Improved Visualisations of Offshore QRAs

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Offshore quantitative risk assessments (QRAs) are traditionally carried out using spreadsheet models which often have a lack of visualisation of results and employ relatively simple calculations, especially when modelling escalation effects. In order for decision makers and key stakeholders (such as the offshore workforce) to understand a QRA and fully appreciate the potential hazardous events offshore, DNV GL has developed an improved method for carrying out offshore QRA.

The improved method incorporates 3D models of offshore installations and presents consequence results (e.g. fires, explosions, smoke) in a 3D viewer. A significant improvement over standard spreadsheet calculations is the detailed escalation modelling, where the development of fires and how these might escalate through walls and decks with time can be seen. Another improvement over standard spreadsheet calculations is the muster calculations, where the movement of personnel is tracked against time.

Such features allow decision makers to be better informed about the impact of key safety-related decisions, and the offshore workforce to have a greater appreciation of potential hazardous events, relative to standard spreadsheet-based systems.

The Rough Bravo installation, owned and operated by Centrica Storage Limited (CSL), is the first project in the UK to utilise the improved method, which is delivered through DNV GL's Safeti Offshore software. This paper presents an overview of a practical application of Safeti Offshore, using the Rough Bravo QRA as a case study. It describes the process involved in creating the QRA model, the improved modelling, the range of information that can be generated from Safeti Offshore and how this information can provide input to key decisions and engage the range of non-specialist stakeholders.

Keywords

Quantitative risk assessment, consequence modelling, escalation, mustering analysis, engagement, visualisation

Introduction

Offshore QRAs are traditionally carried out using spreadsheet models, which often have a lack of visualisation of results and employ relatively simple calculations, especially when modelling escalation effects. The analysis (e.g. fire calculations) within the models tends not to be geometrically aware and hence does not automatically take account of the presence of multiple walls and decks. At best, spreadsheet models account for a single escalation stage from one module to another or to another item of equipment (e.g. a riser), resulting in rather simplified escalation calculations. In reality, there are more escalation paths on an offshore platform than assessed by the necessarily simplified approach used in spreadsheet type models and the escalation might have multiple stages, sometimes referred to as domino effects.

Another area of simplicity in offshore QRAs is the estimate of immediate fatality rates for fire scenarios. They are often informed by external consequence modelling which the analyst needs to interpret and turn into a set of input data, but there are few tools which model fires accounting for the specifics of an offshore platform such as congestion and confinement.

Finally, whilst traditional offshore QRAs might carry out time dependent release rate calculations, this is not normally transferred to the calculation of fatalities during the mustering phase following a hydrocarbon release.

Until now the traditional method for offshore QRAs was considered fit for purpose even though it was difficult, if not impossible, for operators, the workforce and other stakeholders to be able to verify that the correct data was being used or to interpret results meaningfully beyond the headline total risk values. However, with an increasing need for stakeholders to be informed about the impact of safety related decisions and for the offshore workforce to have an understanding of major accident hazards on their platforms, the simplicities described above need to be addressed. Safeti Offshore attempts to address these simplicities.

This paper presents an overview of a practical application of Safeti Offshore, using the Rough Bravo QRA as a case study. It describes the process involved in creating the QRA model, the range of information that can be generated from Safeti Offshore and how this information can provide input to key decisions and engage the range of non-specialist stakeholders.

The Development of Safeti Offshore

While most integrated QRA models are based on spreadsheet approaches some other approaches have been used. Notably DNV developed the Offshore Hazards and Risk Analysis Toolkit (OHRAT), a graphical framework in which models that undertook distinct parts of the analysis could be linked together with data flowing between them. This was developed in UNIX and subsequently adapted for a Microsoft Windows environment, when it became known as Neptune. While many models were developed successfully in OHRAT and Neptune, the system was time consuming and became uncompetitive with other approaches.

Around 2008, DNV Software considered an alternative approach which utilised elements of its existing Phast Risk software which had been used for many years for onshore QRA. Discussions were held with offshore QRA practitioners in DNV's risk analysis units and work on software development commenced in early 2011.

One of the key decisions was to incorporate a 3D graphical display of the various elements which had a bearing on the physical layout of the installation from a safety perspective. This was later extended to include a separate 3D view to illustrate the extent of fires and give some indication of the location and strength of explosions and smoke concentrations. The advantages of this feature were immediately apparent in making the modelling more transparent to clients and other stakeholders.

Other key aspects were:

- a model that is 'geometrically aware' so that the fire and explosion modelling can take appropriate account of the separation between the source event and other parts of the installation and also the effect of intervening barriers
- increased accuracy of the analysis generally and in particular to improve the resolution by being able to take better account of the multitude of combinations of weather conditions and success or otherwise of the safety systems
- modelling of the movement of personnel around the installation
- improved calculation of the timing of the progression of the incident
- processing of results from "raw" data rather than assessed data thereby improving consistency

After 2 years of development Safeti Offshore was used for the QRA model of the Asgard B installation which was completed in parallel with modifications to the software itself.

In February 2014, Centrica Storage Ltd (CSL) commissioned DNV GL to carry out a QRA of the Rough Bravo installation. This was the first bridge-linked platform to be analysed in a commercial project and the first installation of any type in UK waters.

