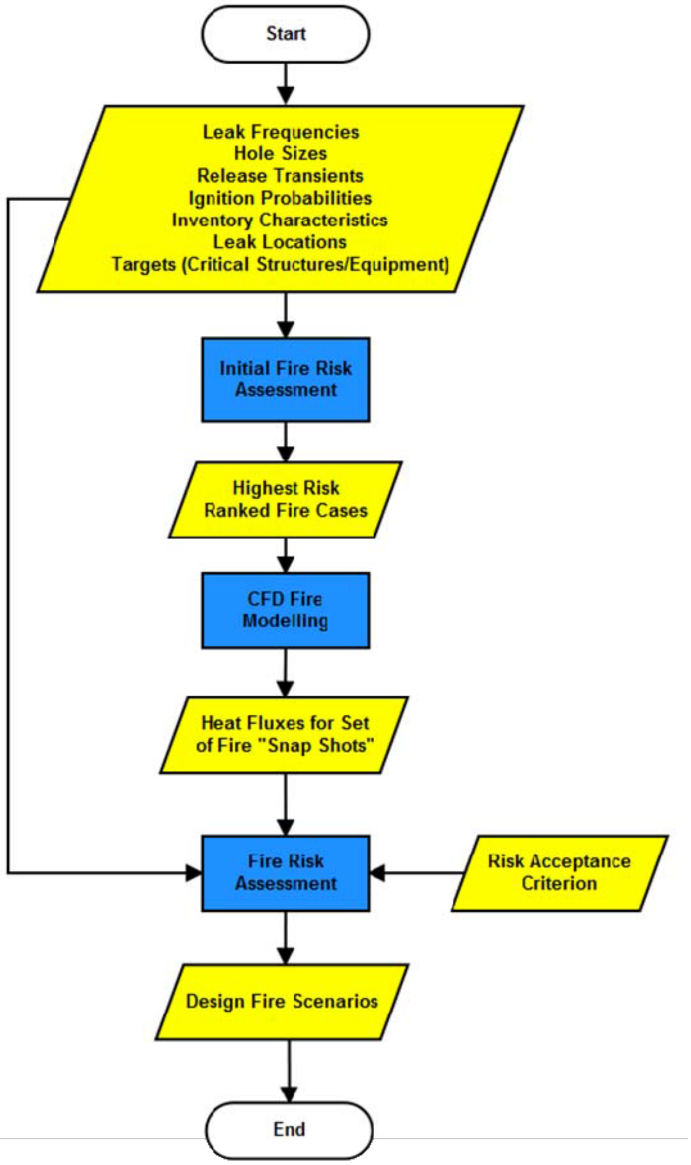


Figure 2 FABIG TN-13 approach to defining the DAL

However, the benefit of the additional complexity is often realized when assessing the extent of PFP required, since the more detailed approach can provide an improved level of understanding of the fire hazards, which can then support a reduced PFP coverage compared to other approaches where a degree of conservatism is required because the fire hazards are not as well defined.

Other Exceedance-Based Approaches

Other exceedance-based approaches can be implemented whereby exceedance curves are developed based on flame impingement duration or, more simply, fire duration. These approaches tend to be limited to phenomenological modelling techniques and require an understanding of the separation distances between leak sources and critical structure and equipment (i.e. targets) that are required to survive the fire events under consideration.

A simple rule set is adopted for survival of the identified targets and individual fire scenarios are screened based on the process shown in figure 3. The frequency of fire induced failure is then calculated based on a summation of the frequencies of those scenarios identified as initiating failure of each target under consideration.

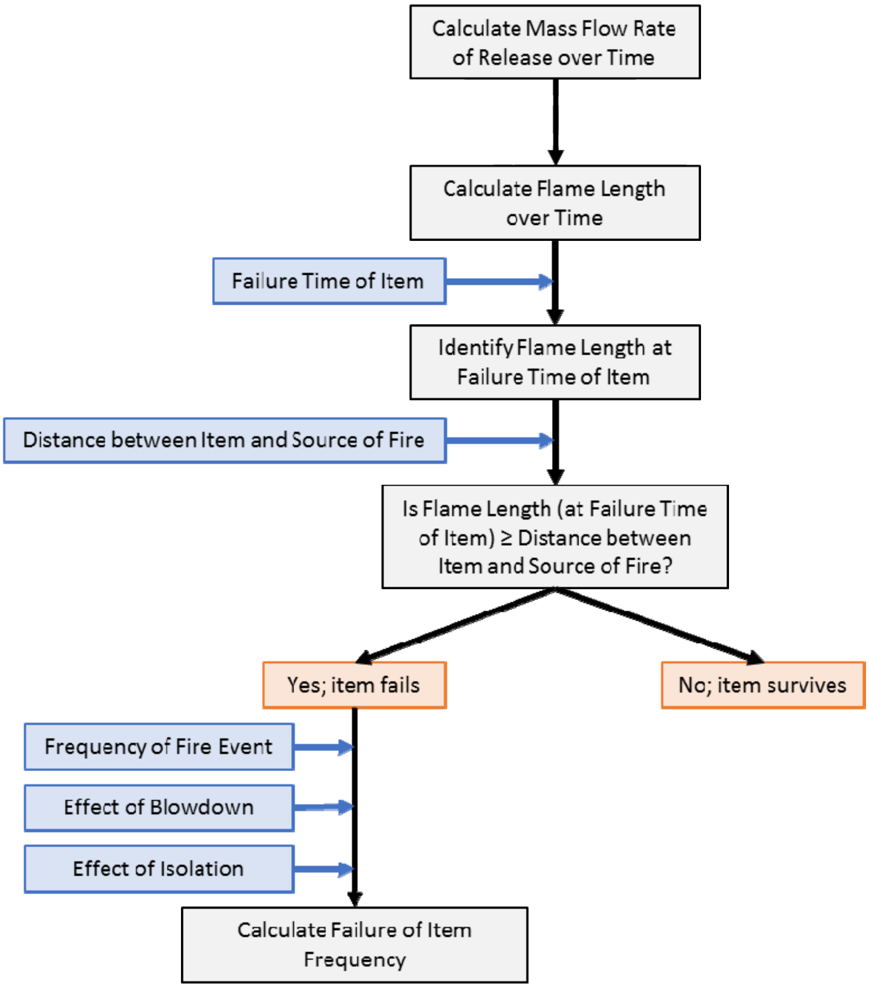


Figure 3: Failure frequency of item flowchart

The DAL is then defined in terms of a heat flux and the bounding fire duration or survivability requirement (i.e. duration).

Here the heat flux levels are taken from published values provided in guidance such as FABIG TN-13, Oil & Gas UK Fire and Explosion Guidance or Scandpower Guidelines, rather than being explicitly calculated. Typical values are:

- 250 kW/m2 to 350 kW/m2 for jet fires.
- 100 kW/m2 to 150 kW/m2 for pool fires.

The approach tends to be quicker and easier to implement than the FABIG TN-13 approach since it does not require specialist CFD input. Its use is often considered as being conservative because in a congested/confined area it will over-predict the hazard range because it assumes no obstructions are present for the flame to interact with, unless the data is modified to account for this situation.

In the example presented in figure 4, CFD modelling techniques predicted much higher and widespread heat loads compared to the phenomenological modelling techniques. As such, the analyst should be aware of the potential non-conservatism in the assessment process and compensate for these accordingly.

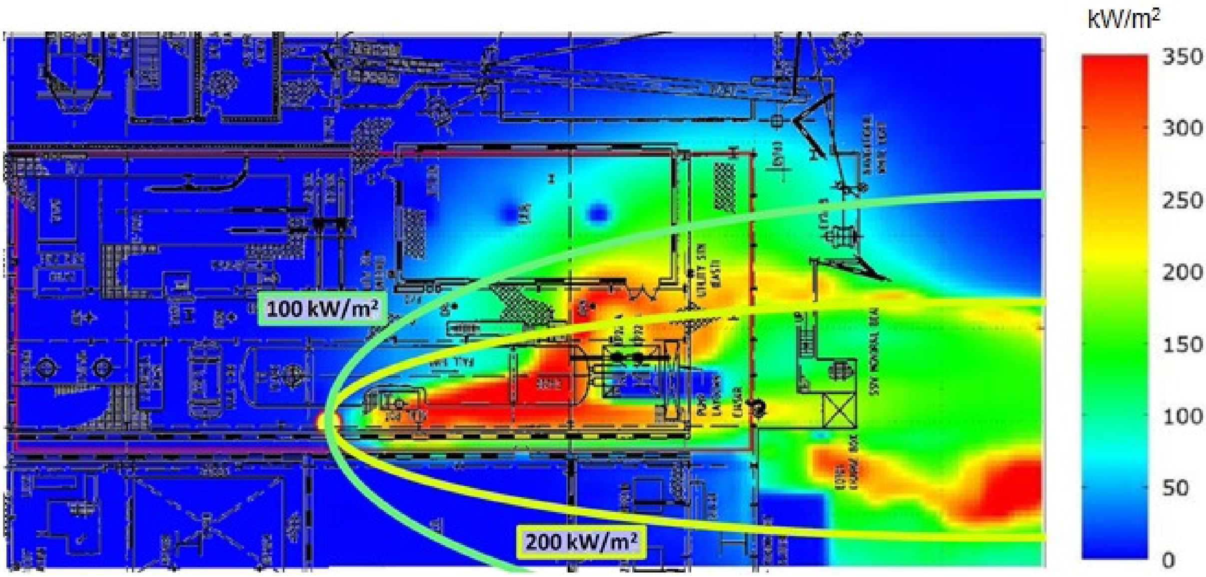


Figure 4 Differences in fire loads between CFD models and phenomenological models

However, the lack of fire- structure interaction (both in terms of flame shape and ventilation conditions) can be non-conservative as it can under-predict background heat loads that are influenced by flame spread and ventilation conditions. The approach should be used with care to avoid the potential for not achieving compliance with the risk criteria specified.

