Factors in the selection philosophies and criteria to improve F&G detection and use of PFP

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Following a release of hazardous materials, fire and gas (F&G) detection and Passive Fire Protection (PFP) are significant control and mitigation measures in the prevention of escalation. However, the design specifications for F&G detection and PFP such as: the requirement for, extent of coverage of, and functionality, often default to the following of prescriptive guides and qualitative 'rule of thumb' philosophies based on the initiating release and fire hazard. This fails to fully take into consideration the potential type and scale of the ultimate escalation consequences for which the F&G and PFP measures are to protect against.

In the worst case this can lead to under specification and lack of appropriate cover. But, over specification of F&G and PFP can also occur with cost implications, potential degradation of response and increased maintenance requirements. This could also lead to increased risk to the associated maintenance teams due to increased exposure to facility hazards.

This paper details the roles and issues associated with F&G detection and PFP application. It also details how these measures should be determined using performance-based selection and design assessments. This can be though qualitive assessments through semi-quantified (risk matrix) to quantified modelling using probabilistic screening criteria.

Keywords: Fire and Gas (F&G), detection, PFP, Escalation, Hazard, Assessment, Consequence, specification, Design accident load.

The problems with current F&G and PFP selection

Historically specification for and the functional design requirements of Fire and Gas (F&G) Detection and Passive Fire Protection (PFP) measures has been though the application of prescriptive based generic standards and guidance. Increasingly the specification of measures, for Major Accident Hazard risk management, is being made based on performance-based assessments of the hazards to which the measures apply. However, there is little current detail on some key factors which need to be taken into consideration when undertaking assessments to both determine the need for F&G detection and PFP and the design and function of these measures.

For example for facilities with Major Accident Hazards there are no specific standards governing the requirements for and the locating of gas detectors in the main process areas.

To quote BS EN 50073:1999 Guide for the selection, installation, use and maintenance of apparatus for the detection and measurement of combustible gases or oxygen [1] "Sensors should be located in positions determined by those who have knowledge of gas dispersion, the process plant systems and equipment involved and in consultation with both safety and electrical engineering personnel".

Fire detector standards are little better although some determination of area coverage is sometimes given. From HSE Offshore: Fire and Explosion Strategy - Fire and Gas Detection [2]. 'Various rules of thumb are used to determine the location and coverage of the different types of fire detector'. And it then goes on to detail some typical area coverage densities for detectors.

Guidance and standards on PFP selection and design specification have also been lacking and were typically based on structural steel work protection.

Where some form of assessment has been used in the determination for F&G and/or PFP requirements, this often stops once a Hazardous condition such as gas release or fire is identified. Detection and PFP are then identified as appropriate escalation risk management measures but further assessment of their function is not undertaken. The specification and design of these measures is undertaken by application of basic rules of thumb as detailed above.

Failure to adequately review the requirements for and function of F&G detection and PFP as part of escalation risk management can lead to both under and over specification of these escalation risk management measures.

Failure to have sufficient detection and PFP has been seen in a number of major incidents. A failure to detect overfill for 40min at Buncefield contribute to the development of a significantly large vapour cloud with significantly increased consequences following delayed ignition. With the introduction of increased ignition source controls associated with the DSEA Regulations [3] there is reduced potential for ignition of released combustible vapours and gases. This reduction in ignition potential can however increase the overall event risk by increasing the potential for unignited gas collection. This increases the potential for delayed ignition with potentially greater VCE type consequences compared to early ignition and small flash fire and jet flames consequences. This improved control over ignition sources increases the requirement for effective fire and gas detection particularly in open plant areas with low manning levels.

Over specification can also generate issues. For fire and gas detection this leads to increases in spurious alarms with degraded manual response. Large numbers of detectors also increase the required maintenance on-going costs. For PFP, if properly managed, there would also be a increased maintenance cost if extent of coverage is over specified. Poor PFP management, and over specification of PFP coverage also introduces potential CUI and hazards from falling sections of degraded PFP materials.

For both over specification of F&G detection and PFP, the increased maintenance and support will generate additional workforce requirements and cost on the facilities. The increased exposure of these maintenance crews to the site major accident hazards could also increase the risk profile for maintenance crews, seen as PLL offshore (including increased transport risk) and FN curve increases onshore.

But isn't there work to quantify F&G detection requirements based on detector mapping?