Background to Rough Bravo QRA

The Rough reservoir is used as a seasonal gas storage facility for the UK market. During warm months, when the demand for gas in the UK is relatively low, gas from the National Transmission System (NTS) is transported from an onshore terminal at Easington along a 36" pipeline and riser and into the Rough reservoir via wells on the Rough Bravo installation. During cold months, when demand for gas in the UK is relatively high, gas is produced from the reservoir via wells on the Rough Bravo installation and is transported along the 36" riser and pipeline to Easington terminal and eventually the NTS. In addition to Rough Bravo, there is another installation (Rough Alpha) which produces from the reservoir. Gas from this installation is transported along an 18" pipeline and riser to Rough Bravo where it is routed into the 36" pipeline to Easington.

The Rough Bravo installation, operated by CSL, comprises three bridge-linked platforms: the BD accommodation and wellhead platform, the CD wellhead platform and the BP central production platform.

The BD platform provides accommodation for personnel on board the installation. The accommodation module on BD also serves as the Temporary Refuge (TR). The installation's helideck is located above the accommodation modules. The BD platform also contains two well bays with a total of 12 wells.

The CD wellhead is the most northerly platform and contains two well bays with a total of 12 wells. Both the CD and the BD platform are bridge linked to the central processing platform, BP, where the gas processing, power generation and injection facilities are located. A diagram and a photo of the installation can be seen in Figure 1 and Figure 2 respectively.

There are seven lifeboats available on the Rough Bravo platforms, four on BD platform, one on BP platform and two on CD platform, each with a capacity of 38 persons. There are also numerous liferafts, donuts, ladders and ropes to aid escape from the platforms if required.

Figure 1. Schematic of Rough Bravo Installation

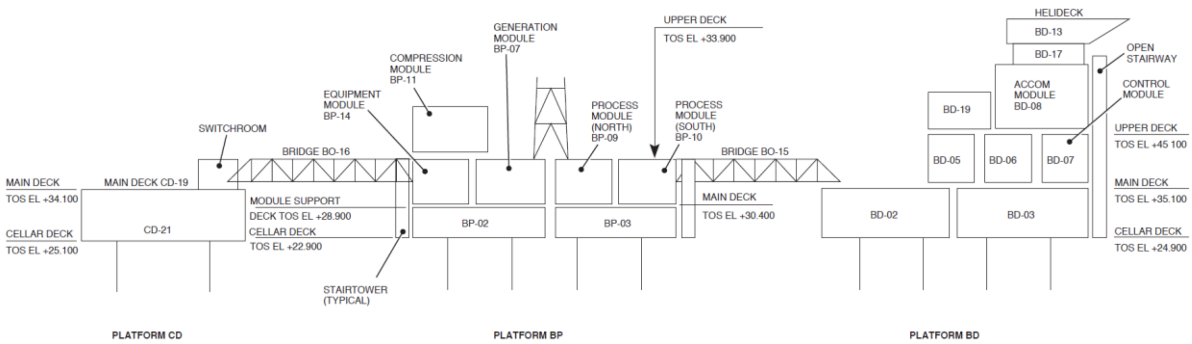


Figure 2. Rough Bravo Installation

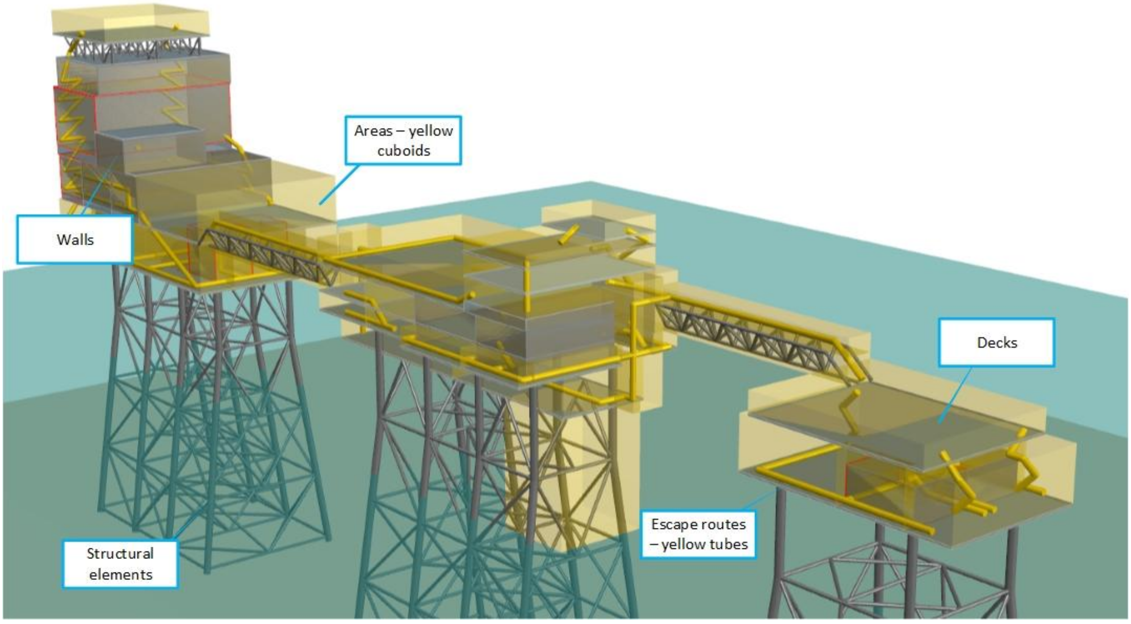
It was proposed by DNV GL to use Safeti Offshore for the Rough Bravo QRA, despite the software not being fully developed. It was expected that deficiencies would either be resolved during the project or would have only a minor effect on the accuracy of the results. Despite this, CSL appreciated the long term benefits of using Safeti Offshore, particularly the visualisations aspects of the software and the ability to have detailed results with respect to escalation and mustering.