6.4 Risk Acceptance Criteria

Risk acceptance criteria should take into consideration, in order of precedence:

- National Regulations.
- Facility Basis of Design.

- Company Standards.
- International, National and Industry Codes and Standards.

Risk-based approaches are aligned for use in risk-based regulatory regimes and are intended to support the regulatory requirements to manage risk to a level that is as low as reasonably practical (ALARP).

It is common practice to adopt a frequency criterion of 1×10^{-4} per year to define the design event. This is consistent with the treatment of other major hazards (e.g. earthquake, storm, or vapor cloud explosion) and the specification of the design accident event. However, under such regulatory regimes it is still required to demonstrate a more onerous design event frequency is not reasonably practicable to adopt.

6.5 Defining the Extent of PFP Coverage

Items that require fire protection are those whose failure may lead to escalation such that the consequences to people, the environment, or the commercial interests of the business are greater than those of the initiating event. The types of structure and equipment that are candidates for protection are informed by the protection philosophy and strategy (see section 4) and evolution of other assessments such as those investigating emergency response for the range of fire scenarios, survivability and escalation studies.

A performance-based design will factor in the fire response of critical structure and equipment for the DAL and any required sensitivities to account for the fact that fires can be characterized in terms of duration, size, intensity and fire source location. Typically, the fire load response can take the form of either:

- A 'multi-physics' based engineering assessment to factor in thermal conduction, subsequent heat-up and degradation, and mechanical or structural response.
- Application of a simple rule set to define the expected survival of structure and equipment under generic heat loads such as those published in industry guidance.

A multi-physics approach offers an engineering assessment that fully captures the impact of the fire on the structure and equipment and can predict the time to failure. Application early in the design process can support the application of inherently safer design principles and support the optimization of PFP coverage and manage competing requirements.

A rule set approach, although quick to apply, is more suited to QRA rather than the engineering process since it fails to account for the specific design features and inherent fire resistance. Its unqualified use can lead to the unnecessary application of PFP, or in some cases, failure to specify PFP in locations where it is warranted.

Following definition of the fires and the protection required (i.e. protected items, extent of coverage, and limiting temperatures), it is necessary to determine the type and thickness/dimensions of the PFP material/system selected to provide the required fire protection.

For the majority of PFP solutions this will come from certificates of compliance such as those issued by Class Organizations such as Lloyd's Register, DNVGL, ABS, etc. It is to be noted that characterization of the fire determined earlier on in the process may not reflect that used for standardized fire testing.

6.6 Considerations

As noted earlier, there are several alternative modelling approaches that may be adopted to characterize both the fire effects and the thermal-mechanical response of structures and equipment.

To characterize the physical effects of fires the range of options available range from adopting published values for thermal intensity, through to phenomenological models and then more complex CFD models.

For structures and equipment, a range of analysis techniques can be adopted ranging from simple published rule sets, through to thermal inertia and heat-up calculations (e.g. using Hp/A calculations), to more complex finite element and multi-physics calculations.

The increasing level of sophistication in the modelling comes at a cost and time penalty. When selecting which approach it is necessary to understand the level of uncertainty inherent in the assessment and tailor the approach and the levels of adopted conservatisms appropriately. It is also advisable to apply the same level of rigor to both the fire characterization calculations and the thermal mechanical response calculation methods, as the benefit of a highly accurate calculation approach for one element may be cancelled out by the use of a simplified calculation or broad -based assumption elsewhere.

The adoption of the simpler modelling approaches may appear to save time and cost, but their use necessitates a high degree of experience otherwise an inappropriate protection scheme may be developed.

The adoption of more complex modelling approaches offers the opportunity to better target the PFP coverage and may offer significant savings in the implementation phase of a project.

Section 9.3 describes how the information generated from a performance-based design approach is used to develop a PFP specification and how that specification is translated into the selection of appropriate PFP products and systems. This is supplemented by descriptions in Appendix A.

7 PFP Optimization

Key points

Optimization supports the development of a PFP scheme that targets critical structures and process equipment items that are unable to withstand the thermal heat loads that are associated with the DAL fire scenario.

Offers an extension to performance-based design approaches.

Increased engineering complexity to rationalize protection.

Potentially significant cost and schedule savings when compared with traditional approaches relying on limiting temperature and back face temperatures.

A truly holistic approach to optimization will trade off the performance and coverage of safety systems such as ESD, EDP and AFP against the extent and performance of PFP to ensure fire protection performance is attained.

Care should be taken when performing structural redundancy analysis using phenomenological models. Such models can grossly under-predict the thermal loads that may occur and lead to an inadequate level of protection.

PFP can be over-optimized - care is required to ensure sufficient safety factor remains to account for weathering and damage of PFP. and that PFP schemes on assets are “future proofed” against potential changes later in life, or that the limitations of the optimized scheme are clearly documented

7.1 Overview

This section describes techniques for optimizing the PFP used to protect some items of structures or equipment.

Optimization is the targeted development of a PFP system such that it enables the protected item to meet its performance requirements. It results in the use of PFP only where it mitigates the design fire threats on a facility. PFP optimization is typically targeted at structural and process systems where there is inherent resistance to the effects of fire loading. Its application can present a cost-effective alternative to the blanket application of PFP in fire affected areas.

Optimization of PFP coverage early in the design phase offers the opportunity to offset the need for PFP through modifications to other systems such as:

- Process isolations.
- Performance of EDP and relief systems.
- Active fire protection systems.
- Passive measures such as bunds and drains.

A true design optimization process can also look at the selection of materials with inherently greater fire resistance, the sizing of structural steelwork and the placement and classification of barriers and partitions; very much bringing into consideration inherently safer design principles.

As the design progresses and for brownfield modifications, there tends to be fewer opportunities to optimize, but the application of more sophisticated analytical techniques that are a feature of the optimization process can still lead to a targeted application. Characterization of the fire types may lead to an increase in thickness or decrease in thickness however in general studies show PFP quantity can be reduced.

There are a number of benefits that can be potentially realized through optimization, when compared to blanket coverage in fire-affected areas:

- Cost and schedule savings during the implementation phase attributed to:
    - Reduced material costs.
    - Reduced labor installing the systems.
    - Reduced supplementary works such as scaffolding and surface preparation.
    - Reduced workface conflicts.
- Additional lifecycle costs savings may also be realized through reduced inspection and maintenance of the PFP systems, and the need to remove and reinstall systems to inspect and maintain protected structure and equipment.
- Elimination of potential corrosion under fire proofing site locations.

Care is required in the following areas:

- Sufficient safety factor remains to account for weathering and damage of PFP.
- Assets are "future proofed" against potential changes later in life or that the limitations of the optimization are clearly documented
- Increased number of terminations in the jet fire zones require attention to make sure critical items are protected throughout the fire
- It is possible that fire protection requirement may lead to an increase in thickness and heat transfer effects from secondary members may have to be treated with a greater degree of rigor
- The stickability of fire protection at high limiting temperatures (e.g. >600°C) where used is not evaluated in fire testing and certification process.
- The insulation performance of the fire protection may be required to more closely match the "design fire nature" when considering overall fire response of the structure, and time-temperature curves in the fire testing standards may not be sufficiently onerous.

Guidance is provided here on the methods available to optimize PFP coverage for critical structure and equipment including:

- Analytical methodologies to quantify performance under fire loading and to determine the time to failure of critical structure and equipment.
- Failure mechanisms and acceptance criteria.
- Discussion of relative complexity/cost/time for each method.

