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A practical approach to fire hazard analysis for offshore structures

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Abstract

Offshore quantitative risk assessments (QRA) have historically been complex and costly. For large offshore design projects, the level of detail required for a QRA is often not available until well into the detailed design phase of the project. In these cases, the QRA may be unable to provide timely hazard understanding. As a result, the risk reduction measures identified often come too late to allow for cost effective changes to be implemented. This forces project management to make a number of difficult or costly decisions.

This paper demonstrates how a scenario-based approached to fire risk assessment can be effectively applied early in a project's development. The scenario or design basis fire approach calculates the consequence of a select number of credible fire scenarios, determines the potential impact on the platform process equipment, structural members, egress routes, safety systems, and determines the effectiveness of potential options for mitigation. The early provision of hazard data allows the project team to select an optimum design that is safe and will meet corporate or regulatory risk criteria later in the project cycle.

The focus of this paper is on the application of the scenario-based approach to gas jet fires. This paper draws on recent experience in the Gulf of Mexico (GOM) and other areas to outline an approach to fire hazard analysis and fire hazard management for deep-water structures. The methods presented will include discussions from the recent June 2002 International Workshop for Fire Loading and Response.

Keywords: Hazard analysis; Fire hazard; Fire modeling; Process safety; Design safety

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1. Introduction

The production of hydrocarbons in offshore installations has the potential for events involving major fires and/or explosions. This was demonstrated in the 1988 Piper Alpha incident in the UK North Sea.

Offshore quantitative risk assessments for large deepwater platforms have historically been complex and costly. A large deepwater platform project will be well into the detailed design phase before the degree of detail required to complete a QRA is available. By the time the results of the QRA are published, it is often too late to make cost effective changes. Therefore QRA is often viewed by project teams as a number crunching exercise with little or no practicable benefit.

As a result, scoping and designing recommended basic safety systems are left to the projects detailed design stage. By then the platform design has progressed with space, weight, schedule, and budget assigned for the other elements of the design and the project has lost the opportunity to manage hazards through simple engineered design changes. If input can be provided earlier in the project, these systems could be incorporated in the design and become a fixed part of the design, at a greatly reduced cost.

To facilitate this, an analysis method has been developed that can be applied early in the design yet give results with sufficient accuracy that costly and important decisions to manage hazards can be made early in the design process with some confidence. The solution proposed here is to use a scenario-based approach to fire risk assessment which puts the focus on maintaining facility integrity in place of calculating the number of fatalities.

The scenario-based methodology proposed is fairly simple. However, the method is vigorous enough that it gives realistic and comprehensive results. This builds credibility with the project team so they are willing to explore simple, cost effective design changes to manage significant risks.

The major difference in the scenario-based approach and QRA is that only selected "design basis fires" are analyzed in place of analyzing every fire. Reducing the number of scenarios to be analyzed places the focus on the most significant hazards. This decreases the time required to evaluate the effectiveness of proposed design changes and eliminates time spent on hazards which are not significant enough to impact the design.

The scenario based process allows a design team to have an early understanding of the fire hazards. Understanding the fire size, development and heat loading from credible releases allows protective measures to be selected that are appropriate to the degree of hazard posed.

However, the aim of the approach is to assure that by this approach does not mean there is no value in conducting a full, detailed QRA. The aim is that by the time the design is mature enough for a QRA, the QRA should hold few last minute surprises. Additionally, some project teams which are not governed to conduct a QRA, have utilized the design basis hazard analysis as the starting point which feeds design changes. The design basis hazard analysis is also used to screen scenarios selected for more detailed fire modeling using computation fluid dynamics (CFD), and structural response using linear and non-linear methods.

As fire risk analysis is too broad an area to be discussed in a single paper, this paper focuses on the application of fire risk assessment to gas jet fires in process areas. The methods described in this paper were discussed in the June 2002 MMS International Workshop for

Fire and Blast Considerations in the Future Design of Offshore Facilities [2]. This paper combines experience gained in performing fire risk analysis in the North Sea, Gulf of Mexico and other major offshore producing areas with some of the discussions from the MMS workshop.

1.1. The design basis accident approach

The design basis fire approach defines credible worst case releases then focuses on estimating the consequences to the facility. Emphasis is placed on defining what fires the platform can survive. Other potential fires, both outside and within the design basis, may be analyzed later during the QRA, and additional protection measures implemented where necessary. However, the fire cases analyzed later should have less of an impact on the platform design.

The design basis accident approach was used in some industries before QRA. The basic assumption is that less severe events are bounded by the design basis accidents. More severe beyond design basis events are not credible and do not require mitigation.

The key to the methodology is to have a well defined and realistic design basis to analyze. A poor design basis or scope will invalidate the effort. This requires the use of experienced personnel with knowledge of risk assessment and the dynamics of large offshore platform design projects.

