Risk-based fire engineering for offshore installations

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Operators of offshore installations have a need to understand the impact of potential fires on their installations and equipment (referred to as fire targets). Such information is particularly important at the design stage, to ensure that sufficient protections are given to safety critical components.

Dimensioning accident loads (DALs) provide a convenient metric to assess appropriate level of fire protection. A target exposed to fire will experience the DAL (or greater) with a defined frequency. Frequencies in the range 10^{-3} to 10^{-5} are usual. The DAL should account for all possible fire sources which can impair a target. These sources can number hundreds on a typical offshore installation though typically the most infrequent or low consequence fires would be screened out during initial assessment. We deliberately do not define the "load" because it can take many forms. Typical load measures are exposure duration, heat transferred or temperature rise. Exposure duration is the simplest and most widely reported DAL; it is the duration for which a target can be exposed to a known radiation level, at a set frequency, but does not take account of the time dependent variation in radiation levels.

The fire load depends on many factors: number of potential fire sources, fuel release rates, system pressures, release direction, distance to the target, wind speed, fire protection measures, escalation pathways and others. Numerical models of various complexities calculate the loads, though generally computation fluid dynamics (CFD) is regarded as the most detailed (though not necessarily the most accurate). However, CFD is too computationally intensive to analyse all possible offshore fire scenarios. Analysis of all expected fires requires the use of simplifying assumptions and correlations. Nevertheless, it is still possible to describe complex scenarios.

In this paper we present a computational method to analyse a large number of offshore fire scenarios and their effects on multiple fire targets. Ultimately the method produces a duration exceedance curve for each target from which the DAL can be read. The method extends existing models of fire frequency and consequence by including information about the targets: their relative position to fire sources, their endurance and the presence of intervening barriers.

The algorithm implementation automatically calculates target fires loads and does so very quickly. This is computationally efficient and allows hundreds of fires and targets to be analysed in a few minutes. The risk analyst therefore has more time to specify the model detail, assess the results and spot input errors. Crucially, the risk analyst has control of all model inputs. Because the simulations are quick, different designs can be rapidly assessed. This has applications for early-stage design engineering.

Introduction

Fires contribute significantly to the risks of offshore oil and gas production. Operators have a need to understand the potential impact of fires on their installations and equipment (referred to here as *fire targets*). Such information is particularly important at the design stage, to ensure sufficient protection is given to safety critical components.

In the UK, the PFEER regulations (1) require operators to identify major fire and explosion hazards, assess their consequences and select appropriate measures to protect people from those hazards. Similarly in Norway, the NORSOK standards (2) require an assessment of the risks to main safety functions from fire and explosion loads.

It may be impractical to design against all possible fire scenarios on an offshore installation. In the UK, the legislation allows for a risk-based approach to manage hazards, often within an ALARP (as low as reasonably practicable) framework. This allows the design to account for the frequency of major events, including fires, rather than just their consequences. Design decisions may be based on consequences alone in certain circumstances but this could lead to measures not considered “practicable”.

Dimensioning accident loads (DALs) provide a convenient metric to assess appropriate level of fire protection as part of a risk-based approach (3). A target exposed to fire will experience the DAL (or greater) with a defined frequency. Frequencies in the range 10^{-3} to 10^{-5} per year are usual. The Oil & Gas UK fire and explosion guidance (3) includes a thorough discussion to aid selection of an appropriate DAL frequency for different safety functions.

The DAL should account for all possible fire sources which can impinge a target. These sources can number hundreds on a typical offshore installation though often the most infrequent or low consequence fires, or those remote from a particular target, would be screened out during initial assessment. We deliberately do not define the "load" in the following discussion because it can take many forms. Typical load measures include:

- duration of flame impingement,
- exposure to radiation levels above a defined value,
- heat transferred, or
- temperature rise.

Exposure duration is the simplest and most widely reported DAL. This DAL is the duration for which a target can be exposed to a defined radiation level, at a set frequency, but does not take account of the time dependent variation in radiation levels.

The fire load depends on many factors: number of potential fire sources, fuel release rates, pressures, direction, distance to the target, wind speed, fire protection measures, escalation pathways and others. Numerical models of various complexities calculate the loads, though generally computation fluid dynamics (CFD) is regarded as the most detailed (though not necessarily the most accurate). However, CFD is too computationally intensive to analyse all possible offshore fire scenarios. Analysis of all expected fires requires the use of simplifying assumptions and correlations. Nevertheless, it is still possible to describe complex scenarios.

In this paper we present a computational method for analysing a large number of offshore fire scenarios and their impacts on multiple fire targets. Ultimately the method produces a duration exceedance curve for each target, from which the DAL can be read. The method extends existing models of fire frequency and consequence by including information about the targets: their relative position to fire sources, their endurance and the presence of intervening barriers. Often this method is used to determine the barrier properties; their values may be model outputs rather than inputs – both are possible.

The algorithm implementation calculates target fires loads very quickly but the analyst must first specify the model geometry inputs (fire–target relations) which can be a time-consuming process. This is computationally efficient and allows hundreds of fires and targets to be analysed in a few minutes. The risk analyst therefore has more time to assess the results and spot input errors. Crucially, the risk analyst has control of all model inputs. Because the simulations are quick, different designs can be rapidly assessed. This has applications for early-stage design engineering.

Fire modelling

The Oil and Gas UK fire and explosion guidance (3) provides a detailed explanation of release and fire modelling, and the application of dimensioning accident loads (DALs), such as used in this work. Here we summarize the key model concepts only.

This paper considers fire loads exclusively. It does not consider impairment loads due to other mechanisms (such as explosions, unignited gas exposure or impacts).

Before we can determine the fire load on a target, we must calculate the fire properties. Properties of interest include:

- Flame length (time dependent) and duration,
- Thermal radiation level / surface emissive power (SEP), and
- Flame direction.

