Risk assessment in the offshore industry

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Abstract

This paper describes the implementation and use of risk assessment in the offshore industry in relation to safety aspects — safety to people’s life and health, as well as environment and property. Although risk assessments may be based on both qualitative and quantitative methods, the main focus here will be on quantitative risk assessments (QRA). The development of offshore QRA has been lead by a mutual influence and interaction between the regulatory authorities for the UK and Norwegian sectors of the North Sea as well as the oil companies operating here. The experience from this area has been the main basis during the writing of this paper. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The EC–JRC International Workshop on “Promotion of Technical Harmonisation on Risk-Based Decision Making” (Stresa/Ispra, May 2000) investigated the use of risk-based decision making across different industries and countries. This paper presents the contribution to the workshop covering risk assessment for the offshore industry. The format is in response to a set of questions prepared by the organisers of the workshop and summarised in the “Preface” of this special issue.

The attention of the risk management in the offshore industry is focussed on safety of the crew and the installation, prevention of environmental damage and production regularity. Unlike the onshore process industry, the potential for threatening third party is quite limited for most offshore installations.

This document will be limited to cover safety aspects — safety to people’s life and health, as well as environment and property. Although risk assessments may be based on both qualitative and quantitative methods, the main focus here will be on quantitative assessments.

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The development of offshore Quantitative Risk Assessment (QRA) has been lead by the mutual influence and interaction between the regulatory authorities for the UK and Norwegian waters as well as the oil companies operating here. Also, other countries have participated in this development, but to some extent this has often been based on the British and Norwegian initiatives.

2. Development, purpose and general principles of risk assessment use

2.1. History of offshore risk assessments

*Present the historical development and status of the use of risk assessment techniques in your specific technical area, with special emphasis on standardisation efforts.*

2.1.1. Development and use of risk assessments in the Norwegian sector

2.1.1.1. Concept safety evaluations. Early Norwegian offshore developments were based on international practice. The Ekofisk and Frigg fields both had separate accommodation platforms with bridges to link them to the wellhead and production platforms. Several accidents in the Norwegian Sector at this time, including a riser fire in 1975 and a blowout in 1977 on the Ekofisk field, demonstrated that more attention to safety was needed.

The Norwegian Petroleum Directorate (NPD) issued their ‘Regulations Concerning Safety Related to Production and Installation’ in 1976. These included the requirement that if the living quarters were to be located on a platform where drilling, production or processing was taking place, a risk evaluation should be carried out. At that stage, such an evaluation would have been mainly qualitative.

In 1976, after the Statfjord A platform had been designed and approved as an integrated production, drilling and quarters (PDQ) platform, following contemporary practice in the northern UK Sector, a broadly similar design was put forward for Statfjord B. The NPD rejected this design, and requested the living quarters be put on a separate platform. Eventually an integrated PDQ design was accepted, after much improved protection was provided for the living quarters. The cost of making these changes at such a late stage in the design demonstrated the need for consideration of safety aspects early in the design, before the layout is fixed.

As part of the approval procedure for a new production platform in the Norwegian Sector, the NPD require submission of a general development plan, containing a safety evaluation of the platform concept. The NPD issued their “Guidelines for Safety Evaluation of Platform Conceptual Design” in 1981 (Norwegian Petroleum Directorate, 1981). These were the world’s first formal requirement for offshore QRA.

The resulting studies became known as Concept Safety Evaluations (CSEs) and produced a major improvement in Norwegian platforms, without eliminating the PDQ design concept.

The CSEs focused on availability of safety functions — escape routes, shelter area, main support structure and safety related control functions. No design accidental
event should cause impairment of the safety functions. In principle, the design accidental events should be the most unfavourable situations possible relative to the safety functions. However, it was allowed to disregard the most improbable events, but the total probability of occurrence of each type (see Section 4.1.8) of excluded situations should not by best available estimate exceed $10^{-4}$ per year.

2.1.1.2. Total risk analyses. Once the value of the QRA had become apparent, Statoil and other Norwegian operators extended CSEs into more comprehensive Total Risk Analyses (TRAs). These differed from CSEs in the following respects:

- They were conducted during the engineering design phase, much later than CSEs. Consequently, they addressed more detailed safety systems rather than the broad concepts in a CSE.
- They were much more exhaustive, including HAZOPs, reliability analyses, occupational risks and detailed hydrocarbon event modelling.
- They estimated the risks of fatalities rather than safety function impairments. This allowed comparison with other safety targets.