7.2 Structural PFP Optimization

7.2.1 Overview

Structural PFP optimization is an engineering-based assessment of the performance of fire exposed steel structures that considers:

- The intensity, size and duration of the design fire event (DAL).
- The utilization of the structural elements.
- The levels of redundancy and the ability of the structure to accommodate load redistribution arising from thermally induced failure.
- The ability of the structural elements to accommodate increased temperatures above the limiting temperatures that are traditionally used to specify PFP systems.

Consideration of PFP optimization early in the design process affords the opportunity for the DAL to be optimized through tailoring the performance of other safety systems as described in Section 7.1.

The use of structural PFP optimization during design has become increasingly popular for greenfield offshore projects given the widespread adoption of performance-based design offshore and the need to manage topside weight and lifecycle costs. It has also been successfully applied to brownfield projects, such as life extension and refurbishment, subsea tie backs and other field developments. Its application to brownfield facilities where there has been a change on the fire hazards on a facility (e.g. through the introduction of high- pressure gas as a result of a subsea tie back), offers a means of managing the scope of PFP application and the challenges that are brought about on a live offshore production facility.

For onshore facilities, structural PFP optimization hasn’t been as widely used in design due to the widespread adoption of prescriptive design approaches as defined in section 5. However, its approach can offer a practicable way forward on new build facilities to rationalize the coverage of structural PFP and may offer a cost-effective means to manage refurbishment scopes on older plant where integrity of the PFP is a concern.

To optimize PFP it is necessary to identify those critical structural components that need to remain intact when exposed to the identified fire scenarios, in order to withstand the structural loads for the required time to meet the acceptance criteria.

Critical structures can include:

- Structures directly supporting, or whose failure could impair, access routes for escape and evacuation.
- Structures supporting hydrocarbon containing vessels or pipes, including pipe supports of the flare system, the failure of which could lead to significant escalation.
- Structures supporting fire and blast rated partitions and muster areas.
- Structures supporting critical equipment required to function in the event of a fire to support emergency response activities.

The identification of critical structure is typically a multi-disciplinary activity with the criteria for selection defined as part of the fire protection philosophy and strategy (see section 4).

Optimization as part of performance-based design relies on the definition of acceptance criteria and the use of analytical models to analyse the structural system's performance under the define fire loads; both of these aspects are discussed further below.

7.2.2 Acceptance Criteria

The acceptance criteria applied to critical structure is typically defined in terms of a level of damage that is acceptable and the time to that damage being exceeded. The time period is often tied back to emergency response requirements and/or the duration of the DAL characteristic fire scenario. The damage level is defined in terms of the following:

Allowable Deformation of Critical Structures

This criterion refers to structures in which a failure in serviceability (large deformation but no structural failure) could be detrimental to emergency response. This can be the case for members supporting firewalls, vessels or pipework required during EDP, the flare supports, lifeboat davits and doors required for evacuation. The limiting allowable deformation varies depending on the purpose of the structure.

Strength

This criterion is specified in terms of a limiting plastic strain. Structural elements making up critical structures can undergo plastic deformations (e.g. development of plastic hinges in deck beams) if no collapse mechanism develops that can impair the integrity of a critical structure within the required endurance time.

Further information regarding the initiation of material rupture of carbon steel at elevated temperatures can be found in Eurocode 3 Part 1-2, and for full penetration welded connections, guidance on failure strain is given in ISO 19902.

Collapse Criteria

Partial collapse of critical structures (i.e. local collapse) is permitted if no collapse mechanism is developed that compromises the overall integrity of the critical structure within the required endurance time.

7.2.3 Analysis Approaches

The analysis approaches adopted to optimize structural PFP vary in terms of levels of sophistication; but given the need to evaluate the structural system and to develop an understanding of the levels of redundancy the analysis approaches adopt Finite Element Analysis (FEA) methods. It is to be noted that expansion effects are not robustly assessed but that allowance is made in some codes (e.g. Eurocode) to ignore these effects.

The FEA modelling approach should be capable of capturing non-linear response and the various failure mechanisms that can affect the structure, such as plastic collapse/rupture, elastic buckling and lateral torsional buckling (LTB). It should also present a formal demonstration that the protected structure can withstand the additional loads generated by the redistribution of loads that will occur due to the load shedding of the failed, unprotected, members.

The two most commonly adopted approaches are:

Member Redundancy Analysis

Structural redundancy analysis is a method widely adopted by structural engineers to determine the need for PFP on structural members. It can be applied as an enhancement of the prescriptive design approach but also as part of performance-based design approaches.

The method involves the removal of one or more load carrying members from a structural system to determine which members are critical to avoid global progressive collapse of the structure. The analysis is repeated until all load-carrying members have been assessed. Those members identified as critical to preventing collapse are protected with PFP.

The method is often used with phenomenological fire modelling, where the fire is represented by an idealized heat flux contour. A weakness with this approach is the treatment of jet fire hazards, as noted earlier.

Non-Linear Progressive Collapse Analysis

Non-linear progressive collapse analysis is a more sophisticated approach to optimizing PFP than the member redundancy analysis approach. It follows an iterative approach whereby spatial and temporal variations in the fire load are captured and the impact of these dynamic effects on the structure are simulated. The method is best suited to the CFD based approach to defining the DAL and is outlined in detail in FABIG TN-13 but can also be used with phenomenological fire models.

- Where used with the latter, caution must be exercised in the analysis as it is subject to the same potential non-conservatisms as those outlined for the redundancy analysis. Such limitations can be overcome through the adoption of industry guidance on flame impingement and background heat loads.
- When the method is paired with the CFD derived DAL it permits a more rational design of the PFP scheme. Time varying effects on the spatial variation of the heat loads, along with fire–structure interaction, can be simulated. Benefit may be gained from the consideration of such effects, for example; the DAL fire scenario may show that the fire is initially very severe, but with emergency shut down (isolation) and EDP; or the impact of drains and run-off, the heat load reduces more quickly than structural failure can occur. In addition, the structure affected by the fire may change due to a reduction in the size of the fire.

The method adopts an iterative approach as shown in Figure 5 comprises of both thermal response analysis and structural response analysis, as discussed below:

Thermal response analysis:

The thermal response analysis determines the heat-up of the structure. The calculated temperature history for each individual structural member is subsequently input to the structural response analysis.

Structural response analysis:

The structural analysis determines the response of the structure subjected to a combination of dead, live and thermal loads. The structural analysis traces failure of structural components, force redistribution within the structural system, local and global collapse, and establishes the deformations of the structure during the fire. Subsequently, it can be determined if the structure meets the relevant acceptance criteria.

The approach commences with the analysis of an unprotected structure exposed to the effects of the DAL fire. PFP is then incrementally added to the structure until the performance criteria is satisfied.

To account for potential variations in the source of the DAL fire, the associated heat flux contours, can be positioned at several locations throughout the considered fire area. This ensures that multiple leak locations are considered, to account for variability in the location of the fire. This is achieved by running a series of independent thermal response analyses for each fire location and release. Each thermal analysis is then followed by a structural response analysis.

The increased level of sophistication with this method has a cost and schedule impact on engineering activities, but there is less reliance on engineering judgement (that is inherent in the member redundancy analysis) that can introduce either:

- Non-conservatisms resulting from a lack of experience and insight into flame–structure interaction and the effects of ventilation conditions on heat loads; or
- Over-conservatisms that can impact the extent of PFP coverage and a consequential cost and schedule impact during the implementation phase of a project.

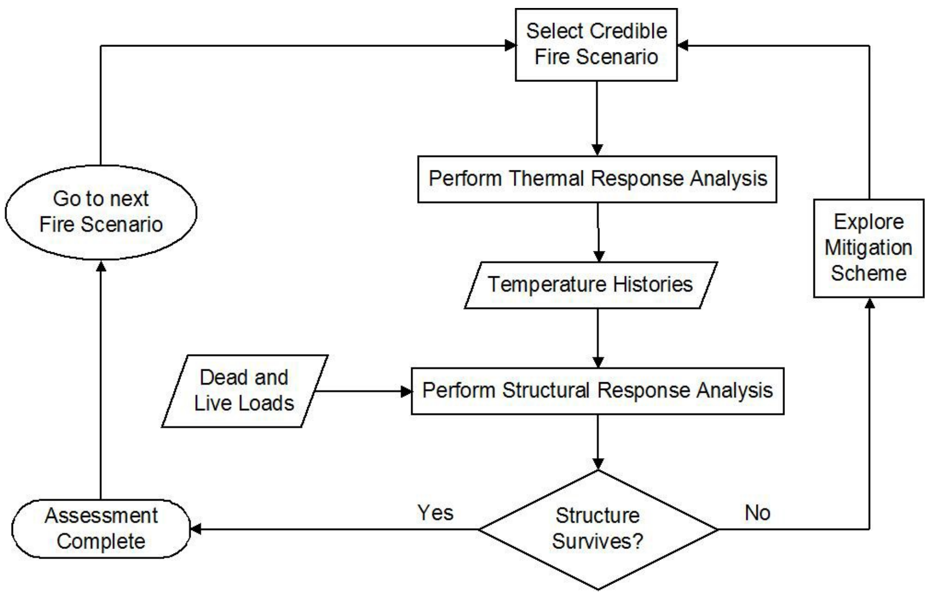


Figure 5 Overview of structural PFP optimization process

7.3 Optimizing Steel Fire Barriers

Fire and blast barriers are used to segregate areas of high fire risk from areas of low, or no fire risk. They are designed to prevent the passage of flame, smoke and hot gases and may be insulated to prevent heat transfer via conduction to protect personnel or safety critical equipment on the other side.