Design basis hazard analysis is simpler and requires less effort than QRA. This makes it easier to apply early in the project. Since early designs are not as well defined in either process or protective measure, the analysis will require agreement on the general rules, such as target depressurization times and types of fire detection. The design basis hazard analysis can be used to compare the risks of different conceptual design options.

This fire assessment does not quantify release frequencies or ignition probabilities as would be done for a full QRA. A risk based approach is simulated by the selection of the credible fire scenarios. However, the team performing the design basis assessment may need access to data which supports the “credible” scenarios. This assists by increasing the project team’s belief that the scenarios are practical.

1.2. Defining credible release scenarios

Determining what are credible failures will usually be based on company and industry experience. Industry failures can be researched in public domain resources such as E&P Forum [1]. The following section describes in general terms the characteristics of some of the most common causes of failure.

Flange Leaks: Appear as a small hole with an effective diameter of 1/32 to 3/8 in. The actual hole will likely to be a slit that results in a spray or “fan” release rather than a clearly defined jet.

Overpressure: Caused by process upset conditions, process surging, hydraulic shock, relief valve failure or isolation, gas or liquid breakthrough or process control failure. The leakage could be of three types; flange leakage (see above), bolted joint failure (particularly long stud bolts), or catastrophic failure. Overpressure tends to cause either a small or a massive catastrophic releases; mid sized releases (1–2 in. holes) are less likely.

Impact or dropped objects: Unless it is a major impact, such as a dropped container, a catastrophic failure is unlikely. Failure of an instrument or small bore tapping is more likely resulting in a 1/2 or 2 in. clean break. Impact may also over-stress piping joints leading to a smaller flange leak.

Corrosion: This may cause local pitting leading to a pinhole leak, (e.g. 1/32 in.), or to general thinning of the vessel and piping walls. The latter could initiate as a small leak that could grow to a medium to large release (e.g. 1–2 in. effective diameter). Corrosion may also occur around welds. In the case of a vessel, this may lead to catastrophic failure (e.g. loss of a vessel end), although it is more likely to occur in tappings, piping stubs or piping dead legs. Tapping failures may be 1/2, 1 or 2 in., although smaller leaks of 1/16 to 1/8 in. could occur if total failure did not occur.

Erosion: This is likely to occur at bends and restrictions on the well flowlines, recovery systems and up to the first stage separators. It will cause thinning of the pipe or vessel wall until a small release occurs. However, the release will quickly open due to wall thinning, the higher stresses on the pipe wall and the erosive nature of the fluid contents. Holes would range from 1 to 4 in. effective diameter and would be rough edged resulting in a shorter, wider flame.

Isolation failures: These can occur where there is regular breaching of containment, such as relief valve or instrument testing and pig launching. Releases may be either full bore where the wrong valve is opened, or flange leakage where fluids are introduced to un-tightened pipe work.

Component failure: This is the failure of proprietary equipment such as sight glasses, pressure gauges, pump seals etc. If the team is concerned about these components, then each equipment type selected should be individually examined to determine the type and size of probable failure.

For gas jet fires, two categories of design basis fire scenarios are defined. The scenarios are based on leak size and actions of the platform fire detection, isolation and blowdown systems in response to the leak. These basic scenarios are evaluated for leaks from all defined isolatable gas sections on the platform.

1.3. Example of scenarios selected for a platform design

For the purposes of this paper, 1/2, 1, and 2 in. diameter holes were selected as credible small, medium and large holes. Hole sizes greater than 2 in. have not been considered as release rates and hazard zones calculated for 2 in. leaks are sufficient to have catastrophic impact.

- The first fire scenario is a small (1/2 in.), medium (3/4 in.) and large (2 in.) gas or liquid leak in which primary automatic safety systems work according to design. Primary safety systems are flame detection, isolation and blowdown.
- The second fire scenario is a small leak (1/2 in.) in which automatic safety systems fail to operate. Manual intervention allows closure of isolation and blowdown valves or equivalent within 5 min.

Since the second scenario involves some degree of system failure, the medium and large leaks are not considered credible.

1.4. Hazard management for scenarios

An effectively mitigated design basis fire is one for which it can be demonstrated that:

- The event does not escalate and fail equipment in adjacent modules.
- Primary structural steel does not fail.
- There is at least one credible escape route available for all fires.
- Integrity of primary refuge and muster areas is maintained.

These measures are evaluated for the 45–60 minute period until the platform is evacuated. No attempt is made to calculate the number of initial fatalities in the fire. Rather, the emphasis is on demonstrating that overall platform integrity will be maintained for some credible severe fires. Experience has shown that if overall platform integrity is maintained the risk from fire should be in the acceptable or on the edge of the ALARP (as low as reasonably practicable) area.