TRAs remain among the largest and most comprehensive offshore risk assessments ever carried out, and formed the basis for offshore QRA throughout the 1980s.

2.1.1.3. Risk management. The original NPD guidelines set numerical criteria for acceptable safety levels, and expected operators to use QRA to demonstrate compliance. However, safety requires appropriate management attitudes. Therefore, the 1990 NPD regulations relating to implementation and use of risk analyses (Norwegian Petroleum Directorate, 1990), require the operator to manage safety systematically, using QRA as a tool, and defining their own safety targets and risk acceptance criteria. This might appear to be a relaxation of the regulations, but by making operators take greater responsibility for the safety of their own operations, they are expected to use QRA to greater effect.

QRA is no longer seen as an isolated activity, but as an integral part of an overall risk management strategy promote.

2.1.1.4. Mobile offshore units. The loss of the Alexander Kielland in 1980, followed by the loss of the Ocean Ranger in 1982, led to additional prescriptive technical requirements, as well as improved techniques of risk assessment for semi-submersibles. Both these rigs capsized in rough weather, and much of the loss of life was due to the difficulty of evacuation in such conditions.

A large and continuing number of losses of jack-up rigs, often while in transit under tow, led to the use of risk analysis for insurance purposes, but because few lives were lost in these accidents, this remained relatively low-profile work.

In 1993, the Norwegian Maritime Directorate (NMD) issued “Regulations Concerning Risk Analysis for Mobile Offshore Units”, (Norwegian Maritime Directorate, 1993). They require risk analyses at concept, design and construction stages for each mobile unit, but do not specify the precise form of the analysis, except that it is
to include lists of dimensioning accidental events/accidental loads as well as recommendations related to possible risk reducing measures. The regulations specify that the overall risk to people, the unit and the environment is to be reduced as far as practicable, but the owner may specify additional acceptance criteria as well.

A reliability/vulnerability analysis is also required for specified systems important to safety on the unit. Acceptability criteria for these specify that single faults should not cause critical incidents, vital systems should be redundant, and the degree of redundancy should be related to the degree of hazard.

2.1.2. Developments in the UK sector

2.1.2.1. Pre Piper Alpha. Many developments in QRA occurred in the onshore industries during the 1980s, particularly in the UK. Many UK operators used QRA methods as an integral part of the design process but, prior to the Piper Alpha accident, QRA tended to be applied to specific aspects of the design, rather than to overall risks. Consequently, it was mainly used as part of the detailed design when the scope for changes was limited. Examples include the prediction of the risks of ship–platform collision, and modelling of the risks in emergency evacuation. Several operators used the latter to assess and improve their arrangements for evacuation by lifeboat.

Other techniques were borrowed from the onshore petrochemical industry, including hazard and operability studies (HAZOPs), techniques for modelling the consequences of hydrocarbon releases, and reliability analyses of key safety systems. Many of these form the building blocks of modern QRAs.

2.1.2.2. Effects of Piper Alpha. The Piper Alpha accident in 1988 provided tragic confirmation that the major accidents that risk analyses can predict were indeed realistic, and that QRA could be useful in trying to reduce the risks.

QRA techniques were then applied to many UK Sector platforms, as operators attempted to discover the extent of their exposure to fire and explosion hazards. The Department of Energy requested operators to re-evaluate emergency isolation arrangements for risers and subsea pipelines, and this concentrated studies on riser hazards and the effect of installing sub-sea isolation valves. QRA was found to be an appropriate tool for evaluating the relevant hazards (fire and explosion, dropped objects, valve reliability, diving risks, etc).

As a result of this activity, significant reductions in risk were achieved on many platforms by moving or installing isolation valves on risers and sub-sea pipelines or, in extreme cases, by relocating accommodation. Because multi-national oil companies wished to apply similar safety evaluation to all their offshore operations, the effects were not confined to the UK Sector, and in the few years following the Piper Alpha accident, QRA was applied to platforms in areas as diverse as Australia, New Zealand, Malaysia, Brunei and Canada.