The involvement of CSL in the development of the Rough Bravo QRA using Safeti Offshore was similar to the involvement for a traditional QRA – that is, the customer is normally involved in agreeing the assumptions for the QRA at the beginning of a project and would also be given updates at regular intervals on the status of the project. A benefit of a 3D model of the platform in Safeti Offshore is that it was easier for CSL to confirm that the layout and location of process equipment defined for the QRA was accurate compared with tabulated data that would often be found in a spreadsheet model.

Development of the 3D Model

Safeti Offshore requires the analyst to develop a 3D model of the installation (see Figure 3), which comprises the following elements: areas, decks, walls, escape routes, structural elements, and process equipment.

Figure 3. Rough Bravo 3D Model



Areas: The 3D model is built from a number of areas which are assigned a number of properties. These include the number of personnel present, the fire and gas detection capability, the level of congestion and the ventilation rate. In the Rough Bravo Model there are 63 areas defined.

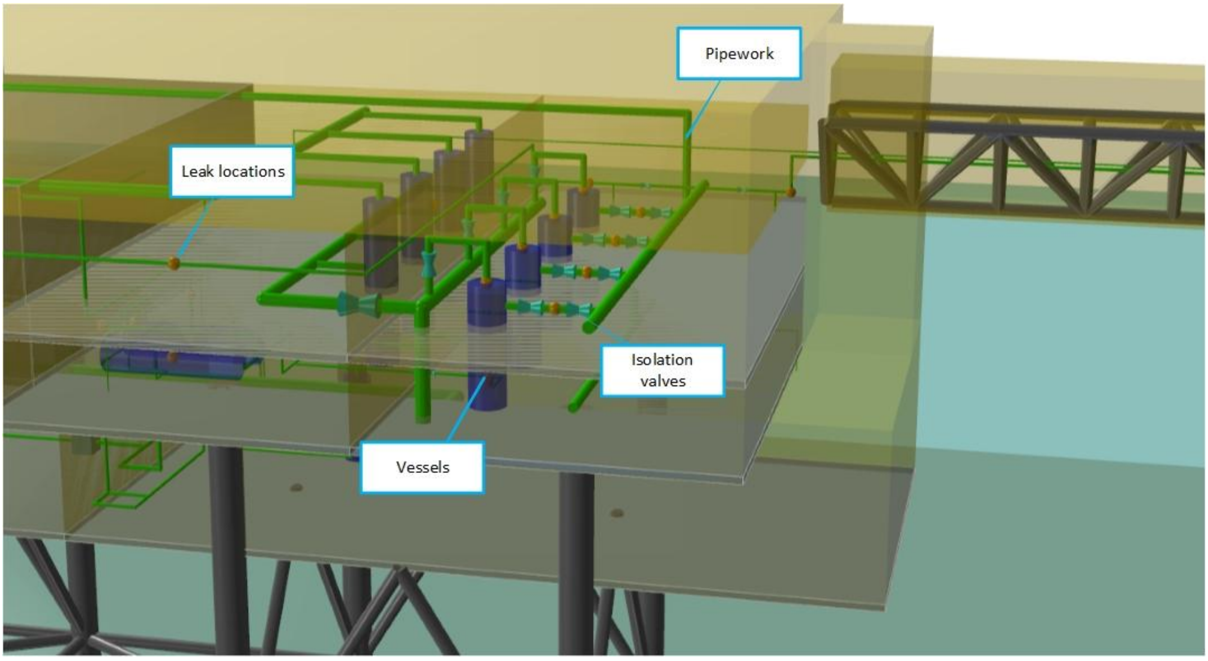
Decks and Walls: The fire rating and blast rating of each deck and wall is defined so that the modelling can determine if and when they become impaired as a result of exposure to overpressure and heat radiation. In terms of fire ratings, the analyst defines the time for which the deck or wall must be exposed to a user-defined radiation level for escalation to occur. Prior to this time or below this radiation level, the modelling does not consider escalation to have occurred. Decks are specified as either plated or grated, and this determines the ease with which scenarios can escalate. In the Rough Bravo model there are 49 decks and 51 walls defined.

Escape Routes: Following the detection of a leak on an offshore platform, personnel would travel along escape routes to attempt to reach their designated muster location. To model this process, escape routes are located with respect to the areas defined in the 3D model. The escape routes are shown as yellow tubes which have a start area and an end area. During the developing incident, Safeti Offshore determines whether each escape route is passable or whether they have been impaired by overpressure, radiation or smoke. This determines the viable routes to the designated muster location for each area in which personnel are located. In the Rough Bravo model there are 100 escape route elements defined.

Structural Elements: Structural elements such as jackets, derricks and bridges can be formed, but they do not have an effect on the calculations. In the Rough Bravo 3D model the jackets, bridges and helideck have been replicated using structural elements.

Process Equipment: As is standard practice, a parts count was performed for the Rough Bravo QRA. The parts count was input into Safeti Offshore and used in the leak frequency calculations. Of the equipment counted, Safeti Offshore can display vessels, pumps, heat exchangers, compressors, pig traps, isolation valves and pipework. This is for visual purposes and does not affect the modelling. Subsequently, the parts count was distributed to various leak locations defined across the installation, as per typical offshore QRA. Figure 4 shows process equipment and leak locations within modules BP-09 and BP-10 of the Rough Bravo 3D model.