2. Methods of calculation

For fire analysis, it is assumed people can be injured or killed in three ways; being caught in the initial fire, being affected by the escalation while sheltering or evacuating, or by risking their lives to save the lives of others.

Equipment can fail if subject to high heat loads for a given period of time. Failure of equipment can lead to escalation of the incident and additional loss of life. By comparing the extent of the hazard zone for fires against the equipment location on the plot plan, the effectives in the safety system can be evaluated. For gas jet fires, any identified structural and equipment failures due to heat loading are typically protected against through the application of passive fire protection (PFP).

Examples of some basic assumptions used in the analysis include:

- Estimated time to fully evacuate the facility is 60 min (hazards and escalation beyond this period are not evaluated).
- Releases immediately find an ignition source (i.e. explosion and gas detection are not considered).
- Process control valves continue to operate as normal during process and emergency shutdowns.
- Non-process hydrocarbon inventories will be equipped with containment and drainage, and are generally not considered as design basis scenarios.

The methodology describe below can easily be incorporated into a series of linked spreadsheets. These spreadsheets can be modified in a few hours to review the impact of any proposed design changes. Simplicity is the key to allow rapid changes in the analysis. By conducting the analysis in a flexible format, the model can be changed on the fly during design team meetings to help illustrate the hazard impact of proposed design changes.

2.1. Identification of flammable inventories

Risers and process topsides can be divided into a number of isolatable sections based on the position of shutdown valves (SDV) and blowdown valves (BDV). Typically, there will be around 5–10 isolatable gas sections on an average offshore platform.

For isolatable gas sections containing compressors, or having sections at different temperatures and pressures a settle out pressure has been calculated based on the change in process conditions after the SDV valves have closed. Following isolation the entire isolatable gas section will quickly reach the settling pressure. The settle out pressure has been used to calculate section blowdown and fire characteristics.

2.2. Accounting for process blowdown

Conservatively, assume prior to full closure of SDV and BDV valves the gas leak continues at the initial rate. This is conservative for larger (2 in.) high pressure gas releases as the release rate is often comparable to, or higher than the normal platform gas throughput rate. These release rates are sustainable and will start to drop off prior to operation of SDV and BDV valves.

On successful operation of all isolation valves, the pressure will start to fall as gas or liquid leaves through the leak. On successful operation of the blowdown system, the rate of pressure loss will be greater as additional gas is evacuated through the blowdown valve.

The time from first flame to full closure of SDV and BDV valves is typically around 60–90 s. This is based on a 30–45 s detection period and a 30–45 s valve closure time. Subsea isolation valves for well fluid risers can take longer to close with 2–3 min being typical closure times. The blowdown of gas from the isolatable volume has two components. First, the escape of gas through the leak site and second, the release of gas to the blowdown system.

The flare system on offshore platform often has a velocity tip design that requires significant backpressure to operate. This back pressure can have a significant impact on the operation of the blowdown system. Thus, a back pressure of 50–75 psig is assumed from the opening of the BDV until the operating pressure of all equipment feeding into the flare header has reduced to 100 psig. After this period, the flare header back pressure is reduced to around 10 psig.

The initial release rate of hydrocarbon gas through a hole to the atmosphere depends on the pressure inside the equipment, the shape and size of the leak, and the molecular weight of the gas. The process is treated as an isentropic free expansion of an ideal gas using the equation of state:

$$Pv^k = \text{constant} \tag{1}$$

where v is the specific volume of the gas; k the isentropic expansion factor which is equal to γ the ratio of specific heats for pure isentropy; but in practice pure isentropy is not achieved, hence k is less than γ.

Eq. (1) is combined with Bernoulli's equation. Assuming flow on a horizontal axis and using a coefficient of discharge to account for friction at the orifice, the mass flow rate of an ideal gas through a thin hole in the containment wall is:

$$M = C_d \rho_{\text{ambient}} A_h \sqrt{\frac{2P_{\text{process}}}{\rho_{\text{process}}} \frac{k}{(k-1)} \left[1 - \left(\frac{P_{\text{ambient}}}{P_{\text{process}}}\right)^{(k-1)/k}\right]} \quad (2)$$

where M is the mass flow rate (kg/s); P the pressure (Pa); C_d the coefficient of discharge, typically 0.85 for gas releases; A_h the area of hole (m^2); ρ the density of the gas (kg/m^3).

If the pressure ratio is above a critical value given below, the exiting mass flow is limited to a critical maximum value. This is sonic or choked flow.

The loss of pressure in the isolatable gas volume is calculated using an Excel Spreadsheet as follows: the density of the gas is calculated using the non-ideal gas equation:

$$PV = nZRT$$

where n is the number of moles ($=m/M_w$), m the mass of gas, M_w the molecular weight; Z the compressibility; R the ideal gas constant; ρ ($=m/V$).