The Piper Alpha accident also raised the question of whether a suitable risk reduction measure would be needed to accommodate personnel on nearby semi-submersible accommodation platforms (flotels) rather than on PDQ platforms. This would have the advantage of separating personnel from fire and explosion hazards,
but the disadvantage of exposing them to hazards of flotel capsize. QRA was seen as an appropriate means to compare these hazards, and in 1988 the Department of Energy commissioned a study of various accommodation alternatives. In order to compare these different concepts, the study had to develop new risk analysis techniques. It concluded that an estimate of the risks of high-fatality accidents, despite the many necessary simplifications, provided a better basis for decision-making than the CSE approach using impairment frequencies.

The Cullen Report on the Piper Alpha accident (issued in 1990) recommended a major change to a more modern system of safety regulation in the UK Sector, symbolised by the transfer of responsibility to the Health and Safety Executive (HSE).

2.1.2.3. Safety cases. Under the UK safety case regulations (UK Health and Safety Executive, 1992), each operator in the UK Sector is required to prepare a Safety Case for each of its installations, fixed or mobile, to demonstrate that:

- the management system adequately covers all statutory requirements;
- there are proper arrangements for independent audit of the system;
- the risks of major accidents have been identified and assessed;
- measures to reduce risks to people to the lowest level reasonably practicable have been taken; and
- proper systems for emergency arrangements on evacuation, escape and rescue are in place.

QRA is one of the most important techniques used to identify major accident hazards and to show that the risks have been made as low as reasonably practicable (ALARP), and is explicitly required under the regulations. Several other countries have followed the new UK approach, greatly increasing the requirement for offshore QRA worldwide.

Before an installation is allowed to operate, the Safety Case must be formally accepted by the Health and Safety Executive (HSE).

2.2. Purpose of risk assessment

For which purposes are you performing risk assessment?

Risk assessments are required by Authorities in order to document the risk level to be within specified acceptance criteria. To some extent, this is believed to have been an important reason for doing risk assessments — initially. Later it has been taken into active use as support for decisions, regarding design, construction as well as operation of offshore installations.

The objectives of a QRA may include:

- Estimating risk levels and assessing their significance. This helps decide whether or not the risks need to be reduced.
- Identifying the main contributors to the risk. This helps understanding of the nature of the hazards and suggests possible targets for risk reduction measures.
Defining design accident scenarios. These can be used as a design basis for fire protection and emergency evacuation equipment, or for emergency planning and training.

Comparing design options. This gives input on risk issues for the selection of a concept design.

Evaluating risk reduction measures. QRA can be linked to a cost–benefit analysis, to help choose the most cost-effective ways of reducing the risk.

Demonstrating acceptability to regulators and the workforce. QRA can show whether the risks have been made ALARP.

Identifying safety-critical procedures and equipment. These are critical for minimising risks, and need close attention during operation.

Identifying accident precursors, which may be monitored during operation to provide warning of adverse trends in incidents.

Taken together, these possible uses of QRA provide a rational structure for monitoring risks and providing guidance for decision-making about safety issues.

2.3. Availability of supporting documents

Are there any specific requirements related to availability of supporting documents for your risk assessment studies?

For operation in UK waters, the Safety Case must be formally accepted by the Health and Safety Executive (HSE).

Section 9, “Documentation” of NPD’s Regulations relating to implementation and use of risk analyses (Norwegian Petroleum Directorate, 1990), states that:

The operator shall submit necessary documentation to the Norwegian Petroleum Directorate. The type and extent of documentation as well as the time for its submission shall be stipulated by the Norwegian Petroleum Directorate in consultation with the operator.

The above means that the respective authorities may require submission of any document necessary to support the risk assessment studies. NMD’s Regulations concerning risk analyses for mobile offshore units have similar requirements.

Hence, in principle, there is no specified limitation to what might be required by the regulatory authorities with regard to supporting documents for risk assessment studies.

2.4. Quality of risk assessment documentation

What is the nature and quality of risk assessment documentation? Do you follow any established standards/guidelines?