Figure 4. Process Equipment and Leak Locations

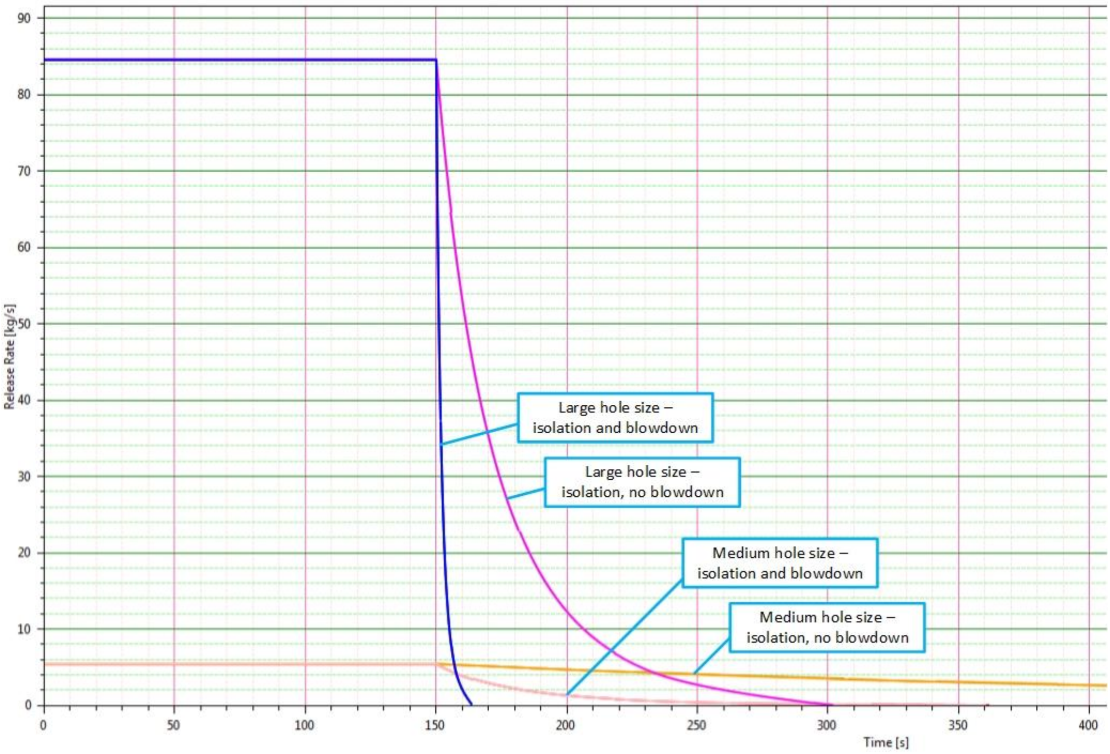


Time Varying Discharge Modelling

A time varying discharge (TVDI) model is built into Safeti Offshore and models the discharge effects that result from isolation and blowdown activation, accounting for the initial inventory, initial operating conditions, and the time for isolation valves to close and blowdown valves to open. Figure 5 shows an example.

The results from the time varying discharge model are used as input into the fire modelling as described later.

Figure 5. Time Varying Discharge Model

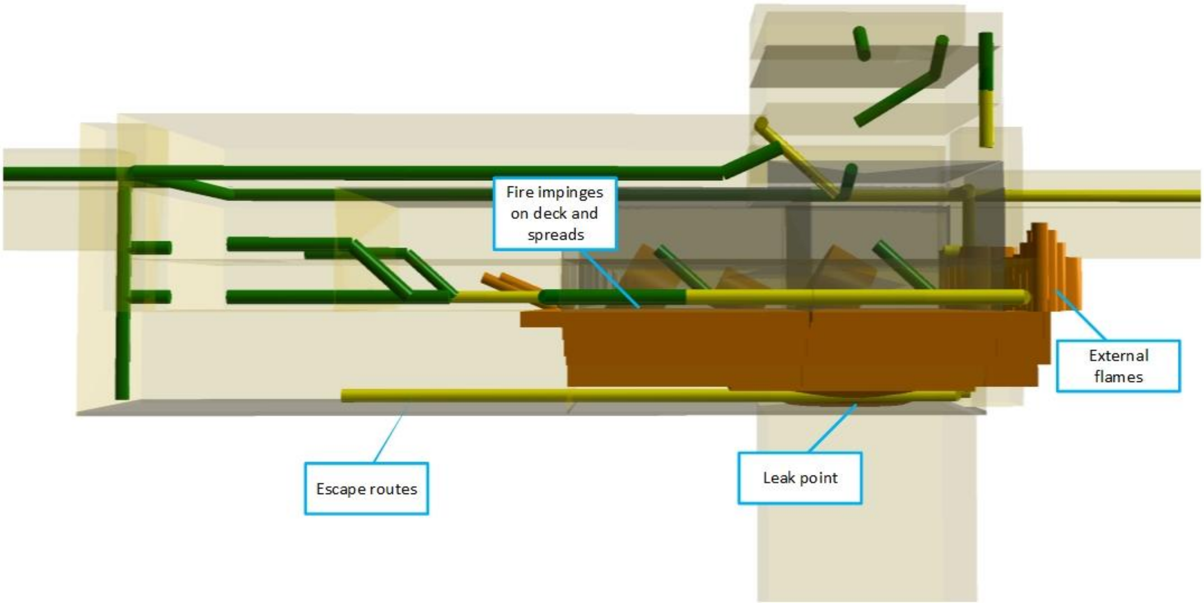


Fire Modelling

A fire model known as MODFIRE (Xu, 2013) has been developed and implemented in Safeti Offshore to account for physical boundaries such as solid decks and walls found on offshore platforms. MODFIRE defines a series of cuboids between the decks and walls in the 3D model, and spreads a fire into the spaces occupied by the cuboids. Fires inside a cuboid are represented by a cone or a cuboid. If the fire impinges on a physical boundary (such as a wall or deck), the fire is assumed to spread across the boundary and wherever there is no restriction by a physical boundary the fire will continue in its original direction. The part of a fire spreading outside of the area would be considered as external flames and represented by cylinders. External flames tilt according to the wind direction and wind speed, and a large fire could consist of multiple flames in MODFIRE.

