Guidance on Passive Fire Protection for Process and Storage Plant and Equipment

Draft 1st edition
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Draft for stakeholder review. Please record general and specific comments on the proforma and send to Sam Daoudi sdaoudi@energyinst.org by 23rd October 2015.

Not to be referenced or used until technically finalised.
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1 Introduction, Scope and Application of Passive Fire Protection

1.1 Introduction
This guide brings together the knowledge and ‘good practise’ of many specialists and practitioners within the hydrocarbons and passive fire protection industries, including major asset owners, design engineers and consultants, fire protection specialists, Competent Authorities (CA’s) and PFP manufacturers.

This document aims to provide guidance on the use of PFP materials and their application across the life cycle of an asset. In this respect it has been set-out to work through from the initial determination of PFP requirements, specification of PFP performance, material details, application and ongoing inspection, maintenance and the effects of changes on PFP duty.

It was identified that there are a number of good standards and guides in existences that deal with parts of PFP use and application. However, these have suffered from being focused on specific applications e.g. Structural or Vessels or have been too general and broad in application e.g. use of default performance durations to generic fire types. This guidance document has aimed to provide a PFP overview to enable PFP to be fully integrated in the arsenal of Major Accident Hazard control and mitigation measures.

1.2 Scope
This guidance in this document applies to the use of Passive Fire Protection (PFP) materials for the fire exposure protection of Process and Storage Plant and Equipment in a fixed location, whether that facility is onshore or offshore.

It is therefore applicable to the use of PFP materials on items such as the main process unit structural steelwork, Process Vessels, Storage Vessels, Process Pipework, Emergency Shutdown Valves (ESDV), Control Valves, Bolted Flanges, etc. It also includes the support structures for equipment items (e.g. vessel saddles and skirts, steel pedestals, lugs), etc. The guidance does not address the use of PFP materials within civil ‘building’ structural elements neither does it cover fire walls/barriers as these subjects are covered in other literature.

The guidance is not intended to cover mobile items such as road, rail and sea tankers, however, if PFP materials are required to protect the equipment that is used to fill these mobile items, such as fixed storage and transfer systems to the mobile units then this equipment is included.

It is important to recognise that this document is a guide and as such is not a prescriptive set of ‘rules’ that must be followed. Neither is it a detailed ‘how to’ assessment procedure. It aims to provide overriding guidance to those who select, specify and have ownership of PFP materials as part of fire protection measures.

1.3 Application
The process asset duty holder has a responsibility to ensure that, in respect to Major Accident Hazards (MAH), all legal requirements are complied with, that all hazards are identified and documented and that all risks are fully understood and mitigated where necessary. One aspect of
mitigating risk from the Major Accident Hazard from fire in the hydrocarbons industry is by the use of passive fire protection (PFP) materials. This guide aims to assist the duty holder in the selection and use of PFP materials as part of MAH risk management.

This guide has focused only on the function of PFP materials and not on their handling. The user is reminded that some if not all PFP materials are likely to have safe handling considerations and therefore the Materials Safety data Sheet (MSDS) should be read and any local or national legislation complied with.

1.4 Who should use it
The guidance should be useful to operating companies, consultancies, EPC contractors, regulators, inspection service companies, etc. to help them to understand the issues, specify requirements, make decisions, and manage PFP on an on-going basis. Although not specifically intended for PFP manufacturers, it will help to inform them on issues associated with PFP use and application.

1.5 Existing vs new build
This guide is intended to provide a better understanding of the selection, specification and application of PFP materials. As such it applies equally to both existing assets and new projects.

1.6 UK only or EU/Worldwide
This guide has as far as possible referenced internationally recognised standards including those sourced from the UK, USA and Norway. Although written with a UK centric focus the authors feel that it should be applicable to assets and projects world-wide.
2 Process Fire Hazards and the use of Passive Fire Protection

This section provides background information on the use of passive measures to control the risks associated with process fire hazards. The intention is to show that passive fire control and mitigation is not just achieved from the application of PFP materials.

Process fires present a complex range of fire hazards and associated risks. Fire risks are determined by the type of fires, the potential for escalation and the severity of the resultant consequences.

Fire safety was historically based on a prescriptive selection of a range of fire protection measures, amongst which was the use of Passive Fire Protection materials. However, the complex nature of fire hazards within the process industries means that it is preferable to base the selection of fire protection measures on a ‘risk assessment process’, which should form part of the overall Safety and Environmental Management System (SEMS) employed by the asset owners and operators. This ‘Risk Based Approach’ is captured in the latest safety legislation replacing, to a large extent, the reliance on prescriptive selection of fire protection measures.

Fires are the oldest process hazard and have the most complex associated risks. Fires have two distinct phases:

- Fire start, which can also be coupled with Explosion events, and
- Fire escalation.

The ultimate consequences of a combustion event will depend upon the type of fire and the factors which allow the fire to escalate.

Where there is a combustible material and an available oxidiser, a fire hazard will be present. The risks associated with this fire hazard require the selection of appropriate measures (also known as barriers) in order to limit the likelihood for fires to start; or once started the potential for the fire to escalate. These measures fall into one of four generic types, which in order of decreasing integrity are:

- Inherent
- Passive
- Active
- Procedural.

These measures can be applied at different stages in a fire event life cycle. The earlier that a measure can be applied the more powerful the measure is in controlling the associated risks. A hierarchical approach to the selection of measures in fire scenarios should be undertaken. This hierarchical approach, for example, can be seen in ‘The Offshore Installations (Prevention of Fire and Explosion, Emergency Response) Regulations 1995 (commonly known as “PFEER”) [1] and is also outlined in the Oil and Gas UK ‘Guidance on Risk Related Decision Making’ [2] and in the Energy Institute Guidance - IP 19 ‘Fire Precautions at Petroleum Refineries and Bulk Storage Installations’ 3rd edition [3].

Measures should be selected by reviewing the following hierarchal stages in the development of a fire. The risks associated with this fire hazard require the selection of appropriate measures (also
known as barriers) in order to limit the likelihood for fires to start (prevention barriers); or once started the potential for the fire to escalate (mitigation barriers). This has been highlighted in the recent EI document “Guidance on applying inherent safety in design: Reducing process safety hazards whilst optimising CAPEX and OPEX” [4]

- Elimination and minimisation of hazards by design (inherently safer design);
- Prevention (reduction of likelihood for fires to start);
- Detection (transmission of information to control point);
- Control (limitation of scale, intensity and duration of fire event);
- Mitigation of consequences (protection from the effects of a fire event);
- Evacuation, Escape and Rescue (EER) also including Emergency Response.

API 14J ‘Recommended Practice for Design and Hazards Analysis for Offshore Production Facilities’ [5] provides a good definition of Passive fire protection as ‘any fire protection system that by its nature plays an inactive role in protecting personnel and property from damage by fire’.

It is very important to note that Passive fire protection is not just the application of insulating materials, which is the focus of this guide. Examples of other passive features in fire risk management include;

For Prevention (of fire start) passive measures include:

- Design standards (prevention of loss of containment)
- Flame barriers (flame / detonation arrestors)
- Ignition source Control (earthing, equipment rating)
- Prevention of flammable atmospheres (though natural ventilation)

For Control (limiting fire escalation) then passive measures will include:

- Layout and spacing, including orientation
- Equipment design, including material selection and wall thickness
- PFP material application (see next section),
- Liquid containment (including bunds, drainage and fire water run-off)
- Physical segregation (fire walls, fire doors)

The focus of this guide is on Passive Fire Protection (PFP) as materials applied to, or installed on process plant and equipment. However, in determining appropriate fire protection measures the additional non-PFP fire measures noted above, should also be reviewed when undertaking the initial fire risk assessment - see section 3.

PFP will not prevent the initial fire event from occurring. An amount of damage to personnel, plant or equipment may occur irrespective of how much, or how little PFP has been installed. This loss would be associated with the initial fire and explosion event. The role of PFP is to mitigate the thermal effects and thereby limit the potential for fire escalation. This is of particular benefit for small and medium fire events in order to reduce the risk of escalation occurring with significantly
larger consequences. PFP achieves this by controlling the rate at which energy from the fire event is transferred to the underlying structures and equipment.
3 Determining the need for PFP

This section provides detail of the processes that assets should employ to understand their fire hazards and the selection of appropriate measures to control the fire risks. This can be through Fire & Explosion Hazards Management (FEHM) onshore, or Fire & Explosion Strategy (FES) offshore as examples.

3.1 The role of Process Hazard Assessment

All current major process safety legislation has a requirement for a Safety and Environmental Management System (SEMS) to be in place where operations have the potential to cause harm. Within the framework of the SEMS the operator should be able to demonstrate that it has an effective means to identify and manage fires and explosion on its process installations. This should be determined through Process Hazard Assessment (PHA) of the MAH. The output of this assessment process should be the determination of the appropriate measures, including PFP or AFP, required to control the risks associated with identified MAH fires, to levels that meet a defined risk criterion, such as in the UK a level ‘As Low as Reasonably Practicable’ (ALARP).

When it comes to the determination of measures required for controlling and mitigating fire hazards the PHA method should be the application of specific Fire Risk Assessments (FRAs), examples of the Fire Risk Assessment process are shown in the Fire and Explosion Hazard Management (FEHM) process - see IP 19 [3], and the Fire and Explosion Strategy (FES) - The process that uses information from the fire and explosion evaluation to determine the measures required to manage these hazardous events and the role of these measures in ISO 13702 [6]. Fire risk assessments have a different focus to other process hazard assessments methods, such as HAZID and HAZOP studies; although fire risks may still be identified as part of these other methods. A key part of FRA is the consideration of escalation factors and ultimate worst case consequences which are not typically covered by other PHA methods.

Fire Risk Assessments need to consider the full range of fire prevention, detection, control and mitigation measures that could be applied. These measures, however, need to be applicable to the type and scale of the fire hazard - see section 4, and will vary from asset to asset. The EI guidance note IP19 [3] sets out good guidance on overall FEHM practices and in particular the role of fire scenario analysis as the first step leading to the determination of the fire hazard design/credible scenario selection.

Failure to adequately define and assess process fire hazards has been a key feature in the lack of PFP usage on critical plant and structures. Selection of PFP has often been seen as a prescriptive building design feature rather than as a specific measure in process hazard assessment. For example a ‘prescriptive’ design for PFP is generally based on industry recognised standards and guidance intended to comply with regulations, insurance requirements or company procedures. ‘Site-specific factors’ may not be fully considered and the design has a more generalized approach based largely on past incidents and experiences. One common ‘prescriptive’ approach to the determination of PFP requirements for onshore facilities is the use of the American Petroleum Industry standard ‘API Recommended Practice 2218: Third Edition, July 2013: Fireproofing Practices in Petroleum and Petrochemical Processing Plants’ [7]. However, this focuses on PFP application to structural steelwork exposed to Pool fire conditions and does not cover use of PFP in other fire protection
duties and under jet fire conditions. This is a weakness in the use of prescriptive standards for the determination of PFP requirement.

The UK Health and Safety Executive (HSE) provide a good overview of the levels of risk assessment in its guidance note ‘Guidance on Risk Assessment for offshore Installations’ Offshore Information sheet No. 3/2006 [8]. Depending on the severity of hazard consequences and the complexity of the risk, the types of ‘risk assessment’ range from qualitative, through semi-quantified to fully quantified. What is the difference? This is related to the level of assessment undertaken to identify the hazards, assess the nature of the hazard development from cause to ultimate adverse consequence, and the determination of the effects of prevention, control and mitigation measures on both the ultimate consequence and the likelihood of the consequence being realized.

In regard to Fire Risk Assessments, Qualitative assessment will include a qualitative review of the fire scenarios using basic ‘what if’ and HAZID type studies and then application of appropriate standards and guidance in the determination of appropriate fire measures, including PFP. Semi-quantified assessments include HAZOP and other assessments using judgment models and risk matrices to determine ‘order of magnitude’ consequences and likelihoods, an example fire risk matrix is shown in IP 19 [3]. Quantified assessments will include specific modelling of the fire cases. It may also apply numerical determinations of consequence likelihoods based upon initiating (cause) event frequencies and failure probabilities of control and mitigating measures.

What determines selection of qualitative, semi-quantified or quantified risk assessment? This should be based upon two linked criteria of consequence severity and complexity of the risk. For example multiple fatality events should have quantitative risk assessments no matter what the complexity of the risk. In regards to complexity - this is often thought of as complexity of the production process or operation to which the hazard and risk are associated, whereas, it should be based upon the complexity of the hazardous scenario which is critical. In regards to Fire hazards this is the complexity of the event from initiating causes, through initial fire case through escalation to the ultimate undesired consequences.

Qualitative fire risk assessment is the basic application and compliance to appropriate codes and standards. This prescriptive compliance can also be considered as following recognised ‘good’ practice standards and Guidance and as such is a minimum risk management requirement. Selection of PFP based upon further review and detailed assessment of the site specific fire scenarios, as part of a fire risk assessment, is now seen as more comprehensive identification and selection practise and a number of standards call for the selection of PFP to be on this basis. In addition more detailed ‘quantified’ assessments of the fire hazards should lead to the minimisation of PFP (and AFP) measures compared to prescriptive application. This is in general due to the conservative nature of prescriptive standards.

The following subsections detail the use and application of PFP materials, within the scope of this guide. This PFP use information should be used to aid in the undertaking of the initial Fire Risk Assessment, namely the Hazardous scenario determination and selection of appropriate measures. This is supported by section 4 which provides details on the types of fires PFP may be exposed to and
section 5 which details both the prescriptive and more quantified performance requirements of the PFP materials once selected.

3.2 The concept of Safety Critical Elements (SCE) and PFP

The EI document ‘Guidelines for the management of safety critical elements’ 2nd edition, 2007 [9] defines Safety Critical Element’s (SCE) as any part of the installation, plant or computer programmes 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.

One of the potential failure mechanisms for these SCEs is as a result of exposure to fires. The thermal exposure of the SCE then results in its failure. PFP materials, as part of the scope of this guidance note, will therefore provide a thermal barrier that protects the integrity of the underlying SCE for a finite period, when exposed to fires.

The following outline individual SCE’s as appropriate fire protection measures in preventing escalation in typical process plant operations where integrity under fire conditions is required. Hence these are the areas in which PFP materials also need to be a selected fire protection measure to ensure the underlying SCE integrity.

3.3 PFP as an ‘SCE in its own right’ - Fire walls / Temporary Refuges / Occupied location protection.

Although the following is outside the scope of this guidance note it is considered beneficial to provide a brief overview of PFP used in this context.

These are in general fire and in some cases explosion, rated segregations that prevent the spread of fires to areas with ‘at risk’ occupancy. This also applies to general structural steel work where the integrity of the structure is required in order to facilitate escape from a fire incident. PFP materials can be used to provide both fire rated segregation and protection of general structural steel work.

Penetrations through fire rated segregations (fire and blast walls) should be protected to the same level as the main segregation. Such penetrations include pipework and cabling.

3.4 SCEs - Primary containment

In the application of PFP this is typically the protection of primary process containment provided by the walls of major process vessels and connecting pipework containing inventories of hazardous materials. The failure of process containment under fire exposure can lead to the release of significant inventories of hazardous materials resulting in major escalation of the initial fire event. The aim of the PFP is to delay failure to the point either beyond the duration of the expected initial fire cases, or until the consequences of failure will not significantly increase the event consequences e.g. failure occurs after personnel escape or, if coupled with inventory depressurisation, at a point where remaining inventories, if released, will not significantly increase the consequences.

The following thermal failures and uses of PFP are required for primary containment integrity.

3.4.1 Isolated inventory - Process vessels and pipework - pressurised failures.

Two mechanisms will apply to trapped inventories that can lead to failure of the primary containment.
3.4.1.1 Over pressurisation failure -
Thermal exposure of trapped process inventories will result in an expansion of the contents with resultant increase in internal pressure. This can exceed the design ratings of the vessel/pipework and lead to overpressure failure. PFP may be applied for this mechanism to limit the rate of energy transfer to the trapped inventory in order to reduce the sizing of pressure relief devices. PFP application on its own will normally be insufficient to prevent thermal over pressurisation of isolated inventories.

3.4.1.2 Thermal weakening failure –
Where the walls (shell) of a vessel are heated by the exposing fire case. For process vessels under pressure there is also the potential for a pressurised failure at or below the maximum allowable working pressure (MAWP) of the vessel, due to loss of strength of the containment wall at elevated temperatures. This will generate a sudden catastrophic pressurised release. If the contents are liquids at temperature well above their atmospheric boiling points this can cause a Boiling Liquid Expanding Vapour Explosion (BLEVE) event. Such pressurised failures can have catastrophic consequences for safety of life, environment and surrounding plant and equipment. Vessels and pipes under internal pressure and in a fire are subjected to both an increase in internal pressure, rising to the set point of the over pressure relief devices, coincident with a weakening of the pressure envelope (the walls). When the pressure envelope becomes too weak to contain the pressure inside rapid catastrophic failure will occur. It should be noted that operation of a pressure relief device is only to limit the maximum pressure a vessel could experience - see over pressure case above. Thermal failure due to wall weakening can occur at pressures at or below the maximum working pressure of the vessel. Pressure relief devices are hence not protection against this thermal weakening failure mechanism on their own. PFP is fitted to the external surface of the vessel to reduce the rate at which the wall of the vessel increases in temperature.

Low pressure Process vessels without significant internal pressure can also suffer wall failure from thermal exposure, both though generation of internal pressure and wall weakening. But without the coincident pressure release as the vessel should fail at a low pressure. The extent of escalation, following the loss of containment, is unlikely to be significant when compared to the initial exposing fire case consequences. The exception to this is usually were there are significant inventories e.g. low pressure storage tanks, in which cases PFP application is an option but is generally not cost effective due to the large surface area to be protected and AFP (active fire protection e.g. water deluge) may be used as a suitable alternative.

3.4.1.3 Vessel supports failure from thermal weakening –
If the supports for a vessel are weakened in a fire such that they can no longer support the load imposed by the vessel, it may collapse. This may lead in turn to severed connections and subsequent leaks that can ‘feed’ a pool fire, or a pressurised release that can ‘feed’ a jet fire. In a worst case scenario the entire vessel may collapse and fall onto other plant items potentially causing even greater escalation. Often the vessel and its support (e.g. saddle or skirt) will be located in a steel frame which itself will need to have PFP applied.

3.4.1.4 Flanges thermal failure –
Piping is used to carry inventory from one item of process equipment to another and as flanges are a source of leaks they should be kept to a minimum although they are essential for many reasons and so cannot be avoided completely. A flange leaking flammable inventory can create a pool of fuel if liquid, or vapour cloud if gaseous. These may build up to an extent where either a fire or a vapour
cloud explosion (VCE) can occur. PFP will not stop leaks but PFP is fitted to flanges to prevent heat from a fire causing flange bolts to loosen and in turn ‘feed’ the fire escalating the event¹.

### 3.5 SCEs - Secondary systems protection

These are related to failures that prevent interaction with other inventories, or SCE that are being used to mitigate the event consequences. Such items include fire protection to fire water pump enclosures, flare and vent headers and systems, detection, alarm and emergency communication systems; and emergency shutdown systems, including valves, actuators and any power/instrument and hydraulic systems required to initiate or maintain the function of critical shutdown systems. Fire exposure failures to be considered are:

#### 3.5.1 Valves and Actuators

Valves in a process plant fulfil many varied uses but in relation to fire safety they are used to isolate sections of inventory (ESD) limiting the quantity available, or to depressurise isolated sections in an emergency situation – Emergency Depressurisation (EDP). It is important to protect the valve body from the effects of heat as seals may fail quickly in a fire leading to leakage and possible escalation. Unless a valve is ‘fail safe’ then the actuator will need to remain operational in a fire; and where the valve is protected and the actuator is not, heat may be conducted through the actuator to the valve within as little as 15 minutes after the start of the fire².

#### 3.5.2 Structural support to Flare /vent systems

There is typically no requirement to provide thermal protection on the vent/flare lines themselves. This is typically because these lines are in elevated positions and hence are less likely to receive significant thermal exposure from pool fire conditions. Jet flames may cause vent/flare line failure but the operating pressure inside the vent/flare line will be low and the resultant fire escalation will be small compared to the impinging jet fire. Vapour flows through vent and flare lines will also provide some internal cooling, which may be significant if depressurising from high pressure sources due to Joule-Thompson (JT) effects. This internal cooling will also protect the vent/flare lines under fire conditions. Of greatest concern for vent and flare systems is thermal exposure to the supporting structure. Failure of the vent/flare supports will result in twisting and potential rupture to the lines. This could result in the release of large amounts of hazardous vapours from the vent/flare system. In the worst case this could be into areas that were not significantly affected by the initial fire case and would result in significant escalation. The structural support to vent and flare lines should be provided with PFP for pool fires where the vent and flare may be required in emergency response e.g. depressurisation.

