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Use of QRA for decision support in the design of an offshore oil production installation.

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Abstract

QRA is today widely used as a tool for decision support in the offshore industry. Its use has gradually changed from a prescribed analysis for verification purposes to a tool being actively used in an integrated mode. The paper describes its use in the design of a modern offshore platform. The paper addresses work methodology, selection of tools and data, organisation of QRA with other activities. Specific examples are given. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: QRA; Decision support; Offshore platform

1. Introduction

Risk analyses have been used actively in the offshore industry in the North Sea for more than 20 years. In the initial years, QRA was used primarily as a verification activity, and it was also required by the Norwegian authorities [1]. The risk analyses were often carried out isolated from the main design process and the overall planning, while the implementation of the findings and results was not effective. Important effects were, however, to direct attention to safety critical elements such as escape routes, importance of safe shelter integrity (TR, i.e., Temporary Refuge). The impact of these guidelines on the design practices for offshore platforms in the Norwegian sector in this period is significant. The focus on the segregation between hazardous areas, escape

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routes and shelter areas has been particularly important. But in many cases the best solutions were identified late in the design process resulting in costly variations and, in many cases, compromises which could have been achieved much simpler if these issues had been identified earlier.

Since then experience in use, changes in legislation, and some very costly experiences have changed the use of QRA. Today it is a tool that is actively used throughout the planning and design period. It is used for decision support as well as to explore the safety implications of the choices being made. The QRA activities are closely integrated with the design processes and are in many respects considered as routine.

This paper describes the application of QRA on typical North Sea planning projects, outlines the scope of the analysis and the co-operation mode within the design and engineering team. The paper is based on recent projects to illustrate the use, contents and application of these services. Examples of concrete problems and their solutions are included.

2. Approach

Active use of QRA in the decision support in the planning and engineering phases of platform process poses several challenges to the risk analysts, the engineering team and the decision-makers.

Initially, effective *communication* between the risk analysts and the design team is essential. Both to ensure a proper understanding of the design problems so that these can be effectively addressed in the QRA, and then to assure that the QRA results are understood by the design team and decision-makers.

Another important communication aspect is that the risk analysis process is *synchronised* with the engineering activity. It needs to provide the right information at the right time. The level of detail in the design increases and the uncertainties are reduced as the design progresses. The risk analysis needs to reflect this in order to address the decisions as the design progresses. It is therefore necessary to aim for a living QRA, i.e. a risk model of the platform that is updated and refined in details as required. Assumptions being made at an early stage to compensate for missing information need to be followed up and eventually replaced by factual information when available.

Finally, the QRA results need to be ‘‘translated’’ into engineering terms. Risk is measured in terms outlined by the risk acceptance criteria (PLL, FAR, etc.) and required risk reduction will typically be specified as, e.g. reduction in potential loss of life (PLL). This is not valuable information for the engineering team. The requirements must be specified as, e.g. design loads for explosion barriers or location of critical equipment. The risk analysis needs to be sufficiently detailed to address the effects of engineering solutions, and that alternatives can be assessed. Therefore, the risk analysis needs to be closely integrated with detailed engineering studies to be able to provide more detailed information than can be extracted from, e.g. event trees.

In order to meet these challenges, the following basic approach was selected:

- The organisation of the risk analysis team was set up to ensure close and direct communication with the engineering team.

- The tools for the QRA were selected to allow for frequent updates and refinement of the risk model as required. This assures an updated risk picture as the design develops and it will also allow for sensitivity analysis to explore the effects of different design alternatives.
- The QRA process was defined in the following three main steps:
  1. To establish a conceptual QRA which provides basic design criteria for, e.g. blast barriers, fire walls. This version of the QRA had an integrated Emergency Preparedness Analysis (EPA) and formed the basis for sensitivity analyses, assessment of alternative solutions in the early phases of the detailed design and operational aspects with impact on design.
  2. The conceptual QRA was updated when the basic design features where frozen, i.e. approximately midway in the detailed design. This version was used to support a detailed decision at the final stages, but also to document and verify that the detailed solution complied with project goals and acceptance criteria.
  3. At the end of the detailed design the QRA was updated to reflect the final design. This version documents the final solution and will be transferred to the operational phase to provide risk based decision support to future decisions related to operational or modification issues.
- The QRA was closely integrated with other engineering studies for scenario based design in areas like detector layout, passive protective measures, location of HVAC intakes and exhaust pipes, etc.

In the following, more details and examples are given on the QRA, the engineering studies and the actual decision support.