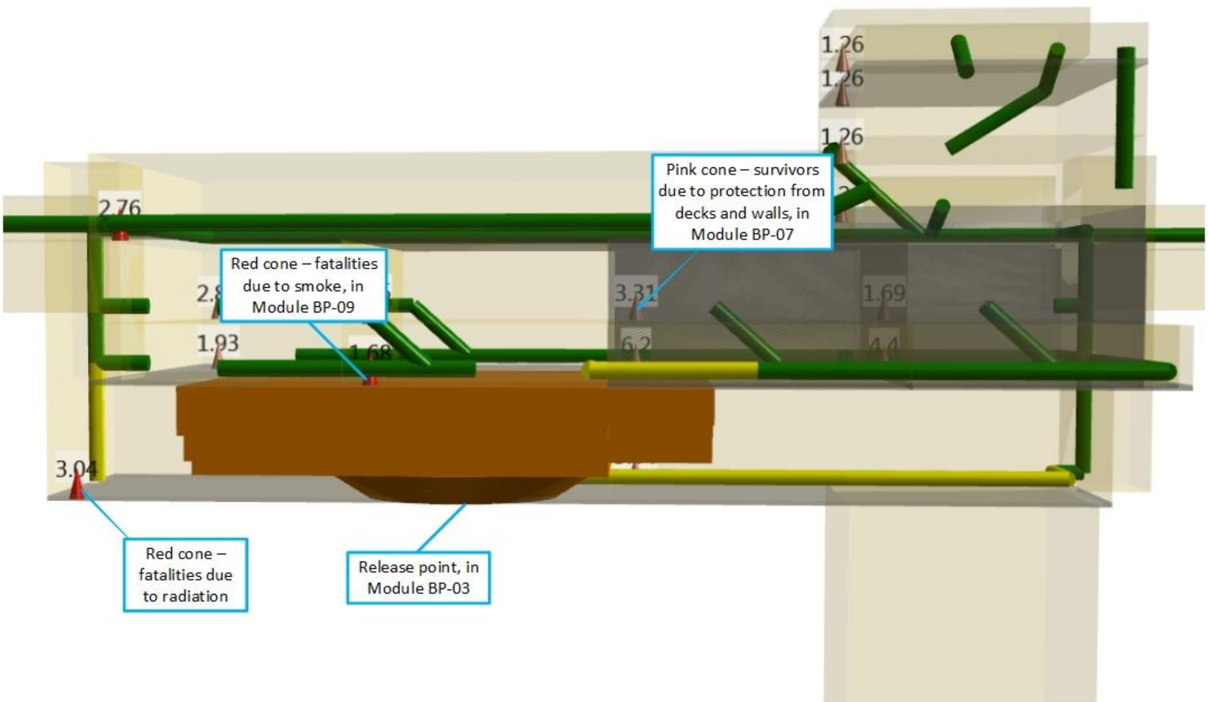
Figure 6 shows an example of a fire in the Rough Bravo QRA. The fire occurs within module BP-02, impinges on the plated deck above and spreads out in all directions. External flames can be seen outside of module BP-02. MODFIRE takes account of the presence of decks and walls, which is why flames do not initially spread into modules BP-07 or BP-14 (above module BP-02).

Figure 6. Example Fire in Rough Bravo QRA



Safeti Offshore uses MODFIRE's representation of fires to calculate radiation levels and smoke concentrations at representative locations and hence predict fatality rates across the installation. Figure 7 shows a fire which occurs in module BP-03 and impinges on the solid deck above. There are some fatalities from radiation on module BP-03 and from smoke in module BP-09; however it can be seen clearly that there are survivors in other areas of the platform. One such area is module BP-07, which is protected from the immediate effects of the fire by the solid decks and surrounding walls.

Figure 7. Example Fire in Rough Bravo QRA



Escalation Modelling

Escalation modelling is an important aspect of an offshore QRA, given the congested and confined nature of offshore installations. Traditional QRAs tend to be quite simplistic in their escalation modelling in that they often account for escalation from one module to another or to another item of equipment (e.g. a riser) only. In reality, there are more escalation paths on an offshore platform than assessed by this rather simplified approach.

It has been mentioned earlier that fire and blast ratings (termed ‘impairment criteria’) of decks and walls are defined in the Safeti Offshore 3D model. The calculations performed by Safeti Offshore give the consequence effects at the decks and walls at various time steps. If the consequence effect at a deck or wall exceeds the escalation criteria then that element is deemed to have failed and is removed from the model allowing flame and smoke to pass through. The shape of the flame will change and may now impinge on other barriers which themselves could subsequently be impaired. Fires can therefore escalate to multiple areas.

Safeti Offshore also accounts for escalation to other equipment in the same area where the fire occurs. This is known as ‘local escalation’. The analyst defines the flame length and the duration of flame impingement required for local escalation to occur. If local escalation is assumed to occur then the largest inventory of equipment within the area is added to the fire.