#### 3.5.3 Critical cabling - Power and instrumentation (also critical pneumatic and hydraulic lines)

The insulation on cabling will thermally degrade when exposed to heat fluxes well below that of expected damage to plant items. Ignition of cable insulation should be considered as a particular failure mode for critical cabling. A review of cabling passing through fire zones (pool fire affected areas and incident high heat fluxes from jet fires) should be undertaken to identify potentially critical cabling and control lines as the criticality of these lines is often overlooked in other studies and the routing of these cables and lines is usually based upon ease of installation. PFP is not the sole passive

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¹ FABIG technical note TN8 [10] makes reference to testing of unprotected flanges where flange nuts sheared off bolts within 5 minutes after the start of a hydrocarbon fire.

² FABIG Technical Meeting January, 2004
fire protection measure for cable and critical control line protection. Other passive options include ‘dual routing’ and routing outside of the identified fire zones. Care should be taken when apply PFP to cabling as, due to additional insulation, this can result in elevated operating temperatures in use that may in turn lead to potential signal/power failures.

3.5.4 Protection of fire pump rooms / UPS / Communication systems
This links into Temporary Refuge (TR) and occupied building type impairment studies and Escape, Evacuation and Rescue (EER)/occupied building assessments. This is outside the scope of this guide, but the requirement for passive fire ratings for these emergency response critical locations should be included in the Fire Risk Assessments.

3.6 Advantages of PFP vs AFP
When undertaking the review of the identified fire scenarios it is often the case that PFP and AFP are identified as providing similar functions - namely the thermal protection of underlying SCEs to provide integrity of those SCE under fire conditions. Hence there is often a case of PFP vs AFP determinations being made.

There is a benefit of PFP over AFP in the following areas:

- Where there is a potential significant fire water run-off concern then contaminated fire water run-off should be assessed. This may require retention of fire water run-off to prevent undesirable impact to adjacent environmental and drinking water locations. It should be noted that even some firefighting foams have been identified as environmentally harmful. Large quantities of fire water run off can also be difficult to contain, requiring large retention areas which may be difficult to accommodate on process sites.

- Where there are limits to fire water supply and application (including containment as mentioned above), PFP use compared to installed AFP deluge installation can reduce the fire water demands. In some cases aggressive fire response using large water application rates will require maximising fire water for mitigation use. In which case use of PFP will free up water supplies that could have been used for deluge based protection duties.

- Reliability of AFP systems. These are mechanical systems and can suffer failures such as blocking of nozzles, failure of valve operation, fire pump failures and failures of the initiating devices. In addition PFP is present prior to the initiation of an incident requiring no activation and hence has no response time. This could be a factor if initial fire cases develop quickly.

- Correct PFP selection, over AFP systems, will also have a reduced failure potential where explosion is a potential initial event concern. This is due to the fact that some PFP materials are resilient to blast over pressures which could significantly damage AFP, particularly deluge, systems. Explosion and impact resistance are discussed later in section 8.

- Jet fire cases. AFP systems cannot be demonstrated to provide thermal protection where impinging jet fires occur. The momentum in jet flames results in the shedding of water films at the point of impingement. PFP validation has been proven for jet fire cases. If jet fire protection is required, PFP should be considered as the only validated protection measure.
This guidance does not preclude use of AFP in combination with PFP; however, there is very little evidence of the benefit of combined systems other that AFP being provided as fire response e.g. firefighting via hose streams.

3.7 Potential disadvantages in the use of PFP materials

The above are factors that can be considered as positive in favour of PFP materials where SCE thermal protection is required. The following are areas in which negative PFP factors could arise.

These are often thought of as generic PFP issues, but are more often related to specific materials in inappropriate applications i.e. in poor selection of the correct PFP system.

- Increased corrosion of materials under PFP - the CUI case - see sections 11, 13 and 14. This has often been the overriding concern against application of PFP. This view has been driven by poor operational experience in the use of PFP materials where major CUI issues have arisen. This has not been the fault of the PFP materials but due to poor selection, poor application and poor ongoing inspection and maintenance of installed PFP systems.

- Flexibility in protection. PFP will only protect the SCE to which it is applied. AFP can provide flexible protection - particular where this is provided by mobile and oscillating monitors and through active firefighting. Fixed deluge, however, doesn’t have this adjacent system protection flexibility.

- Reduced access for regular inspection and maintenance of equipment protected by PFP materials - examples are blanket type PFP and failure to replace on valves etc. - see also section 12. This can also increase the time and manpower required for these regular maintenance activities to fit and replace/repair the PFP.

- Increased weight - this is more of an issue for offshore installations than onshore.

- Increased space requirement - this can cause problems in retrofitting PFP to existing equipment where there are insufficient clearances to accommodate the PFP material thicknesses.

- Increased explosion overpressure and increased Drag loads due to the increased dimensions of columns/beams/ pipework/ vessels as a result of the thickness of the PFP materials. However, it should be noted that fixed deluge type systems AFP will also contribute to increased explosion overpressure due to the presence of the deluge pipework adding to congestion.

- Maintenance of PFP - This is more of an ownership issue in that systems are often overlooked and seen to be part of fabric maintenance. As such there may be no budget allocated for the maintenance of PFP systems.

- Increased cost compared to AFP. This can apply where large areas require protection. This can be seen in the protection of large storage vessels, where application to the large surface areas would not be cost effective.

- Thermal operational requirements. Issues on cabling have already been detailed. In addition there may be thermal insulation requirements e.g. energy conservation. This can introduce operational issues that can affect PFP application and operation. Combined PFP and thermal insulation systems are possible and these are discussed later.
4 Fire types that PFP needs to protect against.

This section provides some background on the fire types that may impinge upon SCE and which may therefore utilise PFP in improving the integrity of the SCE under fire exposure conditions.

Although a Fire Risk Analysis may identify the type of fire events for which PFP is required, in order to determine the extent and performance of the PFP it is necessary to understand the extent and potential thermal and mechanical effects that these fires can generate. This is both in order to determine the required PFP performance in regards to limiting the protected SCE item temperature and the duration that this temperature limitation is required for. It is also required to correctly undertake the fire tests required to validate the specific PFP material performance.

The main fire types used to define and to test and ‘prove’ process PFP products include:

- Hydrocarbon fire Pool & Diffuse, Open and confined
- Hydrocarbon Gas and 2-phase Jet Fires

Other fires not considered within the scope of this guide:

- Cellulosic
- Translucent (clear) Flame - methanol - hydrogen etc.
- Chemical fires

This section provides some basic details on the nature of these process fire types. This understanding may be used to aid in the identification of the fire hazard, via FES or FEHM FRA practises as detailed in section 3. It may also help in determining additional measures and factors when determining the required PFP performance, such as alternative means to limit fire durations and exposure. This can in turn reduce the demand placed on any PFP application selected. Further details on Process Hydrocarbon based fires may be found in such guidance as the EI IP 19, and pressure vessel protection documents.

4.1 Hydrocarbon fire

PFP is designed to provide resistance to fire but it is essential that the required performance specification and the selected material testing and certification are based on the type of fire appropriate to the Identified fire hazard.

4.1.1 Hydrocarbon Diffuse/Pool fires

ISO13702 describes a diffuse or pool fire as:

“A pool fire is the turbulent diffusion fire burning above a horizontal pool of vaporizing hydrocarbon fuel under conditions where the fuel has zero or very low initial momentum”.

Thus a ‘pool fire’ should be more correctly termed a ‘diffusion fire’ since it is the vapours above the pool that are burning. The term ‘pool fire’ implies a liquid fuel but it could apply to a gaseous or solid fuel that was orientated in the horizontal plane and burning as a turbulent diffusion fire. However, this document is concerned with the hydrocarbons processing industry where in the majority of cases the fuel is either liquid (where it may create a pool of fuel) or pressurised gas (where it may present a jet fire hazard). MMU155-P03-R-01
The term ‘pool fire’ is extensively used within the process and fire protection industries and therefore it will be used in this document to represent a non-pressurised liquid fire as defined above.

Pool fires can occur where liquid inventory can accumulate (e.g. a non-pressurised undetected leak). They can be static (e.g. contained by a bund), or ‘running’ (non-contained so the pool can spread). A non-contained pool fire will spread over a wider area and hence potentially expose more structural members and safety critical equipment. However, the pool will have less depth and so will consume the available fuel more quickly, reducing the intensity and duration of the fire. A contained pool fire will put less structure and equipment at risk but will burn for longer and with greater intensity. In dealing with liquid fires the size of the fire will be related to the surface area of the liquid.

![Photo 1 Large 'pool' fire at Buncefield Terminal, UK](image)

Inventory available for escalation and impairment is minimized by the following mitigation measures:

- Speed of process isolation on confirmed gas or liquid leak, or fire detection
- Containment of liquid releases by the provision of bunds and open drains. This should aim to slop the area around potential sources of release so that liquid does not collect under critical items or items with the potential to escalate the pool fire.
- The use of grated decks or elevated floors to minimize the potential for a pool to form at these levels

The duration and severity of hydrocarbon pool fires will vary depending on factors such as ventilation, fuel type, quantity, etc. It should also be noted that drainage also has a factor on pool fires. Pool fires can last longer than the time for the initial releases from the process containment if liquids are allowed to collect.
4.1.2  Gas jet fires
Gas jet fires result from the combustion of a fuel continuously released with significant momentum in a particular direction. They reach their full intensity rapidly but in principle they are dependent on the gas inventory available for release. Thus isolation and minimization of inventory are important techniques to reduce the potential impact of jet fires.

Gas jet fires can occur where gaseous inventory under pressure is released via a hole, crack or other failure in process equipment or pipework and where there is then an ignition source. The length of the jet flame will depend on the quantity and pressure of the inventory, the hole-size causing the release and on the process isolation and blow-down capabilities. On effective gas or fire detection where there is functioning automatic shutdown, the inventory volume and pressure will be reduced which in turn will reduce the jet fire flame length and intensity. This will limit impingement on the safety critical elements and structures as well as the duration of the jet fire flame.

Thus a credible jet fire event may have a range of heat flux and fire protection time periods for the PFP to be specified against. Consequently it is normal to consider a fire event where the jet fire component may reduce relatively quickly but the fire may continue as a non-pressurised release (a pool fire) for a longer time period. For example the Fire Risk Analysis (FRA) may define total fire duration of 120 minutes of which the first 60 minutes as a jet fire; or another example may be total fire duration of 60 minutes of which the first 15 minutes is a jet fire. The aim of this is the fact that combined pool and jet fires may occur - e.g. short duration jet fires followed by longer duration pool fires. These combined jet and pool fire exposure cases should be included in the determination of the PFP performance requirement.

4.1.3  2-Phase jet fires
Spray fires are similar in nature to jet fires in that they are the result of a release of pressurized inventory but in this case the inventory may be either liquid or multi-phase. Ignited releases of this type can have higher heat flux than a similar gas jet fire and the erosive effects of the spray can be more onerous but currently there are no standard fire tests using multi-phase or liquid phase conditions. Thus currently PFP products for such fires are specified using the gas jet fire criteria.

Spray (2-Phase) jet fires are also more likely to generate a burning pool due to the rain out of the liquid fraction. As detailed above the potential for both jet and pool fire exposures should be
evaluated when determining the PFP performance specification and required durations - see section 5.

### 4.1.4 Heat fluxes

Once the fire type has been determined use is made of the potential incident fluxes to determine the specific PFP performance requirements. This is of particular requirement when trapped inventories may be exposed to fire conditions.

Typical incident heat fluxes are provided in a range of standards and guides, such as API 521[11], The NORSOK standard S-001 [12], and the Scandpower [13] and EI [14] pressure vessel protection guides. These typical heat fluxes may be applied in later PFP specifications. These standards and guides quote global average heat load and local peak heat load at for typical jet and pool fire conditions. The global average heat load is that which could be seen as exposing a significant part of the target. This global heat load provides the major part of the energy into larger exposed items and is of particular focus when determining the PFP requirements on trapped inventories such as vessels and in large bore pipework. The local peak heat load is only for small (localised) exposure and provides a value for determining the highest heat flux which is used to determine localised material weakening. This is of particular focus again when determining trapped inventory (vessels/ pipework) rupture conditions, but may also be used as the basis for structural steel failure.

Table 4-1 Typical Heat fluxes from standards

<table>
<thead>
<tr>
<th>Local peak heat load</th>
<th>350</th>
<th>250</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global average heat load</td>
<td>100</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

These heat loads are only for guidance only and may be used in the absence of any detailed or other thermal evidence. Detailed thermal loads may be determined from detailed modelling of the fire cases, in particular this can include the use of CFD modelling for complex scenarios and locations.

It should be noted that for the testing of PFP products, standard time/temperature curves and furnace test conditions are defined in a number of standards (see section 7 on testing).

The term ‘pool fire’ is also often used incorrectly within the PFP industry when referring to fire testing – people refer to ‘pool fire testing’ when they actually mean ‘furnace testing’ using a standard time/temperature curve. However, the term ‘pool fire’ and ‘pool fire test’ are both in common use within the PFP industry and provide brevity and a useful differentiation between this and other tests for PFP where the hydrocarbons are under pressure (i.e. a gas jet fire or a spray fire).

It is generally held that standard hydrocarbon furnace tests reach total heat flux values in the region of 100kW/m² - 200kW/m².
5 Determining the PFP design requirement

This section provides commentary on the means for determining the specific PFP requirements for plant and equipment based upon fire types, heats and required performance durations.

5.1 Risk assessment or prescriptive determination

Once PFP has been determined as an appropriate and necessary requirement in order to maintain the integrity of SCE in the most comprehensive manner by some form of assessment process such as FES or FEHM, see section 3, it is necessary to specify the type and application of the PFP in order to develop a particular performance requirement for the selected PFP option (see section 8).

This performance requirement determination should be based upon the following input factors:

- The type of fire
- The energy produced by the fire
- The response of the SCE to the fire
- The duration of the exposing fire
- The acceptability or otherwise of the failure of the SCE

Similar to the FRA identification process, the technical performance determination of the PFP can be specified either qualitatively following ‘prescriptive’ requirements by reference to appropriate standards / guidance, or quantified through a technical risk assessment. The end results should still have taken the input factors to arrive at the following set of PFP performance requirements.

- The extent of PFP application required
- The type of fire exposure
- The required ‘Limiting’ or ‘Critical Core Temperature’ (CCT)
- The duration required

5.1.1 Extent of PFP application and fire exposure

Different equipment types can have quite different limiting or CCTs. This will depend on the failure mode of the individual item when exposed to particular fires. In addition the fire type can also influence the PFP requirement, for example the higher heat fluxes associated with jet flames will lead to greater PFP requirements compared to pool fire exposure.

It is therefore essential to identify the item to be protected by PFP prior to defining the performance criteria. This will also be required to confirm the correct validation tests for the selected PFP materials.

5.1.2 Maximum temperature of the protected item

Often called the ‘Critical Core Temperature’ (CCT) or ‘limiting temperature’ this defines the maximum temperature that the item can be allowed to reach at the end of the fire protection time period. The value may be defined within a standard or guidance document, or may be determined from analysis. Temperatures may vary widely depending on the item to be protected, its design characteristics and on other mitigation methods. Further item specific details are provided later in this section.
5.1.3 Duration

The function of the PFP is to prevent the SCE item, when exposed to particular fire conditions, from reaching the critical core/limiting temperature for an acceptable period of time.

If using qualitative ‘prescriptive’ standards this is usually given as a required time without consideration of particular fire dynamics or response of the exposed SCE item. The following are typical durations for fire types commonly seen in projects, guidance and standards:

- ‘Pool fire’ durations tend to be in the range from 1 hour to 4 hours with 2 hours duration being commonly specified.
- ‘Jet fire’ durations tend to be in the range from 15 minutes to 2 hours with times in the range 30 minutes to 60 minutes commonly specified.
- Combined jet fire and pool fire criteria are frequently encountered, especially offshore. Common examples might include for example, a total fire duration of 2 hours of which the first 60 minutes is a jet fire. In this case the PFP type and thickness is based on a combination of the two fire resistance criteria.

Quantified PFP should take into account these fire and exposed item variables. For example the duration may be based upon the duration of the exposing fire, or it could be based on a point where failure is seen as acceptable. Further specific details are provided later in this section.

5.2 Qualitative determination - Use of prescriptive standards/codes and guides

A factor in the failure to correctly specify PFP has been the fact that there are multiple standards, codes and guidance that make mention of PFP use. However, these typically only apply to specific fire cases and to the protection of specific systems. If applying prescriptive codes then multiple codes may be required.

There is nothing fundamentally wrong in using appropriate PFP standards, codes and guidance so long as there has been some form of qualitative Fire Risk Assessment used to define the fire scenario and the appropriate PFP application (section 3). This should cover both the type of fire and the SCE to be protected.

Table 5-1 lists many of the codes/standards and guidance commonly used for fire safety in the process industries and identifies where these are intended for use; their limitations in as far as their application (structure, vessel, etc.), and fire type (jet in this case covers both gas and 2-phase) plus any other applicable selection details.
Table 5-1 Appropriate standards and guides related to PFP use.

<table>
<thead>
<tr>
<th>Standard/ Guidance</th>
<th>Main Application</th>
<th>Intended facility type</th>
<th>Fire case (load) determination</th>
<th>Criteria (CCT and duration)</th>
<th>HC Fire types</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>FABIG TN 13 [15]</td>
<td>Structural</td>
<td>Mainly offshore, but does apply onshore</td>
<td>CFD or range of thermal loads depending on fire type.</td>
<td>DAL fire withstand.</td>
<td>Jet and Pool</td>
<td>Guidance</td>
</tr>
<tr>
<td>Scandpower Pressure systems guidance [13]</td>
<td>Vessels</td>
<td>On and Offshore</td>
<td>Background thermal fluxes plus peak load.</td>
<td>Critical Inventories and pressures at time of failure (or if &lt;3 min)</td>
<td>Jet and pool</td>
<td>Guidance</td>
</tr>
<tr>
<td>API 2510 [17] and 2510A [18]</td>
<td>Structural</td>
<td>Onshore</td>
<td>UL 1709 standard</td>
<td>1 ½ hours to UL1709 on W10x49 column. Also refers back to API 2218</td>
<td>Pool</td>
<td>This and API 2218 only mention PFP requirement if there is no AFP. Hence this is only justified for pool fires.</td>
</tr>
<tr>
<td>NFPA 58 [19] (LPG code)</td>
<td>Vessels</td>
<td>Onshore</td>
<td>In Section 6.23 - incident review or if available fire safety analysis.</td>
<td>To restrict vessel temperature (internal wall) to 800°F (427°C) for 50 min</td>
<td>Torch flame - simulated jet fire at 2200°F ± 100°F (1200°C ± 56°C).</td>
<td>Has a performance section that has combined fire and hose stream impingement test. 50 min thermal with 10 min combined hose</td>
</tr>
<tr>
<td>API 14G [20]</td>
<td>Structures</td>
<td>Offshore</td>
<td>Very generic - typical areas</td>
<td>No specific performance details</td>
<td>Not detailed</td>
<td>Guidance not a design standard</td>
</tr>
<tr>
<td>Standard/Guidance</td>
<td>Main Application</td>
<td>Intended facility type</td>
<td>Fire case (load) determination</td>
<td>Criteria (CCT and duration)</td>
<td>HC Fire types</td>
<td>Comments</td>
</tr>
<tr>
<td>---------------------------------------------------------------------------------</td>
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<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>API 520 part 1 API 2001 [22]</td>
<td>Vessels</td>
<td>On and Offshore</td>
<td>PSV sizing only To prevent thermal over pressurisation.</td>
<td>Based upon wetted surface area and standard heat load</td>
<td>Pool fire</td>
<td>Design Standard for PSV sizing for fire exposure only. Refers to API 521 for ways to reduce pressure and restrict heat input</td>
</tr>
<tr>
<td>API 2 FB [23]</td>
<td>Structural Fire/Blast walls</td>
<td>Offshore</td>
<td>Nominal loads 300 to 400kW/m² jet and 100-160 kW/m² for pool</td>
<td>Three methods. Zone (screening), Strength and then ductility</td>
<td>Jet and pool</td>
<td>Design standard</td>
</tr>
<tr>
<td>ISO 13702 [6]</td>
<td>Structural Fire walls, Critical equipment</td>
<td>Offshore</td>
<td>To be based upon an FES</td>
<td>Structural - 1 hour limiting to 400°C (or 200°C if aluminium). Table C6 for critical equipment.</td>
<td>Jet and pool</td>
<td>Design Standard</td>
</tr>
</tbody>
</table>

**5.2.1 Qualitative determination limitations**

Many of the ‘prescriptive’ standards, codes and guidance define critical ‘core’ temperatures and fire durations for PFP performance. The critical ‘core’ temperature is usually a maximum temperature that the underlying SCE should not exceed. The duration is the expected duration over which the PFP is required to perform in order to prevent the critical temperature from being reached. The prescriptive approach does not take into account variables in the fire such as limited inventories which can reduce fire durations; and for pressure vessels the effects of depressurisation which can reduce the stresses on the vessel walls altering the critical failure temperature as higher.
temperatures may then be allowed. Such variables are outside the scope of direct prescriptive standards, codes and guidance and require a more qualitative determination - see later in this section. As a result the use of Qualitative ‘prescriptive’ standards can result in an over specification of PFP though use of lower CCTs and longer durations, but can also result in insufficient PFP specification if incorrectly used e.g. pool fire rather than jet fire exposure basis.