On an offshore oil & gas installation, major accident fires are the consequence of ignited loss of hydrocarbon containment incidents (leaks). Leaks usually manifest as high-pressure gas or liquid discharges. Emergency systems can control such leaks by means such as emergency shutdown (ESD) and blowdown (BD). These limit the hydrocarbons available to a leak but are not 100% reliable; sometimes they fail. Offshore quantitative risk assessment (QRA) tools, such as DNV GL's in-house and commercial software — SOQRATES (4), ARAMAS (5) and Safeti Offshore (6) — account for the potential failure of ESD and BD in their discharge models. Typically the models consider a number of discrete scenarios, including:

1. Isolation success, blowdown success;
2. Partial isolation failure, blowdown success;
3. Isolation success, blowdown failure; and
4. Partial isolation failure, blowdown failure;
5. Detection failure, with manually initiated isolation.

Partial isolation refers to the failure of a single emergency shutdown valve (ESDV[1]). This is the assumed most likely failure mode; simultaneous failure of multiple valves being less common.

Offshore QRAs further categorize leak scenarios by size (usually by hole size or initial release rate). DNV GL have historically used three (SOQRATES) or four (ARAMAS) representative leak rates in offshore QRAs, however, a paper at the IChemE Hazards 24 conference recommended that offshore QRAs should use a minimum of five holes to sufficiently reduce numerical error (7).

Assuming the QRA uses only three leak sizes, then each leak event has 12 scenarios (four ESD/BD scenarios times three leak sizes) as far as the dimensions of the flame and resulting radiation are concerned. A typical offshore installation may contain 50–200 representative potential leak events, depending on the sectionalisation. Hence the QRA performs 600–2400 transient discharge calculations. Further subdivision could be envisaged by considering ignition controls, detection time, active fire protection (deluge) and ventilation control, among other factors.

The discharge model depends on the fluid release and the system design. For example, a gas/oil separator (ignoring water separation) will have at least three associated leak events:

1. Well-mixed gas/liquid at the inlet,
2. Predominantly gas after separation, and

[1] ESDVs are used to segment the process into isolatable sections, reducing the hydrocarbon inventory available to any single leak.

3. Predominantly liquid after separation.

QRA software tools, such as those above, solve a set of ordinary differential equations (ODEs) to describe the time-varying discharge to atmosphere (the leak) and blowdown where applicable. Development of those equations is not the subject of this paper.

Once we have determined the transient discharge behaviour, we can use it to determine fire sizes, assuming ignition occurs. Ignition modelling is beyond the scope of this paper; it is sufficient to know that whether immediate or delayed (causing explosive overpressure), ignition is necessary for fires to occur. The ignition probability is generally low on offshore installations because potential ignition sources are strictly controlled. Hence, the fire frequency is typically several orders of magnitude lower than the leak frequency.

Jet/spray fire model

The Shell Chamberlain model (8) describes jet flame lengths in terms of the hydrocarbon mass release rate. This model applies to gas releases. Though it can also be used as an approximation for light oil sprays, such application must be used with caution as it is not accurate at low flow rates. The Shell Chamberlain model assumes a cone-shaped flame surface, resulting in approximately ellipsoidal radiation contours. Using the DNV GL PHAST software (9) we can determine the radiation contour extents parallel and perpendicular to the main flame axis. The contour sizes depend on numerous other factors (such as the gas composition and weather conditions) but for QRA purposes an average correlation is sufficient.

In offshore QRA, there are typically three main radiation bands of interest, in addition to direct flame impingement, to facilitate design, all related to fatality:

1. Above 37.5 kW m^{-2} thermal radiation persons will likely die in a few seconds.
2. Between 12.5 and 37.5 kW m^{-2} thermal radiation escape within a few seconds may be possible, suffering severe burns.
3. Between 5 and 12.5 kW m^{-2} thermal radiation persons would not voluntarily enter the affected area but could escape with minor burns.

Depending on the design requirements, other radiation levels could be considered. For example, when accounting for protective coatings, meshes or grills; or impairment of lifeboat stations.

Pool fire model

Pool fires are described by their width and characterized by the flame height; they are usually modelled as sheared cylinders with circular cross-sections parallel to the ground (10). The Thomas correlation (11) can be used to describe pool fire flame height. Once discharged, liquid hydrocarbons can pool on solid surfaces (decks), possibly constrained by bunds. Without constraint, pools will spread to a uniform depth defined by the surface tension. For typical hydrocarbons, a pool depth of 2 mm can be used (10). The burn duration of a pool fire is decoupled from the hydrocarbon release profile because it depends on external factors. Bunds will limit a pool diameter, thereby limiting the free surface available for combustion. Drainage systems will remove liquid from the pool; for small leaks the drains may remove all the liquid before a sustained fire can develop. Water/foam deluge systems can also disrupt pool fires.

Frequency model

Determination of the fire frequency is an important aspect of the model, but the details are unimportant for this analysis and are considered standard in QRA practice. Typically, the model accounts for known leak frequencies of equipment compiled from historical databases such as the HSE hydrocarbon release database (12) and statistics (13). These frequencies are combined with an ignition probability to determine fire frequencies. The ignition model published by the Energy Institute (14) is often used in the UK for offshore QRA as the industry “standard”. The failure probabilities, derived from such statistical sources as OREDA, are used to determine the individual fire cases for when safety systems, such as ESD operate or fail to operate.

Impairment assessment

The fire risk model attempts to describe a complex 3D system with a few parameters. Geometry information is largely neglected, though the analyst may use 3D models to determine the parameters. Parameter determination tends to be the most time-consuming part of an assessment. The model consists of three types of elements:

1. Fire sources,
2. Targets, and
3. Barriers

The following sections describe these elements in detail. The model considers fire–target pairs in isolation to determine the impairment frequency. Escalation to other fire sources leading to impairment is not considered here for simplicity, though such information is generally considered in a QRA to determine the overall risk level.