Figure 8 shows the development of a fire scenario in the Rough Bravo QRA. The fire is initially contained within the source module (0 seconds) but at later time steps the fire is seen to escalate through decks to other modules. By 1200 seconds the fire has escalated through all decks within modules BP-07, BP-14 and BP-11.

These views all relate to the same incident distinguished by such parameters as wind direction, safety system success etc. Other options can be displayed by changing the options on the menu selections provided as shown in Figure 9. This allows the analyst to compare the difference in consequences resulting from changes in the input parameters.

Figure 8. Escalation by Fire

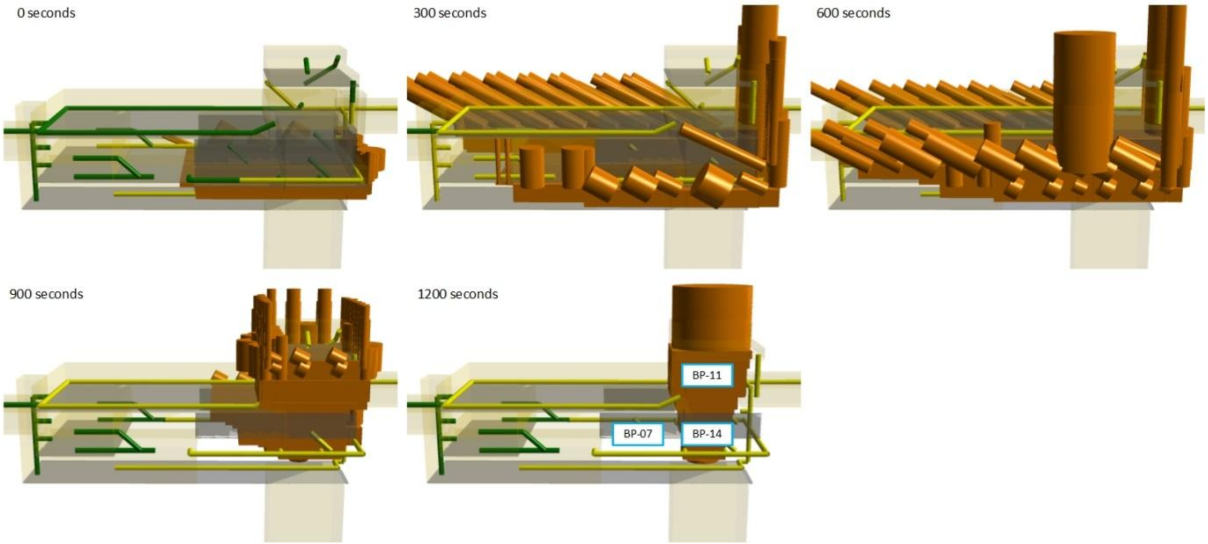
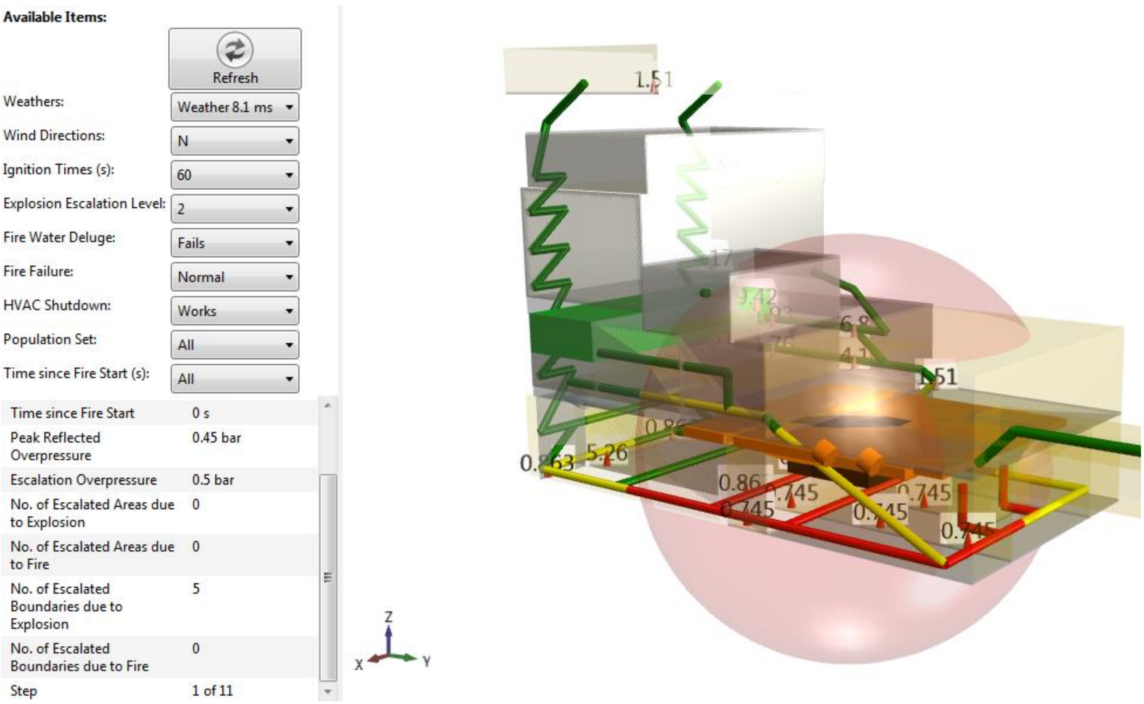


Figure 9. Selection of Parameters



It is common in an offshore QRA to model immediate ignition, resulting in jet fire effects only, and delayed ignition, resulting in explosion plus subsequent fire effects. The fire scenarios discussed so far in this paper are all from the immediate ignition branch within Safeti Offshore's event tree structure. If there was no immediate ignition there is the potential for gas accumulation within a module, which is a significant hazard to personnel. Safeti Offshore models delayed ignitions at various time steps, resulting in various levels of severity depending on parameters such as the size of the gas cloud at the time of ignition, the amount of congestion, etc. Safeti Offshore considers the effect of these parameters to produce a relationship between overpressure and exceedance frequency.