5.3 Quantified Performance determination

It is possible to determine PFP performance requirements by making a quantified technical assessment of the exposing fire cases and thermal response of the exposed plant items. This approach, although taking more effort, will be able to take into account variations in the exposing fire case and the response of the SCE item up to the point of failure. This should result in more precise PFP specification, particularly compared to the use of Qualitative ‘prescriptive’ standards.

5.3.1 Quantified determination general - Thermal design loads

The first part of any Quantified assessment and determination of PFP specification should be to better determine the exposing fire case type and heat load. This is different from the qualitative ‘prescriptive’ standards which typically refers to fire types, such as pool fire or jet fire as seen in API 2218 and ISO 13702. This exposing heat load is often referred to as the Design Accident Load. Design Accidental Load (DAL) is, according to NORSOK S-001, (which also defines DAL: as dimensioning accident load) defined as “the most severe accidental load that the function or system shall be able to withstand during a required period of time, in order to meet the defined risk acceptance criteria”.

For fires and explosions, DAL analyses seek to illustrate for what length of time equipment and piping systems must withstand heat and pressure. Hence, fire protection needs to be designed so that the heat load values are within the defined requirements. The Fire heat fluxes can be determined through use of applicable fire case ‘fluxes’ - see section 4 on fire types; or may in the most detailed cases be determined through software modelling, such as CFD. This fire scenario modelling is more applicable to off-shore installations where the confined and congested nature can lead to significant variation in the fire heat fluxes, but may also be used onshore when the fire scenario is complex.

5.3.2 Quantified determination general - Failure criteria

Once the response to the fire is known and the failure mechanism detailed the performance duration of the PFP needs to be determined. In the simplest case this should be that the PFP prevents the critical core temperature being reached during the period of the exposing fire. For failure of the primary containment, this is the most conservative protection case requirement covering the fire duration. However, this can introduce significantly long durations and unrealistic requirements on the PFP.

Other durations can hence be based upon the required function of the underlying SCE. This is a fire variable that requires determination though more quantified analysis. The PFP performance duration can also be linked to the period after which SCE item failure is considered acceptable. This is of particular relevance where PFP is provided to protect trapped inventories or SCEs that prevent escalation.

Two other cases may be considered. The first of these is the duration beyond which failure and escalation should not affect additional populations e.g. escape should have been enabled and there should be no populations at risk from exposure of the failed vessel. PFP required to prevent escalation beyond this period is not necessary on life safety grounds, although environmental and commercial factors may still require consideration.
The second case is where trapped inventories may be reduced through depressurisation /de-inventory systems to the point at which the remaining pressure/inventory at time of failure will not present a significant escalation risk. For example both the Scandpower and EI guidance detail acceptable failure consequences to determine the PFP performance duration. The Scandpower guidelines present the following inventory limits:

- Maximum total HC mass - 4,000kg
- Maximum HC gas inventory - 1,000kg
- Maximum pressure in pipes - 20barg
- Maximum pressure in vessels - 4.5 bar
- Minimum time to rupture < 3 minutes.

These are however examples and should not be seen as absolute - they may be used as a starting point for individual sites/assets to determine their own acceptance criteria.

5.4 SCE supporting structural steel - PFP specific performance requirements

This guidance covers the structural steel used to support major and critical process equipment items such as vessels, pipes, valves, etc. This includes the direct equipment supports such as vessels legs and saddles, as well as major process steel work used to hold tall equipment items or equipment items at elevated levels. It does not cover structural steel work as used in civil applications such as in buildings, or the main structure on an offshore platform such as the jacket.

Steel structures may be considered to be a Safety Critical Element (SCE) and hence needing PFP as a barrier to fire for the following reasons:

- The protection of life by preventing or delaying collapse of critical equipment structures and temporary refuges (TR’s). Note: maintaining the integrity of the means of escape (especially offshore) though the provision and support of fire and blast walls is not covered in this guidance;
- The mitigation of escalation by preventing or delaying collapse of structures (including supports) carrying equipment and piping with large volumes of flammable inventory;
- The mitigation of escalation by preventing or delaying structure toppling and damaging other plant and equipment that may then lead to an escalation incident.

5.4.1 Critical core temperature for structural steel in fire.

In the prescriptive standards this temperature is often linked to the fire test standard and relate to the temperature at which significant structural strength is lost. This can vary and commonly used CCT values are 400°C, 427°C (800°F), 538°C (1000°F) and 550°C depending on SCE item and usage in service. For example design to API 2218, commonly used in onshore facilities, considers an average ‘limiting’ temperature for steel structures of 1000°F (538°C). For offshore structures the maximum steel temperature is more often than not limited to a more conservative 400°C.

In quantified assessment the critical core temperature for structural steel should take into consideration the material type, and imposed loads. As the temperature of steel increases its strength decreases and the rate of decrease increases significantly above 400°C. The actual critical yield temperature varies depending on the grade of steel and the imposed load on the structure but
for commonly used construction grades it is typically considered to be in the range from 400°C to 550°C depending on the design load utilisation.

In a hydrocarbon fire the critical yield temperature of unprotected steel structures can be reached in as little as 5 minutes. This is insufficient time to allow EER to be effected or even to allow escalation mitigation such as Emergency De-Pressurisation (EDP) to take effect.

PFP is used to extend the time it takes for the steel structure exposed to fire to reach the defined ‘critical yield’ temperature (or other more conservative ‘limiting’ temperature). This then allows time for EER; or for other safety systems such as EDP and firefighting to be effected and hence mitigate the risk of escalation due to collapse of structures that support vessels or pipework containing large volumes of flammable inventory, or themselves present a ‘swinging or toppling risk’ that may in turn lead to escalation.

For TR’s located on offshore platforms a typical fire protection time for structures is of the order of 60 minutes as it is considered that escape and evacuation should have been completed within this time. For steel structures supporting vessels and pipework, etc., offshore the fire protection time required may be in the region of 2 hours, and onshore these can be even longer (up to 4 hours in some ‘prescriptive’ cases). For onshore plant the extended fire resistance times can be related to greater separation distances and the desire to ‘firefight’ in order to save plant and equipment – onshore evacuation is easier and faster and so life preservation may not be the dominating criteria for design. When specifying the performance duration for structural steelwork on equipment with large inventories there should be consideration of the equipment e.g. vessel, protection. There is little point in providing PFP to extend the life of the supports beyond the period required for vessel protection. This is particularly true where equipment de-inventory e.g. depressurisation may be in place.

Vessel supports may be identified simply as “supports” or separately as vessel skirts and vessel saddles.

Additionally if the supported vessel is at an elevated temperature then the support may also be at a temperature that could affect the PFP due to conduction, especially if the vessel is insulated. Therefore this fact would need to be advised to ensure correct specification of PFP.

One area of ambiguity regarding the fire protection of vessel skirts is whether they should be protected on both the inside and outside or just the inside. There is no simple factual answer to this question as it depends on many factors such as diameter and thickness of skirt plate; the size and number of man-way access points; pipe penetrations; the size duration and type of fire risk, etc.; and structural calculations should be carried out to be sure of the consequences. However, in general if there are openings in the skirt through which fire can penetrate and the inside can be accessed for fire protection application, then it should have PFP applied to both sides. If a fire risk is only from the outside (e.g. a jet fire) and there are no access ways, or the man ways are covered with plates, then PFP may only be needed on the exposed side.

It is normal to use PFP on vessel supports (skirts and saddles) for a period of time at least equal to that required for the vessel wall. In many case PFP is only applied to the supports and not to the vessel itself.
5.5 Hazardous inventory containment - Vessels and Process Pipework

Pressurized vessels, process equipment and piping should have adequate fire resistance to prevent escalation of a dimensioning fire scenario. This includes pipe and vessel supports. It is important to recognise that PFP is not the sole measure in preventing escalation of fire events involving equipment containing large volume of inventory, particularly when under pressure. Pressure relief is required for protection against thermal overpressure, and process isolation and fast EDP are key aspects in mitigating the risk of vessel or pipe rupture and consequent escalation due to thermal weakening of the primary containment walls.

Prescriptive vessel and pipework (trapped inventories) limiting temperature standards may range from 200°C to 400°C depending on the size and wall thickness, the steel grade, the inventory and pressure, etc. For LPG tanks the value tends to follow a ‘code’ based approach, e.g. NFPA 58. For many pressure vessels use of specific limiting values is too simplistic and analysis to determine the critical point where loss of wall strength converges with increasing pressure should be undertaken. It is now also normal to also consider pressure relieving in such calculations, as this could eliminate the need for PFP and AFP if sufficiently sized.

For example, OTI 92 610 [24] indicates that, for carbon steel vessels or pipes built according to the usual codes (with a burst pressure at normal temperature some 2.5 to 4.0 times the maximum working pressure and operating at the maximum working pressure), the reduction in strength is such that failure would be expected at around 500°C to 550°C if thermal stresses are negligible. If the vessel is operating below its maximum working pressure, the failure temperature is correspondingly higher, for example, if the pressure is 50% of the maximum working pressure, failure might be expected at 550°C to 600°C.

Piping may be considered similarly to vessels especially where inventory is under pressure and typical Prescriptive CCT’s are in the range 200°C to 400°C.

Hazardous inventory, primary containment failure due to fire exposure will occur in one of two ways and both should be protected against. These are:

- Overpressure due to thermal expansion, where the greatest effects are from trapped-in liquid containing inventories.
- Material weakening at elevated temperatures resulting in failure at pressures below the maximum allowable working pressures.

Both cases will result in sudden catastrophic release of the hazardous inventory leading to an escalation of the initial fire case.

As a means for reducing the potential for escalation PFP protection of primary containment is most suited to application in small and medium fire events. Large scale fire events, could already be at a scale of consequence that escalation is unlikely to represent a significant consequence increase.

5.5.1 Trapped inventory protection - Thermal overpressure failures

As already detailed, thermal over-pressurisation above the maximum allowable working pressure of a vessel can occur. Primary protection for this overpressure case should be provided by a pressure relief device. PFP can however, reduce the energy transfer under fire exposure and help to reduce the relief requirements on the relief device. The thermal relief requirement is detailed in standards such as API RP 521 and ISO23251 [25] and the sizing of relief devices to meet this thermal relief load is detailed in API RP 520. In this guide there is an empirical equation (Equation 15) that can be used
to determine the vent load for use in relief device sizing. In this, the concept of the ‘Environment ’ or ‘F’ factor is described where the use of vessel insulation/PFP can be taken into account when designing the size of the pressure relief system.

The ‘F’ factor is derived in part from the thermal conductivity of the insulation or PFP but is really intended to take account of products that have thermal conductivity (k-value or λ-value) that is both known and has a predictable change with rising temperature. Thus this method is more suited to those PFP systems that have more stable thermal conductivities over the fire duration such as high temperature insulation wool (HTIW) and lightweight cementitious. The fire exposure case should use the dry thermal conductivity value. For epoxy intumescent PFP, thermal conductivity in the ‘normal un-reacted state’ is not particularly good but improves dramatically as char is formed in a fire. The challenge with epoxy PFP is that the char development is not always uniform or predictable as it can depend on rate of heating, mass of steel (wall thickness), applied PFP thickness, etc. However, some epoxy PFP manufactures may have had fire test data evaluated using thermal modelling equations to predict char k-value. For epoxy PFP the ‘worst case’ k-value is given in the un-reacted state with values improving during a fire event to a ‘best case’ k-value at the end of the reaction phase (occurring at some time during the fire event). Thus for an epoxy PFP, if using the ‘worst case’ k-value in equation 15 of API Standard 521 provides the required ‘F’ factor then no further analysis is required. If this is not the case but the ‘best case’ k-value does provide the required ‘F’ factor then an evaluation of available data would be required. This is because the rate of reduction in k-value in a fire event would be ‘competing’ against the required rate of relieving for a given size of relief system.

5.5.2 Trapped inventory protection - Thermal wall weakening and failures below Maximum Allowable Working Pressure (MAWP)

The second thermal failure mechanism for equipment with trapped inventory is through the thermal loss of strength in the primary containment walls.

“Guidelines for Protection of Pressurised Systems Exposed to fire”, Report 27.207.291/R1-V2 (2004) by Scandpower Risk Management AS [13]; the EI guidance on pressure vessels [14]; and the alternative methodology examples shown in API 521, can all be used as guidance for the design of depressurisation systems and the requirement for PFP. These have been written to maximise the use of the EDP system and to minimise the use of PFP. PFP can work with the depressurisation system to maintain the trapped inventory containment integrity during Design Accidental Loads (DAL) fire exposure for the required period of time.

5.5.3 Trapped inventory protection - Interaction between PFP and Pressure relief and blow down systems

The following Figure 5-1 is a simplified decision flow chart for optimising Depressurising and PFP systems from the Scandpower document ‘Guideline for the protection of Pressurised Systems Exposed to Fire’ noted above. For information in reading this flow chart P(t) and T(t) are the pressures and temperatures at time t.
The desired depressurisation rate can vary significantly based on:

- Vessel wall thickness
- Material of construction
- Initial temperature
- Type of fire (pool fire or jet fire)
- Type of failure to be mitigated (vessel yield or vessel rupture)
- Presence of PFP or other fire protection means (water spray systems)

In the event of a fire the primary protection of pressurised process vessels and pipework should be by Emergency Depressurisation (EDP) via the blow-down system. These systems are currently designed to industry guidance, using empirical equations for wetted area as shown in API RP 521. It is widely recognised that in some respects this is inadequate. For example, only heat transfer from approximately 100 kWm\(^{-2}\) fires to the liquid wetted wall is considered. This would not take account of the greater heat loads from hydrocarbon fires (implicit in the guidance and in the region of
150kWm\(^2\) for peak loading in ‘pool’ fires); or from an impinging jet fire on the un-wetted region of the vessel wall (up to 350 kWm\(^2\) peak loading for jet fires). This has been acknowledged and the 6th edition of API 521 includes details of an alternative (quantified) methodology for the design and protection of pressurised storage vessels.

The effects of heating on primary containment walls is shown in the figures below (extracted from HSE guidance Offshore Technology report - OTO 2000 051 [26] ‘Review of the response of Pressurised Process Vessels and Equipment to Fire Attack’, June 2000 where in Figure 5-2 Graph ‘A’ the rate of temperature rise of the vessel wall is much faster, as might be the case where the vessel has no PFP protection, than in Figure 5-2 Graph ‘B’ which represents the response of a vessel without PFP.

**Figure 5-2 Vessel response figures extracted from UK HSE guidance**

![Figure A - No PFP protection](image)

![Figure B - PFP protection](image)

In many cases EDP is implemented in phases so as not to overload the blowdown/flare system and PFP may be used to protect the vessel for a period of time during which controlled EDP can be implemented (e.g. 30 minutes). In other cases PFP may be used for the duration of the credible fire event, e.g. 2-hours.

In other cases thermal insulation is required on the vessels walls for reasons of process heat conservation. If such vessels also require fire protection, then provided the selected insulation system is also tested and rated for fire protection, then credit can be taken in the overall PFP design.

Note the following observations which are paraphrased from Scandpower “Guidelines for Protection of Pressurised Systems Exposed to fire”, relating to Pressure Safety Valves (PSV):

*An PSV will not prevent a vessel or pipe from rupturing if the material in the system is heated above the critical temperature. Rupture may occur even before the PSV starts relieving the inventory. This is often related to situations where the heat input into the liquid is low but the heat input into the wall is high. Such situations may occur where there is local fire only or where there is localised heating of the non-wetted segment, such as may occur in a directional jet fire.*

This is often a failure where pressure relief devices are seen to provide protection against both over pressurisation and thermally weakened wall failure as in the BLEVE case.
Detailed consideration regarding the design of the pressure relief and EDP systems and their interaction with the decision to use PFP on process vessels and pipework is beyond the scope of this document which assumes that suitable analyses have been carried out and that PFP is required to meet defined fire safety criteria. Reference should be made to the methods in the EI and Scandpower guides and the alternative methodology in API 521 for this dynamic assessment.

5.6 Other trapped inventory specification considerations - Vessel design
Where the vessel wall requires PFP then the dimensions including wall thickness (or a detailed drawing) will be required. In addition the vessel operating and design temperatures will need to be identified as most PFP products have limitations for use in relation to temperature. Additionally any maintenance operations such as ‘steam out’ also need to be identified as the temperatures involved can cause breakdown of some PFP types. Aspects such as manway access points and other attachments also need identifying as the PFP used for these may need to be different to that used for the body of the vessel. Where a vessel needs PFP it is normal to include the nozzles and at least the first flange even if the attached pipework does not need PFP.

5.7 Other trapped inventory specification considerations - Thermal insulation
For many process vessels thermal insulation is required for process reasons as well as the need to provide fire protection. Some thermal insulation products may also have a ‘fire rating’ and so can fulfil both criteria; in other cases a combined system of thermal insulation and PFP may be required. Thus it may also be necessary to provide the process thermal requirements for the vessels as well as the fire protection requirements.

5.8 Other trapped inventory specification considerations - Piping
Piping will require that similar criteria to vessels are defined as pipes carry inventory that may be under pressure. Pipe diameter and wall thickness (or pipe schedule) will need to be identified. Piping may also have process thermal requirements and operational temperature parameters that fall outside those tolerated by the PFP product. As with vessels some thermal insulation products can also provide fire protection requirements but this needs to be carefully explored to ensure a fit for purpose specification for both criteria.

5.9 Other trapped inventory specification considerations – De-pressuring system interface and interaction
When interfacing with depressurisation systems consideration of low temperature effects in the de-pressuring system also need to be considered as JT cooling may occur at the relief point (blow down valve). High velocities may also be generated which can generate sonic and vibration failure risks.

5.10 Hazardous inventory containment - associated Valves and Flanges
Bolted flanges at valves and pipe-pipe connections are prone to leaking. HSE OTO 2001 055 [27] indicates that for the UK sector of the North Sea:

- 61% of all releases are from pipework systems
- 15% of all releases are from flanges
- 14% of all releases are from seals and packing
These leaks are a potential source of fuel for a fire event and it is recognised that the use of PFP will not prevent the initial leak or the potential for that leak to be ignited. However, for unprotected flanges exposed to a fire then according to FABIG Technical Note TN8: “Flanges that have no fire protective coatings will lose their tightness and new leaks will develop within a few minutes; where the inventory is flammable, it may be ignited by the fire”. Thus PFP is used to provide a barrier around the connection to mitigate the risk of additional leaks from other flanges that are impinged or engulfed by the fire event; and by this means reducing the potential for escalation.

Emergency Shutdown Valves (ESDV) and Process Isolation Valves (PV) are used to shut down a process and to isolate sections of a process to minimise the contained inventory available as a source of fuel in the event of a leakage or fire. Emergency Depressurisation valves (EDP) are used to control the release of isolated inventory via the blow-down system. Such valves (and their control systems) are Safety Critical Elements (SCE) and as such require fire protection in order to prevent escalation of a small incident.

In some cases valves are designed to ‘fail safe’ but in other cases control of the valve is required during an emergency event and so the control systems for these valves will also need to be protected.

Most valves are connected into pipework using bolted flange joints which are prone to leakage and early failure in a fire (see above) but in addition valve seals/glands may also be damaged and/or the valve assembly may no longer work efficiently following exposure to high temperatures. There are two factors causing this failure: Thermal degradation of the material and thermal expansion. The limiting temperature for valves is very dependent on their construction and method of operation and so ‘typical’ limiting temperatures are not really appropriate, however, experience indicates these are often 200°C or less. Actuators may have a CCT as low as 80°C.

Flanges are very susceptible to leakage and hence risk of escalation by ‘feeding’ a fire. Flanges fail early in a fire either due to seal failure or due to the bolts losing their tension. FABIG technical note TN8 references testing that showed that bolts fail more quickly than flanges in a fire and that high strength bolts fail more quickly. Scandpower guidance document recommends that bolts remain below 500°C.

Valves, flanges and actuators will need to be considered as part of the piping in some respects but in others they have quite different requirements such as the need for access for maintenance. Such items need to be fully dimensioned (detailed drawings are ideal) and the need for access needs to be defined along with any process thermal requirements and the fire protection needs. Suitable accessible PFP systems will require joints that may need to be suitably weatherproofed.