Yes, but these often do not take into consideration the type and scale of the escalation consequences. The requirement for detectors in an area has typically already been determined at high level or qualitatively prior to any mapping studies. Determination of the need for and performance requirements of F&G detection and PFP should be based on a hazard scenario assessment working back from ultimate consequences rather than forward from initiating hazards.

This is highlighted by considering which is of the following hazard scenarios has potential the greater risk concerns:

1. High frequency combustible gas releases, but at low releases rate (low pressure) in open non-confined and uncongested area well away from exposed populations, OR
2. Low frequency release, but at a high release rate (high pressure) in a heavily congested area close to populated areas

It can be seen that although the initiating frequency for the second case is lower, the overall risk is potentially greater due to the higher consequence potential. This second case could therefore benefit more from unignited gas detection.

Similarly, for fire cases consider these scenarios:

1. Large scale guillotine type failure resulting in large jet flame with impingement on multiple plant items
2. Small ignited release (jet or pool fire) in area with limited adjacent equipment.
3. Small/ medium ignited release in area with adjacent equipment containing significant inventories under pressure.

For the first case, detection would probably not provide any benefit as the scale of the initial incident would be such to have wide scale consequences and would escalate before any effective response could be initiated. The second case has very limited escalation potential and hence detection and response would generate little overall risk benefit. In the third case though the escalation consequences could be significantly greater than the initial event and response to a detected fire may also be effective reducing escalation likelihood or consequences. In this case fire detection would have the most benefit.

For these same fire cases a similar review on the benefits of PFP could also be made. In the first case PFP, if it survives the initial event, could provide protection of exposed plant and prevention against further escalation. But this may only provide asset protection as life safety consequences may already have been dominated by the large scale of the initial event, and any later escalation may not result in exposure of any populations not already affected by the initial event. For the second case small releases may be insufficient to cause failure of the limited adjacent equipment. In such cases PFP may be of limited benefit. In the final case PFP could be of significant benefit and should be considered along with fire detection coupled with suitable detection response.

The role of F&G detection

The most important overriding factor in reviewing and assessing F&G detection is that on their own detection provides no control or mitigation benefit. It is the response to the detection that provides the risk reduction measure. The majority of F&G detection relies on human response to the detection signal and is often preferred to reduce potential shutdowns on 'spurious' detection. It is the combination of detection and response that needs to be assessed particularly to ensure that it does not provide 'stable door' coverage. This is where the detection only triggers after large scale events have already occurred or is provided for those events where there is no chance of adequate response to the detected event. If the scale of escalation consequences and hence overall escalation risk are high, then in these cases detection should be either linked to automated actions or additional measures provided.

The role of detectors can be summarised as:

1. Warning of early stage in either a gas release or fire incident, where escalation could expose a greater population compared to the initiating event. This is to reduce the potential size of any exposed population e.g. initiate evacuation to a safe location.
2. To initiate escalation reduction activities:
    a. Ignition source inhibits (unignited combustible vapours/gases only)
    b. Isolation and depressurization / de-inventory
    c. Activation of deluge, etc
3. To initiate emergency response - Emergency response teams and fire crews. However, note this could then increase numbers potentially exposed to an escalation event if not correctly controlled - see item 1.

The role of PFP

The first and most often insufficiently assessed issue in PFP specification is the lack of sufficient determination of the role that PFP is providing as a protection measure.

PFP may be used to protect:

- Critical control and refuge buildings and the integrity of escape routes to these if required
- Pressure vessels or hydrocarbon containment equipment and their associated supports and supporting structures. The failure of which could lead to escalation due to a catastrophic sudden failure.
- Structures supporting additional risk reduction measures e.g. isolation, shutdown and de-pressuring systems
- Potentially exposed Emergency Response (ER) activities

The initial review of the hazard (HAZID/HAZOP) and escalation potential should ensure that the full benefit from the different uses of PFP has been considered. Failures seen in PFP specification have resulted from poor PFP knowledge resulting in the limited scope of PFP application. For example cases seen where PFP has been insufficient specified have included: restricting provision only to structural steel (result from following API 2218 where protection of structural steel is the main focus), protection of vessels but failing to protect the vessel supports, protection to critical valves but failing to protect the actuator, etc.