Steel fire barriers can fail either by splitting, buckling or other similar mechanism where the integrity of the barrier is compromised and will no longer prevent the passage of flame and hot gases from the fire side to the non-fire side. For a load bearing barrier (e.g. stress skin design) then a loss of stability may lead to a collapse that may escalate an event.

Non-linear FEA can be used to optimize PFP on steel barriers, however, this is not frequently requested. Most barriers are defined in current specifications by reference to 'A' or 'H' rating however most projects require properties from fire barriers which are defined using REI classifications, see Appendix B for more information.

Where PFP optimization is required then one can use simple heat transfer models to establish the heat-up characteristics of a wall or deck. However, where the barrier is of a stressed skin design then it will be necessary to resort to FEA.

FEA can also be used to establish the potential for buckling of a barrier under fire load and the potential for this buckling to lead to weld seams opening-up to allow the passage of smoke and flame.

7.4 Process Equipment PFP Optimization

7.4.1 Overview

For pressurized systems exposed to fire, there is the potential for thermal weakening and failure at, or below the maximum allowable working pressure (MAWP), due to loss of strength of the pressure containment shell at elevated temperatures. Typical steels used in the fabrication of pressure systems will experience a temperature dependent reduction in strength (both yield stress and ultimate tensile strength (UTS)) similar to that provided in Figure 6.

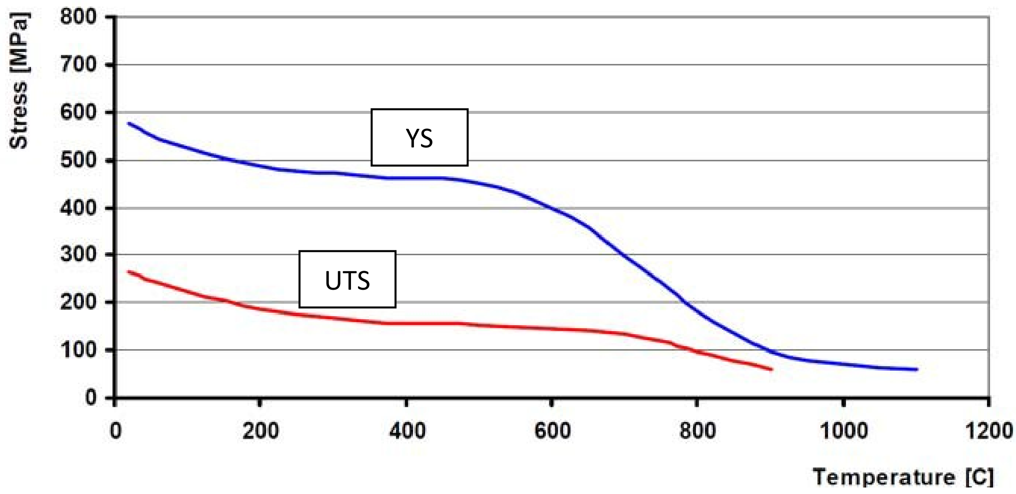


Figure 6 Impact of elevated temperature on Yield Strength (YS) and Ultimate Tensile Strength (UTS) of Type 316 steel (courtesy of Scandpower)

The loss in strength can occur simultaneously with a rise in pressure due to heat transfer to the system's inventory or, where there is EDP and/or thermal relief, a slower than expected time to depressurize. Such conditions may lead to rapid catastrophic failure, generating a sudden release of pressurized contents. If the contents are liquids at temperatures well above their atmospheric boiling point, the sudden release takes the form of a Boiling Liquid Expanding Vapor Explosion (BLEVE) event. Such failures have serious consequences for the safety to life, the environment and the surrounding plant and equipment.

Traditional design practices typically apply API RP 520 and 521 to design pressure relief systems with:

- Thermal relief to maintain pressures (before activation of EDP systems) within a margin of the design operating conditions.
- EDP systems being designed to remove gaseous inventories and reduce operating pressures within the system.

BS/EN/ISO 23521 (API 521) design typically requires EDP systems to reduce the vessel pressure to 50% of design pressure or to 6.9 Barg in 15 minutes; however, it should be noted that there may still be an appreciable residual fire at this point. Therefore, it should be recognized that this performance level of the EDP system may be inadequate to prevent fire-induced over pressurization and to manage the potential for escalation.

Industry guidance such as that prepared by Scandpower as illustrated in figure 7, offers a process by which the performance of pressurized systems under fire loading can be optimized in the design phase of a project.

The methodology is often referred to as the 'Scandpower method'.

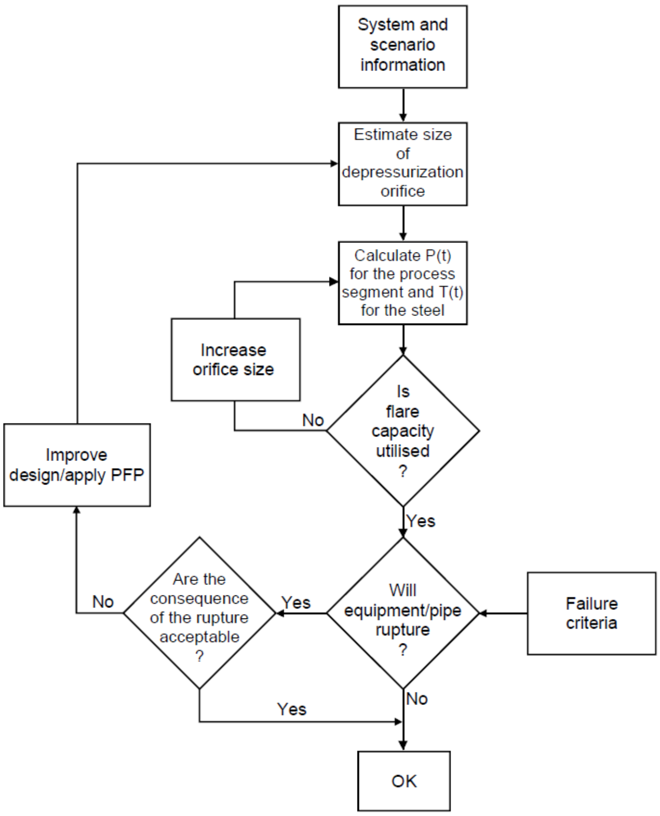


Figure 7 PFP Optimization for Pressurized Systems

The Scandpower method seeks to employ inherently safer design principles by seeking to maximize the benefit of EDP in reducing the pressure of the fire impinged process segment, and then only adopting PFP if this measure cannot fully avert a hazardous rupture of the process segment. Failure acceptance criteria are adopted to assess the effectiveness of the EDP system's performance in preventing or mitigating the consequences of failure. Where failure is still possible, and the consequences of the failure are not acceptable, then PFP should be applied to safeguard integrity.

The optimization method is primarily targeted at DALs that are characterized by jet fires, but can be applied in part to pool fires, particularly the thermal response analysis components that form the 'rupture' assessment. However, it is worth noting that active fire protection is often employed to control and mitigate the effects of pool fires on pressurized systems. These have been shown to be ineffective for jet fire scenarios with passive fire protection being the primary means of protection when pressure system design cannot mitigate against failure.

7.4.2 Acceptance Criteria

Failure criteria are defined as follows:

Strength limit

Failure is typically defined as the point where the operating stresses in the system exceed the allowable stress in the system. Note, the UTS is typically factored to account for uncertainty in the performance of materials at elevated temperature with an allowable tensile stress (ATS) defined. Information on adopting UTS and the application of appropriate safety factors can be found in the Scandpower guidance.

Strain limit

The strain limit will be dependent on the system's fabrication material and the system geometry.

Displacement limit

Tolerable deflection limits will be informed by strain limits and support configurations.

Time to failure

Where failure occurs, it is necessary to understand the time of failure so it can be compared with predicted emergency response times for personnel. Typically, a failure with 3 to 5 minutes would be deemed unacceptable if occurring in an area that is routinely occupied by personnel, and which would result in a significant escalation of the initial fire effects.