5.11 Safety Critical Cabling and other SCE critical systems.

Power supply and instrument cabling that is vital to safe process isolation and shutdown of safety critical equipment during fire exposure should be installed in such a way that they are protected against direct heat radiation and flame impingement.

Fire heat exposure should be determined using modelling. Separation distances using Fire Area rules or Fire Protection Zones (FPZ) rules will not be adequate since cabling cannot withstand high temperature. If adequate protection via spacing is not possible, then special fire-resistant cables may
be used, such as those that are in accordance with IEC-60331-21 [28], i.e. able to withstand temperatures of at least 750°C.

The PFP or fire rated cabling should provide protection long enough for the SCE to fulfil its performance requirement - this is applicable to Critical cabling and valves/actuators. For example, once a valve has closed protection of the actuator may no longer be required. The same applies to power and instrument cabling. The Fire risk assessment should be used to set the acceptable performance duration which according to ISO13702, can be a great as 90 minutes in the case of emergency lighting cable.

All cable penetration through fire safety barriers such as fire walls, decks, etc. should be sealed using suitably tested and approved ‘fire stopping’ PFP products to provide a level of fire resistance equal to that of the barrier through which they pass. This is to ensure that the barrier fire rating is not impaired by the passage of the cable through the barrier.
6 Interactions between PFP and AFP

This section considers how PFP and AFP systems interact with each other; whether one can be used to take ‘credit’ for the other and how PFP is affected by AFP systems such as deluge.

Passive Fire Protection (PFP) may be installed as one of a number of other fire mitigation measures, which should have gone through the selection process as detailed in sections 3 and 5 and consequently may interact with these other measures. For PFP the other mitigation measures that are of particular interest are:

- Pressure Relieving and Emergency De-Pressurisation (EDP)
- Active Fire Protection (AFP)

Pressure relief devices and EDP do not have a negative impact on PFP and can be shown to work together when protecting primary containment of hazardous materials - see sections 3 and 5.

Section 3 discusses the choice between using PFP and AFP. However even where PFP is used in preference to AFP for the same extent of protection, the PFP can still interact with those AFP systems using water, such as water deluge, foam application, fire monitors (fixed and mobile), and general firefighting actions, etc. This is of considerable significance as water can have a detrimental effect on many types of PFP.

Many if not all process plants have both AFP and PFP installed. According to ISO13702, the objective of AFP is:

- To control fires and limit escalation
- To reduce the effects of fire to allow personnel to undertake emergency response activities or to evacuate
- To extinguish the fire where it is safe to do so
- To limit damage to structures and equipment

For the purposes of this document we are considering AFP only in terms of fixed deluge and firefighting measures, how it is used within a process plant and how it inter-relates with and affects PFP systems.

Fixed deluge systems include fixed pipework with spray nozzles (similar to sprinkler systems) arranged around vessels and storage tanks or within pipe racks or process units where safety critical elements (SCE) such as valves and flanges are located. For this section we also include fire ‘monitors’ that may be fixed or mobile which project water from a distance and at an angle (usually 45°) over an area where equipment requiring protection is located. In all cases the medium used may be water or a fire fighting foam solution, or a combination of both at different zones within the plant depending on the fire hazards identified. Such fixed deluge systems aim to provide thermal protection to the underlying SCE similar to that provided by PFP. For this reason combined PFP and AFP is not normally found. There can be some cases though in which AFP and PFP protected SCEs overlap. Examples have included deluge protection to LPG spheres but the supporting legs are provided with PFP.
Fixed deluge systems will normally be triggered automatically on confirmed detection of fire. Large volumes of water / foam will be sprayed onto the target area with the aim of cooling adjacent plant and supressing flame.

Fire mitigation i.e. firefighting will entail the use of AFP; nominally the use of mobile monitors or fire hose stream. These will be brought to bear by first responders onto a fire engulfed area for both direct firefighting and also for the protection of potentially exposed adjacent plant areas for the purposes of cooling and preventing escalation. Such monitors may be strategically located around a process plant or may be brought to site by the firefighting personnel.

Fixed water deluge systems need to function in the event of a fire and so will be tested on a regular basis, thereby soaking plant and associated structures, and hence installed PFP in the area on a regular basis.

6.1 Interaction of AFP and PFP – one taking ‘credit’ for the other in design
A question that is often asked is: “where I have AFP in place can I reduce the amount of PFP required?”

It is considered standard practice that one should not ‘take credit for’ PFP when designing AFP system requirements and vice versa. There are a number of reasons for this:

- Water deluge is ineffective in high pressure jet fires.
- PFP systems have no effect on the fire and so can only prevent escalation by insulating affected plant. PFP cannot prevent flame from reaching other areas of plant, nor can it cool adjacent plant that does not have PFP applied.
- Explosion may damage AFP control systems, pipework, etc. rendering them non-functional during a fire event.
- AFP systems may not function correctly when required during a fire (e.g. due to corrosion).
- Historical poor selection or installation of PFP may mean that it cannot function in a fire event or may not survive an initial explosion event rendering it ineffective.
- Little if any testing has been carried out in the area of combined AFP/PFP systems.

6.2 Interaction of AFP and PFP – the effect of water on PFP
Where PFP is installed in zones that are covered by AFP systems, or in adjacent zones, then they are likely to get soaked during testing. In the case of deluge testing then the PFP in that locality may be subjected to water soaking over many years. Some PFP systems are far more prone to water damage than others and so this factor should be considered in PFP selection where it interfaces with AFP systems.

6.2.1 Effect of water on blanket type PFP
PFP that uses a thermally insulating product such as mineral wool or high temperature insulation wool (HTIW) is prone to water ingress. Such systems include blanket wrapping (with or without metal cladding), pre-formed sections and ‘soft jackets’ all of which are ‘dry fit’ over the item to be protected and assembled with joints between sections of material. Any over-cladding will also have joints unless it is a seamless polymer coating. As these systems tend to be used for pipework and on vessels there will be bends, T’s and penetrations that need to be sealed. The saturation of mineral
wool and HTIW with water will affect thermal insulation performance but will have a minimal effect on fire resistance. This is because any absorbed water will evaporate during the fire and due to latent heat of evaporation, further temperature rise above 100°C cannot occur until all the water has evaporated.

However a major threat, especially with regular deluge testing is the likelihood of water penetration leading to corrosion under insulation (CUI) that can become catastrophic to the substrate if left unchecked over years (see EI guide on insulation [29]).

6.2.2 Effect of water on cement based PFP
Both concrete PFP and lightweight cementitious PFP can shrink and crack over time allowing water to penetrate and leading to corrosion under fireproofing (CUF) as well as degradation of the PFP. This subject is covered in more detail in section 11 (Failure mechanisms of PFP). Regular testing of deluge systems will exacerbate this problem far more than as a consequence of normal weather exposure.

Water saturated PFP will not adversely affect fire performance so long as the PFP has not degraded over time but there is an increased risk of explosive spalling of concrete in a fire due to high water content. This is a risk to both first responders and to instrument lines potentially leading to escalation. For lightweight cementitious that has been softened by years of water saturation there is an added risk of PFP erosion from the use of high pressure water hoses by fire fighters. Although not normally a problem very soft PFP could be removed by water erosion resulting in a reduced fire resistance time.

6.2.3 Effect of water on polymer based (epoxy and phenolic) PFP
Provided the correct specification is used then the most durable of the polymer based PFP products are largely unaffected by water spray. However, it should be recognised that there is a wide variation within the group of polymer PFP products and some formulations may be more susceptible than others to water absorption when they are exposed to ‘immersion like’ situations; i.e. situations where water can ‘pool’ such as in upturned channel section steelwork, vessel support rings, etc. and therefore where the PFP is effectively immersed for many days/weeks at a time. Durability to water soaking or immersion is dependent on the individual product formulation and is related not only to the polymers used but also to other raw materials within the formulation. This subject is also covered in section 11 (Failure mechanisms of PFP).

Intumescent products provide fire protection by development of a ‘char’ on exposure to fire and this char can be relatively friable and may be eroded due to impact from firefighting water hose streams. If char is removed then unreacted PFP will be exposed that will then char again to provide insulation but the action of water erosion may cause loss of char more quickly than it otherwise would. This in turn could lead to a reduction in the duration of fire protection performance due to a reduced overall char thickness. This is only likely to be an issue where firefighters use hose pipes in a directional manner aimed at the PFP. For deluge and monitors where water is ‘cascaded’ rather than directed the char is most likely robust enough and the action of water could provide cooling and potentially extend the PFP fire resistance time.
7 Testing and certification as evidence of performance

7.1 Introduction
This section provides guidance on the appropriate fire testing and certification used to validate PFP materials used for specific duties.

Fire testing relevant to the hydrocarbons processing industry developed primarily from two areas – fire safety in occupied building and maritime shipping, with some specific testing relating to the safety of pressure vessels.

It is important to recognise that fire tests do not necessarily replicate ‘real’ fire events and even where they are similar to a ‘real’ fire they do not provide information for all eventualities. Similar comments can be made for explosion testing where there are currently no formal standards published.

For PFP products, testing is a means of establishing that:

- The product will perform under a defined fire (or blast) load condition (those conditions may or may not be representative of a real event).
- Establishing data for performance, such as thickness required for a given protection time period.
- Establishing product configuration requirements for a defined set of conditions, for example determining the required cladding overlap to provide jet fire resistance for a defined time period.
- Evaluating one product against another and evaluating performance against cost
- Evaluating product performance against real events where similar products have been exposed to actual fire or explosion events.

Process equipment can operate at extremes of temperature and in very aggressive environmental conditions, thus it is prudent to establish the suitability of candidate PFP products to those conditions by means of testing and by considering ‘track record’ in a similar environment where possible.

It should be noted that it may not be necessary for a PFP product to be tested using all methods that are available but it is important that they are tested (so far as is possible) under conditions that are representative of the end use requirements; for example if a PFP product is never intended to be used to protect against a jet fire then there is no need to undertake jet fire testing. However that product could then not be used on any project where a jet fire event was identified as a credible risk.

It should also be recognised that there are not always standard tests available to evaluate a PFP product for an unusual set of process conditions and risks. In these cases ‘ad hoc’ testing may need to be designed or data from the ‘closest available’ standard test used and perhaps interpreted in a different way. Testing should be relevant to the required use, the environment in which the PFP is used and the length of time it is expected to be in service. Testing will therefore need to include some or all of the following:

- The fire type (e.g. diffuse/pool fire or jet fire)
- Fire duration (or blast load)
• Test specimens to be representative of the item to be protected
• Substrate and PFP product responses
• Durability and suitability for the end use operating and environmental conditions

7.2 Fire Testing
Historically fire testing was carried out using a ‘standard test curve’ based on the requirements of occupied buildings where cellulosic materials such as wood were considered to be the main fuel source. Similarly the original fire tests designed for the shipping industry were based on the combustion of cellulosic materials.

With the advent of the hydrocarbons processing industry it was recognised that fires based on hydrocarbons as fuels had a more rapid rise in temperature, greater heat fluxes and the propensity to significant erosion where pressurised inventories were involved.

Thus PFP products needed to be capable of surviving these more onerous conditions and so a number of “hydrocarbon fire tests” were devised. For the purposes of testing hydrocarbon fires are split by the industry into two predominant types as follows:

• Diffuse/Pool hydrocarbon fire
• Jet fire

In addition the environmental conditions of process plants can be severe, especially offshore and so suitable testing is needed to ensure that PFP products will survive in such environments.

7.3 Hydrocarbon ‘pool’ fire
A definition of a pool fire and the use of the term within the fire protection industry is given in section 4.

In order to test the performance of PFP products to a hydrocarbon fire, standard fire tests using defined time/temperature curves are available. These include BS476 [30], ISO834 [31] and UL1709 [16]. UL1709 is a specific standard for the testing of structural columns whereas the ‘hydrocarbon curve’ defined in BS476 and ISO 834, whilst are used primarily for steel elements of construction, are also used for other items such as fire barriers, valves, etc. Data from structural element fire testing may be utilised for determining the fire protection requirements of vessel saddles, and possibly for small diameter skirts as these can be considered to approximate to ‘hollow section’ structural members.

The fire test curve defined in BS476/ISO834 is also used in steel plate deck and bulkhead testing to the requirement of the Safety of Lives at Sea (SOLAS) regulations [32]. This test and the data obtained may be of relevance to equipment where some manufacturers may use it to justify PFP thickness on large diameter vessel skirts on the basis of “steel plate testing” as the standard bulkhead steel plate thickness is only 4.5±0.5mm and most skirts are significantly thicker than this.

It may also be used by manufacturers for determining PFP thickness on vessel walls in the absence of any other defined vessel testing but there are other factors to consider (see section 5) that may make this assumption unjustified.
There is currently one hydrocarbon fire test that is carried out on small LPG ‘bullet tanks’ filled with LPG under pressure at the BAM Institute\(^3\) to the German Federal Standard TRB801 [33] and this may be of relevance to the use of PFP on vessel walls. Historically a French test programme called GASAFE was undertaken that involved various tests on PFP products, including testing on a pressure vessel and a jet fire evaluation. A number of PFP products that were on the market at the time of this test programme were evaluated but once the original work had been completed and the budget spent the programme was closed and consequently products that were introduced to the market since then will not have been tested. Specification and use of PFP on pressure vessel walls is therefore an area where testing is limited and engineering judgement will need to be made based on the available data from testing that most closely represents the fire protection need.

This limitation in available test standards has been recognised and an ISO committee (ISO TC92 SC2 WG12), is currently drafting a standard for the testing of pressure vessels in hydrocarbon fires that will be published in the near future. As this has not yet been published it is not possible to provide further commentary at this time, but it highlights the need for users and specifiers of PFP to be aware of changes and developments in testing and standards.

### 7.4 Hydrocarbon Jet fire

A definition of a jet fire and the use of the term within the fire protection industry is given in section 4.

Testing of PFP products for exposure to and protection against the risks associated with processing gaseous hydrocarbons under pressure, is carried out to the “jet fire test” ISO22899-1[34].

\(^3\) Bundesanstalt für Materialforschung und –prüfung (BAM) (translation - Federal Institute for Materials Research and Testing)
Unlike hydrocarbon furnace testing the jet fire is not defined by a time/temperature curve. The test parameters are defined as:

- A specified gas mass flow rate and gas jet nozzle shape and size
- A specified distance between the gas jet nozzle and the target specimen under test
- Specific test specimen types, shapes and sizes, as well as the capability to test other ad hoc specimens.

For structural steel elements the test specimen consists of a flat steel plate forming the back of the test chamber to which is fixed a ‘web’ (a steel plate perpendicular to the back plate and projecting forwards towards the jet nozzle). For flat specimens such as panel systems, etc. a ‘planar’ specimen is used and for pipes and structural hollow sections a tubular specimen is used. For bulkhead and deck plates, data can be derived from either a flat planar specimen or from the ‘back plate’ that forms a part of the structural ‘web’ specimen. Suitable diagrams are given in ISO22899-1.

Jet fire test data can be used ‘stand-alone’ but the certification will be restricted to items that are exactly as tested. For jet fire ‘add-on’ thickness for a range of (say) structural section then the jet fire test data is compared to the data available from similar shaped items tested to the hydrocarbon curve in a furnace. ISO22899-2 (35) gives some information as to how this comparison should be made.

Manufacturers will normally obtain certification that provides an ‘add-on’ (or ‘scale-up’) thickness of PFP that is added to the thickness given in their certification tables for hydrocarbon ‘pool’ fire. This additional thickness is intended to take account of the increased heat flux of the jet fire test and the increased erosion factor. For example, a given size of H-profile steel beam may need 10mm of PFP to provide 1-hour fire resistance in a pool fire. If say 30 minutes of that fire was defined as a jet fire then an additional thickness would be added to the 10mm. The thickness will vary depending on product and jet fire duration but an example might be an additional 2mm thereby requiring 12mm total PFP thickness for this example.

The jet fire ‘add-on’ thickness derived from ‘plate test data’ (i.e. the planar test or the ‘web’ test using the ‘back plate’ data) is the most appropriate thickness to use when determining the ‘add-on’ thickness for items such as vessel skirts. For saddles the most appropriate ‘add-on’ thickness would be that derived from the structural ‘web’ test.

There is currently no standard jet fire test that involves vessels and so the plate test data is the most appropriate when considering the ‘add-on’ thickness for vessel wall protection in a jet fire.

Recently some projects have identified a jet fires with greater thermal energy that the standard ISO22899-1 test are credible. Typically the ISO22899-1 test is reputed to deliver heat flux values that vary in the region 250kWm$^{-2}$ to 300kWm$^{-2}$, whereas the heat flux values being identified in some projects are in the region of 350kWm$^{-2}$ or more. One test laboratory has developed a version of the standard jet fire test where they claim to be able to achieve heat flux values in the order of 350kW/m$^2$. This test method and these claims have not yet been evaluated by a cross-industry body as was done with the development of the ISO22899-1 test and so this remains a proprietary test that has yet to be ratified. As noted in section 7.3, these new developments serve to remind users of PFP
that testing is not ‘static’ and one needs to maintain an awareness of changes and developments to ensure that latest knowledge is considered.
8 Specification to meet performance requirements

8.1 Introduction
This section of the guide provides various information, tests and certification that are necessary to define performance requirements in order that a PFP specification can be compiled which can then be provided to PFP material suppliers and applicators.

PFP may be in place for many years without incident but then be suddenly needed to fulfil its intended function during a fire event. Thus it is essential that PFP systems are selected and installed correctly taking into account the service conditions, environment and other mitigation measures such as water deluge; and for them to be inspected and maintained correctly to ensure the required performance is attainable across the required PFP life cycle.

See sections 6 for interaction of PFP with other AFP (mainly water interaction issues) and section 9 for PFP types, section 11 for their failure mechanisms and section 12 and 13 for integrity management and inspection & maintenance.

In order that an effective PFP specification is developed that can then be given to PFP material suppliers and applicators, it is necessary to ensure that the following are known:

- The type of fire against which protection is required (e.g. ‘pool’ fire or jet fire) - see sections 3 and 4 for determination of the need for PFP
- The type of item to be protected (e.g. vessel skirt or saddle, vessel wall, structural section, pipe, valve, actuator or flange) - see section 3 for the determination of the need for PFP
- The maximum temperature that the protected item must not exceed over the duration of the fire protection time period (often called either the ‘limiting temperature’ or the ‘critical core temperature’) - see section 5 for the technical performance required from the PFP.
- The time period (duration) over which the PFP has to provide protection - see section 5 for the technical performance required from the PFP.
- Any requirement for the PFP to resist a defined explosion overpressure load and interactions with other AFP (water) applications.
- The operating and design process temperatures for protected vessels and pipework
- Process operational requirements where large deviations from normal operational conditions exist such as vessel steam out, etc.
- The environmental conditions in the region of the plant such as temperature range, rainfall, location, plant airborne pollutants such as NOx and SOx, etc.
- Whether or not access requirements mean that a non-bonded PFP solution may be required and if so then being aware of the risk of corrosion under insulation where non-bonded solutions are implemented.
- Validation of selected materials for the required duty - see section 7 - Testing

Depending on the item to be protected, the environment and other issues such as access the PFP specification may result in one, or a range of different PFP types being listed.
8.2 Explosion

In relation to PFP, explosion and fire are linked due to the explosive and flammable nature of the inventory especially in hydrocarbons processing but PFP is only used to mitigate the risk of escalation of a fire event. Explosion is important to PFP only in that it needs to be capable of surviving an explosion event in order that it can remain 'in place' and able to carry out its primary function of fire protection.

An explosion is the sudden and violent release of energy and will create overpressure (impulse) forces and drag forces with a high probability of projectiles being generated from damaged objects.

As well as being capable of causing injury to personnel, structural failure and damage to plant and equipment; the pressure wave, drag forces and projectile impact can damage or even remove PFP.

In calculating blast overpressures account should be taken of the effects of PFP material presence which can increase equipment diameters with the result in increasing overpressure and also increased drag forces.

Some PFP products are inherently more blast resistant than others but the method of installation can also be a major factor in survivability. Additionally some PFP types may exhibit acceptable blast resistance when installed but this may be detrimentally affected by degradation in service. In some cases preventative maintenance may mitigate this degradation; in other cases it may be a case of selecting a PFP type that is more suited to the environmental service conditions.

There are currently no recognised standards for performance testing PFP products for blast resistance. Thus where an explosion event has been identified as credible, care should be taken when specifying PFP to ensure that supporting performance data is available and relevant to the blast load and the type of item to be protected.