3. QRA (Safety and Emergency Preparedness Analysis)

A detailed QRA (Safety and Emergency Preparedness Analysis) was carried out during the engineering and construction phase in accordance with authority requirements, company internal Guidelines for Risk and Emergency Preparedness Analyses and company Risk Acceptance Criteria. In this case, the risk modelling was carried out with OHRAT [2] which is an integrated software package for frequency and consequence analysis, impact analysis and risk summation with automatic data transfer between these part-analyses.

In utilising OHRAT, a comprehensive risk model of the installation was developed which is easy to update in the course of the project phases. All frequency, consequence and risk calculations were stored within the model and are thus traceable during the project phases. The OHRAT-model will also be handed over to the operations.

The detailed safety and emergency preparedness analysis forms input to the design accidental load specifications and general requirements to layout and other safety related aspects. It is important to focus on having a risk model that may be continuously updated during the project and thereby having an updated basis for decision support.

The safety and emergency preparedness analysis work are divided into the following sub-activities.

Safety analysis:

1. description of concept;
2. hazard identification;
3. frequency calculations;
4. consequence calculations;
5. risk calculations;
6. comparison of risk results with acceptance criteria;
7. establishment of Emergency Preparedness Analysis;
8. Conclusions.

The project applied the company Risk Acceptance Criteria during the engineering phase. These included criteria for:

- personnel risk;
- impairment of escape ways and evacuation means and safe haven;
- probability for escalation of accidents.

The integrated emergency preparedness analysis was carried out by use of Safety Information Database (SID) in order to store all information with respect to the emergency preparedness analysis at one location. The SID database was also used to store the assumptions and important design requirements. In this manner, it was easy to update the emergency preparedness analysis and the assumptions during the engineering and construction phases. SID is DNV proprietary software applied by the operator as it is a standard data base tool for this type of analysis.

Data that was necessary for the emergency preparedness analysis were easily retrieved from the OHRAT-model.

The emergency preparedness analysis included the following main tasks:

- Establishment of the Defined Situations of Hazards and Accidents (DSHAs) on results from the safety analysis and evaluations of other hazards which are not necessary, contribute to the risk picture but are important to take care of in the dimensioning of the emergency preparedness.
- Establishment of the Specified Emergency Preparedness Requirements for the Activity (SEPRAs) based on the defined (DSHAs).

Risk to personnel is measured against the Fatal Accident Rate-value (FAR), which is defined as:

$$\mathrm{FAR} = \frac{\mathrm{PLL} \times 10^8}{NT}.$$

where: PLL = potential loss of life per year; N = number of persons on the platform; T = exposure time per person per year.

FAR is defined as the expected number of fatalities during 100 million exposed hours (e.g. a group of 1000 persons working 2000 h per year during a period of 50 years). The FAR value for a platform describes the risk level an average person will be exposed to. In practice, the individual risk level will vary significantly, depending on the operations performed and work place location on the installation.

Fig. 1 presents the calculated personnel risk at each main step of the project.

Fig. 1 shows that the calculated personnel risk decreases as the project develops. Assessments of issues where the uncertainty is significant tend to be on the conservative

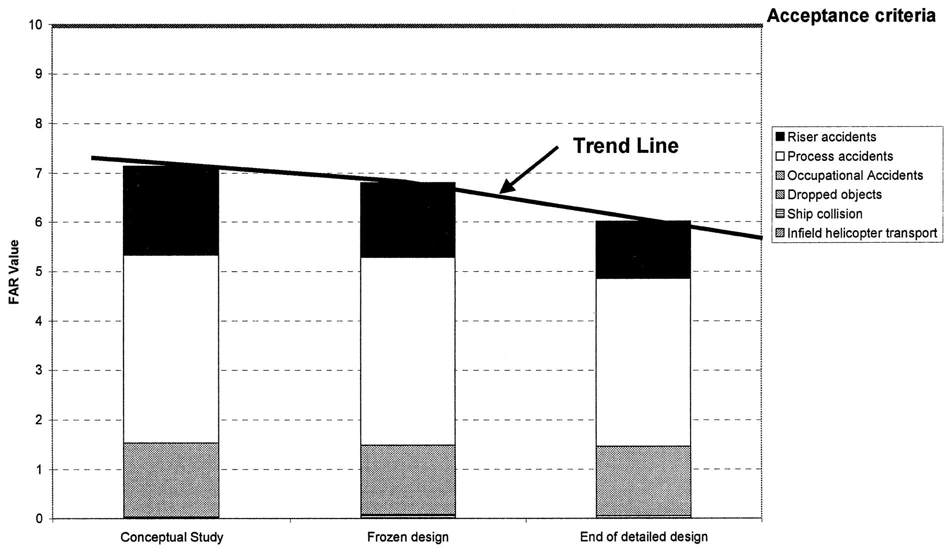

Fig. 1. Calculated personnel risk (FAR value) at each main step of the project.

side. The trend shown in Fig. 1 is therefore normal in such projects as the uncertainty in the evaluation basis decreases with increased degree of detailisation in the project.