Substituting for V and n

$$\rho = \frac{ZM_w P}{RT}$$

The compressibility of the gas is taken from the heat and material balance on the process flow diagram (PFD) and simply adjusted for pressures away from those given on the PFD as described below:

$$Z = \frac{1 + PB}{RT}$$

where B is a constant determined for the compressibility given on the PFD.

During each time step, the loss of mass from the system is the loss through the leak and loss to the blowdown system is calculated using the gas release equation. The gauge pressure to the blowdown system is the difference between process pressure and flare header backpressure. The mass loss to the isolatable volume over the time step is calculated and gas density is recalculated.

Temperature of the isolatable gas volume is assumed to remain constant. In reality, as the gas expands, the temperature would reduce, lowering the pressure. This would be balanced by the heat input from the fire:

$$\rho = \frac{\{m_{\text{start}} - \text{time step} \times (\text{leak rate} + \text{blowdown rate})\}}{\text{isolatable volume}}$$

Using the recalculated density, the new lower pressure is calculated using the equation:

$$P = \frac{\rho RTZ}{T}$$

Other similar exponential based methods exist for calculation of blowdown, for example those presented in [3].

A blowdown curve for the four basic scenarios and the no leak case for a separation isolatable volume with a 15 min blowdown to 100 psig is shown below:

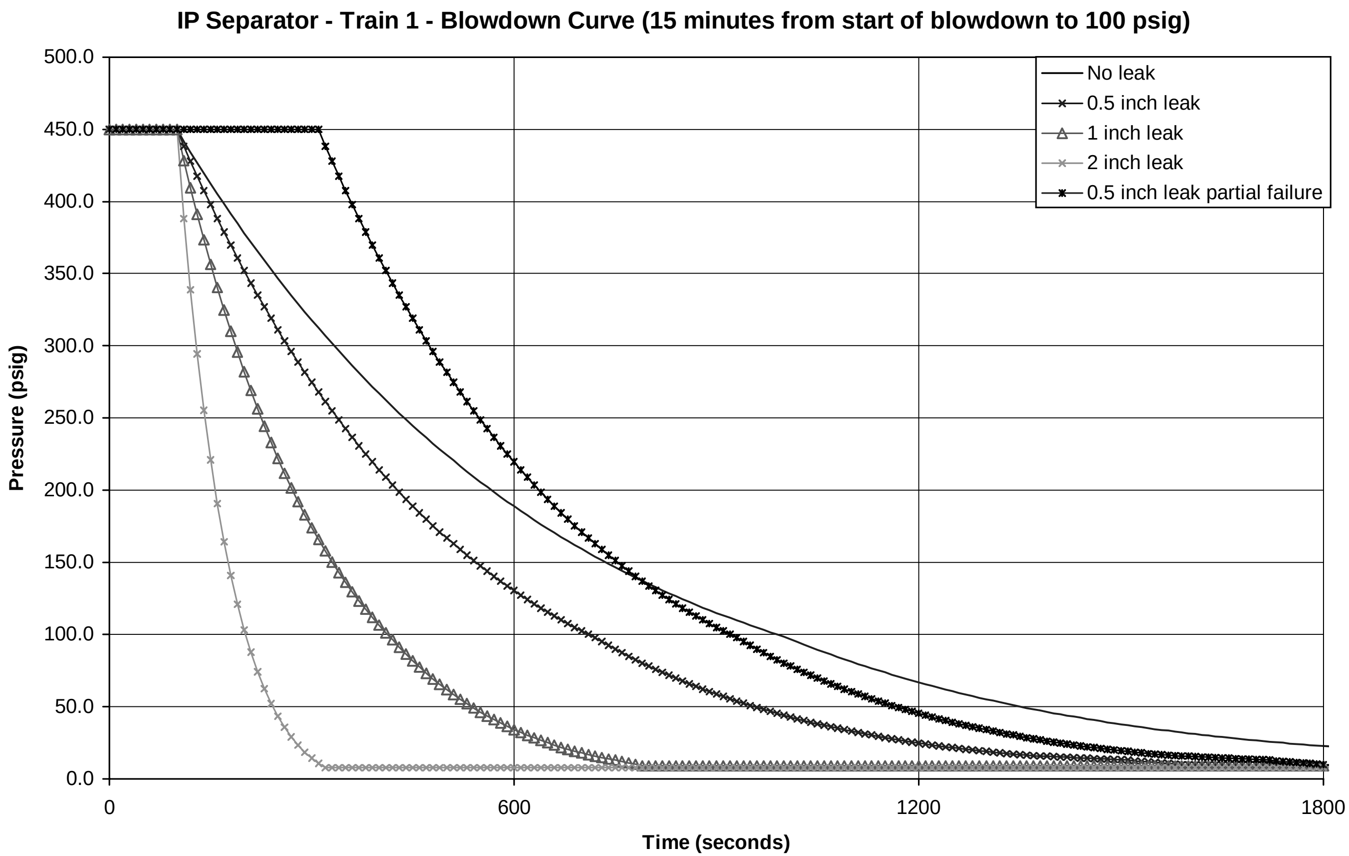

Fig. 1. 15 min blowdown curve for IP separator isolatable volume.