Fire sources

Fire sources are representative release points from any hydrocarbon containing equipment. The model defines fire sources by:

- frequency, and
- transient flame size;
    - for jet and spray fires this is the length, and
    - for pool fires it is the width and height.

The model retains no fire shape information; this must be inferred by the analyst when defining fire–target parameters. The fire properties are determined using the methods described above.

Targets

Offshore installations include many *safety functions* (targets) which may be impaired by fire, for example:

- Hydrocarbon containment (vessels, pipework);
- Safety system components (such as ESDVs and fire pumps);
- Escape routes and evacuation systems (lifeboats, liferafts);
- Primary steelwork, firewalls and jacket structures; and
- Anything which could form an escalation hazard.

The fire damage potential depends on the duration to which the target is exposed to flame or high thermal radiation levels. The exposure duration depends on the hydrocarbon inventory and the depleting release rate, according to the physical models described above.

A target is either unimpaired or failed; there are no degrees of failure. In the model a target remains unimpaired until it is exposed to a fire for its assigned endurance time.

The point at which a target "fails" is a subject for interpretation. It depends on the target nature and its potential failure modes. Other references give more thorough discussions about this (10). Here, we define the failure point as:

"The point at which the target has been exposed to the impairing radiation level for its endurance time."

This assumes immediate failure rather than progressive. This is conservative but may not be realistic for steel structures, which may fail in numerous, progressive ways such as penetration, plastic deformation or collapse (10). The CMPT guide to offshore QRA (10) gives typical endurance times for different steel structures exposed to fire. Unprotected steel can be expected to withstand 5 minutes direct jet fire impingement and 10 minutes direct pool fire impingement. Pool fires are typically cooler and do not have a strong convective heat transfer component, hence the endurance time is longer.

The risk model defines a fire target by parameters common to all fire sources

- Jet fire endurance time,
- Pool fire endurance time;

and parameters specific to each fire source

- Representative distance,
- Barrier endurance times (jet and pool), and
- Directional probability (jet fire only).

Representative distances

The model assumes a single representative distance between each fire source and each target. This is a particularly coarse approximation for an offshore installation; if a fire source is an isolatable section (defined between isolation points) then it could include several vessels and distributed pipework. Hence, defining a single distance (implying a single point source and point target) is not practicable nor particularly realistic. We define a simple rule here to facilitate determination of representative distances:

"Choose the shortest possible distance between a fire source and a target. This will maximize the likely fire impingement duration and is therefore conservative."

Other rulesets could be applied to reduce conservatism but with a consequent increase in complexity. The model always compares the representative distance to the flame size. However, some targets become impaired when exposed to lower radiation levels, escape routes for example. Radiation levels decay the further away you get from the fire source. As lower-level radiation contours extend beyond the flame length, the representative distance needs to be *reduced* proportionately (shorter flames still produce sufficiently large radiation contours to impair such targets). For example, the SOQRATES program includes multiplication factors to estimate the size of elliptical radiation level contours from the flame length (see table 1) with results correlated using the PHAST software (9). The model assumes a standard jet flame surface emissive power of 250 kW m^{-2}.

Table 1. Jet radiation contour factors to convert flame length to elliptical contour length and width.

Radiation level (kW/m^2)	Length factor, a	Half-width factor, b
37.5	1.2	0.36
12.5	1.45	0.625
5	1.75	0.875

Hence, the radiation contour length is aL_f and the half-width bL_f. We apply the same factors to spray fires, even though spray fires are typical cooler, shorter and wider than the equivalent mass flow gas jet. This approach is considered conservative. Similar to jet fires, we can use DNV GL PHAST to determine radiation contour extents horizontally away from a pool fire. The radiation extents of a pool fire depend on the fuel, SEP and pool diameter.

Barriers and obstructions

To impinge a target a fire may have to first breach one or more physical barriers or obstructions. Such barriers include walls, solid decks or high-congestion areas.

The risk model defines intervening barriers by their endurance time. This is clear for firewalls, which may have endurance times as listed in the CMPT guidance (10). For more complex barriers such as high-congestion areas or non-rated firewalls the analyst must make an expert judgement, based on a rule set defined in discussion with the design team.

To make the analysis of multiple targets tractable, the model assumes barriers are either unimpaired or failed. Upon failure the model deems barriers completely ineffective, as if they were instantly removed. Barrier impairment occurs at their defined endurance time in the same way as target impairment. Once all barriers are breached, a fire may impinge the target, leading to impairment.

As the relevant barriers are different for each fire–target combination, the risk model does not describe barriers separately. Instead barrier effects are set per fire–target per fire type.

Directional probability

In addition to having a length greater than the representative distance, the fire must also be directed appropriately to impinge the target. For directional fires, such as jets and sprays, the model includes a *directional probability* to account for flame direction. The analyst must estimate this probability from available data such as layouts, isometrics and 3D CAD (computer aided design) models. On an offshore installation direct line-of-sight may be impossible due to equipment congestion between the fire source and the target. However, other factors could increase the directional probability, such as fires reflecting off equipment or solid walls/decks. For example, if the flame points upwards and impinges the underside of the deck above then it may spread out and form a radial fire and the whole module could be exposed to high radiation levels.

In reality, a jet fire in an enclosed space will not be a well-formed 1D flame. It will more likely be a dispersed fire. The analyst should account for such indirect impingement through the directional probability parameter.

For detailed fire assessment a thorough study of directional probabilities is appropriate, however often such detail is unwarranted as a simplified approach could be used. An appropriate (and common) level of simplification is to use six orthogonal flame directions (up, down, left, right, forwards and backwards). Discretizing the directional probability further would be very time-consuming and unlikely to be justified due to the uncertainties in other aspects of the model.