4. Integrated engineering studies

As part of, and in parallel to the QRA work, several engineering studies were performed. An overview of engineering studies interacting with the QRA and the design process is presented in Fig. 2. The studies were based on the design scenarios from the QRA and the output from the studies provided input to the design process and in some areas improvement of the QRA.

4.1. Dispersion studies

In order to meet the objectives of this study, a numerical CFD model of the platform was developed capable of representing all major equipment in three dimensional mode. The numerical simulations was carried out using the Computational Fluid Dynamics (CFD) computer code PHOENICS from CHAM, UK [3]. This programme solves the Reynolds averaged Navier–Stokes equations, the continuity equation and the equations for heat and mass transfer with a first order turbulence closure ($k-\varepsilon$ model) in three-dimensional complex geometries. PHOENICS was the first commercial CFD-code on the market and a large number of publications verify its leading quality.

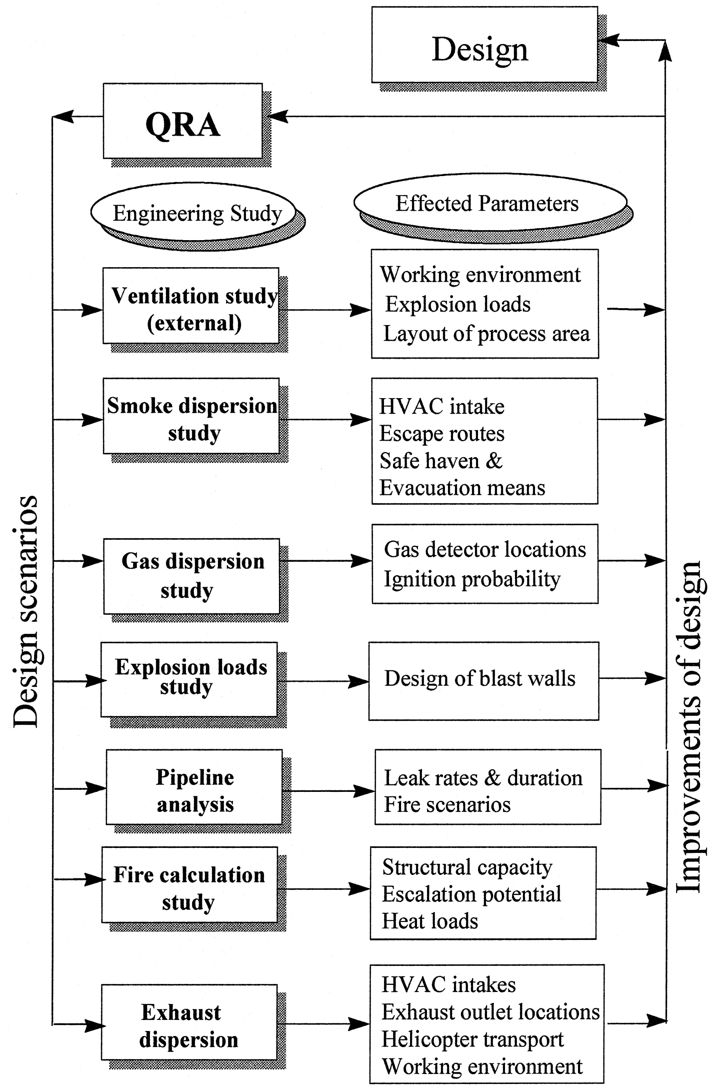

Fig. 2. Correlation between QRA and risk related engineering studies.

The gas-, smoke-, and exhaust dispersion cases were defined based on the dimensioning scenarios defined in the QRA. The studies included sensitivity studies for the following variables:

- leak locations
- leak rates
- wind speed/direction.

A total of 35 CFD simulations were performed and distributed as follows:

- 14 gas dispersion scenarios for process leaks;
- 8 gas dispersion scenarios for riser leaks;
- 9 smoke dispersion scenarios;
- 4 exhaust dispersion scenarios.