The documentation of offshore risk assessments is considered normally to be of good quality. It must be on a format and to a quality satisfying the needs of the
Authorities. If it shall be used actively in decision making it must provide sufficient confidence as well as a necessary basis for the decisions.

Generally, the technical aspects are better documented than aspects related to human factors. Often an improvement of the presentation of the results would be beneficial. During the development of the documentation it should be kept in mind that risk is just as important to others as it is to risk analysts.

The NORSOK Standard Z-013, Risk and emergency preparedness analysis (NORSOK, 1998), states that the following should be included in the documentation of a quantitative risk analysis:

- Statement of objectives, scope and limitations.
- Description of the object of the analysis, the phases and operations that the analysis is valid for, the categories of accidental events that are covered and the dimension of risk. The descriptions should preferably be accompanied by drawings or similar.
- Statement of the assumptions and premises on which the study is based.
- Description of the analytical approach used.
- Extensive presentation of results in relation to objectives, scope and limitations. The presentation shall include the main contributions to the risk levels.
- Presentation of the sensitivity in the results with respect to variations in input data and crucial premises.
- Description of dimensioning accidental events and dimensioning accidental loads.
- Presentation of conclusions from the study.
- Presentation of possible measures that may be used for reduction of risk.

The results shall be expressed in a way that makes them useful to all relevant target groups, including the work force. This may imply that different result presentations may be required for different groups.

2.5. Updating

*Is the risk assessment maintained as a “living” entity? If so, how often is it updated?*

Whenever major modifications are made, to the design and/or the operation of an installation, the risk analysis should be updated.

In UK waters, safety cases are required at the design stage of new fixed installations, when installations are involved in combined operations (e.g. a drilling rig working alongside a fixed platform), are significantly modified or are abandoned.

Section 15 of the Norwegian Petroleum Directorate’s Regulations relating to implementation and use of risk analyses in the petroleum activities gives the following requirement with regard to updating of risk analyses:

Risk analyses that have been carried out shall be updated to follow the progress of the activities in order to ensure continuity in the basis for decisions relating to the safety of the activities.
The conditions or criteria which will require updating of previous risk analyses during the operational phase, shall be defined.

To manage risks in complex facilities, software tools for risk assessment is a necessity. Neptune is such a tool that supports the offshore operators needs for genuine lifecycle, living QRAs.

Several key operators and consultants in the UK and the Norwegian offshore industry banded together in 1991 to develop a software environment specifically for risk assessment studies. The product of that collaboration was Offshore Hazard and Risk Analysis Toolkit (OHRAT). Neptune is a new and improved toolkit, developed based on the lessons learned with OHRAT.

2.6. Competence

How do you ensure the competence of your risk analysts?

In general, our risk analysts are engineers with education from a technical university. Younger engineers participate in projects in close co-operation with experienced analysts. We run several internal courses and participate on external courses and conferences. Further, we utilise DNV’s Intranet to share and distribute knowledge.

The following personnel competence requirements are given in the NORSOK Standard (NORSOK, 1998):

The analysis team for a quantitative (or an extensive qualitative) risk analysis shall have special competence in risk analysis methods and relevant consequence modelling, as well as relevant project and operational competence. The latter may include, when such activities are analysed, competence within fabrication and installation activities, relevant marine and manned underwater operations.

2.7. Consistency with state-of-the-art

How do you ensure consistency with state-of-the-art?

DNV Management Manual gives requirements for “Consultancy Services” including QRAs and other risk analyses to be performed according to approved DNV methods. These are described in Technical Risk Management Procedures (TRiM) published on the DNV Intranet and available to all DNV units worldwide.

A dedicated department is responsible for providing the necessary tools, methodology and support to DNV’s risk analysts, and co-ordinates DNV’s efforts on research and development in the area of technological risk management.

3. Terminology

The basic terminology used within the context of the EC-JRC project “Promotion of Technical Harmonization on Risk-Based Decision Making”, presented in the “Preface” paper of this special issue is quoted in Table 1.
3.1. Hazard

Could you use for your specific risk assessment purposes the above definition of hazard (Table 1)? If not, what is the definition you are currently using?

In offshore risk assessments, hazards will normally also include potential threat to assets and property.