The maximum blast overpressure should be defined and manufacturer's test data considered accordingly. Where possible the test data should be on an item similar to that to be fire protected although this is not always possible. Certainly where removable systems such as panels or enclosures are used these should be tested as such rather than as a spray applied product bonded to a steel substrate as blast response and performance will be quite different.
8.3 Environmental conditions

When specifying PFP it is important therefore that not only is fire and explosion test data considered but also environmental test data. There are great differences in the environmental conditions that different PFP technology types can withstand and even within one technology type different products have different behaviour characteristics.

Often overlooked is the role that water can play in degrading either the PFP system or the underlying steel that is effectively ‘hidden from view’. Often there is a perception that in onshore facilities there is no need for a PFP that can withstand immersion in water as there might be in the offshore environment; but poor design, inverted channels sections, vessel support rings, etc. can all create a situation where water can ‘pool’ for many days or weeks. In these areas the PFP may be effectively experiencing immersion conditions.

The environmental conditions local to that in which the PFP products will be exposed should be identified to ensure that the most appropriate products types are specified. Two recognised standards that have an ‘environmental component’ for performance testing of PFP products are UL1709 and Norsok M501 [36]. Additionally manufacturers own data (ideally obtained via an independent lab) will most likely also need to be considered. Where possible, track record of use in similar environments to the project should also be taken into consideration when evaluating suitable PFP products.

Another aspect that may need to be considered is the environmental temperature range especially in cold climates such as the Arctic where sub-zero temperatures can cause cracking of certain PFP types. If such conditions are of concern to the project then manufacturers should be asked to provide suitable test data to support the use of their products under those conditions.

8.4 Impact hazards

There are a wide variety of PFP types available with significant differences in their ability to withstand impact damage. This damage may arise from dropped objects such as scaffolding components, from impact by vehicles such as fork lift trucks, or from incorrect use such as climbing up or over insulated piping. Other physical damage may be intentionally caused when for example PFP is removed to allow the attachment of new items such as ladders, cable trays, etc.

It should also be recognised that some PFP types are quite dense and so may present a dropped object hazard if damaged or degraded to such an extent that they can fall from height potentially causing injury.

PFP falling from an elevated level can lead to process equipment damage; for example, causing fracture of an instrument connection or line, damage to a valve control stem or to a flange joint; any of which may be under pressure. Each of these has the potential to create a leak and lead to a fire or explosion event.
8.5 Process temperatures

Despite being designed to withstand the effects of fire the different PFP technology types and individual products have different temperatures within which they can be used over extended periods of time (this is covered in more detail on sections 9 and 11). In addition to maximum operating temperatures many PFP products also have minimum operating temperatures – especially if below zero °C.

Thus it is essential in specifying PFP that consideration is given to the min/max process temperatures and any ‘upset’ conditions that may occur. Both temperature and duration should be identified and the PFP manufacturer’s advice sought. There are solutions to many of the commonly occurring process temperature limitations and correct products selection will ensure the PFP is able to perform as required at some future date in the event of a fire event occurring.

8.6 Specifying the correct PFP Thickness

Specifying the correct PFP thickness can be fraught with complications due to the way in which different standards are used, how manufacturers test, the item to be protected and on the item type and size.

All PFP products work by insulating the steel in one way or another although the way in which they achieve this varies by product technology type (see section 9). The thickness of some PFP types varies depending on the item size far more than it does for other types.

Due to this variability it is essential that the required fire protection (in terms of critical temperatures and durations - see section 5), explosion resistance (if required) and long term durability are accurately defined and incorporated into the PFP specification. The responsibility for the correct selection of PFP thickness should then be given to the manufacturer as they are aware of the relevant certification and test data that is available for their product; but the specifying engineer needs to understand how these relate to the project fire protection requirements so they can ensure that these needs are met.

To aid in this understanding the general concept of ‘section factor’ (also known as A/V) is discussed with more detail in Annex D:
8.6.1 Structural steel
This includes saddles, skirts and pipe supports. The basis of the section factor concept is that heavy steel section takes longer to heat up to a defined CCT than does a lighter section under the same heating regime. As a consequence the thickness of PFP required on a heavy section is less than that required on a lighter section. Manufacturers have certified tables that relate PFP thickness to A/V (Hp/A) and to fire resistance time and CCT. Unless the steel section is of a standard size, the A/V (Hp/A) will have to be calculated (see Annex D).

8.6.2 Vessels and pipes
Although the concept of A/V (Hp/A) can be used for pipes care needs to be taken as this strictly applies to structural elements. Some manufacturers use vessel wall thickness and calculate A/V (Hp/A) when determining the require PFP thickness. There is lack of clarity within the PFP industry whether or not this concept should be used and to address this issue an ISO standard is being drafted under ISO TC92 SC2 WG12 but at this time the conclusions are unknown.

Currently there is only one standard test available for pressure vessels - the so called “BAM test” carried out on LPG bullet tanks (see section 7).

Until the ISO standard has been published it is suggested that where possible the manufacturer should have at least one test on a vessel as well as on varying thickness of steel plate to allow for consideration of the correct PFP thickness to be used with varying wall thickness.

8.6.3 Valves, actuators and flanges
It is not possible to define a PFP thickness for these items as there is a wide variation in both items type & size as well as fire protection needs. Typically such items are protected using removable enclosures that are manufactured to provide a given fire resistance period under a defined fire load. Often the thickness is related to the PFP enclosure needing physical strength to withstand repeated removal and re-fitting. Specification should ensure that the selected PFP enclosure is tested to the project credible fire event on equipment items that are similar to those to be protected on the project.

Valves may be specified by the project as ‘fail safe’ and these are not normally fire protected, however, care should be exercised when considering ‘fire safe’ valves as these are often tested to a standard that has little if any relevance to the fire exposure conditions of typical hydrocarbon pool or jet fires.
8.7 Example specification

In order to provide PFP material suppliers and / or applicators with the necessary information the above technical performance requirements and other factors should be collated into a Performance and Specification Requirement. An example sheet is shown in table 8-1 below.

Table 8.1 Typical Example PFP requirements for performance and specification

This has been populated to provide an example and is not indicative of what should be recorded

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Requirements (the responses in this column are just examples of what may be required)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item to be fire protected</td>
<td>Vessel saddles</td>
</tr>
<tr>
<td>Construction material</td>
<td>Carbon steel</td>
</tr>
<tr>
<td>Saddle details</td>
<td>See drawing Number ‘ABC123’</td>
</tr>
<tr>
<td>Operating temperature range</td>
<td>Ambient (-5°C to + 25°C)</td>
</tr>
<tr>
<td>Design temperature range</td>
<td>-5°C to + 80°C</td>
</tr>
<tr>
<td>Location</td>
<td>Marine coastal temperate Northern Europe</td>
</tr>
<tr>
<td>Environmental conditions</td>
<td>Ambient (-5°C to + 25°C), marine coastal saline</td>
</tr>
<tr>
<td>Access to vessel required?</td>
<td>Yes via man ways. Manway covers to have removable PFP system.</td>
</tr>
<tr>
<td>Credible fire event</td>
<td>Hydrocarbon pool fire and Jet fire</td>
</tr>
<tr>
<td>Required fire protection duration</td>
<td>2 hours total fire of which 30 minutes is jet fire</td>
</tr>
<tr>
<td>Critical Core Temperature for saddles</td>
<td>400°C</td>
</tr>
<tr>
<td>Required test standards?</td>
<td>ISO 834 Appendix D (hydrocarbon fire test curve) and ISO 22899-1 (jet fire)</td>
</tr>
<tr>
<td>Fire Approvals required?</td>
<td>Yes (name of acceptable approval or certification authority)</td>
</tr>
<tr>
<td>Durability performance required?</td>
<td>Yes – Example may be Norsok M501 System 5 plus manufacturers test data and previous track record</td>
</tr>
<tr>
<td>Surface preparation</td>
<td>Normally blast clean but check with PFP supplier if this is required.</td>
</tr>
</tbody>
</table>
8.8 PFP Coatback, Reinforcement and Termination

The specification of these items is highly dependent on the type of PFP product and to some extent on the manufacturers test data and application guidance. Thus it is impossible to cover all potential variations within this document. A number of ‘typical issues’ will be discussed on a PFP ‘generic’ type basis but in all cases the PFP manufacturer’s guidance must be sought prior to finalising the specification.

8.8.1 Coatback

Coatback is a term used to describe PFP that is applied to a ‘secondary item’ that is attached to the ‘primary item’ that has been identified as needing PFP. The intent is to reduce heat transfer by conduction from the attachment. There are no ‘formal’ rules for coatback and it is an area where there is much ambiguity and decisions are often made on a project basis.

The traditional coatback distance is 450mm from the connection point ‘back along’ the secondary attachment. Small attachments (typically <3000mm² - although other values such as <1000mm² and <500mm² are used) are often excluded on the basis that they are too small to create a ‘hot spot’ on the primary item. The thickness of the PFP used on the coatback is traditionally the same as that used on the primary item but again there are different opinions.

For equipment and plant items coatback is most often considered for vessels and supports. For example small attachments to skirts or vessels such as brackets for cable trays may be excluded under the ‘size rule’ above but larger items such as ladder & walkway support brackets may require coatback. Vessel nozzles will require coatback even if the attached pipework does not, and it is

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Requirements (the responses in this column are just examples of what may be required)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primer / Paint system</td>
<td>No example given but some notes for the reader to consider:</td>
</tr>
<tr>
<td></td>
<td>- The options here are numerous and in all cases refer to the project painting specification.</td>
</tr>
<tr>
<td></td>
<td>- Bonded coating type PFP may need only a single coat of primer endorsed by the PFP manufacturer. Some may need a ‘key coat’ to be applied over the primer.</td>
</tr>
<tr>
<td></td>
<td>- For systems with joints a full anti-corrosion system is often required to ensure any water ingress does not lead to corrosion under insulation (CUI).</td>
</tr>
<tr>
<td></td>
<td>- Topcoats and/or sealer coats are often required.</td>
</tr>
<tr>
<td></td>
<td>- The paint system must be appropriate for the design &amp; operating temperatures. This may require additional insulation products that will need to be endorsed by the PFP manufacturer.</td>
</tr>
</tbody>
</table>
normal to include the first flange as that would typically be a ‘weak point’ in a fire that could lead to escalation.

The above commonly used approach is not ‘cast in stone’ and projects may elect to take a different approach for example some manufacturers may have applicable test data that defines a different set of coatback parameters and that will allow for PFP thickness and distance to be optimised. A decision in whether or not to use this information would be made on a project basis.

It may be possible to carry out thermal modelling of a structure or equipment item to analyse the implications of not specifying coatback, or specifying a reduced coatback distance or PFP thickness. Such analyses would consider the criticality of the element under investigation, for example in a structure how loads may be re-distributed to other elements and whether there was a credible risk of collapse.

8.8.2 PFP Reinforcement

The oldest PFP used to protect steel is concrete cladding which needed a galvanised steel reinforcing mesh incorporated to provide strength and to ‘hold’ the concrete in place around the protected item. Similarly when lightweight cementitious (LWC) PFP products became available these also included a galvanised steel mesh although it was normally lighter in weight than that used with concrete PFP. Under certain environmental conditions the galvanised mesh can corrode quite quickly and this in turn can lead to ‘spalling’ of the PFP. Later LWC products started to use a plastic coated mesh to overcome this problem.

Heavy duty mesh needs to be ‘pinned’ (often using capacitance discharge (CD) welding methods) to the steel substrate especially around more complex shapes such as H-profile steel, vessel saddles, etc. As CD welding is not allowed on pressure vessels, for vessel fire protection the mesh is wrapped around and ‘tied together’ using galvanised steel wire or ‘hog rings’.

It is normal for the mesh to be located in the ‘middle one third’ of the PFP thickness.

When polymer based PFP products (e.g. epoxy intumescent) first came to market they used a galvanised mesh as this was in ‘normal use’ within the PFP industry, however, lower PFP thickness meant that there was a risk of the mesh protruding beyond the surface of the PFP. Additionally it is very difficult to install a semi-flexible steel mesh around more complex shapes and keep it ‘tight’ to the surface or located within the middle one-third thickness; and CD welding is a ‘hot work’ process. Unlike cement based PFP, the mesh in a polymer based PFP is not required to provide ‘strength’ to the PFP under normal conditions but is only required to strengthen the ‘intumescent char’ (see section 9 on PFP types).

Thus polymer PFP manufacturers looked to find alternative reinforcement methods and settled on special (proprietary) heat resistant fabric ‘scrims’ that do not rust and that can simply be ‘pressed’ into the PFP products before it hardens. Being fabric these cloth scrim materials do not corrode and in most case do not need fixing to the substrate (although there may be ‘approval’ reasons to fix to the substrate). The proprietary scrim cloth used is an integral part of the fire resistance characteristics of the specific PFP product and so are not interchangeable. Depending on PFP products, test data and certification, the cloth scrim may not be needed for all fire protection duties.

Cloth scrim reinforcement is normally installed in the ‘middle one third’ of the PFP thickness.
In more recent times manufacturers of epoxy PFP products have introduced products that do not need any reinforcement even for jet fire.

As can be seen there are many variable depending on the PFP generic type and specific product, test data, certification requirements, fire protection requirements, etc. Thus it is impossible to cover all eventualities in this document and it is essential when specifying PFP that the manufacturer’s certification and guidance documents are considered. However, where reinforcement is required then, in general, it should be fitted within the middle one-third (nominally mid-point) of the PFP thickness.

8.8.3 PFP terminations
Where a PFP protection system terminates at an ‘open edge’ then for the ‘coating types’ (concrete, LWC and polymeric) it is important that the reinforcement does not project beyond the edge of the PFP coating. The retention mesh (or scrim) should be fully encapsulated within the PFP product. Termination requirements and details vary depending on a number of factors including: the approval or certifying authority rules, the product certification, the item type being protected and the manufacturers own specification requirements. It is therefore essential that the manufacturer’s guidance and certification criteria are reviewed and referenced in the project specification.

Where ‘coating type’ PFP products terminate in the horizontal plane, the upper most exposed edge should be chamfered at 45° to fall away from the substrate to encourage ‘water shedding’.

PFP enclosures and PFP systems comprising thermal insulation and an outer cladding must have all joints sealed to prevent water ingress. The correct retaining bands and fasteners must be installed in-line with product certification requirements which may differ for ‘pool fire’ and ‘jet fire’ even with the same PFP product.
9 Characteristics of generic PFP systems available

9.1 Introduction

This section provides information about the different types of PFP materials that are commonly available and looks at characteristics that are common amongst a given generic type.

There are many different PFP materials available that can provide the necessary hydrocarbon and jet fire protection measures to process plant and equipment.

It is essential when selecting and specifying PFP materials to ensure that they have been tested in a manner that is appropriate to both the defined credible fire and/or blast event; and to the item type that requires protection. It is equally essential to ensure that the selected PFP product is capable of surviving both the general environmental conditions at the location, as well as the equipment item process and upset conditions. All materials considered should have been independently tested and where possible certified as suitable for the intended use.

Each PFP type has its own advantages and disadvantages, some of these relate to the service conditions (environment) and some relate to the location where the PFP is applied (e.g. in a workshop or on site). Other consideration may be the weight of the PFP material and/or transportation. Many offshore projects are quite weight sensitive and some systems increase the weight significantly (also important for modular construction), whilst some systems are more prone to cracking or spalling during transport or lifting activities.

For many projects a number of competing PFP types may all meet the fire protection requirements and material selection may then become one that is based on cost. However, if selected inappropriately for the service environment, a saving on capital expenditure may quickly become both a fire safety problem, as well as a significant remediation cost. Thus ideally selection of the most appropriate PFP should consider not only the fire protection requirements but also the service environment, the PFP material properties, the required life expectancy and other issues such as weight, transportation and lifting operations.

In other words it is not sufficient just to look at the fire performance when considering the selection of the most appropriate PFP type for a project.

This material review will be restricted to the main PFP ‘technology types’ that are currently used in both onshore and offshore process plant environments.

Within each of the main PFP types there may be a number of variations but broadly speaking the most commonly used technologies include:

- Concrete
- Lightweight cementitious
- Polymer resin based
  - Epoxy intumescent (undergo chemical reaction to fire)
  - Phenolic resin (normally do not undergo a reaction to fire)
- Mineral wool (stone wool) or High Temperature Insulating Wool (HTIW) blanket overlaid with a metal cladding as an outer protective layer.
- Micro-porous silica thermal insulation.
- Soft ‘jacket’ systems utilising stone wool or HTIW encased within an outer ‘fabric jacket’ as an outer protective layer.
- Cellular glass insulation systems designed to provide fire protection

Other specialised systems are used such as fire resistant rubber for riser protection and for sealing; as well as pipe and cable penetration sealing systems manufactured from a wide variety of rubber or polymeric materials, often with mineral or HTIW blanket internally. These systems are not relevant for the fire protection of process equipment and so are not detailed in this guidance document.

Table 9.1 PFP – typical areas of use

<table>
<thead>
<tr>
<th>Protected Item</th>
<th>Item type for PFP</th>
<th>Suitable PFP types</th>
<th>Where used</th>
</tr>
</thead>
</table>
| Vessels, Tanks, Spheres, Exchangers | Vessel wall | Polymer resin  
Lightweight cementitious  
Mineral wool or HTIW  
Cellular glass (where insulation also required) | Onshore & Offshore  
Onshore  
Onshore & Offshore  
Onshore & Offshore |
| Vessel saddles and skirts  
Pipes supports | Structural steel | Polymer resin  
Lightweight cementitious  
Concrete (for low level vessel supports) | Onshore & Offshore  
Onshore  
Onshore |
| Pipework (carbon steel and stainless steel) | Piping | Polymer resin  
Mineral wool or HTIW  
Cellular glass (where insulation also required) | Onshore & Offshore  
Onshore |
| Valves and Actuators | Valves | Soft ‘jackets’  
Stainless steel boxes with internal insulation  
Rigid epoxy PFP boxes | Onshore & Offshore  
Onshore & Offshore  
Onshore & Offshore |
| Flanges (including nozzles) | Flanges | Soft ‘jackets’  
Stainless steel boxes with internal | Onshore & Offshore |
### Table: Suitable PFP types for various protected items

<table>
<thead>
<tr>
<th>Protected Item</th>
<th>Item type for PFP</th>
<th>Suitable PFP types</th>
<th>Where used</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>insulation</td>
<td>Onshore &amp; Offshore</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rigid epoxy PFP boxes</td>
<td>Onshore &amp; Offshore</td>
</tr>
<tr>
<td>Critical cables</td>
<td>Cabling</td>
<td>Fire rated cables (not PFP)</td>
<td>Onshore and offshore</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fire rated enclosures / boxes²</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fire resistant PFP coating²</td>
<td></td>
</tr>
</tbody>
</table>

¹ Stainless steel may not require passive fire protection but where it has been deemed necessary then PFP products are specified as they would be for carbon steel, although different surface preparation and primers may be required.
² Note that care is required when using PFP to protect critical cabling as it can result in an increase in temperature due to increased insulation of the cables.

### 9.2 Concrete PFP

Concrete contains Ordinary Portland Cement (OPC) and fine and coarse aggregates and when used as a ‘cladding’ over structural steel is one the oldest types of PFP. It may be ‘cast-in-place’ on-site or alternatively ‘spray-applied concrete’ may be used. Concrete may be applied to follow the ‘contour’ of the steel or as ‘solid fill’.

Concrete as PFP protects steel in a fire because it has a much lower thermal conductivity than steel and so provides thermal insulation, reducing the rate of heat transfer. In addition water within the concrete will evaporate at 100°C which will cause the temperature rise to plateau until evaporation is complete. This process extends the time taken to for the steel to reach a temperature at which it is weakened.

Concrete PFP is not used offshore due to weight restrictions. Onshore it tends to be used on structural steel but may (infrequently) be used to fire protect vessel saddles and steel pedestals. As it is not normally specified for vessels the operating temperature of the equipment is not normally something that needs to be considered.

Onshore it has largely been replaced by lightweight cementitious PFP for new-build structures but there is still a lot of concrete PFP existing in process facilities around the world especially at lower elevations. Due to its weight it is not normally used at elevations much above grade.

In routine service conditions (i.e. non-fire) concrete is a hard and resilient material but it can be damaged by impact and this then creates an ingress point for water that may in turn lead to steelwork corrosion.

Depending on the grade of concrete (density, water content and aggregate type and size); and on the speed of heating in a fire, there is a high potential for explosive spalling which can endanger personnel or damage small bore piping and instruments that could then lead to escalation of an event through inventory leakage. Resistance to explosion loads is variable depending on grade, condition and installation method.

### 9.3 Lightweight Cementitious PFP

Lightweight cementitious (LWC) PFP normally contains Ordinary Portland Cement (OPC) with fillers and/or fibres. They are light weight compared to concrete PFP.

LWC is extensively used and probably the dominant PFP type onshore.
LWC may be trowel or spray applied to the substrate using either the ‘contour’ method or as ‘solid fill’. Another method called ‘hollow box’ is also used but most manufacturers and many owners consider this method to be unacceptable (see Annex D). This method of installation should be avoided in external process environments.