The gas dispersion results showed the size of gas clouds identified in QRA for varying wind conditions in order to find the probability of having ignition of gas clouds. The results were then used as input to the explosion simulations as well as for estimation of ignition probabilities. In addition, it was used as a basis for decision support for improved design. The gas dispersion results were also used when considering preferred location of the HVAC inlets and deciding the gas detector layout.

The results of the ventilation calculations were ventilation rates and wind chill index contours and were used as input to probability distribution of explosion loads and to locate zones with unacceptable working conditions. Suggestions to design improvements were then verified by new simulations.

The result from the exhaust dispersion study was used to verify the location of exhaust outlets in relation to HVAC intakes and helideck (temperature and combustion gases) and to provide information on the working environment on the platform. In the following two figures, examples of the dispersion output are given. Fig. 3 shows the dispersed exhaust gas from the turbines and compressors.

The smoke dispersion results were input to the QRA simulations to verify the integrity of escape routes, safe haven and evacuation means. The smoke plumes combined with the wind rise provided information on preferred locations of HVAC intakes from a safety point of view using a scenario based approach.

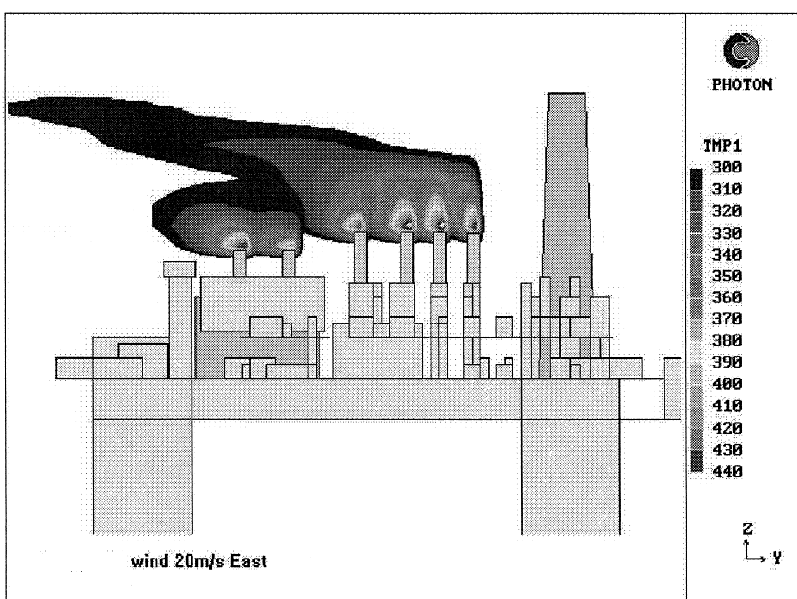

Fig. 3. Temperature at section through the gas turbine outlets.

Example: Fig. 4 shows the smoke generated from a rupture of a 9″ production riser. This simulation was performed as part of the conceptual study (Step 1) and showed that the lifeboat station would be exposed to critical values for smoke and radiation impact in case of large riser fires. For these cases safe evacuation was therefore not possible and as the frequency of such a fire was relatively high, the total impairment of the evacuation function was far above the criteria (see Fig. 5). As a result of these scenarios, it was decided to modify the layout and include a sheltered life boat station in order to secure safe evacuation. The impairment frequency was then bordering the acceptance criteria.

A large contributor to this impairment frequency was smoke ingress through the HVAC system. Changes in the HVAC system reduced the impairment frequency further. The effect of these changes are shown in Fig. 5.

4.2. Explosion study

The dimensioning scenarios given in the QRA together with output from the dispersion studies perform the basis for the Explosion overpressure calculations. These calculations were carried out by use of the FLACS code [5], following a probabilistic explosion analysis using the PROEXP code which is integrated within the OHRAT model.

Fig. 6 gives an example of the output of such a probabilistic explosion analysis.

The graphs show the likelihood of explosion pressures exceeding a given pressure (e.g. the design load for a barrier). Such probabilistic explosion analysis made the basis