2.3. Jet fires flame length and dimension

Gas jet fires have a high forward flame velocity and exhibit an erosive effect on impinged materials due to the momentum of the hot gas flame. Gas jet fires can have high heat transfer rates and have the potential for rapid failure of unprotected equipment.

For quantification purposes, jet fires are often approximated by a cone. The base of the cone will be "lifted-off" from the release point and the cone can be deflected by an ambient wind.

The following equations have been used to give an approximate size of the flame:

$$\text{jet length (ft)} \sim 22.8(m) \times 0.46 \tag{3}$$

$$\text{flame volume (ft}^3\text{)} \sim \text{constant} \times (m)^{1.35} \tag{4}$$

where m is the release rate (lb/s), constant values are as follows: methane, 1100; propane, 1200.

Other, similar equations for flame length are presented in [3].

The flame volume is appropriate for the case when the jet flame impacts onto an object and is deflected into a diffuse fire ball. The extent of the fire ball is calculated assuming the flame volume is spherical. Gas jet flames are also buoyant and exhibit a strong lifting behavior which further causes the flame to have more spherical proportions.

When a jet fire has decayed to a pressure of 10 psig the fire is assumed to have effectively ceased. This pressure is close to the transition pressure from sonic to subsonic flow (Fig. 1).

Using the equations above and the blowdown curve, a graph of flame length versus time can be obtained. This is shown in Fig. 2.

These flame lengths are for unimpeded jet flame. Due to the high degree of congestion on a platform, it is more realistic to assume the flame is a sphere and use the diameter of the sphere to evaluate flame impacts. The flame length envelope is the outer limit of the curve. Initially, this envelope is defined by the larger 2 in. leak and, after around 5 min, the flame envelope is described by the 1/2 in. failure with manual operation of safety systems.

2.4. Failure criteria

The platform is assumed to have failed the fire scenario if one of the following screening criteria listed in Table 1 are exceeded outside the module where the initial failure takes place.

As the focus is on the prevention of escalation, most equipment locations are checked against the flame dimension at 5 and 10 min from the time of initial release. Instantaneous values for 12.5 and 6.3 kW/m^2 are used for the impact of gas jet fires on escape and evacuation routes. Distances to these radiant heat levels are calculated by simple multipliers based on the flame length producing results similar to Fig. 2.

2.5. Use of results

Extracting the flame dimensions at 5 and 10 min allows comparison with the failure criteria shown in Table 1 and allows circles to be drawn on the plot plan. The circles show