If the predicted explosion overpressure at a deck or wall exceeds the blast rating then escalation by explosion is assumed to occur. Safeti Offshore models subsequent fires on the basis of the deck or wall being destroyed completely by the explosion.

In the event of immediate ignition, until walls lose their integrity fires can only spread where there are openings (Figure 10). However, in the event of a delayed ignition giving an explosion strong enough to destroy the walls, fires can spread in other directions (Figure 11).

Figure 10. Escalation from Immediate Ignition

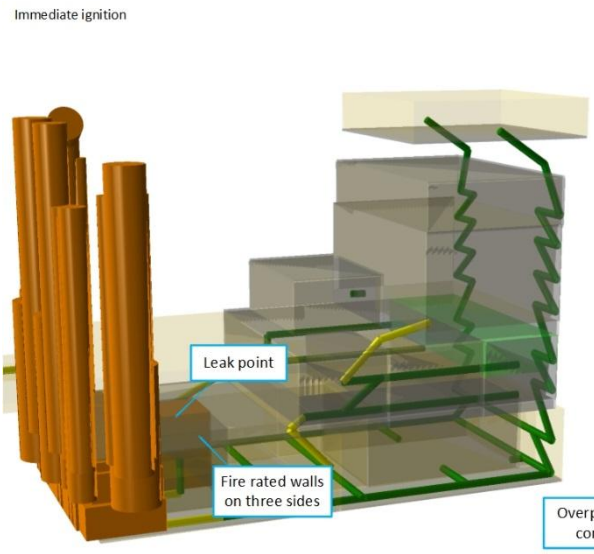
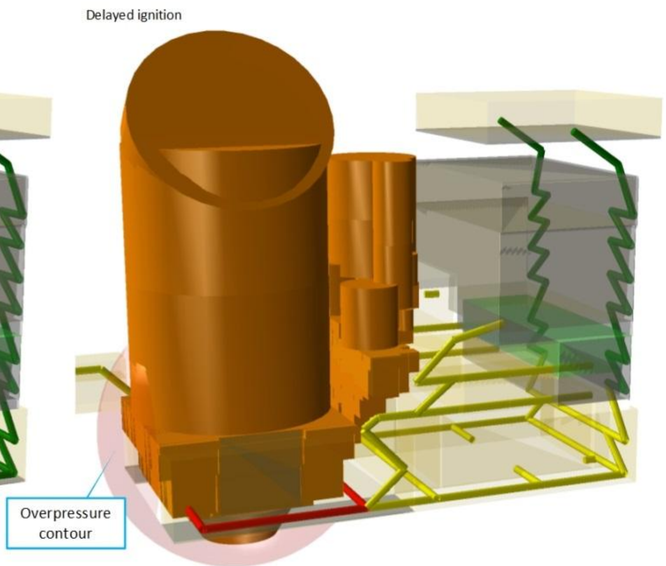


Figure 11. Escalation from Delayed Ignition



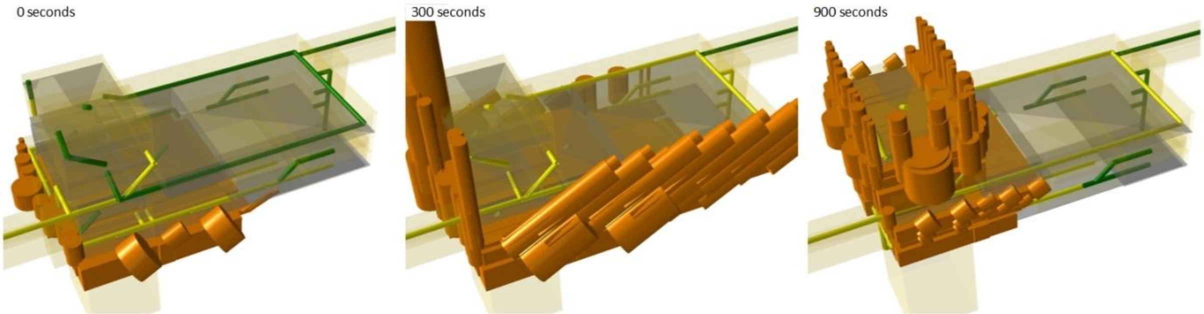
Muster Modelling

In traditional offshore QRAs it is common to assess the availability of escape routes and therefore the potential for personnel to be able to muster in the designated muster location (usually the temporary refuge). Where the assessment predicts personnel being unable to muster, escape from the platform would be modelled, with the potential for escape fatalities. This process is relatively simplistic and relies on a free-field fire model that is not usually tailored for offshore QRA. It also relies heavily on the judgement of the analyst.

Safeti Offshore assesses the impairment of escape routes based on the results from MODFIRE and impairment criteria defined by the analyst. At each time step the status (impaired or unimpaired) of an escape route is evaluated, and this governs the routes that personnel can travel along to reach the designated muster location. The movement of personnel from their location at the time of a hydrocarbon leak to their designated muster location is modelled. If at any time during the muster process the conditions along an escape route exceed the defined fatality criteria (radiation, smoke and overpressure) for the area, any personnel using the escape route are assumed to be fatally injured.