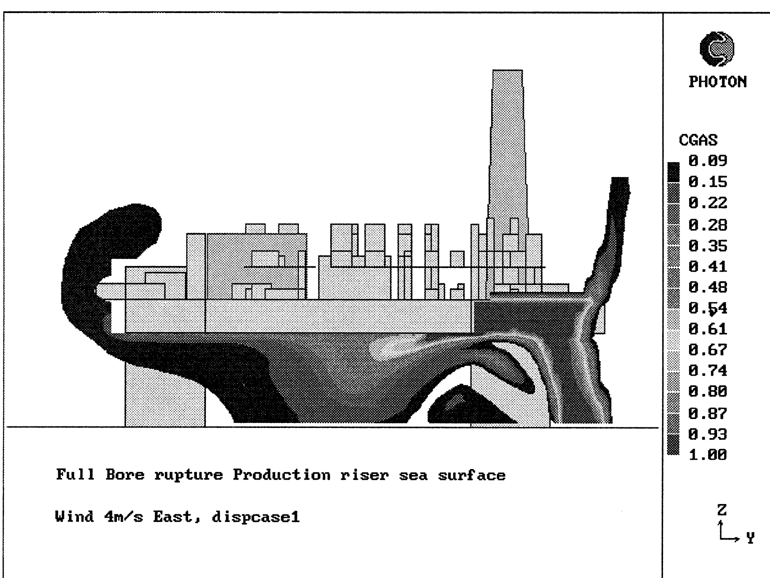

Fig. 4. Smoke plume from a fire following the rupture of a 9″ production riser, section through centre of fire.

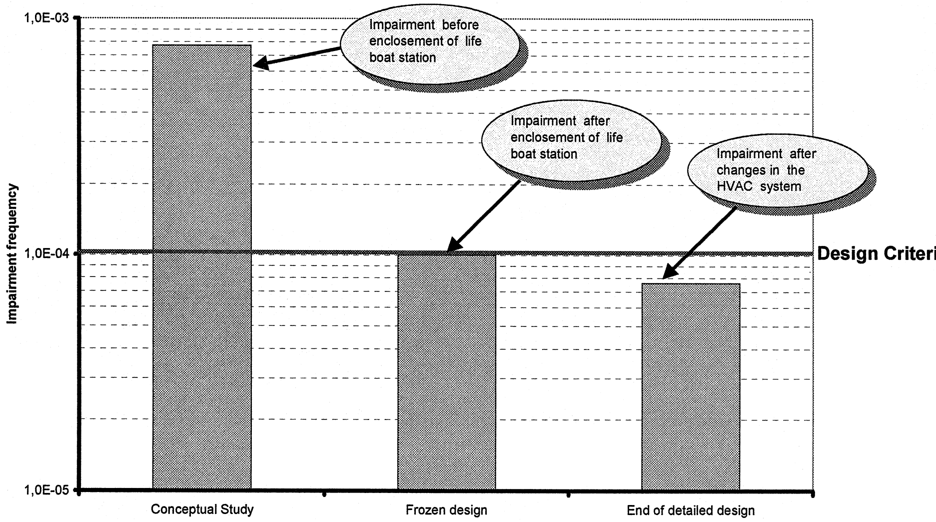

Fig. 5. Impairment frequency of evacuation means from riser accidents estimated at each main step of the project.

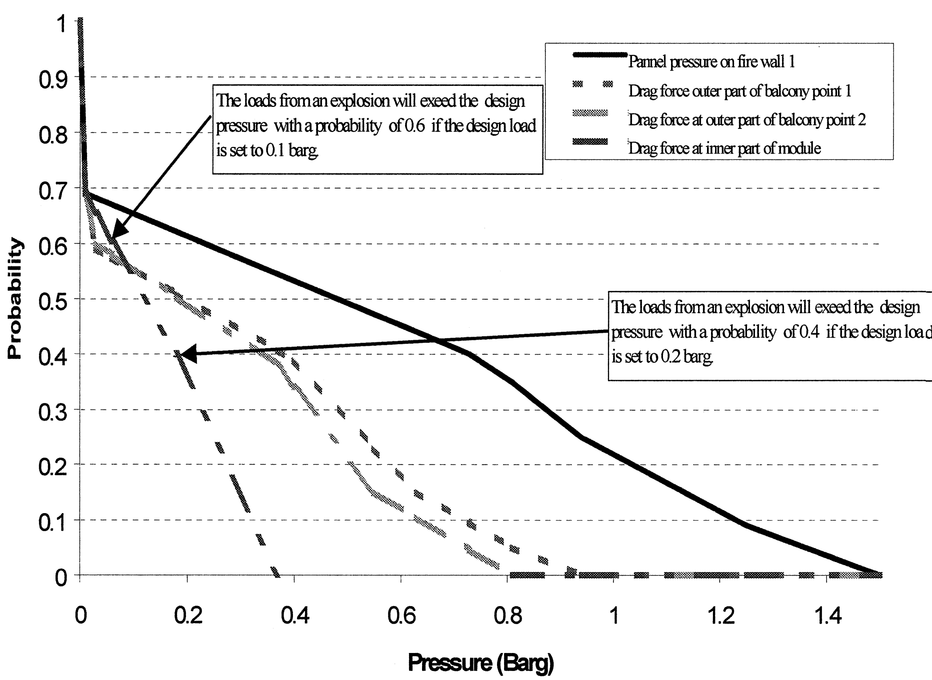

Fig. 6. Output from a probabilistic evaluation of explosion loads.

for design of the blast walls together with establishment of drag forces on critical equipment and structure. In most cases, it was concluded that it was not necessary to design for the maximum pressure to meet the acceptance criteria. In such cases, the design loads could be selected based on a cost optimisation of different alternative solutions for explosion protection.