Amount of hazardous material released

Industry acceptance criteria relating to the quantity of hazardous material released at the time of rupture often adopted are:

- Maximum remaining total hydrocarbon: 4000 kg
- Maximum remaining hydrocarbon gas: 1000 kg
- Maximum pressure in pipe: 20 barg
- Maximum pressure in vessel: 4.5 barg

7.4.3 Analysis Approaches for Process Equipment PFP Optimization

Analytical methods for analyzing pressure systems under fire attack vary in complexity. The most comprehensive approaches will recognize the role that the system inventory will play in determining the mechanical stresses, as well as the performance of safety systems such as ESD and EDP. Less sophisticated models tend to focus on simple thermo-mechanical response, using hoop stress as a key indicator and determining the time is takes for thermally induced reduction of the MAWP to drop below an allowable stress limit (typically the yield stress, but an allowable stress can also be used if there is available elevated temperature material data). When determining the appropriate method to adopt it is important to understand the potential role of the system's inventory to the fire response to avoid non-conservatism in the assessment and a potentially inadequate PFP system design.

The following analysis approaches are typically used:

Multi-Physics Based Analysis

The thermal performance of the system and any subsequent mechanical failure is influenced by a variety of heat transfer mechanisms that are best illustrated by the example presented in Figure 8.

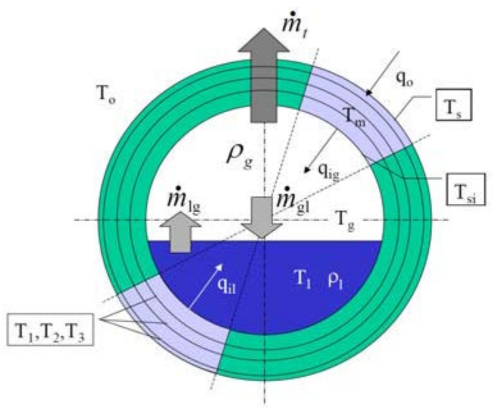


Figure 8 Example heat transfer mechanisms in a vessel/pipe section with a multi-phase inventory (courtesy of FABIG TN-8)

- Heat input to the vessel/pipe shell is from the fire and is characterized as q_o and there is a background temperature T_o.
- The shell heats up: T_s is the outer temperature, T_{si} is the internal temperature.
- q_{ig} is the heat input from the shell to the vapor space and T_g is the temperature of the vapor.
- q_{il} is the heat input from the shell to the liquid contents and T_l is the temperature of the liquid contents.
- $\dot{m}$ is the rate of change of mass between the material phases (liquid to gas, gas to liquid and exiting the system).

These factors combine to influence the rate of change of the mass of the liquid and vapor phases due to heat up and vaporization, and EDP and thermal relief (where installed). The above factors and processes are interdependent and influence the internal pressure of the system, the resultant stresses on the shell and the reduction in strength of the shell due to increased shell temperature.

Specialist software packages have been developed which claim to simulate the above however a number of assumptions may be made which may detract from a robust analysis. The assumptions and impact on the outcome of the analysis is required to be clearly understood.

MAP Approach

The Maximum Allowable Pressure (MAP) approach is a simple approach that does not consider heat transfer to the inventory. It is typically applied to vessels and pipework independently.

The impact on vessel heat-up on the allowable stress in the vessel is determined using elevated temperature material properties. This is then compared to the equivalent stress (sometimes simplified to the hoop stress) in the pipe or vessel wall, and the time is calculated to the point where the stress exceeds the wall strength using a simple time stepping approach. The approach can be simply coded in a spreadsheet.

The pressure reduction inside the vessel can be determined using process engineering tools and can be used to modify the stress in the vessel/pipework shell to remove conservatism from the analysis.

However, the lack of consideration of the thermal response of the vessel/pipe’s inventory can introduce uncertainty and potential non-conservatisms into the assessment and therefore care should be taken when interpreting the results of the analysis.

8 Non-Fire Related Requirements for PFP Systems

Key points

The effectiveness of PFP is not just about how well it performs in a fire

Other criteria are essential when considering credible release scenarios and the suitability of PFP:

- *Survivability when exposed to explosion overloads and drag effects. It is important to ensure that blast testing is relevant to the PFP and to the way it will be used on the project.*
- *Suitability for exposure to cryogenic liquids or vapors; not only the protection of the steel substrate from cold-induced brittle fracture but also ensuring the PFP can survive for subsequent fire exposure.*
- *Resistance to exposure to the environmental conditions that are likely during installation, construction and operations.*
- *The conditions to which the PFP is exposed to such as the operating temperature of process vessels, etc.*
- *The impact of other fire mitigation measures on the PFP such as active systems, and fixed or mobile fire-fighting measures*

Other factors that occur over the short- or long-term during construction and operation can reduce the effectiveness of a PFP system, and are a vital consideration at the specification phase

When selecting PFP products and systems it is essential that all the possible exposure scenarios are considered and that appropriate testing to represent those scenarios is undertaken to demonstrate performance.

8.1 Overview

It is essential that PFP products and systems can provide the required fire performance, validated through testing and certification. However, fire is only one of the possible exposure scenarios that PFP may be subjected to during its service life and upon accidental release.

For hydrocarbons releases, explosion is an ever-present danger that PFP needs to be functional in order to provide subsequent fire protection. For LNG facilities, cryogenic liquid releases not only pose a risk to the steel structure but also to the functionality of the PFP.

PFP is typically used in locations where it will be exposed to extreme weather, considerable mechanical demands and potentially the spillage of chemicals.

It is essential that designers recognize these requirements and ensure that supporting test data is available, and that the provided test data is relevant to the project requirements. To enable these demands to be correctly considered suppliers and manufacturers of PFP systems need to be advised of these at the time of specification or earlier if possible.

The following list of non-fire demands is not exhaustive but is commonly required of PFP. Separately, PFPNet is producing guidance on PFP durability where further information can be found.

8.2 Explosion Resistance

At the time of writing, there is no widely agreed test methodology for exposing materials to blast.

Currently most gas-explosion testing is carried out targeting conservative overpressures and whatever durations can be achieved, without reference to the response on the items exposed to the blast. It is essential that the selection of the PFP is based on blast test data that is relevant to the project conditions.

For PFP it is not just the positive pressure load that matters but also the negative pressure, pulse duration and any drag that results.

High strain levels, where allowed, are generally found in small localized areas and solutions can generally be found to mitigate against loss of integrity. Design for cold climate is more conservative and conducted within the elastic limit of steel due to concerns relating to brittle fracture. Suggestions that maximum deformations observed in finite element analysis are widespread and limiting in relation to PFP integrity are required to be scrutinized as this is not the general case.

It is to be noted that the integrity of penetrations through these barriers will also be exposed to deformations from explosions. Therefore, the maximum deformations of the supporting specimen and the response of any penetrations are of utmost importance.

Additionally, the construction of the PFP is a fundamental aspect of performance (e.g. the use of the 'box' method of installation of lightweight cementitious PFP). This installation method leaves a void behind the PFP that can result in the destruction and removal of the PFP in an explosion event.

8.3 Cryogenic Spill Resistance

Currently there is one international standard for cryogenic testing with three parts; ISO 20088 Part 1 for liquid phase (covers bunded areas), Part 2 for Vapor exposure and Part 3 for jet release (covers pressurized releases of LNG from process up to 6barg) .Temperature drop from a specified ambient temperature as a function of time and loss of containment are the notable properties reported determining performance expectations.

The impact of cryogenic release on PFP thickness required in the event of fire can be found in type approval certification. It should not be assumed that the integrity of PFP is maintained after cryogenic exposure. This can impact corrosion protection of the structural steel, ability to withstand resistance of blast and the thickness required in the event of fire.

8.4 Environmental Resistance

Tests commonly referenced to in specification for weathering resistance are:

- ISO 20340
- Norsok M501 revision 6 system 5
- ISO 12944 Part 9

- ASTM D5894
- UL2431

Many of the tests are derived from coating test standards and therefore may not be applicable to some forms of PFP (e.g. jacket systems) unless testing the total system protecting the steel.

Norsok M501 testing is used to assess passive fire protection systems for corrosion protection, maintenance of integrity and fire insulation properties.

UL2431 testing does not address corrosion protection but does evaluate the maintenance of integrity and fire insulation properties.

ISO 20340 (now superseded by ISO 12944 Part 9) is the cyclic weathering test standard used in Norsok M501 testing. This evaluates the corrosion resistance and maintenance of integrity of a PFP scheme. The cycle is most appropriately applied to coastal or offshore scenarios. It was developed to match real world performance in temperate climates.

ASTM D5894 is an alternative cyclic test standard and is more appropriate for heavy industrial plant rather than offshore scenarios.

There are many other environmental factors not covered by the above test standards. A white paper written by PFPNet outlines these in more detail. Any testing and specification should be relevant to the project and project location.