![Photo 6 Lightweight cementitious PFP](image)

LWC PFP products protect steel in a fire because it has a low thermal conductivity and provides thermal insulation, reducing the rate of heat transfer. In addition water within the LWC will evaporate at 100°C which will cause the temperature rise to plateau until evaporation is complete.

This process extends the time taken to for the steel to reach a temperature at which it is weakened.

LWC PFP products are used to protect vessel walls, pipes, vessel supports and structural steelwork. As it is relatively light it is used at all elevations of a process unit or pipe rack on both the structure and on equipment supports.

![Photo 7 Cementitious PFP on with Insulation and cladding on vessel](image)

Most LWC PFP products have pool fire and jet fire resistance and in pool fires they perform in a very predictable manner. Performance in jet fires can be variable depending on the density of the LWC product. Many have been blast tested but the configuration of the test specimen is fundamental and
should be representative of the installation method on site, e.g. box methods have poor blast resistance [37].

Low density LWC products are at risk from physical damage in service which can then allow water to penetrate to the steel substrate. The ‘box’ method of installation allows water to gain access behind the PFP where cracks open up at the corners, or where damage occurs (see Appendix D).

All LWC products will have an upper and lower operating temperature range and so this should be considered when specifying their use on vessels and piping.

9.4 Polymer based PFP

PFP products that are based on a polymer resin can be of various types but the most commonly used polymers are either epoxy or phenolic based. In general the epoxy types tend to be intumescent with the phenolic types providing thermal insulation by non-reactive means.

All of the polymer based products are ‘coatings’ although most are highly viscous and some are ‘paste like’ and so are often collectively referred to as “fireproofing mastics”.

Intumescent PFP protect steel by undergoing a chemical reaction initiated by the heat from a fire. This reaction is endothermic (absorbs energy from the surroundings) which causes a plateau in the rate of temperature rise; and also creates a ‘char’ that has a low thermal conductivity that insulates the steel. Phenolic types tend not to be intumescent and rely instead on the use of raw materials encapsulated within the polymer resin that have inherent insulating properties.

Most are applied using either trowels or specialist spray equipment and where reinforcement is required there may be an option to use a fabric cloth mesh that cannot corrode, rather than a metal mesh. In all cases where polymer PFP is applied as a ‘wet’ coating then it follows the shape of the underlying substrate.

When applied as a coating they are used to protect structural steelwork, fire and blast walls, vessel walls, piping and equipment supports. Many of these products can also be used as factory manufactured ‘pre-formed’ items that can then be used as a ‘dry-fit’ system for piping and as enclosures for flanges, valves and actuators.

All will have an upper and lower operating temperature range which should be considered when specifying for process vessels and piping. Phenolic resins tend to be capable of withstanding higher operating temperatures than epoxy intumescent but specialist thermal barrier products are also available from some manufacturers to extend the operational range.

Polymer based PFP products are durable, tough and damage resistant and suited to either workshop or site application. When applied as a coating system (with primer and topcoat) they provide a
seamless layer that has low water permeability which in turn provides for excellent weathering properties. Certain polymer types are more susceptible to water damage than others when they are subjected to water immersion (e.g. inverted channel sections, vessel support rings, etc.) but the most durable of the polymer based PFP types are capable of lasting for the life of the asset with only minor maintenance.

The variation in products performance is not only related to the polymer type but also the raw materials that form part of the formulation and so appropriate durability test data should be reviewed when selecting a particular product brand.

It should also be remembered that most organic polymers will burn when exposed to sufficiently high temperatures with the potential liberation of smoke and fume. This does mean that such products are often restricted to use in external areas, or to areas that are not normally manned.

9.5 Man Made Mineral Fibre Insulation (MMMF) as PFP
The family of Man Made Mineral Fibre (MMMF) products include two major groups ‘Mineral Wools’ and ‘High Temperature Insulation Wool (HTIW)’ which can be further sub-divided.

All are used for both process thermal insulation and for fire protection and provide the latter by simple thermal insulation, i.e. they provide a barrier to heat transfer and slow the rate of temperature rise of the protected substrate. In some cases these insulation products are specified to provide both process thermal and fire protection insulation and where this is the case, care needs to be taken to ensure that the specific grade and brand selected has been fire tested and has supporting certification to meet the identified fire protection performance requirements.

Typically the most commonly occurring forms of ‘wool’ products used are blanket (on a roll), pre-formed shapes (e.g. pipe sections, boards, etc.) or within a fabric outer covering to form a ‘fire protection jacket’. In many cases and especially for jet fire protection an outer stainless steel cladding is also installed over the wool product.

MMMF is used as PFP for the protection primarily of piping and vessels. It is not normally used for structural steel although it is occasionally used for vessel supports where the vessel has been insulated. The other major use is as removable ‘enclosures’ for valves, actuators and flanges manufactured from a thermal lining inside a stainless steel box, or as a lining within a ‘soft jacket’.

When specifying wool products the equipment operating temperature needs to be considered as well as the fire resistance requirements as this will determine the type of mineral wool or HTIW selected. Where it is also used for insulation then this will also have a bearing on the product selected and reference should be made to EI guide.

9.5.1 Mineral Wool
The terms ‘mineral wool’ and ‘rock wool’ tend to be used interchangeably with the term ‘stone wool’. Stone wool is the correct generic name for a product type often referred to in industry as “rock wool” which is actually the trade name ‘Rockwool’. Stone wool tends to be used at operating temperatures below 600°C and has limited jet fire resistance. Stone wool is not classified as a carcinogen.
9.5.2 High Temperature Insulation Wool (HTIW)

9.5.2.1 Alkaline earth silicate wool (AES wool)
AES wool is the most commonly used type of HTIW used today in fire protection applications. Unlike the older Alumino Silicate Wool (ASW) it is exonerated from classification as a carcinogen. In many cases it can be used as a PFP without any external cladding in diffuse or pool fires but cladding is often used to provide mechanical and weather protection. For jet fires it is used with cladding.

Proprietary PFP systems may use metal cladding or a weatherproof fabric outer layer to provide what is known as a ”soft jacket”.

Metal clad systems and fabric covered (jacket) systems are used to fire protect vessels, pipe, valves and flanges and can be designed to be removable for access to the valve, actuator or flange as required for maintenance operations.

Photo 9 Alkaline Earth Silicate Blanket
9.5.2.2 Alumino silicate wool (ASW)
Alumino silicate wool, also known as “refractory ceramic fibre” (RCF) were historically used for fire protection and so may be present in old plants. RCFs have been classified as a category 1b carcinogens under European Regulation (EC) No 1272/2008 on Classification, Labelling and Packaging of Substances and Mixtures and so appropriate handling precautions should be taken when removing old PFP. In Europe they are not normally used for fire protection due to the potential health issues.
Old plant may contain these products and so necessary safety precautions must be taken – seek advice from specialists in this field.

### 9.5.2.3 Polycrystalline wool (PCW)

Polycrystalline wool is generally used as an insulation material rather than a fire protection material. It is normally used at application temperatures greater than 1300 °C and in critical chemical and physical application conditions. It is not classified as a carcinogen.

### 9.5.3 Micro porous silica insulation as PFP

These products are generally used as thermal insulation products but can be incorporated into other PFP systems (e.g. system using HTIW) to provide enhanced thermal properties with lower overall thickness. When used as PFP they would be part of a ‘rated system’ (e.g. a 60 minute jet fire jacket system for pipework) and so ‘micro porous’ as a material is not normally specified for PFP (although it may be for process insulation). Normally the specification would define the requirement to use a “PFP blanket system” along with the required fire protection duration and fire type (pool or jet fire).

Micro porous silica insulation systems provide fire protection by thermal insulation in the same way as MMMF products. Performance is significantly reduced if allowed to get wet and so if used would need to be incorporated into a weatherproofed system.

### 9.5.4 Soft Jacket PFP Systems

Soft jacket systems are normally manufactured from a fabric outer that has blanket insulation within. The insulation blanket is normally mineral wool, HTIW or micro porous silica, or a combination. Jackets wrap around the item to be protected and are fastened at the joint using a number of different solutions.

![Photo 12 Soft jacket PFP](Photo 12 Soft jacket PFP)

Jackets can be used to fire protect small vessels although they tend to be used most frequently for the protection of pipework, valves, actuators and flanges as they are easily removed to allow access for maintenance. When removed for access, jackets are often not re-installed correctly, reducing or negating the fire protection capability and allowing water to penetrate underneath leading to CUI conditions. As with all jointed systems even when not removed, preventing water ingress is a major challenge to prevent CUI.
Jackets that are rated only for pool fire are not normally suitable for jet fire as the latter tend to have a greater thickness of insulation as well as a much more robust fastening system, normally comprising stainless steel fasteners and stainless steel band straps.

9.6 Cellular glass as PFP
Cellular glass is manufactured from aerated molten glass and is very impermeable but it is installed as a jointed system and so water ingress at joints needs to be avoided. Its main use as PFP is on vessels, vessel skirts and pipes where elevated operating conditions preclude certain other PFP products.

As with most thermal insulation products it can also be used as a PFP but when used in this context it is always over clad with either a polymer based product, another PFP system or metal cladding – cellular glass does not have any capacity to resist jet fire impingement without over cladding.
10 Installation of PFP Systems to Equipment and Plant Items

10.1 General
This section provides general information on the effective installation or application of the selected PFP system. The verb ‘applied’ tends to be used for PFP products that are ‘coating like’ and ‘installed’ tends to be used for the remaining non-coating types. Within this document both may be used interchangeably to mean the same, i.e. the correct application or installation of the ‘PFP system’ with all its integral parts to meet its certified rating.

Fire protection (or “fire proofing”) is a safety critical element (SCE) and hence correct use and installation/application is fundamental to the successful outcome of that SCE in the hazardous event.

For individual products it is essential that this is done in accordance with the manufacturer’s instructions and relevant certification (if any) to ensure resistance to explosion (where required), the correct fire resistance and good weather resistance to ensure the maximum service life.

The wide variation in technology types used in PFP products, and significant differences between individual products even within one technology type, means that it is unrealistic to consider “PFP” as one ‘all encompassing’ group. However there are common errors and ‘good practice’ methodology within each generic technology type and so this section will consider the installation or application by those generic types identified in section 9.

It is also essential that both the installer and the quality assurance inspector are competent in carrying out the role for which they are employed. Where required suitable audit procedures should be put in place that ensure all steps from manufacture through to final hand over are compliant. In some cases the project may require their own audit of manufacturer’s facilities but in the majority of cases these are dealt with by other means such as under a verified ISO9001 [38] process; or by specific means such as the ‘follow-up service’ offered by the Underwriters Laboratory (UL) when testing and certifying under their UL1709 standard. Suitability and fitness for purpose of the selected PFP products should be done at specification stage and this aspect is covered in section 8 of this guide.

Most manufacture’s will provide a ‘site based’ technical support function but this is a contractual matter and may be free or paid for depending on the extent to which the manufacturer is required to become involved. In the majority of cases the manufacturer will guarantee their product only and will offer advice on site but will not take overall responsibility for the quality of the surface preparation or application/installation of the PFP system. The manufacturer will normally require that the contractor undertakes their own product specific training programme prior to the commencement of any job. It is important to recognise that this training is only related to that product and its specific requirements.

In terms of compliant application/installation it is normally expected that the appointed contractor(s) should have their own clearly defined competency requirements which should include manufacturer’s product specific training. The appointed contractor will be held responsible for the quality of their workmanship.

Quality assurance (QA) inspection maybe carried out by the contractor only or third party inspectors may also be employed by the client or project in addition. The above are all contractual aspects of the specific project and are beyond the scope of this document, however, the importance of fire protection cannot be over emphasised and so suitable quality systems must be put in place by the contracting parties.
10.2 Installer/applicator competence

No matter which PFP type is used it is strongly recommended that a competent contractor is used. In many cases PFP contractors are trained by the PFP manufacturer which may be acceptable where only that particular product is being applied but one should also consider that some manufacturers training is better than others, especially when it comes to a more general understanding of the reason for PFP and the consequences of poor installation.

Competence is difficult to establish especially where there are no formal skills and education based training and qualification systems in place. Unfortunately this is the case in many countries where the various roles involved in being a ‘fire-proofer’ are not defined or mandated. Within such an environment then the team or individual responsible for the PFP must try to ensure so far as is reasonably practicable, that both the contractor and their staff are suitably qualified, competent and experienced. Where possible an independent training course that is recognised and endorsed by industry should be undertaken and supplemented with product specific training. Countries may have their own recognised courses and an example of one such course for ‘fireproofing applicators’ in the UK is run by the Offshore Petroleum Industries Training Organisation (OPITO). However, this training only covers lightweight cementitious and epoxy intumescent PFP products (i.e. coating type PFP).

This course is also at a relatively basic level and so competency will need to be established with additional training (e.g. manufacturers) and ‘on the job’ training by more experienced practitioners.

Insulation based PFP products such as ‘blanket and cladding’ systems are installed in a similar way to process thermal insulation. For example the same skill set is required for aspects such as cutting and fitting ‘blanket’ and carrying out the required sheet metal work for the cladding. There are insulation industry recognised apprenticeships such as those run by the Thermal Insulation Contractors Association (TICA) in the UK, that would demonstrate the required level of competence for the installation of ‘thermal insulation systems’. However, there are differences in the requirements for process thermal insulation and passive fire protection such as the need for stainless steel cladding and additional screwed or riveted fixing, and banding. Thus product specific training will be required to highlight the differences.

10.3 QA/QC record keeping

The extent of quality control and auditing may vary between projects and clients but it should always be recognised that PFP is a safety critical element (SCE) and as such should be evaluated and maintained to ensure it retains the required performance against defined performances standards. Integrity management and maintenance of the ‘installed’ PFP system are covered in greater detail in sections 12 (Integrity Management) and 13 (Inspection and Maintenance) of this guide and Paragraph 10.1 discusses general aspects of auditing the product and the roles of the manufacturer and the application contractor. This paragraph will therefore consider quality control (QC) related to the application/installation of the PFP system and indicate typical attributes that need to be consider in carrying out those QC actions.

There may be areas where specific records need to be kept for one type of PFP that differ from other types but there are many common aspects. The differences should be identified in manufacturer’s recommendations and industry specific training where applicable. A project and/or ‘work scope specific’ quality control schedule of items to be inspected and record shall be common areas for concern and that are routinely measured or observed include:
• Recording each product and batch number used during the installation and if possible ‘mapping’ the location of those batches to specific equipment items or areas of plant.
• Recording the ambient weather conditions including temperature and Relative Humidity (RH) at all stages and at regular intervals during the day; including recording the ambient temperature during the night even when no application is taking place as this is important for the correct ‘cure’ of coating based PFP products. Defined ‘go/no go’ parameters should be established for any ‘out of compliance’ conditions relating to surface preparation, painting or PFP application.
• Recording substrate condition and if required standard of cleanliness following surface preparation. For the coating systems there should be a ‘hold’ point after surface preparation in order that this can be checked prior to applying the paint / primer system.
• Recording any paint system and thickness that needs to be applied under the PFP with a ‘hold’ point established prior to the application of the PFP.
• Recording thickness of PFP installed or applied. Each layer applied should be individually measured and recorded and a ‘hold’ point should be established prior to release for application of subsequent layers.
• Recording all aspects of over-cladding if required and any sealing systems used.
• Recording all aspects of topcoat application and/or sealers used as final weather protection.
• Additional ‘hold’ points for inspection may need to be built-in to the work schedule and inspection regime depending on the type of PFP to be installed.
11 Failure mechanisms of generic PFP systems

11.1 Introduction
This section considers some of the main modes of failure of the most commonly used PFP types. Many of the worst failure mechanisms of all PFP types are related to water, either due to water ingress behind PFP or due to water absorption within the actual PFP product. Other common failure mechanisms may include exposure to UV light or to excessively hot or cold substrates or environments.

There are a large number of generic types of PFP and hence a range of failure mechanisms but even within particular generic types there can be considerable variation, especially in speed of degradation. In addition to this the method by which the PFP is installed will also have an effect on degradation and failure mechanisms.

Thus there is potentially a vast number of failure mechanisms based on combinations of PFP generic type, individual PFP product and installation method and so these cannot all be covered in detail within this guide. However, common mechanisms can be grouped together by either method of instalment (e.g. PFP with/without joints); or by generic type of PFP (e.g. concrete, cementitious, polymers, insulation based systems, etc.).

In this guidance document failure mechanisms will be grouped by ‘generic PFP type’ and within that further comment regarding method of installation will be addressed. Only those PFP types that are most commonly used for the fire protection of process plant and equipment (and covered in section 9 of this guide) will be discussed in detail below.

11.2 Concrete PFP
Concrete is a hard and resilient material but it can be damaged by impact and this then creates an ingress point for water. Natural shrinkage forms small cracks that over time with weathering and freeze/thaw cycling can become larger allowing further water ingress and corrosion of the underlying steel to occur. Corrosion of the reinforcing mesh or the underlying steel increases cracking due to the expansion of the rust which can then lead to large pieces of concrete becoming loose and forming a dropped object hazard. Although more of a problem for steel structures such as elevated beams, this may apply to equipment supports that are above grade.
Variability in the final cured material can arise from poor quality control of locally sourced raw materials and from the drying and curing mechanism which is dependent on atmospheric conditions over long time periods.

Cement based products are very alkaline and so steel buried within or underneath concrete should not normally corrode but over years of exposure to water and carbon dioxide (CO$_2$), the pH of concrete may reduce from around pH 14 to pH 7 due to ‘carbonation’. Under this pH steel is no longer protected by the passivating action of alkaline concrete and so is susceptible to corrosion. In addition more rapid corrosion of underlying steel may occur due to the presence of environmental pollutants such as chlorides (from saline atmospheric conditions) and sulphates to migrate through to the substrate and cause steelwork corrosion irrespective of the alkalinity of the overlying concrete.

Depending on grade and density of the concrete, water content and speed of heating in a fire there is potential for explosive spalling which can endanger personnel or small bore piping and instruments that could then lead to escalation of an event.
Concrete as PFP is relatively cheap but due to reasons stated above there may be hidden costs in future years.

Photograph 12 shows a sphere that had concrete PFP applied to the legs and was undergoing hydro-testing. Advanced corrosion of the steel legs, hidden behind the concrete PFP, meant that they had insufficient strength to support the sphere when it contained water. This incident resulted in one fatality and one serious injury.

11.3 Lightweight Cementitious (LWC) PFP

Cementitious PFP products can vary significantly in their density and physical properties, from dense and tough to relatively light and friable. These differences affect many attributes such as porosity and mechanical strength. All commonly used cementitious products contain Portland cement and so share many of the same attributes as concrete, including many of the same failure mechanisms, however, the wide variation in formulation means that some products are more resilient than others.

All cementitious products are porous and so can absorb water. Shrinkage cracks can form during curing which although small will allow water to penetrate the surface and over time with weathering and freeze/thaw cycling may get larger. This and the ability to absorb water make them susceptible to corrosion of the reinforcing mesh (where galvanised mesh is used); and of the steel substrate due to potential for corrosion under fireproofing (CUF). Corrosion of the reinforcing mesh or the underlying steel increases cracking due to the expansion of the rust which can then lead to large pieces of concrete becoming loose and forming a dropped object hazard. Although more of a problem for steel structures such as elevated beams this may apply to equipment supports that are above grade.

Certain grades of LWC are also susceptible to erosion of the outer surface layers due to water penetration and consequent freeze/thaw damage over time. These can form quite deep ‘pits’ that effectively reduce the PFP thickness and hence fire resistance.

For the low density cement based PFP products physical damage is a potential risk that would then allow water to migrate through to the steel substrate with subsequent CUF problems. In addition any missing PFP would render that area at risk from subsequent fire events.

LWC PFP is normally restricted to less than 50°C operating temperature without the use of additional insulation products, restricting its use on process equipment operating above this temperature. Therefore premature PFP failure may occur if the original specification did not take this factor into account, or if there has been a change in vessel operating conditions.
11.4 Polymer based PFP

Being polymer based ‘coatings’ this type of PFP product provides a seamless layer so that no water can migrate through joints (unless they are installed as pre-manufactured removable ‘shapes’ such as valve and flange enclosures). Water ingress via joints is a major factor in degradation of many PFP products and the underlying substrate.

There are an enormous range of polymer resins that can be used to manufacture this type of PFP coating as well as a large range of other essential raw materials that have varying levels of water resistance. Thus it is impossible to say that all polymer based PFP systems will have the same or similar behaviours and durability. However, when compared to concrete and LWC ‘coatings’ the polymer based systems have in general lower water absorption characteristics. It should be recognised though that whilst the best products can withstand water immersion without top coating, others cannot. In general even those products that withstand water immersion with little effect are always specified with a topcoat. This is for two reasons; one is to provide UV protection and the other is to ensure maximum service life where water immersion is a possibility. Note that water is not restricted to immersion in sea water and ‘water immersion situations’ can occur due to poor design features such as upturned channel section or vessel support rings, etc. without adequate drainage.