Once the requirement to use PFP has been determined then the PFP performance specification needs to be defined. This should set the fire exposure and required PFP performance duration, also known as the design accident load (DeAL). In the most onerous case the PFP needs to prevent the underlying, protected, equipment item exceeding a Maximum Allowable Temperature (MAT) for the total duration of the exposing fire case. However, variations and reduced DeAL requirements, particularly to the length of the required performance duration, may be set if the point at which the MAT is exceeded is determined to be acceptable. For example, the default performance duration if applying API 2218 is 1 ½ hours to structural steel. But, is there sufficient inventory for 1 ½hour fire?-If life safety is the primary concern and full escape can be achieved in ½ hour, why sustain the PFP performance beyond ½ hour?

Hence the performance duration of PFP can be linked to the time when reaching the MAT is determined to be acceptable. Two conditions exist for selection of shorter performance durations:

1. Time after which failure and escalation should not result in any additional population exposure e.g. escape is fully implement. Or
2. Effect of isolation and de-pressurisation, etc. result in a case where escalation consequences would not result in any additional exposure compared to the initial event.

Assessment methods for detector and PFP selection

Assessment of F&G detection and PFP is best undertaken as separate focused assessments once the potential initial need for these measures has been identified as part of higher level Hazard identification and risk assessments. This more focused assessment requirement should form part of F&G detection and PFP selection philosophies. In addition, these assessments should be hazard scenario based, particularly focusing on the development of the escalation scenario following the generation of an initial gas/vapour release and if ignited any initial fire hazard condition.

Hazard linked performance-based specification and design assessments have many advantages:

(a) Less conservative and can therefore be more cost-effective

(b) Designing for a particular location/operation and individual hazard scenarios

(c) Have greater flexibility (not one size trying to fit all)

(d) Allow the use of new technology, materials and interaction of other measures

(e) Provide explicit objectives and performance requirements.

However, there are disadvantages, such as:

(a) Increased design costs and time

(b) Greater expertise required at the design and specification stage

(c) If detailed the need for new tools, methodologies and a fire engineered approach to maximise the benefits.

(d) Significant care required in the management of change both at the hazard location and in the operation and maintenance of F&G and PFP measures.

Assessment should be on the response to release and fires

F&G detection and PFP assessments would be better understood if they are considered as ‘Release detection and response’ and ‘Fire detection and response’. The assessment should ensure that the following are all considered.

1. Where there is a release of a hazardous material generating an initial gas/vapour release or fire
2. The escalation effects. Can they result in unacceptable consequences?
3. Can effective response to the detection be made, and
4. If PFP is proposed is it suitable and has the time to MAT been defined

The primary aim of detection is to provide warning of a hazard which if it were to escalate could generate adverse consequences over a greater range than that of the the initial or ongoing event. From a life safety point this escalation event could affect populations that either survived the initial incident or were unaffected by the initial incident.

For toxic gas releases this hazard warning is to prevent exposure to the toxic gas. This is to prevent entry to and to move populations away from potential cloud movements. For toxic releases, detection may be best applied between release points and potentially exposed populations.

For combustible gases the waring is to reduce exposure to the consequences of release ignition. Early ignition is likely to have localised consequences, as such the dominating condition for unignited combustible vapour/gas release detection is related to delayed ignition. This can be defined as the cloud size at time of ignition that would not affect additional populations. This is the basis for the rule of thumb spacing requirements, for example 5m spacing of detectors etc which would set a maximum cloud detection size. This is likely to be an over specification if exposed populations are generally far way, or if the release location is unconfined and uncongested. The requirement for detection of unignited vapour clouds should be based upon congestion and confinement factors and distance to populations of concern.

Ignition source control, as part of gas detection, as previously noted, has become more critical as management of ignition sources has improved (DESAR compliance). There have been many cases of significant delays in ignition e.g. Buncefield, and even where massive gas releases have occurred over prolonged periods without finding an ignition source e.g. the Elgin Franklin release in 2012 lasted 7 weeks. Even the recent HSE review of the fire and explosion issues associated with the Deepwater Horizon incident (rr1122) [4] has defined shutdown of potential ignition sources as best practice. the potential for the generation of large unignited clouds, can present significant consequences which can significantly outweigh the lower likelihood of delayed ignition. Where large gas clouds could be generated, shutdown of potential ignition sources, outside of zoned areas, such as emergency generators, electrical switch rooms, direct fired equipment, and even fire pumps should be linked, as an automated response, to gas detection. To reduce spurious trip potential this ignition source shutdown could be based upon detector voting. Voting could include a minimum of a detector at the ignition source and any detector at potential release locations and both need to alarm in order to initiate shutdown of the potential ignition source, or just 2ooN at the ignition source location.