8.5 Mechanical and Chemical Durability

The location in which PFP is installed during construction, and subsequently operates may be quite onerous. PFP may be applied to substrates that are subjected to strong vibrations, lifting and construction stresses, abrasion, etc. In addition, there are often chemicals that may contaminate the PFP systems such as hydrocarbons, cleaning chemicals, high pressure water jetting, fixed and mobile monitor testing etc. PFP materials and systems should have test data that is appropriate to the possible exposures when in service.

8.6 Operational Temperature Resistance

Many PFP materials have a minimum and a maximum exposure temperature during their normal service life. PFP which is suitable for continuous high or low temperatures may not always be suitable for cyclical temperature exposure. It cannot always be assumed that because one type of PFP from one manufacturer is suitable for use at a particular temperature, the same type of PFP from another manufacturer will also be acceptable.

Additionally, the acceptable temperature range may not be the same at all stages throughout the PFP life cycle.

Lifetime expectations of PFP applied to process equipment or impacted by process temperatures can be lower than for general ambient temperatures and exposures. Specific testing should be carried out more in line with in-service expectations.

The operating temperature has an impact on the thickness selection for PFP. Often equipment and structure will have a specified limiting temperature than cannot be exceeded. If the operating or exposed steel temperature is significantly different to that used for the assessment of PFP thickness (e.g. type approval assessment) then an alternative limiting temperature may be more appropriate based upon the temperature rise to the specified limiting temperature.

8.7 Resistance to Combinations of Hazards

There are no standards that define how individual tests are combined. For example, design scenarios may include cryogenic spill followed by ignition, or explosion followed by ignition, or even weathering, cryogenic spill, explosion and jet fire combinations. The requirement to perform these tests and requirement for projects is at the discretion of the supplier of the materials, the design engineer and subject to client expectations.

9 Specification Development

Key points

Effective use of PFP starts with effective definition and specification of the PFP requirements.

The most critical aspects are:

- *Item to be protected.*
- *Maximum allowable temperature of the protected item.*
- *Fire type and duration.*
- *Substrate temperature during operation*
- *Environmental conditions at project site.*

Others are listed in Table 1.

Effective specification relies on the use of common language to describe PFP requirements:

- *The use of ‘short-hand’ nomenclature should be avoided.*
- *It is recommended to use the REI method of defining the Stability, Integrity and Insulation requirements respectively.*

9.1 Using the Information from Studies

This document has described methods for:

- Developing a fire protection strategy that uses PFP.
- Using prescriptive and performance-based techniques to determine where PFP is needed.
- Using optimization techniques to target the PFP more effectively.
- Other considerations.

In combination, output from studies using the methods described inform about:

- The design fires - their characteristics and zones of influence,
- The required performance of items that need protection - what fires need to be survived, how long is the exposure, what limiting temperature the protected item can be allowed to reach in that exposure time frame?

- The performance considerations of the PFP.

To implement any PFP scheme or use of PFP, all these factors must be fully defined and clearly communicated. Specifiers need to document the fire threat (pool fire, jet fire), the fire resistance duration, the maximum temperature the protected item must not exceed, and the details of the protected item (this may be by using drawings or other description).

However, where hydrocarbon fires are a threat, hydrocarbon releases prior to the fire case may also be a threat and so the PFP may need to survive this hazard. PFP is also often used in environments that are onerous and hence the survivability requirements must also be specified.

The specification is likely to draw on several codes and standards (examples given in Table 1, although this list is not exhaustive).

9.2 Fire Ratings / PFP Performance Ratings

There is a tendency for short-hand nomenclature to be used in PFP specifications such as J30, but experience has shown these abbreviations can lead to ambiguity.

It is therefore preferable for the specifier to fully describe the requirements of the PFP by fully describing the fires, the items to be protected and the protection duration, as well as any other important factors such as exposure conditions in service; location and weather, climatic conditions, process conditions, etc.

For the fire performance requirements for structure and divisions, it is recommended to use the R/E/I system outlined in ISO 20902 (and described in Appendix B of this guidance), where;

- R = Stability (Load Bearing Capacity)
- E = Integrity
- I = Insulation

9.3 Verification that the PFP will Meet the Specification

Although this document covers the processes for developing a specification for PFP, it is useful to understand how PFP systems are verified as meeting the specification for an installation.

Much of these considerations and concepts are discussed in more detail in the PFPNet Document “General Guidance on Testing, Assessment and Certification of PFP – Part 1”

The certification of performance provided by the accredited certification body takes the form of a Type Approval, a 3rd party approval, listing or certification. This can be provided through a combination of a review of any testing alongside a design assessment that the certified body undertakes and confirms that the PFP design is appropriate for the project. In all cases the approval/certification will state the PFP design and its range of applicability.

A project may also decide to accept the results of tests or assessments that are not certified by the accredited body and are outside the certification process described above. These results may take the form of a test report, which can be witnessed, or analysis/assessment report, or a combination.

Fire resistance testing is well covered by the certification process, as is some weathering testing where the weathering is combined with fire testing. Other forms of testing to satisfy other hazards or threats are less clearly defined, largely due to testing being ad hoc, and therefore careful scrutiny of evidence is required to ensure that the specification is met.

Steel elements of construction and decks and bulkheads have test standards that are clearly documented and understood and are supported by third-party certification providing independent verification of the information provided. Such items are therefore generally well-specified, and compliance should be relatively simple.

For non-coating PFP systems, such as those used to protect valves or other components, certificates will describe the design that was tested, its range of applicability, and document the fire resistance performance over a specific duration. Due to the lack of recognized test standards, a greater level of scrutiny will be required for PFP that is intended to protect vessels, valves and other equipment items.

The importance of a clear specification is essential to ensuring that the correct PFP system is used for the specific requirements of the project.

Table 3 Minimum specification information required by PFP vendor to provide correct PFP

Criteria	Tick if provided
Identify the items that require PFP e.g. steelwork, vessel, valve, deck, bulkhead, etc.	
Provide details of items to be protected This is best done by the provision of drawing unless the structure is very simple where a cutting list might be acceptable.	
Construction material e.g. carbon steel, stainless steel, aluminum, etc.	
Operating temperature range – mainly for risers, piping, vessels, etc. This could be high or low temperature and may affect the selection of PFP material (e.g. the requirement for thermal insulation under passive fire protection).	
Design temperature range - mainly for risers, piping, vessels, etc. This could be high or low temperature and may affect the selection of PFP material. As short excursions to design limits may be tolerable, provide where possible anticipated duration. Provide reason for excursion, e.g. emergency depressurization, process upset, etc.	
Location e.g. coastal, offshore, inland, arctic, desert, etc. as this will affect the selection of PFP and associated protection systems such as paint, stainless-steel jackets, etc.	
Environmental conditions Associated with location and gives ambient and extreme temperatures, wet or dry, humid, saline, etc. however should include local climate effects (for example cold vessel operating in a hot environment will generate its own microclimate)	
Removable sections required? For example, valves may need access for inspection and removable PFP may be required.	
Fire Protection Requirements Define the fire scenario against which protection is needed, e.g. HC pool fire, jet fire, combined HC/JF, cellulosic.	
Required fire protection duration Give the time for which the PFP needs to protect the item against fire – in hours or in minutes and by fire type, e.g. 30 minutes pool fire plus 30 minutes is jet fire = 60 minutes total fire exposure. Use REI instead of A class and H class.	
Maximum Allowable Temperature What is the maximum temperature the protected item must not exceed at the end of the required fire protection duration, e.g. 400°C for structural steel.	
Explosion resistance required? Provide overpressure (and pulse duration if applicable). Provide details of items to be protected as the blast test data should be on comparable items	
PFP reinforcement and detailing requirement. Generally, this comes from PFP manufacturer's certification and application guidance, but some projects demand a specific requirement such as metal mesh on Norsok projects. State if this is applicable. If not leave to manufacturer's certification.	
Required test standards? Define any required test standards, e.g. ISO 22899-1, Norsok M501, etc.	
Fire Approvals required? Define any certification requirements such as DNV-GL, LR, etc.	
Durability performance required? State how long the PFP is expected to last with routine maintenance	
Steel substrate surface preparation May or may not be linked to the PFP system but where it is state requirement or refer to manufacturers recommendations.	
Steel substrate primer for use under epoxy PFP Essential that PFP specifier liaises with specifier of corrosion protection coatings, alternatively refer to manufacturer of PFP.	
Topcoat or other paint system required over PFP Essential that PFP specifier liaises with specifier of protective coatings, alternatively refer to manufacturer of PFP.	