Jet/spray fires are usually easier to define than pool fires because they are highly directional. The majority of a liquid pool fire's thermal effect will manifest vertically due to buoyancy. Targets above the fire can be easily related to the flame height. Targets situated horizontally away from the fire source would typically have to be within the pool footprint to become impaired unless it is tilted by wind; radiation levels decay quite rapidly horizontally away from a pool fire. Targets below a pool fire will almost certainly be protected by the solid surface on which the pool has gathered.

For some fire–target combinations a direct line-of-sight from source to target may not be necessary for impairment. For example, a large jet fire could point over the edge of a firewall and impair a lifeboat station on the far side by a lower radiation level. This could be modelled by adjusting the barrier endurance time and representative distance for that fire–target combination; a manual calculation. Here we neglect the option to specify multiple barrier endurances for different flame directions, however, that is a further sophistication which can be included in the methodology.

Dimensioning load calculation

This model determines the dimensioning accidental loads, not the design accidental loads, based on the definitions:

- A *dimensioning load* is the most severe load a system should withstand to meet the acceptance criteria (for example a 10^{-4} per year impairment frequency).

- A *design load* is the load used as the basis of design. Typically this will be the dimensioning load plus a safety factor, often to account for any future modifications to the process plant.

The two terms are often mistakenly used interchangeably in the literature; both given the acronym DAL. Here DAL refers to the dimensioning load only. The dimensioning fire load should incorporate all design accident events; all potential hydrocarbon loss of containment events on the installation.

Here the dimensioning property of interest is the *critical duration* T_{crit}: the duration for which a fire exposes a target to the impairing radiation level (which could be direct impingement).

Depending on the nature of the release, a fire may initially grow in size and then shrink as the hydrocarbon inventory is depleted. The critical duration for a representative distance d is the duration for which the flame length is greater than d; this may not be the total fire duration. To determine the critical duration, the model linearly interpolates fire scenario size profiles (such as generated by the SOQRATES program). For pool fires, this accounts for periods at the fire start and end when the flame length may be shorter than the representative distance. If a flame is never longer than the representative distance then the critical duration is zero.

The total target fire load is the sum of loads from all fires with the potential to impinge the target. Combined with the fire scenario frequencies, the model can calculate the dimensioning load for a set frequency for each target using the algorithm below:

1. For each fire source:
    a. Define the representative distance d between the target and the fire source.
    b. Define the total endurance duration T_{end} of all intervening barriers (separate values for each fire type) between the target and the fire source.
    c. Define the fire directional probability p_{dir} of the fire being directed at the target.
    d. For each fire scenario (hole size, isolation status and other parameters) specific to the fire source:
        i. Calculate the critical duration T_{crit} for which the fire is long enough to impinge the target ($L_{fire} \geq d$). Separate calculations for jet, spray and pool fires.
        ii. Store the ($f = f_{fire} \times p_{dir}, T = T_{crit} - T_{end}$) point in a list, where:
            f_{fire} = fire scenario frequency
            T = impinging fire duration
            Note, the endurance time of intervening barriers is subtracted from the critical duration.
2. Sort the list of (f, T) by the impingement duration T, shortest to longest. The list contains points for all fires, all scenarios.
3. Calculate the cumulative frequency $\hat{f}$ of exceeding a duration, starting with the longest critical duration point and working backwards to the shortest. This is the target *exceedance curve*.
4. Interpolate the resultant $(\hat{f}, T)$ curve either:
    a. at the target endurance time to get the impairment frequency; or
    b. at the DAL frequency (often 10^{-4} year^{-1}) to get the DAL duration.

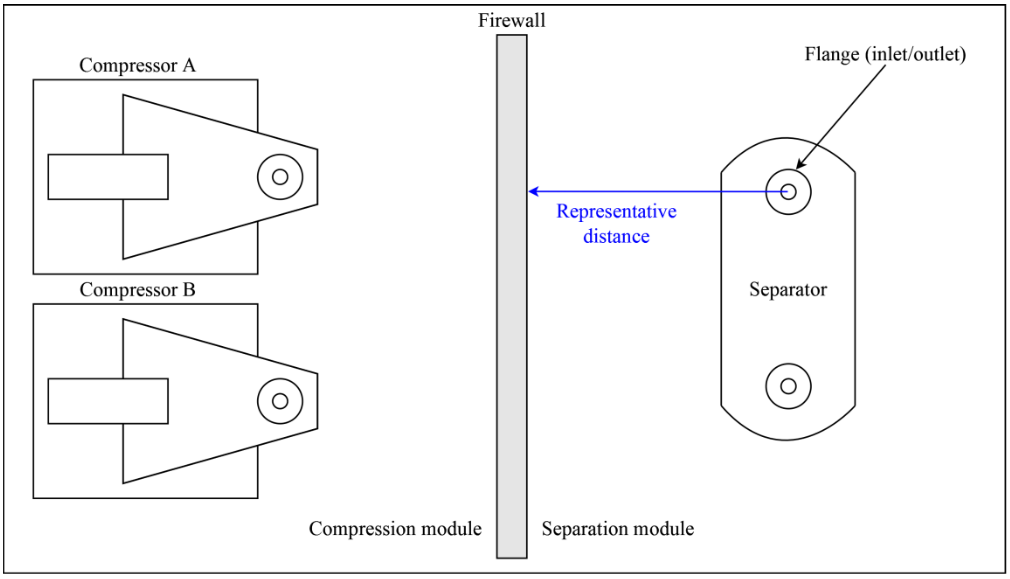
In addition to DALs and impairment frequencies, which are single values read from the exceedance curve, , the model generates the fire duration exceedance curves (jet and pool) for each target, which the analyst can process further if required.