For safety purposes, the definition of hazard in ISO/IEC Guide 51, Safety aspects-Guideline for their inclusion in standards (ISO/IEC, 1999), is more generally applicable. This guide defines hazard as “potential source of harm”, while harm is further defined as “physical injury or damage to the health of people, or damage to property or the environment”.

3.2. Risk

Could you use for your specific risk assessment purposes the above definition of risk (Table 1)? If not, what is the definition you are currently using?

A slightly different definition is normally applied, where risk is defined as a “combination of the probability of an event and its consequences” (ISO/TMB WG, 1999) or “expression of probability for and consequences of one or several accidental events” (NORSOK, 1998). Also, the definition in ISO/IEC Guide 51 may be applied. There, risk is defined as “combination of the probability of occurrence of harm and the severity of that harm”, where harm is defined as given in Section 3.1.
3.3. Risk assessment process

Could you use for your specific risk assessment purposes the above structuring of the risk assessment process (Table 1)? If not, what is the structure you are currently using?

In general, the described risk assessment process structure seems to cover all the main aspects and elements of a typical offshore QRA. However, the split into the different steps and their denomination does not fit completely with the risk assessment process as most commonly used by DNV for offshore applications.

Based on “The Third Working Draft of Risk Management Terminology” and ISO/IEC Guide 51, risk assessment is defined as “overall process of risk analysis and risk evaluation”. In this document risk analysis is defined as “systematic use of available information to identify hazards and to estimate the risk”, and risk evaluation is defined as “procedure based on the risk analysis to determine whether the tolerable risk has been achieved”.

Fig. 1 illustrates the “iterative process of risk assessment and risk reduction” as described in ISO/IEC Guide 51. This is considered to give a fairly good representation of the risk assessment process, applicable for both qualitative and quantitative assessments. Fig. 1 “Risk estimation” covers the steps II, III and IV-A in Table 1, and “Risk evaluation” covers step IV-B, while step V is covered by the decision box “Is tolerable risk achieved” and possible decisions regarding risk reduction.

![Fig. 1. Iterative process of risk assessment and risk reduction (ISO/IEC, 1999).](Image)
Fig. 2 shows the “risk estimation, analysis and evaluation” as described in the NORSOK standard for risk and emergency preparedness analysis (NORSOK, 1998). This description of a quantitative risk assessments (QRA) fits very well with a “typical” offshore QRA.

3.4. Risk standards and/or other guidelines

Are you following any particular risk standards and/or other guidelines? If yes, what is the origin of this standard, and what are your views on its adequacy and applicability to you situation?

With regard to terminology, the most important guideline is considered to be the ISO/IEC Guide 51, Safety aspects — Guideline for their inclusion in standards (ISO/IEC, 1999). This guide is used as reference in the ISO standard for Risk Management Terminology, presently under preparation (ISO/TMB WG, 1999) as well as the latest proposal for a new Regulation for Management in the Petroleum Activities in the Norwegian Sector of the North Sea (Norwegian Petroleum Directorate, 2000). The latter also refers to the NORSOK standard for risk and emergency preparedness analysis (NORSOK, 1998), which have slightly different definitions with somewhat more detailed explanations.

Fig. 2. Risk estimation, analysis and evaluation (NORSOK, 1998).
3.5. Differences in the terminologies

Can you identify differences in the terminologies in your applications versus those listed in Table 1? Please elaborate.

If the scope of the assessment is limited to aspects related to safety, health and environment, then the definition of HAZARD in Table 1 may be used. The definition in the ISO/IEC Guide 51, also taking aspects of loss of or damage to assets and properties into account, is more generally applicable.

The definition of RISK in Table 1 seems to imply that the unit for quantitative expression of risk will be probability [fraction in the interval (0,1)] or expected frequency. Expressing a total risk level for events with different outcomes, will in principle require separate numbers to be presented for each specific outcome and effect. Using a definition where both consequences and probability/frequency is taken into account, e.g. according to the ISO/IEC Guide 51 makes it possible to establish criteria for presentation of total risk levels. This is also considered beneficial with regard to the possibility for comparing estimated risk to possible defined risk acceptance criteria.