Figure 12 shows the development of a fire scenario and how it impacts escape routes. An escape route coloured green is one that is unimpaired, while an escape route coloured yellow is one that is impaired at that time. It can be seen that the impairment status of an escape route changes with time. Due to escalation of the scenario to other equipment, many more escape routes are impaired at 300 seconds compared with 0 seconds. At 900 seconds the fire is affecting a smaller proportion of the lowest deck compared with the fire at 300 seconds, resulting in fewer escape routes being impaired. This latter observation is due to decay in the release rate associated with the equipment which was escalated to at 300 seconds.

Figure 12. Impairment of Escape Routes



The method adopted by Safeti Offshore means that the judgement and experience of the analyst is less important, and will likely lead to more consistent results across multiple offshore QRAs.

Risk Modelling

While most of the effort in the analysis is related to the calculation of consequences, the ultimate aim is to calculate risks and for this the calculation of the frequency for the different scenarios is required. This is performed in two stages:

- Calculation of the leak frequency from the nominated release points.
- Event tree analysis

The first of these stages involves the use of generic hole size distributions for specific pieces of equipment being applied to the collection of process equipment associated with the release point for the release range being considered. This is a standard approach to establish the top event frequency for the event tree.

The event tree takes into account a large number of parameters which may have different states or values for a given occurrence of that loss of containment event. These include wind speed, wind direction, combinations of the success or otherwise of safety critical elements such as isolation valves. There may be so many branches in the event tree that it becomes impractical to show them in one diagram. To accommodate this, Safeti Offshore uses a dynamic display in which each end branch on a given level of the event tree hierarchy links to the top event of a sub-event tree as shown in Figure 13.

Ultimately, the end frequencies are multiplied by consequence results such as number of fatalities to produce the risk associated with that particular combination.

One of the main features of Safeti Offshore is the volume of detailed results it produces. This allows the analyst to examine the progression of the incident in detail (Bain et. al., 2014). Post processing of results can collate the contributions from all the events to provide a detailed risk picture showing the variation of parameters such as radiation, smoke concentration, impairment probability, and fatality rate at numerous locations on the installations. This allows greater insights into the factors affecting the risk levels and hence aid the decision making process for determining cost effective risk reduction measures.

Figure 13. Linking of Event Trees

Standardisation

In traditional offshore QRAs assessment of fatalities due to radiation in areas of the installation which are distant from the flames and where there is partial shielding would generally be performed by the analyst and based on their own judgement. The assessment of workers becoming trapped due to escape route impairment would also be based on the judgement of the analyst in traditional offshore QRAs. These are just two examples where the calculations are based on the judgement of the analyst, inevitably resulting in inconsistency across multiple offshore QRAs.

In Safeti Offshore there are three areas which offer improvement over traditional offshore QRAs:

- Fire modelling
- Escalation modelling
- Muster modelling

Each of these improvements performs calculations based on the 3D model that the analyst builds, meaning that the models are 'geometrically aware'. These advancements enable a greater degree of standardisation and consistency across multiple offshore QRAs and means that the variability of judgement and experience of individual analysts have a smaller impact.

Having a platform for producing offshore QRAs that are consistent with one another provides confidence for operators to use QRAs for making risk-based decisions, rather than them being just a box-ticking exercise for the Safety Case.

Outputs

The outputs from the analysis came in a number of different forms:

- Large amounts of data are output to a database which can then be accessed for further processing using database tools and spreadsheet applications. A feature of Safeti Offshore is that monitor points can be inserted into the model which record the time dependent variation of physical effects and impairment/fatality probabilities.
- Various graphs and tables are generated for inspection at key stages in the analysis. In particular these include leak frequency analysis results, time dependant release curves and overpressure exceedance curves.
- 3D displays depicting the consequences of an accident at various stages in its development and which allow the analyst to zoom, rotate and pan. This aspect of the results is the most novel and provides insights into the complexity of the analysis that was previously not practical. It stimulates discussions between the analyst and the stakeholders who have to make decisions based on the information the model is providing them with.

The graphical information was found to be particularly valuable when compiling written reports since it is easy to go back to the model and generate a 3D image to illustrate a point which is being made in the report. It is now possible to embed videos within report issued in portable document format (pdf) and this was done in a number of places within the final Rough Bravo QRA report.

Conclusions

Offshore QRA are used to a variety of degrees in the industry. Some operators produce QRAs just for the purposes of meeting a regulation; others take them further and use them for making risk-based decisions. In order for offshore QRAs to have the widest impact and to improve safety there needs to be standardisation and consistency in the results that the models produce. This paper has shown the improvements in the modelling and the standardisation that Safeti Offshore offers.

This paper describes a practical application of Safeti Offshore for an operating installation, how such a QRA model works and the highly visual results that can be produced to engage stakeholders.

A significant difference between a traditional QRA and a QRA using Safeti Offshore from CSL's point of view is in the final deliverable – that is, the QRA report. The Rough Bravo QRA report delivered by DNV GL is one that is highly visual and demonstrates how stakeholders can be engaged in understanding major accident hazards.

Another benefit that CSL had from the use of Safeti Offshore is in the presentation of the QRA towards the end of the project. This was taken as an opportunity to highlight the key features within Safeti Offshore, particularly the 3D model of the platform and the visualisation of fires and explosions. Feedback from CSL confirmed that Safeti Offshore added value and that it offered better opportunities to engage stakeholders.

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