Once calculated, the analyst can compare the DALs to the acceptance criterion, to ensure the design meets the set standard. If necessary, the above process can be iterated with different parameters, for example fire barrier endurance times, in order to facilitate design decisions. That is a typical use-case.

Worked example

Here we present the results of a worked example based on fire sizes from a real risk assessment; the layout has been changed to facilitate this discussion (the compressors and separator have been placed closer together). We have anonymized the data for publication. Rather than present all results, this paper presents only the assessment used to facilitate design of a firewall between the separation and compression areas on an offshore installation. Those areas are contiguous and the design proposes a firewall between them to prevent escalation of compressor fires to the separators and vice-versa. The designer wished to know the standard to which the wall should be built, in particular the PFP requirement, using a risk-based approach.

Figure 1. Worked example schematic (not to scale).

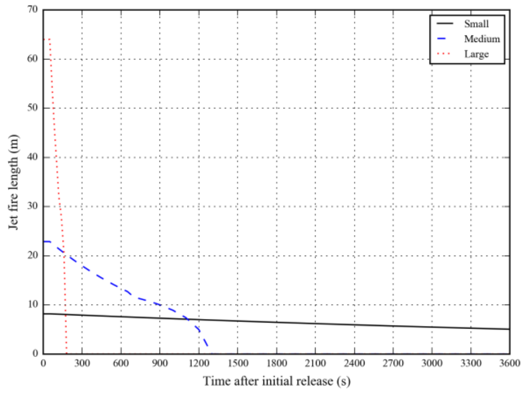


This example is two dimensional as an illustration; the method extends easily to three dimensions.

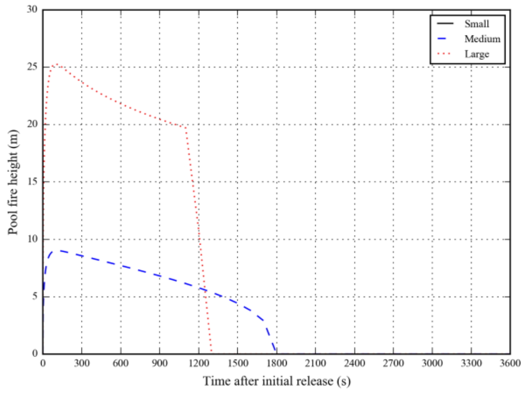
Figure 2 presents representative fire size profiles for the separator releases. There are three simplified release events associated with the separator as discussed above: inlet well-mixed fluids (exhibiting a spray fire), gas release from the vapour space (exhibiting a jet fire) and oil release from the liquid space (exhibiting a pool fire; we assume the pressure is sufficiently low that a spray fire does not occur).

Figure 2. Separator transient fire size profiles, successful isolation and blowdown cases only.

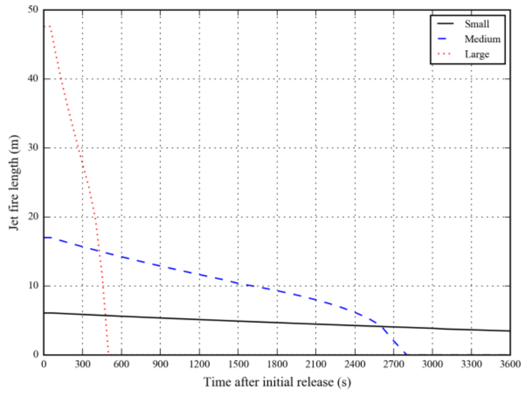
(a) Separator gas release (jet fire)



(b) Separator oil release (pool fire)



(c) Separator inlet release (spray fire)



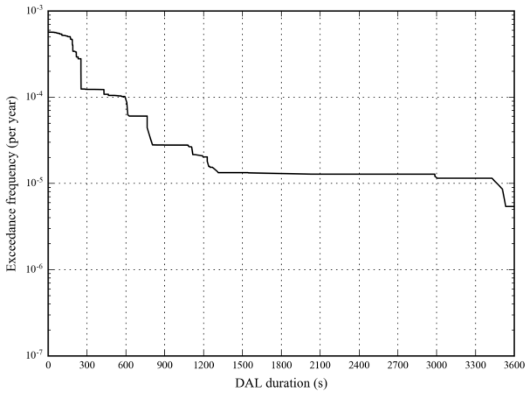
Similar figures could be produced for each of the 35 fire release events considered in the test model but are neglected here; 18 in the separator area, and 17 in the compressor area. As the model includes a simple bund and drainage system around the separator, the small oil leak events do not exhibit a pool fire; the modelled drain rate is sufficient to remove all hydrocarbons from a small release before a fire can develop. Medium and large pool fires initially grow in size as the pool spreads, then diminish as the drains and fire consume the fuel.

Using the method above, we defined the firewall as a target. A representative distance to the wall from all events of 8 m was applied and a jet fire directional probability of 0.5 for all release cases. The endurance time of the wall is not applicable at this stage as this is what we are trying to determine.

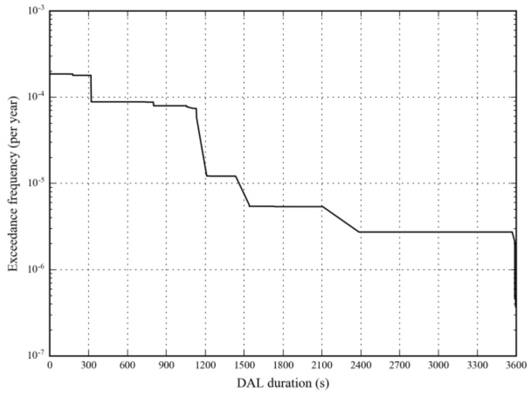
Figure 3 shows the results of applying the fire risk assessment algorithm presented here. The firewall fire impingement duration exceedance curves are reported separately for all fires, separator area fires and compression area fires. Jet/spray and pool fires are also reported separately here; as they have different characteristic thermal loads it is not practical to combine the results. For situations where target impairment by a known radiation level is modelled, then the results from jet and pool fires could be combined, for example escape route impairment.