When correctly specified and applied the best of the polymer based PFP products have quite low water permeability with excellent weathering properties and are capable of lasting for the life of the asset with only minor maintenance. For these systems corrosion of the underlying steel can be negligible.

However, it should be recognised that some polymer based PFP products on the market can be quite susceptible to water degradation due either to the polymer type or to solubility of some of the other essential raw materials.

Where it is known that water immersion may occur (e.g. on offshore jackets) then the protective coating and PFP specification should be suitable for that environment.
Other failure mechanisms relate to the temperatures to which the PFP is exposed during its service life. All polymer based PFP products have an upper and a lower temperature limit although this limit can vary significantly between product and technology types. For many epoxy intumescent PFP the upper temperature is limited to 80°C although other non-intumescent products can be used at much higher temperatures.

All polymers tend to become less flexible as temperature drops and below about -40°C surface cracks can occur. Again the lower temperature limit can vary significantly by product and technology type.

Although these aspects should be considered during PFP specification there are many cases where such factors were not considered or where process conditions have changed, or where there may have been severe or extended process upsets. In these cases the PFP may show signs of cracking, blistering or even scorching.

Not only do equipment temperatures need to be considered but also the environmental temperature in regions that see extreme cold for some or all of the year (e.g. the Arctic).

11.5 Man Made Mineral Fibre Insulation (MMMF) as PFP
As noted in section 9 these systems are similar to, or in some cases the same as ‘process insulation’ and in terms of degradation can all be considered similarly. From section 9, MMMF systems include:

- Mineral wool
- High temperature insulation wool
- Microporous insulation
- Soft jacket enclosures manufactured using one of the above insulation products
- Rigid enclosures manufactured suing one of the above insulation products

The main concerns relating to the degradation of these systems relate to water ingress as they are installed as a system with joints. Water ingress can lead to Corrosion under Insulation (CUI) and effective weatherproofing of the cladding or other barrier, is essential at joints and at other penetrations such as valve stems, etc. These products also absorb water and so exacerbate the potential for CUI and may lead to degradation of the material such that it is less effective as a thermal insulation.

The subject of effective thermal insulation, degradation and integrity management is more fully detailed see EI insulation guide.

Another type of insulation based PFP that is similar to but also differs from those listed above is cellular glass. This product is actually impermeable to moisture but it may still suffer from water ingress at joints as it is fitted in pre-formed sections around pipes and valves, etc.
All of the above listed products have a range of acceptable operating temperatures that need to be considered during specification and there may be some forms of failure that are related to incorrect specification as well as water ingress, although these may not be visible on inspection.

One of the most common failure mechanisms (apart from water ingress at joints) is the failure to correctly replace enclosures that have been removed to allow access for routine maintenance operations. This allows water penetration and does not provide the required fire resistance rating to the safety critical equipment item. The following photographs show an example of a PFP ‘blanket and cladding’ system and a soft jacket.
12 Integrity Management of protected Plant Items
This section considers the requirement for the integrity management of PFP that is applied to process plant and equipment over the anticipated life of the PFP solution.

12.1 General
From section 10 it can be seen that some failure mechanisms are common across a variety of technology types whilst other failure mechanisms are applicable to a specific technology type. In some cases the failure may be product specific or it may be due to poor specification, poor application/installation or a change to the process that was not envisaged at the time of specification.

In the majority of cases failure of PFP systems arises from the following:

- Incorrect specification for the service environment (e.g. elevated temperature)
- Incorrect installation including weather sealing
- Mechanical/physical damage (e.g. standing on ‘lagged’ pipes, high pressure jet washing, etc.)
- Failure to maintain damage or degradation in a timely manner
- Incorrect re-fitting after maintenance operations (e.g. ‘soft jackets’ on valves)
- Inadequate or non-existent inspection leading to faster or greater failure than would otherwise have occurred.
- Failure to consider PFP requirements as a consequence of process changes (i.e. management of change).

Some aspects of PFP suitability for the service environment were discussed in sections 9 and 10 and some of this will be re-visited here. In this section we will consider the various PFP technology types in terms of a broad segmentation that aligns with the main integrity management issues, these are:

- Removable systems (e.g. jackets, blanket, enclosures, pre-formed sections, etc.)
- Fixed systems (e.g. cementitious systems, polymer systems, etc.).

12.2 Removable PFP systems
The systems are designed to be removable so that routine maintenance and inspection operations may be carried out on the protected item (e.g. valves) and the PFP subsequently re-fitted.

Benefits of these systems include:

- Some are easy to fit (others less so)
- No ‘wet trades’ required to install on site
- Can be removed for easy access to protected items such as valves for inspection or maintenance reasons
- May be re-fitted after access to the protected item in order that the PFP may be reinstated
- May also provide thermal insulation (e.g. for heat conservation)
- May be used where surface preparation is not possible
- Sometimes used as a temporary solution to fire protection until other works are completed after which a more permanent solution may be selected.
Concerns with these systems include:
- Not always as easy to re-fit as claimed and hence get re-fitted incorrectly or not replaced
- Have joints and so inherently at risk of water ingress
- Cladding or jackets easily damaged by ‘other trades’
- Poor design or installation may lead to, or exacerbate Corrosion Under Insulation (CUI)

12.3 Fixed PFP systems
‘Fixed’ PFP systems are those that are applied and bonded to the substrate either directly or more often over a suitable anti-corrosion primer or paint system. Such systems include poured and spray applied concrete and lightweight cementitious PFP products, as well as polymer based coatings such as epoxy intumescent and phenolic PFP. Also included here are the polymer based ‘thermal barrier’ products that are design to be used with the polymer based PFP products on hot or cold surfaces.

Benefits of these systems include:
- Seamless – no joints for water ingress
- Bonded to the corrosion protected substrate
- Some are very durable and robust, others are less so (see sections 5, 9 and 10)
- Some are very resistant to CUF others less so (see sections 5, 9 and 10)
- May also provide thermal insulation (e.g. for heat conservation)

Concerns with these systems include:
- ‘Wet trades’ required to install on site
- Often not ‘simple’ to install
- Minor cracks in concrete and cement based systems may increase due to weathering and freeze/thaw cycling, allowing water to ingress, potentially causing corrosion of reinforcing mesh and substrate
- Cannot be removed for inspection
- Cracked or porous PFP systems can hide corrosion

12.4 Inspection considerations
Unmanaged CUI is an integrity threat to protected items in the process industries. Many types of PFP are the same as, or similar to those used for thermal process insulation and the acronym ‘Corrosion under Fireproofing’ (CUI) has come into regular use where the insulation (or other PFP product) is installed for the purpose of fire protection rather than process insulation.

Historically selection of incorrect insulation and PFP materials was linked to CUI problems and although the worst of these products are no longer used, CUI may still occur as a consequence of water containing soluble salts that ingresses behind insulation and PFP. CUI also occurred because of inadequate inspection routines allowing corrosion to advance unseen and unchecked.

Companies now employ rigorous CUI Inspection programmes where process thermal insulation is removed on a routine basis so that the underlying substrate can be examined. However, these
routines may not always be applied to insulation systems that are installed only for fire protection reasons. PFP types that are susceptible to water ingress and consequent CUF should also undergo a similar inspection regime.

The use of removable PFP systems will allow an effective inspection regime that should identify any CUF at an early stage, however, the removable nature of this PFP also means that there are joints that need to be effectively sealed to prevent water ingress. Over time such joints may leak or removable PFP systems may not be reinstalled correctly. This in conjunction with the fact that inspection regimes are not always as well managed as they should be means that CUF can occur such that the protected item has an integrity hazard. Thus with removable PFP systems a well-managed inspection routine is essential.

A commonly seen problem with removable PFP systems on site is the failure to replace them correctly indicating a failure in ‘control of work’ systems. Photo 5 shows a pipe with a ‘blanket plus metal cladding’ type PFP system that terminates at a valve with exposed blanket insulation. Over this insulation and surrounding the valve a ridged enclosure should be fitted to overlap the pipe cladding with joints and penetrations sealed against the weather. In the case shown the PFP will not provide suitable fire protection and water has free access which if not rectified it in a timely manner has the potential to lead to CUF.

For ‘fixed PFP’, those that are cement based will have a tendency to shrink and crack. Over time, especially in cold wet climates, water in the PFP can freeze and cause these small cracks to open-up or cause ‘spalling’ at the PFP surface. These cracks may lead to water ingress and the potential for substrate corrosion (despite the alkalinity of the PFP product). As corrosion products are formed they expand and ‘push apart’ the PFP to an even greater extent leading to detachment and loss of material thickness at the surface. If located at height this it may then become a ‘dropped object’ hazard (see section 4).

As in the case of removable systems, integrity management of fixed PFP systems needs to involve regular and routine inspection. Since inspection beneath fixed PFP systems is not possible one has to
be aware of other signs of problems such as cracking, rust staining, spalling, etc. If defects have been allowed to progress then ‘patch removal’ for substrate inspection may be necessary.

It is possible that Non-destructive Testing (NDT) may be carried out through polymer based PFP systems but current experience is limited in this area. Difficulties in achieving consistent results relate to the high total thickness and inherent variation in the thickness of spray or trowel applied PFP. This is an area where future developments may mean that effective NDT through some polymer based PFP systems becomes possible.

Polymer based PFP products are ‘seamless’ when applied as a wet coating and if correctly applied and weatherproofed (normally with a top coat) then they should be capable of lasting the life of the asset. However many assume that this means they can be installed and then ‘forgotten’. This is incorrect and such PFP products still require routine maintenance (albeit less frequently) and repair of areas that are subject to mechanical damage to prevent premature degradation.

Typical degradation for this type of PFP includes UV degradation or water uptake (certain products only) due to incorrect top coating; cracking over excessively hot or cold surfaces due to poor specification or changes in process conditions.

More information on the inspection and maintenance of PFP systems is given in section 13.
13 Inspection and Maintenance of the PFP System

13.1 Introduction

This section of the guide considers the need for routine inspection and maintenance over the life cycle of the PFP system in order that it remains ‘fit for purpose’ and capable of achieving the defined performance requirement.

In section 2 of this guide the role of PFP as an SCE (safety critical element) was discussed. The specification and selection of a PFP product is based on the known fire performance when tested and in the ‘as new’ condition. However, a fire event is not predictable - it may never occur or it may occur at some future date and so the condition of the PFP at that time is critical to the successful performance in a fire event.

There are differing opinions concerning the use of PFP with the extremes being that it should be avoided wherever possible because it may contribute to CUI (or CUF); to the opposite where it is believed that it can be installed and left for the life of asset without further consideration. The reality is somewhere between these two extremes.

- Most failures of PFP in service are due to one or more of the following:
  - Incorrect specification
  - Variation in process conditions beyond those identified at the time of specification
  - Poor installation methods
  - Inadequate routine inspection and subsequent maintenance to address issues that may be identified such as damage, degradation, etc.

Even though the most durable PFP systems are capable of lasting many decades when correctly specified and installed, the use of the terminology “passive” does not mean “fit and forget”.

As with all safety critical elements there is a need to regularly inspect (and where required maintain) these so that they can provide the desired performance when required to do so as measured against a defined set of performance standards. Thus for PFP products a set of performance standard should also be developed for both the element to be protected and the passive fire protection measure (in this case the PFP). Performance standards are normally client specific and may or may not be informed by legislation or guidance. Two examples of guidance that highlight the need for regular inspection and maintenance are given in the UK PFEER Regulations and in API 2218 (figure 1 and 2). These identify a need to conduct ongoing inspection, verification and maintenance operations.

Regulation 13 Mitigation of fire and explosion

The duty holder shall -

(a) take appropriate measures with a view to protecting persons on the installation during an emergency from the effects of fire and explosion; and

(b) ensure that, so far as is reasonably practicable, any arrangements made and plant provided pursuant to this regulation are capable of remaining effective in an emergency.

Figure 13-1: Regulation 13: Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations 1995 (PFEER)
For many PFP systems (but not all) water is the most likely cause of long term degradation of either the PFP and/or the underlying substrate (e.g. CUI). A significant quantity of PFP is based on one or more types of HTIW overlaid by a stainless steel jacket, fitted around vessels, piping and valves, etc. Such systems are inherently the same as those that are used to provide process thermal insulation and as such should be considered within the CUI Integrity Management (IM) process. EI document “Guidelines for the Design, Installation and Management of Thermal Insulation systems” has considerable detail as to how this type of system should be inspected and maintained. The fact that the insulation is intended to provide a fire protection rather than process thermal insulation does not alter the nature of the system, or the methods of integrity management.

Other PFP systems such as concrete, lightweight cementitious or epoxy intumescent may also be affected by water and other environmental or process conditions such as hot surfaces and so require routine inspection and maintenance. This type of PFP material is closely related in nature to protective coatings and therefore the inspection and maintenance regime would be similar. EI document “Guidelines for the Management of Coatings for External Corrosion Protection” [39] has considerable detail as to how this type of system should be inspected and maintained.

Formal inspection of the installed insulation systems is a critical activity to establish its condition when in-service and to ensure that the condition is maintained to the minimum performance standards. This is the principal means to establish integrity and to ensure that any remedial work required is identified and formally recorded.

In-service inspection of the condition of PFP systems should be planned and managed as part of the company’s asset integrity management system (which is typically aligned with the respective FM and corrosion management (CM) systems). Integrating the PFP system inspections/surveys with those for external coatings or insulation (depending on PFP type) has distinct advantages - refer also to EI Guidelines for the management of coatings for external corrosion protection and Guidelines for the Design, Installation and Management of Thermal Insulation systems.

13.2 Responsibility and ownership

PFP is a safety critical item in its own right and therefore it is ideal that it should be subject to some form of integrity management across its life cycle. PFP materials should be assigned to particular asset disciplines, who will have responsibility for it. This ownership may lie with different disciplines at different stages in the asset life cycle. For example the specification of PFP may lie with a Process safety group during project stages, with the installation and continuing inspection and maintenance falling to possible fabric maintenance groups. UK and European Offshore operations require the production of performance standards to support the life cycle integrity of SCEs. Onshore operations and offshore operations where the performance standard requirements are not as enforced should still look to have similar PFP material data records and requirements as part of their Process safety information (PSI) management systems. Performance standards, for PFP materials, should cover the following:
13.2.1 Function

The key functional requirements for the PFP should be detailed. This should be the basic reason for PFP selection. It should cover the items / areas to which PFP has been applied. The exposure fire type and the PFP functional duration are key details. It should ideally include details of the material type and, thickness, to achieve this performance.

13.2.2 Availability

As a passive system PFP materials are required to have almost 100% availability. In practise this is often quoted as being available at all times during normal operation. Any temporary removal of PFP materials should be subject to an appropriate Management of Change, which may also require some form of operational risk assessment. Temporary removal may include requirements to gain access to underlying systems. An example where PFP may have a higher requirement to be removed can be for the removal of blankets / preformed sections around critical valves etc. in order to maintain the valves.

13.2.3 Reliability

This is similar to the availability requirements and again as a passive system it should have high reliability. One aspect of the reliability is that the PFP maintains its performance throughout the expected life of the underlying equipment. There should be no performance deterioration of the PFP over this period, for example due to exposure to weather and sunlight or any other environmental or regular occurring conditions. In areas with higher potential for impact from due to regularly passing vehicles and personnel movements, the PFP should be resilient enough to withstand expected impacts / erosion.

13.2.4 Survivability

The PFP materials should be able to withstand events coincident with the expected fire exposure case. This can include blast overpressures if proceeded by and explosion and the application of fire water of high pressure water jets could be expected as part of later fire response. In frequent environmental conditions should also be detailed in the PFP performance standard. Examples can include earthquake resistance, Extreme weather (storm) conditions, extreme water exposure e.g. flooding and wave action, and high and low extreme temperatures.

13.2.5 Integration

PFP materials can only perform their required function for a finite duration. Details of the PFP integration with other SCEs is required. In particular this is where PFP interacts with depressurising and pressure protection systems. The design of the PFP can be critical in the sizing and required function of these systems. However, PFP also integrates with general fabric integrity, emergency isolation and other critical systems e.g. flare and vent system integrity.

For routine PFP material inspection there should be Preventative Maintenance Routines (PMR) in place that identify what is considered to be an acceptable condition and what is not; defining an inspection schedule, identifying anomalies and the action to be taken to correct those anomalies.

13.3 PFP inspections and maintenance

The high availability and reliability requirements for PFP materials required to ensure that they meet their performance requirements, over the asset life cycle, means that there should be a formal
inspection and maintenance schedule for PFP material applications. PFP inspection should be carried out by competent personnel who have the ability to identify and record PFP anomalies. Where failure analysis and corrective action are required then more experienced and/or specialist personnel may be required. The severity of identified PFP material anomalies should be assessed by determining the extent and severity of the anomaly against the criticality of the system to which the PFP is applied.

### 13.4 Anomaly assessment of PFP materials

The assessment of PFP anomalies is a difficult process and often, due to the age of the protected asset, little or no information may be available from the initial design and installation to determine the exact materials used and the performance requirements expected.

General guidance on the assessment of anomalies is provided in HSE Information Note 12/2007

It should be recognised that this information note is specific to the materials tested as part of that test programme and guidance from the manufacturers and independent, competent inspection parties should be sought for specific details on these and other PFP materials used. Where it is possible, testing of representative anomalies should be used as the basis for assessment of the criticality of that anomaly to the performance of the PFP. It is also important to assess the combination of anomalies; for example cracking in a cement based system is a far greater issue if it is combined with corroded mesh reinforcement and/or disbondment from the substrate.

### 13.5 Assessment of the importance of anomalies

Anomalies within PFP systems may over years of service render the material unfit for the required fire protection duty. All PFP system faults and anomalies should be identified with a unique reference to track remedial action progress and each should be photographed.

The inspection findings should be incorporated within a maintenance action plan based upon priority established from a risk assessment based on anomaly type and extent, and the criticality of the protected SCE. The resultant data may should then be recorded within the maintenance management system (MMS) for traceability of future maintenance activities.

A typical anomaly ranking system may be used similar to that shown as an example in Table 13-1

<table>
<thead>
<tr>
<th>Anomaly Level</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
</table>
| 1 Immediate Risk | Condition deteriorated so that there is an immediate risk, even before any fire or explosion | Corroded hydrocarbon containment  
Dropped object hazard  
Serious structural corrosion  
Degrading asbestos containing material |
<table>
<thead>
<tr>
<th>Anomaly Level</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
</table>
| 2 Major Anomalies | PFP not present, condition degraded or original design so poor that little or no protection offered against identified fire and explosion hazards | PFP not installed or has been extensively removed  
Condition deteriorating rapidly and likely to become an immediate risk before next inspection  
Multiple or large PFP anomalies  
System would not survive initial explosion |
| 3 Significant Anomalies | Condition degraded or poor original design such that premature failure is probable for identified fire and explosion hazards | Not suitable for fire hazards (e.g. not resistant to jet fire)  
Poor Design and specification (e.g. not suitable for environmental or operating conditions)  
Deteriorating condition (early stages) such as loss of thickness, but not down to reinforcing mesh.  
‘Through thickness’ cracks or excessively wide cracks  
Would be damaged by initial explosion |
| 4 Minor Anomalies | Individual and small anomalies, possible reduction in protection level for identified fire and explosion hazards but not likely to cause global collapse or premature failure | Chips and dents in the surface  
Minor cracking  
Damaged top-coat |
| 5 Acceptable | Meets or exceeds current requirements | Good condition  
Well maintained |

**Table 13-1: Typical PFP Anomaly Levels**

**13.6 Repair strategies**

Based on assessment of the anomalies and the criticality of the item being protected a series of remedial actions can be considered; a typical example of this is shown in table13-2. The strategy for repairs will be dependent on many factors such as availability of personnel, planned shutdowns, fabric maintenance campaigns, etc.
<table>
<thead>
<tr>
<th>Anomaly Level</th>
<th>Item Criticality</th>
<th>Remedial Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – Immediate</td>
<td>High or Medium</td>
<td>Consider mitigation measures. Urgent PFP repairs required</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Remove PFP completely and replace with paint system</td>
</tr>
<tr>
<td>2 – Major</td>
<td>High or Medium</td>
<td>Priority PFP repairs required to meet performance standard</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Remove PFP completely and replace with paint system</td>
</tr>
<tr>
<td>3 - Significant</td>
<td>High or Medium</td>
<td>Remove PFP completely and replace with paint system</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>No immediate action required, schedule for close visual inspection</td>
</tr>
<tr>
<td>4 - Minor</td>
<td>All</td>
<td>No immediate action required, schedule for close visual inspection</td>
</tr>
<tr>
<td>5 - Acceptable</td>
<td>All</td>
<td>No action required, schedule for general visual inspection</td>
</tr>
</tbody>
</table>

Table 13-2: Example Remedial Actions
14 Re-evaluating PFP Systems for change of use
This section provides discussion on factors that can affect installed PFP systems which may result in a change of specification, including the extent of coverage and required performance.