Appendix A – Fire Response of Critical Structures and Equipment

Steel is a versatile construction material but in common with many other materials it is weakened in fire. The loss of effective yield strength of carbon structural steel with increasing temperature is illustrated below:

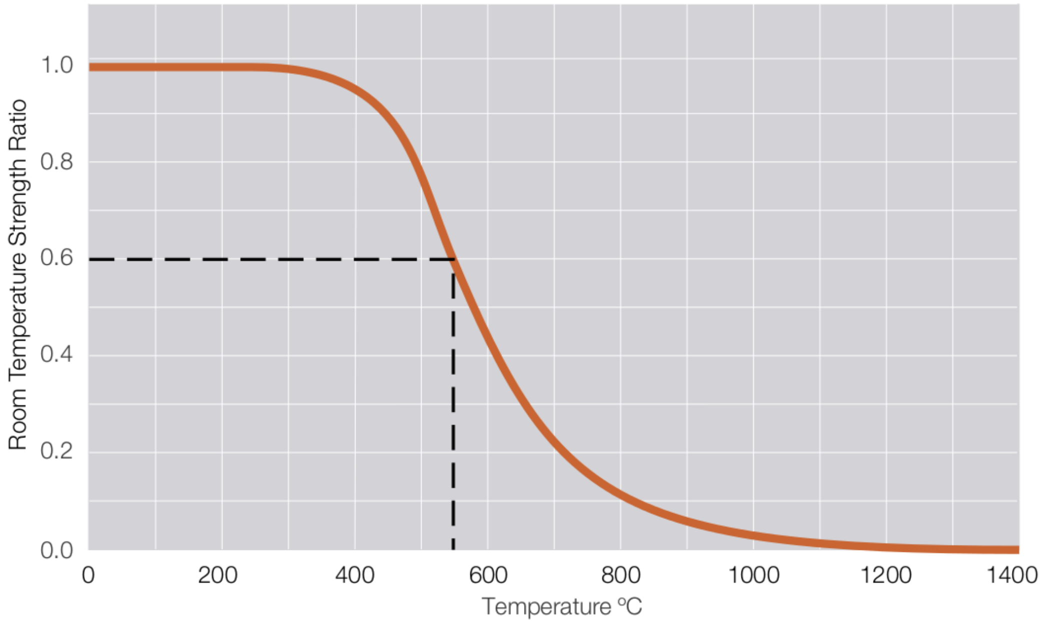


Figure A1 Yield strength reduction of carbon steel with temperature (Typical)

Steel structures

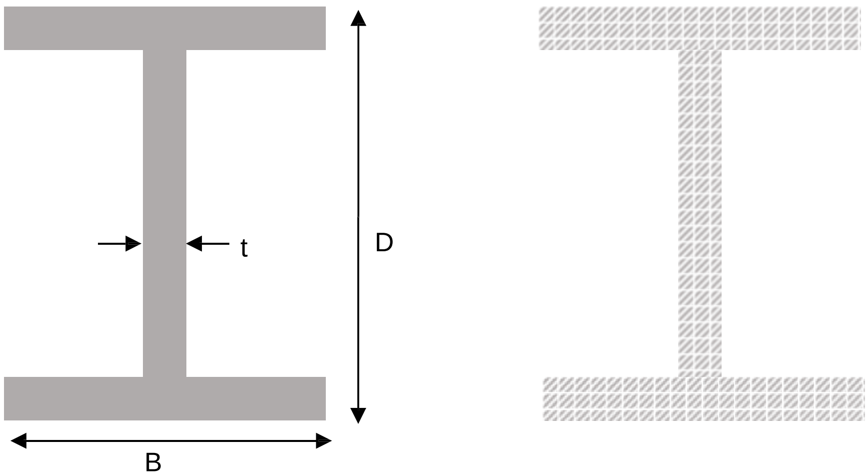
The aim of applying PFP to critical structures is to reduce the rate at which the steelwork heats up in a fire. This then extends the time that it takes for that structure (or part of a structure) to reach the temperature at which it becomes impaired. Impairment may mean total collapse or a progressive collapse that either directly endangers people (or the environment) or prevents people from escaping; or may lead to an escalation event that then endangers even more people than were originally at risk from the initial event. Where people can easily escape, such as at onshore facilities, then the PFP may be used to allow time to undertake firefighting actions so as to reduce the commercial loss to a business

The maximum temperature that the steelwork in a steel structure can attain without impairment will depend on many factors including the rate of heat input from the fire scenario, the shape and size of the steel in the structure, the live and dead loads imposed and any structural redundancy. However, for traditional PFP specification a maximum allowable steel temperature is generally given.

The rate at which a given steel element heats up and attains the limiting temperature in any given fire event is related to the shape of the element (H-section or hollow section), its size (mass or cross- section) and to the exposed surface area. This relationship is referred to as the ‘section factor’.

The section factor is often expressed as A/V (exposed surface area A divided by the volume V) in Europe; and historically in the UK as Hp/A (heated perimeter Hp divided by the cross-sectional area A). In the USA a similar term is used and referred to as W/D (weight of the section W divided by the heated perimeter D). A/P (cross-sectional area A divided by the heated perimeter P) is also used in the USA for circular hollow section elements.

In this discussion the term Hp/A will be used as it is still in common use in industry and is identical to A/V that is used in many building industry standards and guidance for structural steel protection. A brief explanation of W/D will also be given later. It follows from above that a steel section with large mass will heat up more slowly than a section of similar size with a low mass. Similarly, a surface area exposed to fire that is large will heat up more quickly than one that is small.



Heated perimeter (m) = 2B + 2D + 2(B-t)
= 4B+2D-2t

Cross-sectional area

Figure A2 Hp/A description

The equation for the calculation of Hp/A (and A/V) is:

$$\frac{Hp}{A} = \frac{Heated\ perimeter\ (m)}{cross\ sectional\ Area\ (m^2)} \qquad Units = \frac{m}{m^2} = m^{-1}$$

Section factor is important for determining the thickness of the PFP required enabling a given section to remain below its limiting temperature for a defined fire duration. A light thin section will need greater PFP thickness than a small heavy section and so PFP thickness can be tailored to the actual steel elements used in the structure, rather than providing too little or too much PFP with consequent safety or cost/weight implications. Lower Hp/A values require less fire protection thickness compared to higher Hp/A values. The same method is used to calculate the Hp/A of hollow sections where the dominant factor is the steel wall thickness.

In the USA, a similar concept used for H-section steel is known as W/D, which is the ratio of the weight (lbs.) of the section per linear foot divided by the heated perimeter (inches).

$$\frac{W}{D} = \frac{Weight\ per\ linear\ foot\ (lb)}{Heated\ Perimeter\ (inch)}$$

For hollow sections in the USA the term A/P is used and has the following equation:

$$\frac{A}{P} = \frac{Cross\ sectional\ Area\ (in^2)}{Heated\ Perimter\ (in)}$$

When determining the required PFP thickness for a given steel section for a specified design fire scenario consisting of fire type, duration and limiting temperature reference will typically be made to published (and certified) tables from organization such as UL and the Classification Societies. PFP thickness is then a simple ‘look up’ from these tables.

Fire Barriers

Fire and blast barriers segregate areas of high fire risk from areas of low, or no fire risk. They are designed to prevent the passage of flame, smoke and hot gases and may be insulated to prevent heat transfer to the non-fire side.

Failure of fire separation barriers may lead to the integrity of the barrier being compromised, no longer preventing the passage of flame and hot gases. Inadequate or failed insulation may allow the conduction of heat such that personnel or equipment on the non-fire side are compromised.

The optimization of PFP as part of performance-based design is discussed in this document, however, for the majority of projects where PFP is required, the specification is typically done by reference to ‘A’ and ‘H’ ratings where certified PFP thicknesses are established by reference to certified data issued by Classification Societies.

Further details relating to this are given in Appendix B and in the PFPNet Testing, Assessment and Certification (TAC) guidance documents.

Process Vessels

In Section 7.3 the optimization of PFP as part of performance-based design is discussed, however, for many projects where PFP is required, the specification can be somewhat ambiguous as there is limited guidance in this area.

Traditional design practices typically use API RP 520 / 521 to design pressure relief systems where typically the requirement for EDP systems is to reduce vessel pressure to 50% of design pressure, or to 6.9 barg in 15 minutes. These standards also allow for vessel thermal insulation (which can include PFP) to be considered when designing the relieving system (using the so called ‘F factor’). Exactly how the required thickness of PFP for fire protection is determined can be ambiguous. Some manufacturers will have undertaken fire testing on pressure vessels, whereas others will provide data based on other testing that may or may not be relevant. Where test data is provided it will be presented either in a test report or as a ‘verified’ thickness, however, caution is advised to ensure that the testing conducted is relevant to the protection of a pressure vessel containing flammable inventory.

Further details relating to this are given in the PFPNet Testing, Assessment and Certification (TAC) guidance documents, and in guidance published by the Energy Institute.

Risers and pipelines

Risers and onshore pipelines containing pressurized inventory will respond to fire in a similar way as pressure vessels. The failure of a riser offshore is a major incident that can result in the complete loss of the platform and these may need fire protection from just below the water line (in the case of a fire on the sea surface), and/or along the deck to the first ESDV. Risers between the sea surface and the deck may also need to be protected against other threats such as debris, corrosion, impact, etc. Riser fire protection, particularly close to the sea surface is quite specialized and bespoke solutions are generally used.