Figure 3. Compression area firewall impairment exceedance curves.

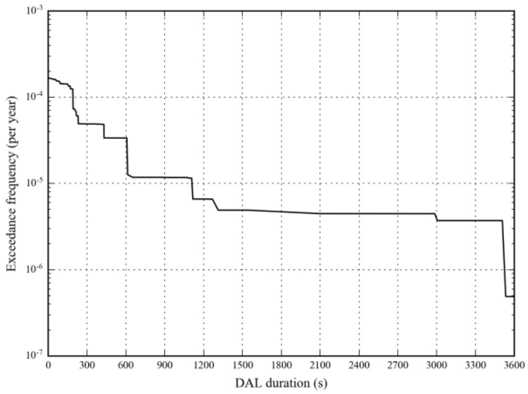
(a) Jet fires; all areas



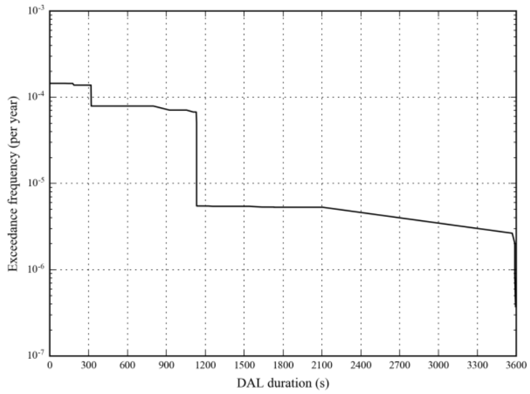
(b) Pool fires; all areas



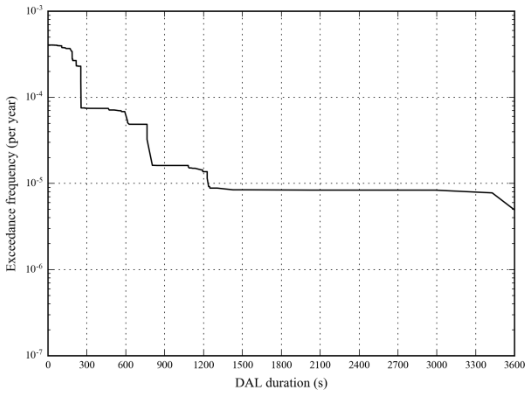
(c) Jet fires; separation area



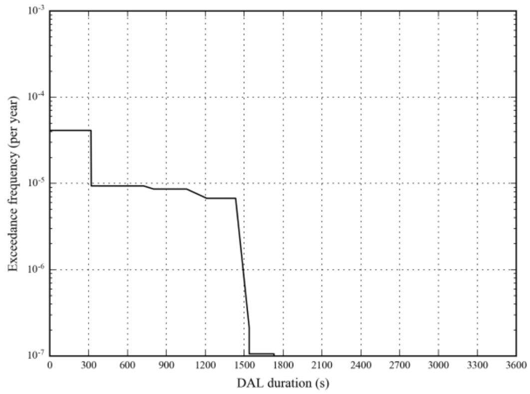
(d) Pool fires; separation area



(e) Jet fires; compression area



(f) Pool fires; compression area



Using a DAL frequency of 10^{-4} per year for design purposes, we can read the DAL durations from the above curves (the algorithm above includes that step). The DAL frequency should be agreed upon by the design team prior to analysis.

Table 2: Fire DAL durations on the compression area firewall.

Target	DAL duration (min:s) for	
	Jet/spray fires	Pool fires
Firewall (total)	9:52	5:18
Firewall (separator side)	3:10	5:18
Firewall (compressor side)	4:13	0

As the firewall's purpose is to prevent escalation between areas, the total DAL is not relevant for design. The firewall is subjected to longer jet fires on the compressor side. This is expected due to the presence of higher pressure gas. Unrated steel plate should prevent passage of jet fires for around 5 minutes, so on the basis of this analysis no passive fire protection (PFP) is required on the separator side to reduce the wall failure frequency by fire to 10^{-4} per year. On the separator side, pool fires are a greater threat, due to the large liquid inventory in the vessel. This is perhaps conservative as the main heat effects from a pool fire manifest upwards rather than sideways. Nevertheless, unrated steel plate should withstand a pool fire for about 10 minutes before failure, hence no PFP is justified on the separator side of the firewall by this assessment.

Rather than consider individual targets, the analyst can consider the DAL load on a 2D grid; this allows regions of high exposure to be readily identified (see figure 4 below). For example, this technique could be used to position the separator at a lower-risk location or inform the decision to supply PFP to the separator, with or without the firewall in place. In order to determine the distance to each grid point, the analyst must specify a point location for each fire source rather than define representative distances (which are then calculated automatically). In figure 4 below all separator fires were positioned on the top-most flange and the compressor-related fires were distributed on a line central to the area, slightly weighted to the upper end. Each event could be located at a separate point but for convenience only a small number of release locations were considered here.

Figure 5 shows the same DAL plot but with credit taken for an unrated firewall (300 s jet fire endurance). This clearly illustrates the effectiveness of the wall in preventing compressor fires escalating to the separator. The residual DAL load at the separator is due to fires in the local area and long-duration compressor fires which last beyond the wall endurance time. This also accounts for the small 300 s DAL region to the right of the firewall, remembering the model completely eliminates the wall after it is exposed to fire for its endurance time. In this case, an unrated fire barrier is sufficient to reduce DAL loads across the wall, hence saving cost compared to a more substantial H-rated firewall.