The study pointed out the critical elements for securing a more optimal design with respect to explosion resistance and probability for escalation.

Example: The explosion pressure is very dependant on the layout and the equipment density of the areas. The equipment density of the process areas will normally increase with the development of the project as the layout of piping, electrical switch boards support systems, etc. become more and more detailed. Explosion loads based only on the current design at the different steps of the project will therefore show an increase of the loads during the different main steps.

Fig. 7 presents the calculated maximum explosion pressure levels for a part of the open process area and show that the explosion load increased from 0.54 to 1.8 bar g during the project. An increase was however expected and the design pressure was therefore at the conceptual stage set to a level higher than the calculated maximum explosion pressure.

Probabilistic evaluations showed that the probability for getting the maximum explosion load in this particular area was low and the effect of an increased explosion level was therefore limited.

Fig. 8 shows the annual frequency of escalation for the process area. In this case, escalation by fire was more probable than escalation by an explosion even though the maximum explosion level was far higher than the design pressure at the end of detailed design.

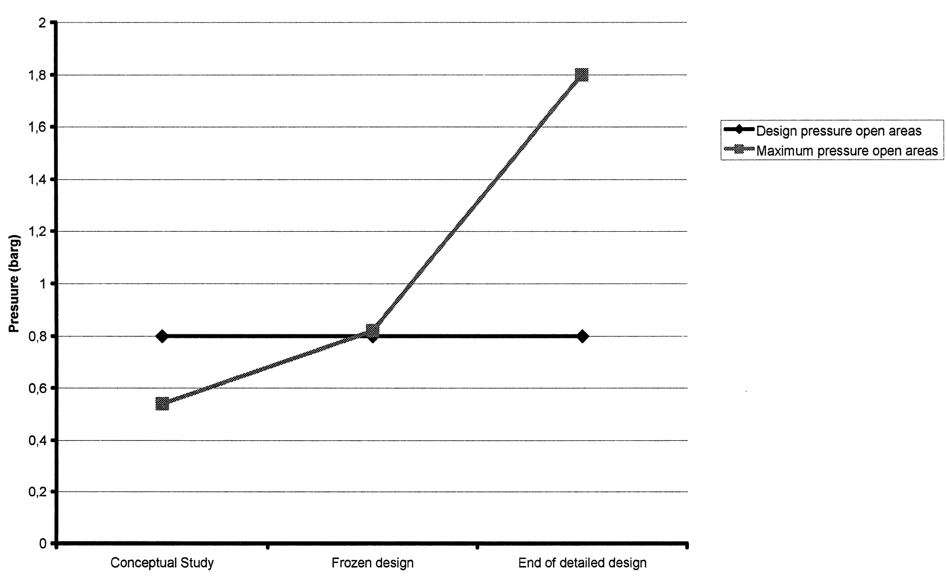

Fig. 7. Explosion pressure levels in open area.