The secondary function of detection is to initiate other response actions. Such as shutdown and depressurisation to reduce overall consequences and duration of release consequences. Other mitigating operations such as general ESD and starting of fire water systems may be determined. These functions may also be automated. The need to automate these functions should be reviewed depending on the benefit that automation could generate in relation to speed of response.

Only when it has been determined that F&G detection and response can have a beneficial effect on overall hazardous scenario progression and hence risk, should detector placement considerations such as mapping and other detection considerations such as gas type/ density etc be applied.

PFP selection is similar to for fire detector assessment in that it needs to be ultimately based on the potential consequences of escalation following sudden failure of equipment from fire induced thermal exposure. However, the interaction with other response activities such as shutdown and depressurisation can have significant impact on the Design Accident Load for PFP performance.

Assessment types

As highlighted, for effective F&G detection and PFP selection and design determination there should be a focused assessment of the potential hazard escalation scenario and contribution that detection and PFP could provide. This should be hazard based and should review the escalation scenarios on an area by area basis.

As per Major Accident Hazard identification and risk assessment, F&G detection and PFP assessments can range from qualitative through to quantified assessments.

Qualitative assessments

The simplest form of assessment is a qualitative review of the hazard escalation scenarios. Application of some standard F&G and PFP philosophies may be set for particular hazard locations. But these should be developed taking into account the potential concerns listed above e.g. ignition source control. Specific location F&G and PFP requirements should be summarised in facility philosophy documentation. Standard location philosophies can include the following:

1. Internal spaces of non-domestic occupied buildings should apply applicable BS 5839 [5]provisions
2. Turbine enclosures should follow F&G practises in the likes of PM84 guidance [6]
3. Intakes to critical control or refuge buildings / enclosures should have gas and smoke detection with potentially automated damper closure.
4. Intakes to generator buildings, emergency fire pumps, electrical switch rooms to have gas detection. Potentially linked to automated shutdown.
5. PFP to LPG vessels and supports where BLEVE potential could impact on occupied locations
6. Etc

Qualitative assessments have been undertaken applying an approach similar to that of HAZIDs. An edited example of a F&G review for a part of a process using Hydrogen is shown in Table 1: This has columns for Cause (initiating hazard) Consequence (escalation consequence) and evaluation of detector benefit.

RELEASE SECTION	**CAUSE (initiating hazard)**	**CONSEQUENCE (Ultimate Consequence)**	**EVALUATION (of measure benefit)**	**REC**
Gas line from roof line to control panel	Failure H2 line at 2.5barg pressure	Release from 22mm gas supply line at 2.5 barg. Flowrate of up to 20 Nm3/hr if online. Previous gas modelling indicates large cloud in roof space - delayed ignition can result in deflagration/ detonation with potential for multiple fatalities from missiles/structural and building collapse.	Major gas cloud and major delayed ignition consequences. Collection in roof space above unit from major release. Gas detection in roof space for larger release scenario with executive action to close common isolation to all units due to scale of consequence, at high gas concentration detection level. Placing of gas detector needs to take into account roof pitch and general air flow movement towards common HVAC. Hence gas detectors should be towards north side of release source.	1) XXX To generate coarse PHAST models (non CFD) to provide indication of flammable plume sizing to validate release assumptions. This is to cover high and low pressure releases associated with the different release locations associated with the units.
Control panel / supply line	Failure of H2 lines at low 40 mbarg pressure	Low pressure (40mbarg) release from 15mm line. Limited release. However, release area is in area where operators may be present and could be unaware of a hydrogen release and fire if ignited (due to low H2 flame visibility). Major injury potential.	Local consequences and injury - automated response not required. Local detection and local warning to reduce exposure to small H2 releases. Local emergency stop to also be provided as part of operator response.	
Discharge line from unit	Failure of discharge line predominately H2 but with small fraction of other HCs	Low pressure release from line size up to 40mm dia. Plume is away from operator areas behind unit. In addition, odour associated with waste gases/ HC products increases manual detection of release. Presence of local ignition source would also result in almost immediate ignition in this area.	Detection of no benefit. Due to permeant ignition source presence in operation, Localised consequences away from occupied areas - no injury potential,	

Table 1: example of qualitative F&G review

Qualitative risk-based assessment for gas and fire detection in plant areas has also been based upon a review of Hazardous area determinations and presence of confinement/congestion. The zoning drawing being used to define potential release locations and if these are in or adjacent to confined or congested volumes then these locations are highlighted as increased VCE risk locations where gas detection of small releases would be of benefit.