These figures were produced using a 1×1 m grid resolution which took around 20 s to compute on a standard desktop computer. This enables quite rapid visual identification of potential high-risk regions between process areas and within process areas. By using a combination of discrete target analysis and area analysis, this technique can be applied to engineering designs to optimize equipment layout, barriers and passive fire protection.

Figure 4. Jet fire DAL contour plot, no credit for firewall.

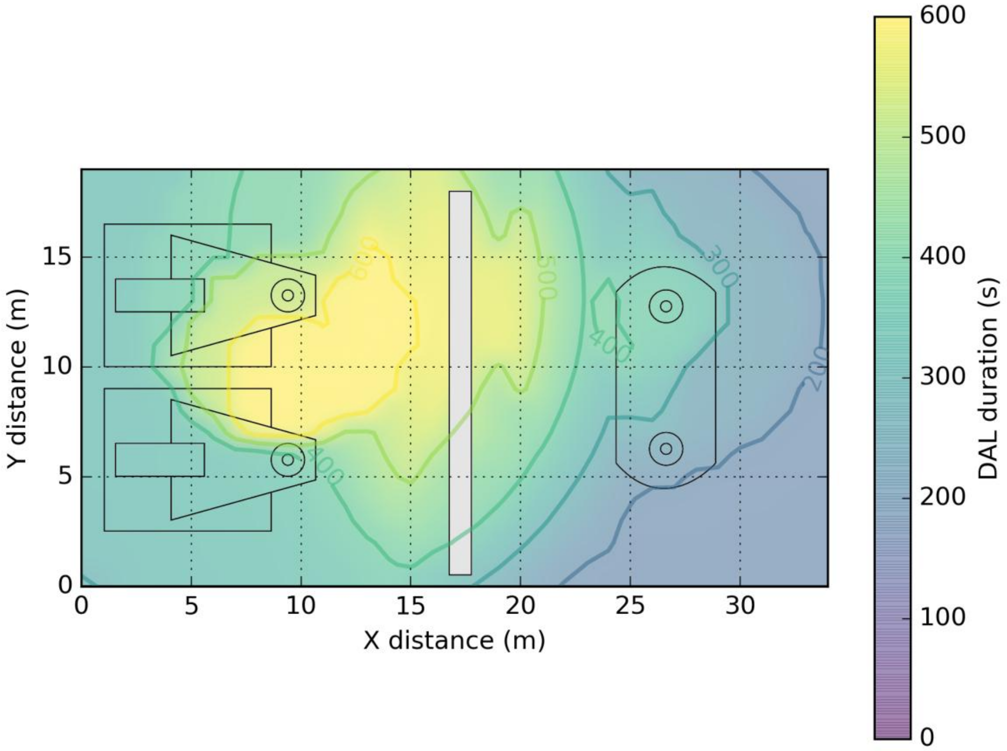
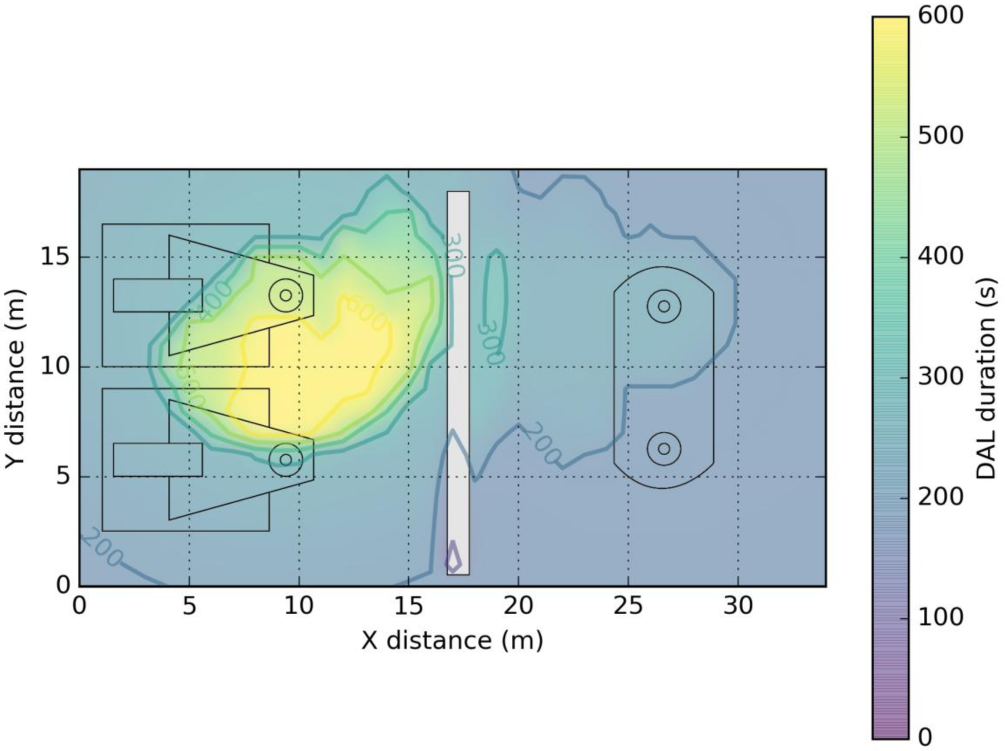


Figure 5. Jet fire DAL contour plot, unrated steel firewall (300 s endurance).



Practical examples

DNV GL has applied this fire risk methodology on numerous real-world projects. Here are a few examples.