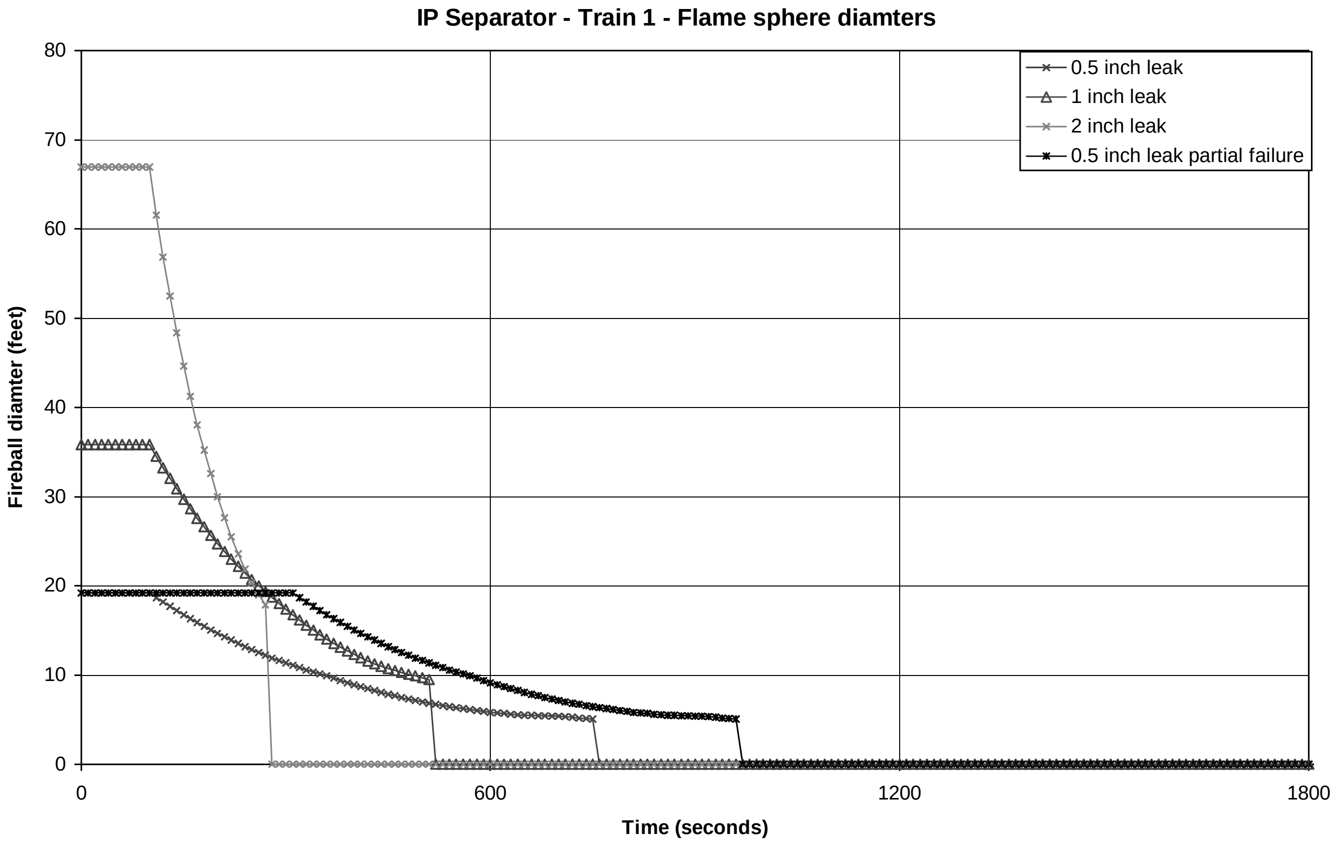

Fig. 2. Fire ball diameters vs. time for IP separator isolatable volume.

Table 1
Course impairment criteria for failure of primary steel and process equipment

Hazard	Impact criteria	Effects
Heat load	200 kW/m^2 jet flame impingement	Failure of small bore piping and other unprotected equipment and structural items in 5 min. This level of heat transfer is typically experienced where there is direct flame exposure from a jet fire
	200 kW/m^2 jet flame impingement	Failure of unprotected large bore piping, vessel support and major structural elements in 10 min. This level of heat transfer is typically experienced where there is direct flame exposure from a jet fire

the location of areas where equipment may be expected to fail. These circles can be used to provide initial estimates for passive fire protection (PFP) or to relocate equipment.

Once the hazard zones from this initial list of design basis events have been predicted, the list can be shortened by selecting the fires which defined the flame length against time envelope. For example, Fig. 2 shows the 1/2 in. leak with delayed operation of safety systems as the bounding case after 5 minutes. This shortens the list of design basis scenarios to a more manageable shortlist which can be used as input to some of the more detailed analysis.

A flowchart showing the logic flow for the evaluation process is shown in Fig. 3.

For scenarios where the impairment criteria are exceeded, the impact of changing some of the parameters below is evaluated to determine which modification provides the most effective hazard reduction. Some examples of the measures considered are listed below:

- automatic versus manual blowdown,
- various blowdown rates (e.g. 5, 10 or 15 min),
- reducing the size of isolatable inventories,
- adding passive fire protection (PFP),
- changing the physical location of process equipment,
- changing the location of escape and evacuation routes,
- changing the location of escape systems,
- location/orientation of leak sources relative to equipment,
- relocating equipment between isolatable volumes,
- changing the location and orientation of flanges,
- upgrading to all welded construction.

The impact of these changes is evaluated and the logic flow process continues. If these approaches cannot be shown to effectively control the hazards, a more detailed evaluation like that shown in the example below can be used.

3. Offshore production facility PFP optimization

The example describes how the use of scenario-based approach can refine the initial passive fire protection estimates for structural steel.