Onshore pipelines are often buried with a minimal length exposed above ground. This exposed section, along with the first ESDV may be protected, although there are cases where only the ESDV is protected.

Where ESDV are protected then it may be necessary to protect the valve body, the actuator and the associated control systems where a valve does not ‘fail safe’.

Risers and onshore pipelines carrying hydrocarbons may be the subject of specific regulation in certain jurisdictions in the world.

Valves and Actuators

The valves primarily protected with PFP are those involved with ESD and isolation; and those that provide EDP.

When exposed to fire, the seals within the valve body may fail and result in escalation. Where valves are not designed to ‘fail safe’, then the actuator will need to remain operational and should also be protected with PFP as should any control elements such as pneumatic accumulators, control lines and cables.

For fail-safe valves it is generally considered unnecessary to protect the valve and actuator. On occasions it is determined that the fail-safe valve body needs fire protection. Even in fail-safe valves, fire exposure of the valve body can prevent the valve from operating correctly and seals to fail, allowing internal leakage through a closed valve.

Depending on the capacity of the flare system, EDP may need to be sequential with a time delay between groups of valves and in these cases, fail-safe valves and associated actuation systems may need PFP in order that they do not close prematurely and disrupt the correct sequence. Therefore, for ESD and EDP duties both the valve and actuator may require protection, or they shall have inherent fire resistance.

‘Fire-rated’ (or ‘fire-safe’) valves are tested to prove operability during a fire test, however, the following should be recognized:

- There are several standard fire tests and they are not all equal.
- The test conditions (fire size and duration) are less severe than conditions anticipated from a hydrocarbon pool fire or jet fire.
- The inventory pressures used to validate seal effectiveness may be significantly less than those of gaseous hydrocarbon lines.
- Actuators are not normally included in the tests.

As with all fire ratings, valve selection should be based on performance requirements set against the potential fire type, duration and design heat load.

Flanges

Flanges can leak in a fire within 5 minutes (FABIG technical note TN 8) from loss of tightness due to thermal expansion of the bolts. Thermal degradation of flange gaskets may also occur. Flanges leaking flammable inventory clearly pose a threat to safety and flanges should be kept to a minimum by design but cannot be avoided completely.

Wafer flanges (or ‘long bolt’ flanges) are more prone to failure from fire exposure than standard short bolt flanges, because the longer bolts are more susceptible to heat distortion, there is a greater exposed surface between the two faces, and there are two joints at each flange from which inventory may leak.

PFP fitted to exposed flanges can delay the thermal effects of fires that may prematurely affect bolts and gasket. Note that PFP materials are not used to prevent flange leaks that might occur due to normal mechanical failure.

Flare and Vent Systems

Flare and vent systems provide a critical safety function and may be required to operate for significant durations under emergency conditions. Failure of the vent/flare support structures may result in rupture of the lines with major escalation into areas not significantly affected by the initial fire.

Often it is considered that the vent/flare lines (headers) themselves do not require PFP due to the cooling effect of the flowing inventory but there may be dead leg situations where flow does not occur, and these may need to have PFP protection. A full assessment of the system is recommended.

Critical Cabling and Control Lines

Cabling will thermally degrade when exposed to heat fluxes well below that at which damage to plant or equipment items is expected to occur.

The need to protect critical cabling and control lines is often overlooked and routing of these is usually based on ease of installation. PFP protection for cables and lines is either by using fire resistant products, or by enclosing non-resistant cables/lines in a PFP material.

Care should be taken when specifying PFP protection to cabling as the additional insulation can result in elevated operating temperatures, which may in turn lead to operational issues.

PFP is not the only passive protection measure for critical cables and control lines. Other passive options include dual routing, underground routing, and routing outside of the identified fire zones.

Failure of such control systems may mean that a safety critical valve assembly cannot be successfully operated during a major accident event.

Appendix B - Fire Rating of Barriers (Decks and Bulkheads)

Fire barriers are generally rated according to International Maritime Organization (IMO) Resolutions and tests identified in FTP 2010 Code. For cellulosic fire threats barriers would have A-Rating (and occasionally B-Rating) and for hydrocarbon fires, an H-or J-Rating. Often these ratings are applied by engineers to structural steel members which generates confusion in relation to the PFP requirements for these items. ISO 20902:2018 has recently been published, dealing with testing of barriers in hydrocarbon fire. The recommendation in this standard is to use the REI system to describe the barrier performance, rather than use the H-Rating system, although the standard does cross- reference the IMO system.

Commonly used fire ratings required offshore are listed in Table 2 which uses the IMO system of rating. The number following the A or H is the insulation time in minutes for which the temperature-rise on the 'non-fire side' of the division must remain below 140°C (mean) or 180°C (maximum). A0 and H0 are cases where the required insulation time is 0-minutes, i.e. no insulation is required. In all cases the division must also maintain stability and integrity throughout the duration of the test which differs depending on rating.

- Stability refers to the load bearing capability of the division (including self-weight) and,
- Integrity refers to the capability of the barrier to remain in place and not distort such that the passage of flame, smoke or hot gases can occur. This also applies to any openings in, or penetrations through a barrier such as windows, doors, pipes, cables, etc.

Table B1: Designation of A- and H-Rated Divisions

Designation	Limiting Temperature (LT) °C	Insulation time to LT (minutes)	Stability and Integrity**
A15	140/180	15	60
A30	140/180	30	60
A60	140/180	60	60
A0	Not defined	0	60
H60	140/180	60	120
H120	140/180	120	120
H0	400*	0	120

*For certification purposes 400°C is typically taken as the limiting temperature value (200°C for aluminium).

** For A-rated divisions with a steel core that are insulated on the exposed side only, and have no openings, then the test may be terminated when the limiting temperature is reached.

For jet fires there can be confusion over the use of nomenclature for ratings. Typically, one will see for example: H60/J30, or may come across the designation J0. For H60/J30 people typically mean an H60 division with a total hydrocarbon fire exposure of 60 minutes with 30 minutes of the total 60 minutes being a jet fire exposure. The use of J0 is ambiguous and is best avoided unless a clear definition is given (e.g. J0 – maintains integrity when exposed to jet fire for 120 minutes).

The rating system used in ISO 20902:2018 defines three parameters:

> **R = Stability (Load Bearing Capacity)** – this is the ability of the element under test when exposed on one or more sides to support the imposed load during the fire duration.
>
> **E = Integrity** – this applies to fire separation barriers as it is the ability to prevent the passage of flames and hot gases when exposed to fire on one side.
>
> **I = Insulation** – this is the ability of the test specimen exposed to fire on one side to limit the temperature rise on the unexposed side below specified limits.

According to ISO 20902 this information should be presented as follows:

Fire exposure type / protected element / Structural stability rating (R) / Integrity rating (E)/ Insulation rating (I).

Problems can occur when using the H-class rating rather than the REI system. This is because, unlike A-class ratings, the H-class is not strictly defined and so misunderstanding can occur.

For example, a specification may call for H120 pool fire resistance when in fact what they really require is H0.

Jet fire ratings and combinations H and J ratings also lead to confusion. For example, PFP is required to provide fire protection performance of H60/J30. Does this mean 60-minute hydrocarbon pool fire followed by a 30-minute jet fire (i.e. total fire duration of 90 minutes), or does it mean a total fire duration of 60 minutes with 30 minutes of this fire a jet fire and 30 minutes pool fire?

Use the fully detailed nomenclature proposed in ISO 20902 (REI) would avoid misunderstanding.

Once the requirements for PFP have been determined then the actual thickness of the PFP protection system is most often taken from certificates issued by Class Societies such as ABS, DNVGL, LR, etc.

Penetrations through Barriers

The key criteria for penetrations through fire barriers is that the rating of the barrier must not be reduced by the hole or opening in the barrier. There are many reasons why barriers are penetrated but the most common ones include the passage of services (pipes and cables), windows and doors, and heating/ventilation ducting and fire dampers.

Where a barrier is required to provide both a fire and blast protection, then it is essential that the installed PFP does not downgrade the fire rating or the blast rating. This means that the PFP must be capable of withstanding the required blast performance as well as the required fire performance.

Penetrations must be designed and tested with the performance requirements of the barrier in mind. The construction of the penetration seal, door, window, etc. is of fundamental importance.

It is recommended that specifiers ensure that either a certificate, or a suitable test report are available that includes not only the designation of the penetration system and the tested fire and blast load, but also describes in detail the construction of the tested system to ensure that this matches as closely as possible the performance requirements. Bespoke systems should deviate from 'as-tested construction' as little as possible and any required engineering judgement should consider all facts as described.