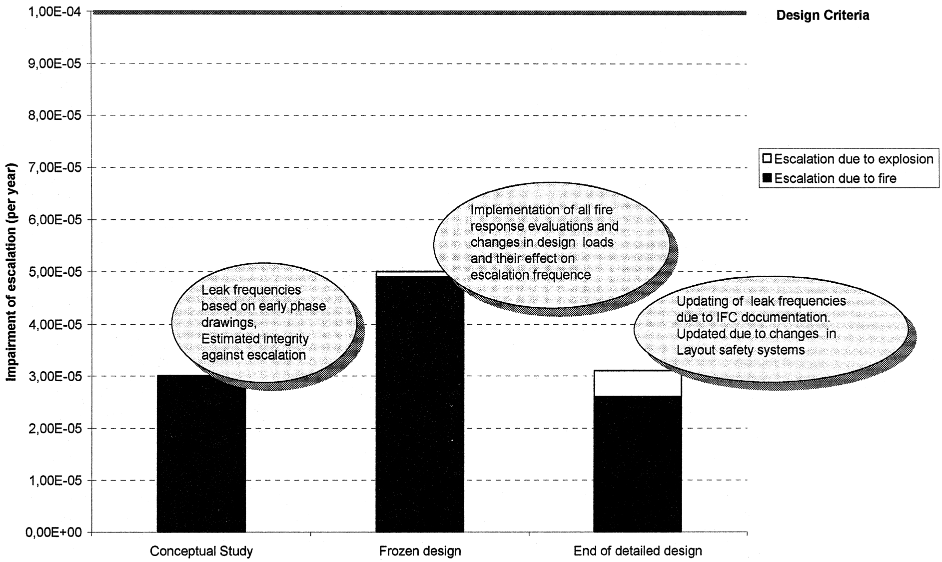

Fig. 8. Frequency of escalation to other areas due to process accidents.

4.3. Fire response calculations

As part of the engineering studies, a fire response study was performed based on the dimensioning fires generated in the QRA conceptual study. The scope of the study was to establish design criteria for several structural elements, in addition to verifying the integrity against the dimensioning fires. This gave an important input to the evaluation of potential for escalation during update of the QRA (Fig. 8).

The following main elements were investigated:

- fire integrity of process/safety equipment and pipelines;
- fire integrity of utility areas;
- fire integrity of process main deck
- design requirement for living quarter and mustering area;
- design criteria for anchor chains.

As an example, Fig. 9 shows a principle sketch of the model used for fire integrity of pipelines. The assessment was carried out with a computer model, VT_VESSEL. This programme determines the temperature rise and corresponding reduction in strength in process pressure vessels exposed to fire, and compares the strength capacity with the actual pressure, accounting for blowdown and potential pressure increase due to heat up. In this case, it was important to verify that the blowdown pipes would withstand a fire until the blowdown system was initiated and the pipes were cooled by escaping gas. Fig. 10 shows the temperature increase of the blowdown pipes as a function of time.

The need for fire protection for the different sizes of blowdown pipes was determined based on these calculations. Normally blowdown will be activated with typically 1-min

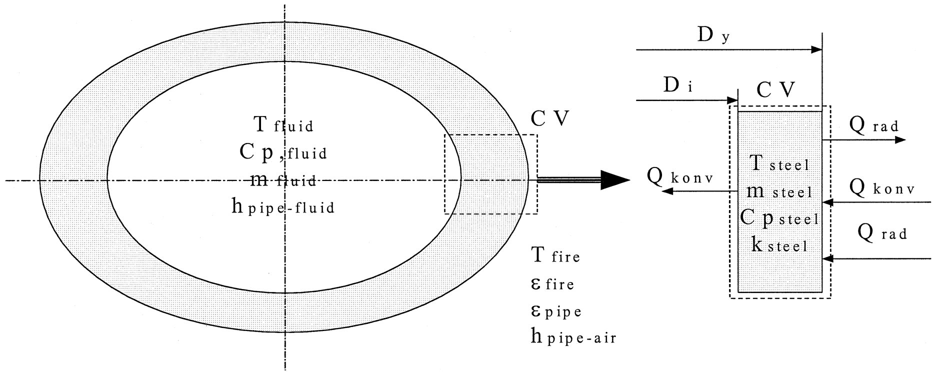

Fig. 9. Control volume used in the calculations.

delay after the start of the fire. The need for protection is therefore higher for the small size piping which lose strength more rapidly.

4.4. Pipeline study

The consequence modelling was generally made with a basis in standard OHRAT consequence models. When deemed appropriate, additional stand-alone models have been utilised to support the OHRAT models.

Example: In the very fist part of the project, releases from risers and pipelines was modelled with simple models. Sensitivity analyses showed, however, that the total risk