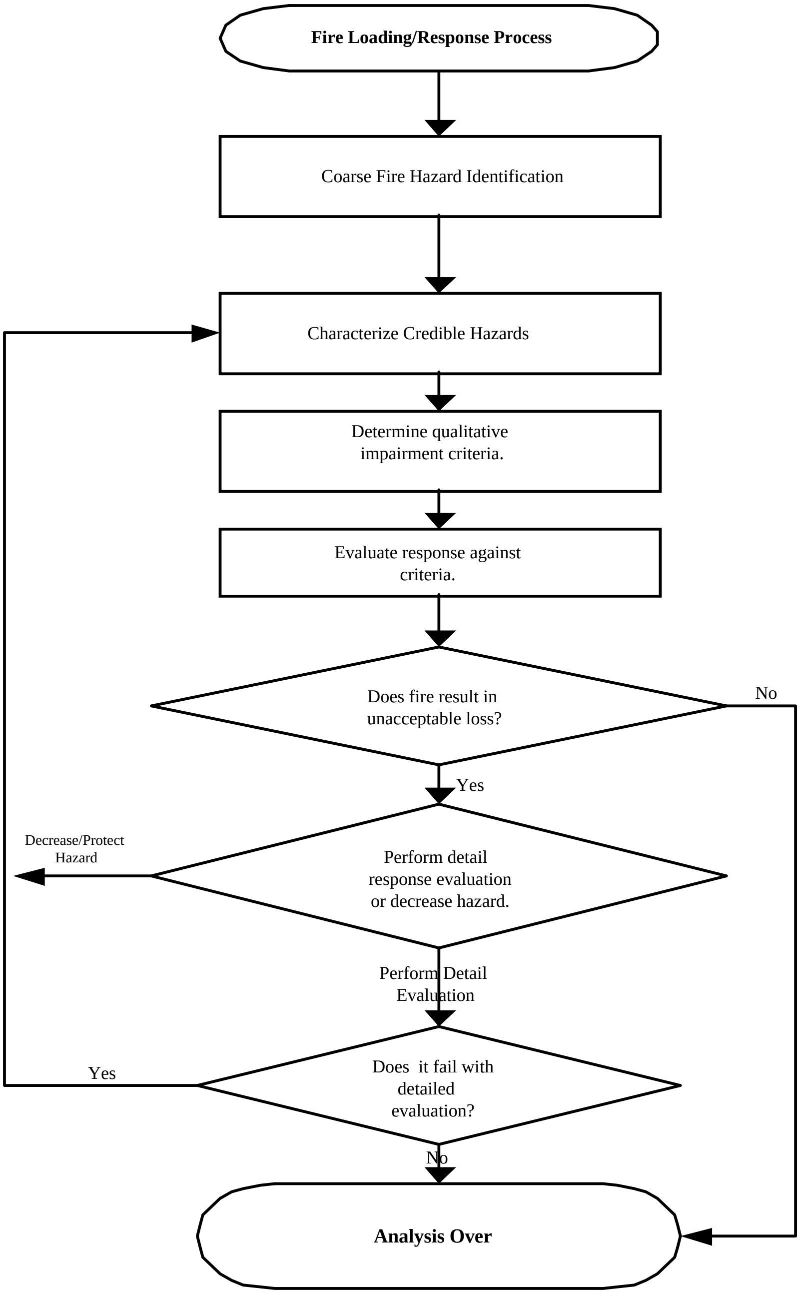

Fig. 3. Flow chart for design basis fire evaluation.

The initial scenario-based fire analysis was conducted and recommendations were made based on the review of the scenarios against the impairment criteria. The recommendations included:

- Adding isolation valves (to limit isolatable inventory size, which resulted in shorter duration fires).
- Increasing blowdown system depressurization rates for some larger hydrocarbon inventories.
- Providing passive fire protection estimates for structural steel.

The initial PFP estimate required considerable installation time and cost and future maintenance costs, in addition to imposing significant weight onto the facility.

A detailed evaluation of the PFP requirements was performed by taking a reduced set of five of the most severe fire scenarios selected from the initial analysis. Detailed structural modeling of the impact of the fire heat loading curves (i.e. like those produced in Fig. 2) on primary steel was undertaken. The structural response to the scenarios was evaluated utilizing linear structural and missing member analysis. The cost of this analysis was returned more than four-fold in direct installation costs of the PFP.

The linear structural response was used as a screen for the detailed non-linear structural analysis. When the non-linear model was complete, only a small percentage of the initial PFP estimates for structural steel were required after some slight structural design changes.

One catastrophic scenario involved a gas export riser that was located in the center of the facility. Due to miles of high pressure export gas pipeline, a small release from this pipeline could result in significant damage to the entire facility.

The initial recommendation in the analysis was made to install a subsea isolation valve to minimize the release inventory and shorten the duration of the fire. However, these valves are difficult to maintain while meeting emergency shutdown valve integrity requirements. Additionally, the distance to the sea floor was greater than a mile and this inventory was still large enough to cause significant damage to the facility.

The gas export riser could not be moved to the outboard side of the facility due to hull structural stresses. Three solutions were proposed by the project team that were considered in combination to effectively mitigate the fire hazard.

The first solution was to insert the export pipe into an outer pull tube which would provide dropped object protection and act to vent pipeline leaks within the center well to the flare.

The second solution was to employ all welded construction up to the bottom of the primary emergency shutdown (ESD) valve and remove all connection (e.g. instrument taps and injection points) from the downstream side of the ESD valve. This significantly reduced the likelihood of releases downstream of the ESD valve.