Lifeboat firewall assessment

An operator required an additional lifeboat on their installation to provide evacuation means for increased manning. In order to maximise protection from process hydrocarbon events, a preferred location behind the accommodation block was identified. However, no space was available at this location due to the presence of the existing lifeboats. Therefore, an alternative location was identified where the line of sight from process hydrocarbon events was limited, but not entirely removed, therefore potentially requiring additional protection. Detailed fire exceedance curves were used to determine a DAL for the lifeboat and its embarkation area. Thermal radiation protection was deemed sufficient to reduce risks to ALARP, saving the operator the costs of installing a rated firewall.

Accommodation PFP assessment

An operator required an assessment of the PFP required on a cantilevered accommodation block extension with a footprint extending beyond the edge of the platform top deck of the platform. Fire exceedance information was generated for the accommodation block supports and panels on each face, including the underside, of the new structure. DALs were determined taking into account the temporary refuge (TR) status of the block and the differing fire loads on each face and each level. The result was that the PFP design could be optimised to the fire scenarios and therefore faces and levels of the accommodation with negligible exceedance did not require PFP.

Bridge structural failure assessment

A bridge between two offshore platforms was identified as a dropped object hazard to nearby production pipelines, should impingement by a sustained process fire result in the bridge structural members failing. A fire exceedance heat map, similar to the example above was used to determine the requirement and extent of passive fire protection on the bridge, its supports and the primary load bearing structures on either platform.

Temporary equipment risk assessment

A temporary offshore drilling module was planned to be installed on a producing installation and its PFP requirements required to be determined. DALs were established against the key criteria of preventing the drilling module from forming an escalation hazard and toppling onto the accommodation module.

Jacket repair risk assessment

Repairs to a fixed installation jacket required removal of the leg PFP for an extended period of time, 2–4 weeks. The operator wished to understand the increased risk to the platform during this time resulting from topside fires and from risers passing through the jacket; in particular they wanted a recommendation on whether this work could be done during normal production or if it would require a shut-down. Assessment using the QRA results (already available) and this fire risk assessment technique enabled DNV GL to report the specific risks to the unprotected leg section and a recommendation on whether to proceed with the work or wait until a shut-down period.

Conclusions

This paper presents an efficient algorithm to determine fire loads on targets using standard QRA outputs. Combining target and barrier information enables the QRA to be applied more widely at the design stage as a design tool, directly linking risk information in the design of offshore installations. By using a combination of discrete target analysis and area analysis, this method can be applied to engineering designs to optimize equipment layout, barriers and passive fire protection. This enables clients to make informed decisions and potentially save costs.

While the computational aspects of the model are fast, it still requires the analyst to thoroughly review the proposed design to define targets, representative distances and directional probabilities. This manual effort is time-consuming but forces the analyst to become familiar with the design, potentially spotting significant flaws.

Further work aims to aid the analyst by automating the data gathering aspects, for example by automatically processing 3D CAD models. We also plan to integrate the technique with the advanced MODFIRE algorithm in the Safeti Offshore software which takes account of obstructions when determining fire shape and radiation contours. Such work was beyond the scope of this paper.

References

1. **UK Health and Safety Executive.** *Prevention of fire and explosion, and emergency response on offshore installations.* HSE. 1995. Approved Code of Practice and Guidance. ISBN 978 0 7176 1386 1.

2. **Norwegian Technology Centre.** *Norsok Standard Z-013, Risk and emergency preparedness analysis.* Norwegian Technology Centre. s.l. : Norwegian Technology Centre, 2001. Technical Standard. Rev 2, 01/09/2001. Norsok Standard Z-013.

3. **Oil & Gas UK.** *Fire and explosion guidance.* May 2007. Issue 1, ISBN 1 903003 36 2.

4. **DNV GL.** *SOQRATES.* [Computer software]

5. —. *ARAMAS.* [Computer software]

6. **DNV GL Software.** *Safeti Offshore.* [Computer software]

7. *Modelling of Accidental Hydrocarbon Releases in QRAs: Hole Size Versus Initial Release Rate Basis.* **Bain, Brian, et al., et al.** Edinburgh, UK : s.n., 7-9 May 2014. IChemE Hazards 24. Vol. Symposium series no. 159.

8. *Developments in Design Methods for Predicting Thermal Radiation from Flares.* **Chamberlain, G A.** 65, 1987, Chem. Eng. Res. Des., pp. 229-309.

9. **DNV GL Software.** *Process Hazard Analysis Software Toolkit (PHAST).* [Computer software]

10. **Spouge, John.** *CMPT Guide to Quantitative Risk Assessment for Offshore Installations.* Energy Institute. 1999. ISBN-13: 978-1870553360.

11. *The size of flames from natural fires.* **Thomas, PH.** Pittburgh, USA : Combustion Institute, 1963. pp. 884-859. 9th International Combustion Symposium.

12. **HSE.** Hydrocarbon Release Database. *HSE Website.* [Online] UK Health & Safety Executive. https://www.hse.gov.uk/hcr3/.

13. **UK Health and Safety Executive.** Offshore statistics. *HSE website.* [Online] [Cited: 11 January 2016.] http://www.hse.gov.uk/offshore/statistics.htm.

14. **Energy Institute.** *Ignition Probability Review, Model Development and Look-up Correlations.* IP, Energy Institute, HSE, UKOOA. London : Energy Institute, January 2006. IP Research Report. ISBN 978 0 85293 454 8.

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Nomenclature

Symbol	Description	Unit
f̂	Cumulative frequency	$year^{-1}$
a, b	Radiation contour length and half-width multiplication factors	-
d	Distance (e.g. between a fire and a target)	m
f	Frequency	$year^{-1}$
L	Length (e.g. of jet flame)	m
p	Probability	-
T	Duration, length of time	s
Subscripts		
crit	"Critical" property (e.g. the critical time to fire impairment)	-
dir	Directional property (e.g. fire directional probability)	-
end	"Endurance" property (e.g. target endurance duration)	-
fire	Fire property	-