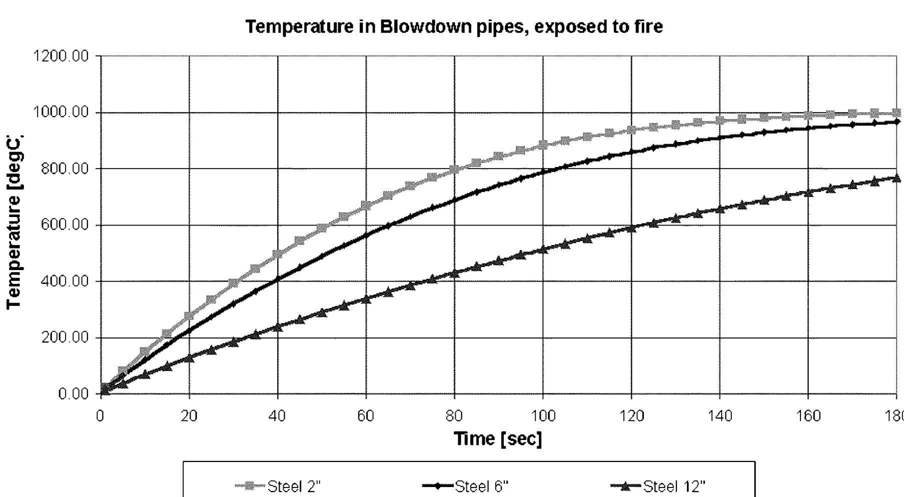

Fig. 10. Temperature variations for the various blowdown pipes.

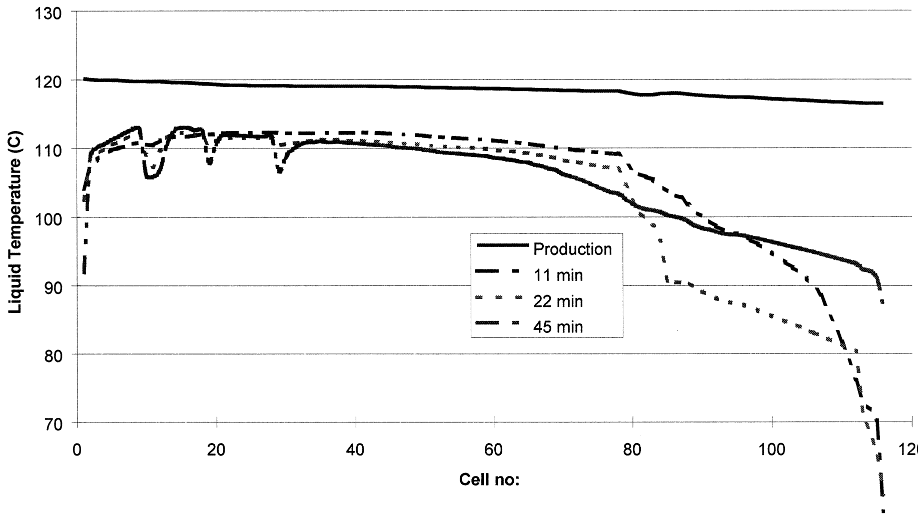

Fig. 11. Temperature profile in the pipeline full bore rupture.

picture at the platform including the design loads was very sensitive to small changes in these results. Releases from the liquid and two-phase risers/pipelines was therefore simulated by the use of the dynamic two-phase pipeline flow PLAC [4]. The results from these simulations was then incorporated in the OHRAT model.

The leak scenarios from the risers were analysed in detail for estimation of leak profiles (time dependent release rates) including effects of liquid flashing during depressurisation. Fig. 11 shows an example of a temperature profile for a two-phase riser.

The main results from the pipeline study were time dependent release rates. These were used for the following activities:

- Input to gas and smoke dispersion calculations.
- Establishment of requirement regarding maximum internal leak, reliability and response time for subsea isolation valves.
- Establishment of fire size and resulting fire loads of the main structure of the platform.

These detailed leak calculations represented a significant improvement compared to the simplified calculations normally performed as part of the QRA.

5. Decision support

The main objective for the QRA and the associated engineering studies was to provide decision support to achieve a cost effective and safe design. In practice this has been accomplished through:

- Reduction of the platform risk level, with cost effective measures.
- Establishment of design requirements for several systems.

Some examples of specific design changes, as a direct result of the QRA, are given below:

- Necessity of subsea isolation valves on production and export rises.
- Redesign of the mustering area.
- Establishment of reliability requirement and response times for safety systems.
- Necessity of nets to protect against ship collisions.
- A traditional flare could be used (instead of a cold vent) without a risk for ignition of released gas.
- Establishment of design criteria for J-tubes.

The main benefits from this approach have been to obtain cost optimisation of safety measures with the end result a safe platform design.

In addition to cost optimisation, it is realistic to assume that significant savings have been made by making the right decisions at the right time. A wealth of experience shows that risk assessments carried out too late (on existing or frozen design) result in excessive costs for modifications and changes, or reveals solutions where unsafe designs cannot be satisfactorily resolved or mitigated.

As we have stated before, the key issue is communication.

- It is essential to have direct and open lines between the risk analyst and the designers.
- It is essential that the timing and synchronisation is correct.
- Risk results must be translated to engineering terms.

We are of the opinion that these have been accomplished and resulted in significant improvements in the product.

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