The third most unique solution was to locate the ESD valves up into the structural I-beams. The massive I-beams (>5 ft in height) on all sides of the ESD valves were coated with PFP. Positioning the ESDs in this manner prevents a release from one export ESD from directly impacting the adjacent ESD. The jet fire heat loading could be absorbed and managed with existing PFP and with deluge for cooling.

The above three changes in design were only economically feasible because they were identified early in the project and because of project team buy in to the hazard analysis approach.

4. Conclusion

Overall aims of fire hazard management (FHM) are to ensure that:

- The hazards associated with process fires are proactively dealt with throughout the design process by integrating hazard based knowledge into the design.
- All credible fire hazards are identified, analyzed and understood in a timely manner.
- Appropriate combinations of prevention, detection, control and mitigation systems have been implemented.
- Systems provided to protect personnel and assets from effects of fires are suitable for the hazards.
- Overall risk from fires is tolerable.

This paper has outlined a scenario-based methodology for fire risk analysis that can be applied early in the design cycle in place of, or prior to a formal QRA. The development of fire hazard knowledge during the design process benefits the overall facility integrity through proactive hazard management. The scenario based approach reduces the number of scenarios analyzed to an easily managed and understood set of bounding events. This, combined with the change in focus from calculating numbers of fatalities to demonstrating that the facility integrity is maintained, puts the results in terms that can be easily understood project team. This facilitates buy in for the implementation of hazard management measures. This allows the primary objectives of fire hazard management to be incorporated at an early, cost effective stage.

Appendix A. Web-links to resources

Classification societies	
ABS	www.eagle.org
DNV	www.dnv.com
LR	www.lr.org
International Association of Classification Societies	http://www.iacs.org.uk/
Statutory	
Canadian Newfoundland Offshore Petroleum Board	http://www.cnopb.nfnet.com/
Code of Federal Regulations	http://www.access.gpo.gov/nara/cfr/index.html
Her Majesties Stationary Office (UK)	http://www.hmso.gov.uk/
MMS	www.mms.gov
National Maritime Safety Committee (Australia)	http://www.nmsc.gov.au/
Transport Canada—Marine Safety	http://www.tc.gc.ca/MarineSafety/Directorate/index.htm

Appendix A. (*Continued*)

United States Coast Guard	http://www.uscg.mil/
United Kingdom Maritime and Coastguard Agency	www.mcagency.org.uk
UK Health and Safety Executive	http://www.hse.gov.uk/research/frameset/offshore.htm
Organizations	
American Petroleum Institute	http://api-ec.api.org/intro/index_noflash.htm
Fire and Blast Information Group	http://www.fabig.com/
Fire Safety World	http://www.fs-world.com/
International Association of Drilling Contractors	www.iadc.org
Institute of Marine Engineering, Science and Technology	http://www.imare.org.uk/default.asp
Institution of Fire Engineers (UK)	http://www.ife.org.uk/
International Maritime Organization	http://www.imo.org
International Organization for Standardization	http://www.iso.ch/iso/en/ISOOnline.openerpage
National Fire Protection Association	http://www.nfpa.org
National Transport Safety Board	http://www.ntsb.gov/default.htm
Royal Institute of Naval Architects	http://www.rina.org.uk/
Society of Fire Protection Engineers	http://www.sfpe.org
SNAME	http://www.sname.org/
Steel Construction Institute	http://www.steel-sci.org/index.htm
UK HSE	
UK Offshore Operators Association	http://www.oilandgas.org.uk/
Underwriter's Laboratory	www.ul.com
University	
Fire Service College (UK)	http://www.fireservicecollege.ac.uk/
Heriot Watt University	http://www.civ.hw.ac.uk/research/fire/
Hong Kong Polytechnic	http://www.bse.polyu.edu.hk/Research_Centre/Fire_Engineering/
Leeds University (UK)	http://www.leeds.ac.uk/fuel/
Lund University	www.brand.lth.se/english/
University of Canterbury	http://www.civil.canterbury.ac.nz/fire/firehome.html
University of Greenwich	http://fseg.gre.ac.uk/
University of Maryland	http://www.enfp.umd.edu/
Worcester Polytechnic	http://www.wpi.edu/

Appendix A. (*Continued*)

Research facilities	
Building Research Establishment (UK)	http://www.bre.co.uk/frs/
Fire and Blast Information Group	http://www.fabig.com/
Human Factors Offshore	http://www.hfw2002.com/
National Institute of Standards and Technology	www.bfrl.nist.gov/
Norwegian Fire Research Laboratory	http://www.nbl.sintef.no/
Steel construction Institute	http://www.steel-sci.org/index.htm
South West Research Facility	www.swri.org
VTT	http://www.vtt.fi/indexe.htm
Warrington Fire Research Center	http://www.wfrc.co.uk/
Firenet (UK)	http://www.fire.org.uk/

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