Semi-quantified risk-based assessment

Where some quantification to Fire and Explosion hazards has been made such as via Fire and Explosion Risk Assessments (FERAs), it has been possible to apply semi-quantified methodology to the determination of F&G detection and PFP requirement. These F&G and PFP assessments have used vapour/gas release and fire hazard frequencies determined for individual plant areas to determine the initiating escalation event frequencies. These are then plotted on risk matrices against the potential escalation event consequence severity. Those areas that result in unacceptable resultant risk based on the combination of initial event (release or fire) frequency and escalation consequence should have further assessment to review effectiveness of all potential, not just F&G and PFP, measures against escalation. Those areas that fall into the ALARP classification are reviewed to determine if F&G and PFP is both feasible and cost effective.

Quantified assessment - PFP specification

The semi-quantified approach covered above starts to bring in a likelihood risk basis to the determination of F&G and PFP requirement. This has been taken further in the determination of structural PFP requirements, by adding in a low likelihood screening criterion to the specification of the design accident loads (exposure and duration). In these assessments in addition to the requirement to set fire exposure type and duration, those fires with a return frequency less than a certain level, typically $1x10^{-5}$ to $1x10^{-4}$/yr are also excluded as not requiring PFP. This approach is known as defining the Dimensioning Accident Load (DiAL). This then allows those fire events that may have fire size and duration of concern to be excluded on the grounds that they have a significantly low enough frequency of occurrence to result in an acceptable level of escalation risk. This use of Dimensioning accident load has been applied in projects to reduce structural PFP requirements. It has also been used on existing facilities when reviewing whether continued maintenance of installed PFP systems is justified. This has particularly been the case where continuation of PFP maintenance would include exposure to facility hazards and transport risks which could exceed the risk benefit provided by the PFP against escalation and as such overrides the reverse ALARP consideration (removal of an existing measure).

For the determination structural steel PFP requirement, applying Dimensional (probabilistic) accident loading, three different approaches of increasing quantification have been used:

Using phenomenological models

Method 1: Based on fire areas

Method 2: Based on inventory and target locations

And finally

Method 3: Using Computational Fluid Dynamics (CFD)

Full details on the Dimensioning accident load (probabilistic) determination are presented in the Fire And Blast Interest Group (FABIG) Technical Note 13 [7]. The procedure is shown in the flow diagram extracted from the FABIG technical note shown below in in Figure 1

The FABIG procedure also includes further quantification of the structural thermal response.

An integral part in these Dimensioning (probabilistic) Accident Load PFP determinations is the generation of ‘exceedance curves’. These are plots of Fire size (Length) and duration are developed from the determination of a range of fire exposure cases with event frequencies at or greater than the screening criterion. This generation of an exceedance curve is shown in Figure 2 - for a range of fire events at a screening frequency of $1x10^{-4}$/yr.

Figure 3 below shows how these exceedance curves can be used in determining the need for and performance requirements for PFP measures. Two cases are shown. The red line is for events where there is no or ineffective blowdown. For these cases there are fire exposure cases where impairment (failure) could occur due to the fire being both large enough and with sufficient duration. PFP may be required for the highest thermal load for a duration of 23minutes after which flame size is insufficient to cause failure. However, the green line shows the benefit provided by say an effective blowdown operation reducing size and duration of the exposing fire cases. In this case the fire curve does not pass through the impairment region and PFP is no longer required.