14.1 Considerations for Long Term Integrity
Modern process safety management techniques (see sections 2, 3 and 5) will look to ensure that PFP is used only where strictly required. Such analysis is normally only undertaken at design and construction stage. However, there are factors that can result in a change to PFP requirements over the life cycle of the installed PFP system.

14.2 Changes in hazard or process conditions
Most operators undertake operational reviews (thorough reviews offshore) of the hazards and associated risks at their facility. Over time the nature of hazards may change as a result of process condition and design changes. This may result in a change to the required PFP function.

For example an old facility may see that the pressures and volumes of hydrocarbons have decreased over time and as a result it may be possible to ‘down-rate’ the requirement for PFP and hence reduce potentially expensive repairs. By contrast the introduction of a new well-stream or installation of a gas compression system may introduce the potential for increased fire hazards such as high heat flux jet fires that may not have been previously accounted for in the PFP design. Under the principals of good risk management, replacement PFP systems should be designed to meet the current fire threats to applicable standards, so long as the costs and any new risks e.g. new material installation hazards, are not disproportionate to the risk benefit gained.

Where there has been a change in hazards there is often a requirement to look at the existing PFP and see if it is capable of resisting the new hazards, or where hazards have been reduced it may be possible to accept a degree of damage or even show that PFP is no longer required and can be removed or monitored.

Up rating of PFP for new fire hazards is a complex process that requires a thorough review of the PFP systems capabilities.

Changes to the process should be covered by Management of Change (MOC) procedures. It is important that such procedures include consideration of the effects on PFP as there has been a tendency to forget that PFP is an SCE in its own right. This should cover changes to hazard, process conditions such as temperature changes and the potential physical damage to PFP during installation or modification to process equipment or structure.

14.3 Effect of ageing / weathering
The rate of deterioration and potential risk of failure of PFP systems is closely related to ensuring the system is suitable for the environment it is installed in.

When inspecting PFP the local environmental conditions should be recorded and assessment made as to the suitability of the PFP system to withstand these conditions or evidence of breakdown in the system. An example of environmental conditions for an offshore asset are shown in table 14-1.
<table>
<thead>
<tr>
<th>Environment</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Immersion/Splash Zone</td>
<td>Jetty Piles, Risers, jacket legs and on process equipment operating below ambient conditions</td>
</tr>
<tr>
<td>2 Extremely Harsh &amp; Exposed</td>
<td>Exterior to module or end columns and beams and external plant and structures offshore</td>
</tr>
<tr>
<td>3 Harsh &amp; Exposed</td>
<td>External plant and structures at coastal terminal structures, internal to modules but regularly exposed to deluge</td>
</tr>
<tr>
<td>4 Exposed</td>
<td>Deck-heads above deluge and beams and columns within closed modules not regularly deluged, external structures in temperate climates</td>
</tr>
<tr>
<td>5 Benign</td>
<td>Internal of fully enclosed modules not subjected to deluge testing.</td>
</tr>
</tbody>
</table>

Table 14-1: Environmental conditions on PFPs
**Annex A – References and list of photographs**


[16] UL1709 - Rapid Rise Fire Tests of Protection Materials for Structural Steel


[23] API 2FB - Recommended Practice for the Design of Offshore Facilities against Fire and Blast Loading.


[29] The Energy Institute - Guidelines for the design, installation and management of Thermal insulation systems.


[33] TRB 801 - Technical Regulations for Pressure Vessels Pressure Vessels for non-corrosive gases and gas mixtures.

[34] ISO 22899-1 Determination of the resistance to jet fires of passive fire protection materials - Part 1: General requirements.


[37] MMI Paper – Are unsafe fireproofing practices still being used in Oil & Gas and Petrochemical Processing Plants? www.mmiengineering.com

[38] ISO 9001 - Quality management systems – Requirements.
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Annex B Glossary of terms and abbreviations

**BLEVE (Boiling Liquid Expanding Vapour Explosion)**
As defined in the CCPS book ‘Guidelines for Evaluating the Characteristics of Vapour Cloud Explosions, Flash Fires, and BLEVEs, provided the following definition.

*The explosively rapid vaporization and corresponding release of energy of a liquid, flammable or otherwise, upon its sudden release from containment under greater-than-atmospheric pressure at a temperature above its atmospheric boiling point. A BLEVE is often accompanied by a fireball if the suddenly depressurized liquid is flammable and its release results from vessel failure caused by an external fire. The energy released during flashing vaporization may contribute to a shock wave.*

**Consequence** - the particular scale of outcome from a Hazard being realised.

**Credible Risk (referring to fire events)**
A ‘credible fire’ is that fire which is most likely to occur in the protected area or zone. For example if the flammable inventory in a process is liquid and is not under pressure then the most likely fire event would be a ‘pool fire’ – thus in this case a ‘jet fire’ would not be a credible fire event and so PFP to protect against a jet fire would not be needed. Similarly it would not be cost effective to protect a safety critical item against the risk of a 2-hour fire if there were only sufficient inventory to fuel a fire for 1 hour - in this case a 1-hour fire would be credible but a 2-hour fire would not.

**Explosion**
ISO13702 (ref?) gives the following description for an explosion event:

*An explosion is a sudden and violent release of energy, with a typical duration of the order of 1s to 2s. The violence of an explosion depends on the rate at which energy is released. When the energy is released, e.g. following a vapour cloud explosion (VCE), it will create overpressure/impulse, drag forces and possibly projectiles from objects due to the overpressure and/or the drag forces.*

The overpressure, drag forces and projectiles are capable of causing injury to personnel as well as causing structural failure and damage to plant and equipment unless appropriate action is taken. The pressure wave impact and drag forces, as well as projectiles can damage or even remove PFP such that it would be incapable of functioning correctly in an ensuing fire event.

**Fireproofing**
An alternative name for passive fire protection (PFP) most often used.

**Hazard** - a condition with the potential to cause harm to people, the environment or business.

**Likelihood** - The potential for a situation to occur. Expressed as a probability, of a set outcome arising from a set number of occurrences, or as a frequency.

**Jet fire**
ISO13702 Annex A, gives the following description for a jet fire:

*A jet fire in the open is a turbulent diffusion flame resulting from the combustion of a fuel continuously released with some significant momentum in a particular direction. In jet fires there is the absence of any direct feedback from the fire to the source. For fires in the open, this suggests that jet fire hazards can be treated more deterministically than pool fires, as the mass flow rate and the behaviour with time are determined to a large degree by the leak characteristics. Unlike pool fires, jet fires have minimal inertia and reach their full intensity almost instantaneously. In principle they
can be turned off very quickly and thus isolation and minimization of inventory are important techniques to reduce the potential impact of jet fires.

Pool fire
ISO13702 (ref?) gives the following description for a pool fire:

“A pool fire is the turbulent diffusion fire burning above a horizontal pool of vaporizing hydrocarbon fuel under conditions where the fuel has zero or very low initial momentum. There is a degree of feedback between the fire and the fuel which controls the rate of evaporation and hence the size of the fire and other characteristics such as flame height and smoke production rates.”

“A pool fire is not necessarily static and may spread or contract depending on the supply of fuel. Depletion of fuel can occur due to drainage or overflow to other areas, perhaps giving rise to running liquid fires. The fire has inertia in that it takes time to develop and cannot be eliminated quickly by isolating the fuel supply. Running liquid fires are broadly similar to pool fires in that they rely on thermal feedback from the flame for their fuel vapour supply, but the liquid fuel is in motion and can be on surfaces of any orientation.”

Risk - the likelihood of a particular consequence being realised.
### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Meaning</th>
</tr>
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<tbody>
<tr>
<td>AFP</td>
<td>Active Fire Protection</td>
</tr>
<tr>
<td>ALARP</td>
<td>As Low As Reasonably Practicable</td>
</tr>
<tr>
<td>API</td>
<td>American Petroleum Institute</td>
</tr>
<tr>
<td>A/V</td>
<td>Area / Volume</td>
</tr>
<tr>
<td>BAM</td>
<td>Bundesanstalt für Materialforschung und-Prüfung (Federal Institute for Materials Research and Testing)</td>
</tr>
<tr>
<td>BLEVE</td>
<td>Boiling Liquid Expanding Vapour Explosion</td>
</tr>
<tr>
<td>CAPEX</td>
<td>CAPital Expenditure</td>
</tr>
<tr>
<td>CA</td>
<td>Competent Authority</td>
</tr>
<tr>
<td>CCT</td>
<td>Critical Core Temperature</td>
</tr>
<tr>
<td>CD</td>
<td>Capacitance Discharge</td>
</tr>
<tr>
<td>CUF</td>
<td>Corrosion Under Fireproofing</td>
</tr>
<tr>
<td>CUI</td>
<td>Corrosion Under Insulation</td>
</tr>
<tr>
<td>DAL</td>
<td>Design (or Dimensioning) Accident Load</td>
</tr>
<tr>
<td>EDP</td>
<td>Emergency De-Pressurisation</td>
</tr>
<tr>
<td>EER</td>
<td>Escape, Evacuation and Rescue</td>
</tr>
<tr>
<td>EPC</td>
<td>Engineering, Procurement and Construction</td>
</tr>
<tr>
<td>ESD</td>
<td>Emergency Shut Down</td>
</tr>
<tr>
<td>ESDV</td>
<td>Emergency Shut Down Valve</td>
</tr>
<tr>
<td>FABIG</td>
<td>Fire And Blast Interest Group</td>
</tr>
<tr>
<td>FEHM</td>
<td>Fire Explosion Hazard Management</td>
</tr>
<tr>
<td>FES</td>
<td>Fire and Explosion Strategy</td>
</tr>
<tr>
<td>FRA</td>
<td>Fire Risk Assessment</td>
</tr>
<tr>
<td>GASAFE</td>
<td>A joint industry project for PFP carried out in France many years ago. No longer running.</td>
</tr>
<tr>
<td>HAZID</td>
<td>HAZard Identification</td>
</tr>
<tr>
<td>HAZOP</td>
<td>HAZard and Operability</td>
</tr>
<tr>
<td>Hp/A</td>
<td>Heated perimeter / cross-sectional Area</td>
</tr>
<tr>
<td>HSE</td>
<td>Health and Safety Executive</td>
</tr>
<tr>
<td>HTIW</td>
<td>High temperature Insulation Wool</td>
</tr>
<tr>
<td>JT</td>
<td>Joule Thompson</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquefied Petroleum Gas</td>
</tr>
<tr>
<td>LWC</td>
<td>Light Weight Cementitious</td>
</tr>
<tr>
<td>MAH</td>
<td>Major Accident Hazard</td>
</tr>
<tr>
<td>MAWP</td>
<td>Maximum Allowable Working Pressure</td>
</tr>
<tr>
<td>MMS</td>
<td>Maintenance Management System</td>
</tr>
<tr>
<td>MOC</td>
<td>Management of Change</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
</tr>
<tr>
<td>--------------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>MSDS</td>
<td>Material Safety Data Sheet</td>
</tr>
<tr>
<td>OPEX</td>
<td>OPerating EXpenditure</td>
</tr>
<tr>
<td>PFEER</td>
<td>Prevention of Fires and Explosions and Emergency Response regulations</td>
</tr>
<tr>
<td>PFP</td>
<td>Passive Fire Protection</td>
</tr>
<tr>
<td>PHA</td>
<td>Process Hazard Analysis (or Assessment)</td>
</tr>
<tr>
<td>PSV</td>
<td>Pressure Safety Valve</td>
</tr>
<tr>
<td>QA</td>
<td>Quality Assurance</td>
</tr>
<tr>
<td>RBI</td>
<td>Risk Based Inspection</td>
</tr>
<tr>
<td>SCE</td>
<td>Safety Critical Element</td>
</tr>
<tr>
<td>SEMS</td>
<td>Safety and Environmental Management System</td>
</tr>
<tr>
<td>TR</td>
<td>Temporary Refuge</td>
</tr>
<tr>
<td>TICA</td>
<td>Thermal Insulation Contractors Association</td>
</tr>
<tr>
<td>UL</td>
<td>Underwriters Laboratory</td>
</tr>
<tr>
<td>UPS</td>
<td>Uninterruptable Power Supply</td>
</tr>
<tr>
<td>UV</td>
<td>Ultra Violet</td>
</tr>
<tr>
<td>VCE</td>
<td>Vapour Cloud Explosion</td>
</tr>
</tbody>
</table>
### Annex C Relevant safety standards and guides for fire and explosion

<table>
<thead>
<tr>
<th>Author / Reference</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>American Petroleum Institute</strong></td>
<td></td>
</tr>
<tr>
<td>API 2FB</td>
<td>Recommended Practice for the Design of Offshore Facilities Against Fire and Blast Loading.</td>
</tr>
<tr>
<td>API 6FA</td>
<td>Specification for Fire Test for Valves</td>
</tr>
<tr>
<td>API 6FB</td>
<td>Fire Test for End Connections</td>
</tr>
<tr>
<td>API 607</td>
<td>Testing of Valves - Fire Type - Testing Requirements</td>
</tr>
<tr>
<td>API RP 14G</td>
<td>Recommended Practice for Fire Prevention and Control on Open Type Offshore Production Platforms.</td>
</tr>
<tr>
<td>API RP 14J</td>
<td>Recommended Practice for Design and Hazard Analysis for Offshore Production Facilities.</td>
</tr>
<tr>
<td>API 2001</td>
<td>Fire Protection in Refineries</td>
</tr>
<tr>
<td>API 2218</td>
<td>Fireproofing Practices in Petroleum &amp; Petrochemical Processing Plants</td>
</tr>
<tr>
<td>API 2510</td>
<td>Design and Construction of Liquefied Petroleum Gas (LPG) Installations</td>
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<tr>
<td>API 520 part 1</td>
<td>Sizing, Selection, and Installation of Pressure-relieving Devices in Refineries.</td>
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<tr>
<td>API 521</td>
<td>Pressure-relieving and Depressuring Systems</td>
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<td><strong>British Standards Institution</strong></td>
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<tr>
<td>BS 476</td>
<td>Fire Tests on Building Materials and Structures</td>
</tr>
<tr>
<td>BS 6755-2</td>
<td>Specification for Fire Type Testing Requirements</td>
</tr>
<tr>
<td>BS 7917</td>
<td>Elastomer Insulated Fire Resistant (Limited Circuit Integrity) Cables for Fixed Wiring in Ships and on Mobile and Fixed Offshore Units. Requirements and Test Methods</td>
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<tr>
<td><strong>CEN European Committee for Standardisation</strong> (the appropriate national code is normally used)</td>
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<tr>
<td>EN ISO 10497</td>
<td>Testing of Valves - Fire Type Testing Requirements</td>
</tr>
<tr>
<td>EN 13501-2</td>
<td>Fire Classification of Construction Products and Building Elements</td>
</tr>
<tr>
<td><strong>Energy Institute</strong></td>
<td></td>
</tr>
<tr>
<td>Energy Institute.</td>
<td>Guidelines for the design and protection of pressure systems to withstand severe fires.</td>
</tr>
<tr>
<td><strong>UK Health &amp; Safety Executive</strong></td>
<td></td>
</tr>
<tr>
<td>HSE OTI (95)634</td>
<td>Jet Fire Resistance: Test of Passive Fire Protection Materials</td>
</tr>
<tr>
<td>Author / Reference</td>
<td>Title</td>
</tr>
<tr>
<td>--------------------</td>
<td>-------</td>
</tr>
<tr>
<td>HSE Offshore Technology OTI 95 634</td>
<td>UK HSE - Jet Fire Resistance Test of Passive Fire Protection Materials</td>
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<tr>
<td>International Electrotechnical Commission</td>
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<tr>
<td>IEC 60331</td>
<td>Tests for Electric Cables under Fire Conditions - Circuit Integrity</td>
</tr>
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<td>IEC 60332</td>
<td>Tests for Electric Cables under Fire Conditions</td>
</tr>
<tr>
<td>International Standards Organisation</td>
<td></td>
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<tr>
<td>ISO 13702</td>
<td>Petroleum and National Gas Industries – Control and Mitigation of Fire and Explosions in an Offshore Production Installation – Requirements and Guidelines (1st Ed)</td>
</tr>
<tr>
<td>National Association of Corrosion Engineers</td>
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<tr>
<td>NACE RP 01 98</td>
<td>The Control of Corrosion Under Thermal Insulation and Fireproofing Materials – a Systems Approach</td>
</tr>
<tr>
<td>Norsok Standards Committee</td>
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</tr>
<tr>
<td>Norsok M501</td>
<td>Norsok M-501, Testing of Protective Coating Systems for Offshore Applications</td>
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<td>Norsok s-001</td>
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<td>Oil &amp; Gas UK</td>
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<td>EHS03</td>
<td>Fire and Explosion Hazard Management</td>
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<td>EHS24</td>
<td>Fire &amp; Explosion Guidance</td>
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<td>Underwriters’ Laboratory</td>
<td></td>
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<tr>
<td>Scandpower Risk Management AS (For Norsk Hydro and Statoil)</td>
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<tr>
<td>Report 27.101.166/R1</td>
<td>Guideline for protection of pressurised systems exposed to fire</td>
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<tr>
<td>FABIG (Fire and Blast Information Group) UK</td>
<td></td>
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<tr>
<td>Technical Note 13</td>
<td>Design Guidance for hydrocarbon Fires</td>
</tr>
<tr>
<td>National Fire Protection Association (NFPA)</td>
<td></td>
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<tr>
<td>NFPA 58</td>
<td>Liquefied Petroleum Gas Code</td>
</tr>
</tbody>
</table>
1. The Concept of Section Factor

1.1. Steel elements in fire and section factor
Steel will lose strength as its temperature rises and depending on the load applied may collapse above a certain critical temperature. This critical core temperature (CCT) will depend on a number of factors including the shape of the element (H-section or hollow section), its size (i.e. mass or wall thickness), the load imposed on that part of the structure and the surface area of the section exposed to fire.

The rate at which a given steel element heats up and attains the CCT in any given fire scenario is related to the size of the steel (mass or wall thickness) and to the exposed surface area and this relationship is often referred to as the ‘section factor’. The section factor is also commonly called the A/V (exposed surface area ‘A’ divided by the volume ‘V’) in Europe and historically in the UK as the Hp/A (heated perimeter ‘Hp’ divided by the cross-sectional area ‘A’). In the USA a similar term is used and referred to as the W/D (weight of the section ‘W’ divided by the heated perimeter ‘D’).

In this explanation the term Hp/A will be used as it is still in common use in industry in the UK and elsewhere and is identical to A/V that is used in Eurocode 3). A brief explanation of W/D will also be given later.

Thus it follows from the above that a small thick (heavy) section will heat up more slowly than a large thin (light) section.

1.2. Section factor (Hp/A) and PFP
The section factor concept is important for determining the thickness of the PFP required to enable a given section to remain below its CCT 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.

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

\[
\frac{Hp}{A} = \frac{Heated\ \text{perimeter}(m)}{cross\ \text{sectional}\ \text{Area}(m^2)}\quad \text{Units} = \frac{m}{m^2} = m^{-1}
\]
Thus 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.

### 1.3. Section factor in the USA (W/D)

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

\[
W = \frac{\text{Weight per linear foot (lb)}}{\text{Heated Perimeter (inch)}}
\]

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

\[
\frac{A}{P} = \frac{\text{Cross sectional Area (in}^2\text{)}}{\text{Heated Perimeter (in)}}
\]
2. Methods of installing/applying Concrete or Lightweight Cementitious PFP

Concrete and lightweight cementitious (LWC) PFP can be applied to either follow the contours of the steel section (Figure 1), or to completely fill around the section and known as ‘Solid Fill’ (Figure 2). Although not shown in the diagram the upper surface of the PFP applied to the lower flange would have a ‘slope’ away from the web to encourage water shedding. Solid fill is normally used on ‘narrow web’ beams and on columns.

LWC may also be installed using the so called ‘box method’ (Figure 3) – not shown on the diagram is the fact that ‘corner beads’ are used to create a neat ‘corner detail’ and support the PFP. The beads used are similar to those used by the plastering trade in buildings.

Although the box method is still used in some facilities it is not recommended as it can be easily damaged, corners tend to crack and water can ingress behind the PFP creating conditions suitable for steelwork corrosion (Corrosion under fireproofing or CUF). This method is also weak when subjected to blast overpressure and so may mean that the PFP would not remain in place were a fire to follow an initiating event characterized by an explosion. A paper has been published by MMI that discusses this method and the risks involved in greater detail (Ref).