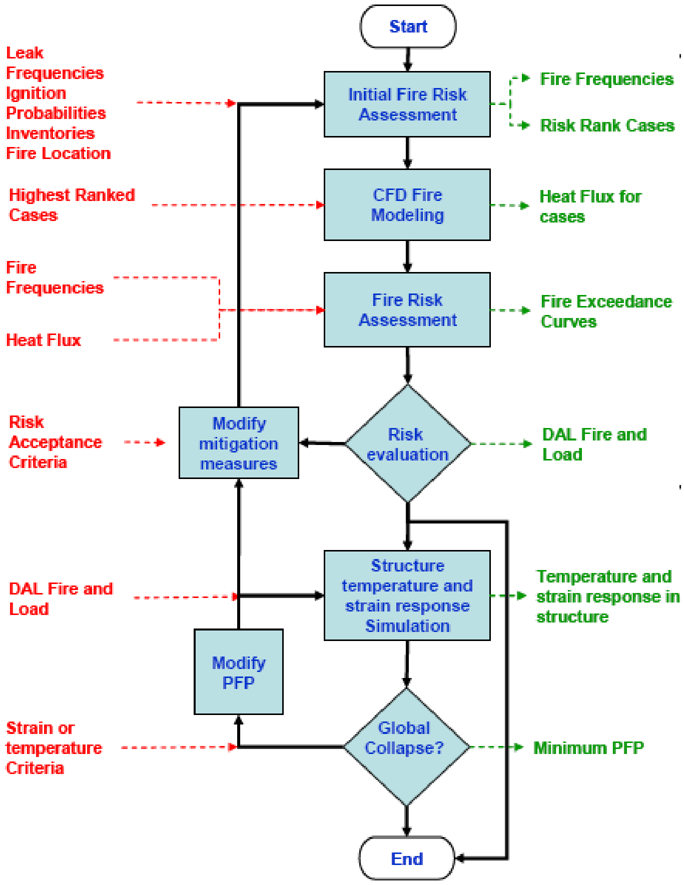

Figure 1: Schematic flow diagram for DAL Procedure - FABIG TN 13

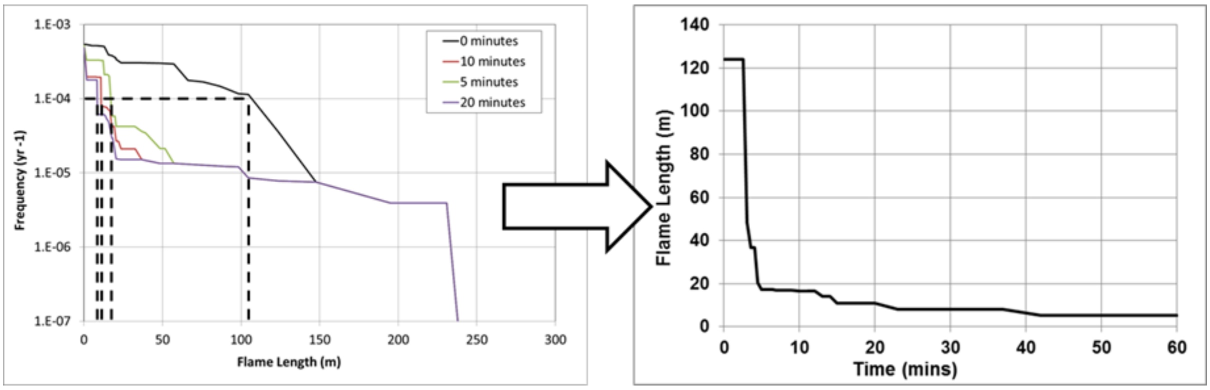

Figure 2: Exceedance curves examples

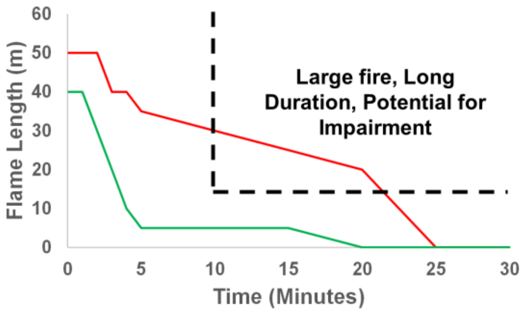

Figure 3: Comparison of fire events - with and without blowdown.

Summary

Failure to sufficiently identify the need for and specification of F&G detection and PFP can, in the worst-case, lead to insufficient escalation risk management.

Poor selection and design specification can also result in over specification of F&G detection and PFP application, with associated costs and potentially some increased risk factors.

Requirements for F&G detection and PFP are not just generated by the identification of an initial hazard with potential for escalation. But should also be based on the consideration of the ultimate escalation consequences and response to the F&G detection and the function of PFP measures.

Requirements for F&G detection, including nature of response and performance, should be assessed using a hazard-based review of identified release and fire scenarios. This can be qualitative, but semi-quantified approaches are available. Detector mapping should be used to validate detector coverage, but that this should be after some assessment of F&G detection requirement.

Similarly, PFP requirements should be based on exposing fire hazard and escalation potential. This again could be through qualitative or quantified scenario-based assessment. For PFP application on structural steel the PFP performance can be set using the the design accident load in the worst case or the dimensioning accident load. The accident loads are the point at which failure and escalation are unacceptable.

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