Planning of the analysis and a system definition should form an integral part of the risk assessment, in order to establish objectives and limitations for the analysis, assumptions on which it is based, and risk acceptance criteria. This also applies to the use of risk acceptance criteria to determine whether or not a tolerable risk level has been achieved. The definitions in ISO/IEC Guide 51 and the NORSOK Standard, as illustrated in Fig. 1 and Fig. 2, respectively, are considered to display this more clearly than the RISK ASSESSMENT process as described in Table 1.

4. Performance of risk assessment

(assume to use the basic assumptions on “hazard”, “risk” and “risk assessment” in Table 1 for your specific technical area and risk assessment application)

In the following, the focus will primarily be on quantitative risk assessments for offshore installations in the Norwegian sector of the North Sea.

4.1. Step I: hazard identification

Identification of sources with the potential to cause undesired outcomes to subjects of concern that is the focus of the estimation of likelihood.

4.1.1. Overall approach

Please describe briefly the overall approach used in this step for your applications.

Hazard identification is often referred to as the most important step in QRA. This is simply due to the fact that what has not been identified, will not be evaluated, and hence cannot be mitigated.

The hazard identification process relies heavily on knowledge retention, i.e. being able to store and retrieve the information and knowledge generated in previous
work, learnt through experienced accidents and near misses, but also include the ability to predict yet not encountered hazards and combinations of hazards.

The process includes identifying and classifying credible and incredible hazards, by cause, location, method of assessment, consequence, impact or any other grouping. The objective is to specify failure cases, or starting conditions for events to be modelled with respect to their frequency (or probability), consequence and impact.

Fig. 3 illustrates the hazard identification process. Techniques applied for hazard identification comprise:

1. **Hazard review** – a mainly intuitive, qualitative review of the installation to identify the hazards that are present.
2. **Hazard checklist** – a review of the installation against a list of hazards that have been identified in previous hazard assessments.
3. **Hazard and operability study (HAZOP)** – a systematic review of the process plant design, to evaluate the effects of deviations from normal operating conditions.
4. **Procedural HAZOP** – a version of HAZOP applied to safety-critical operations such as drilling, rig-moves, heavy lifts etc.
5. **What-If Analysis** – a flexible review technique, which can be applied to any installation, operation or process, to identify hazards.
6. **SWIFT** – The Structured What-If Checklist technique combines the relatively unstructured What-If technique with the more organised and thorough aspects of the HAZOP technique.
7. **HAZID** – a systematic review of the possible causes and consequences of hazardous events.
8. **Failure modes, effects and criticality analysis (FMECA)** – a systematic review of a mechanical system, to evaluate the effects of failures of individual components.
9. **Emergency Systems Survivability Analysis** – a systematic review of the ability of emergency systems to withstand accident conditions.
10. **Safety inspections and audits** – visual examinations of an existing installation and its operating procedures to identify potential safety hazards.

**INPUT**
- Databases
- Previous analyses
- Experience
- Site visits
- Production systems
- Safety systems
- Assumptions

**PROCESS**
- HAZARD IDENTIFICATION
  - Techniques:
    - HAZOP
    - FMECA
    - Checklists
    - Etc.

**OUTPUT**
- Accidents for further modelling

Fig. 3. Hazard identification process.
4.1.2. Considered sources

Which sources with the potential to cause undesired outcomes are you considering?

Typical sources considered in an offshore QRA are:

- releases of hydrocarbons or other inflammable and/or toxic substances;
- well control problems;
- ship traffic;
- crane operations/lifting;
- extreme environmental conditions;
- structural failures including loss of water-tightness; and
- position keeping failure.

4.1.3. “Potential”

How do you define “potential” in the present context?

Under certain circumstances, sources with the potential to cause undesired outcomes will cause such undesired outcomes. The probability of the undesired outcome to occur given presence of the source may range from extremely unlikely (close to zero) to extremely likely (close to 1).

4.1.4. Considered undesired outcomes

Which undesired outcomes are you considering?

In principle, all outcomes causing or having potential to cause, harm or damage to safety, health, environment and/or economical assets relevant in relation to the risk acceptance criteria should be considered.

The following table provides a checklist of possible failure cases that may be relevant in an offshore QRA.

<table>
<thead>
<tr>
<th>Blowouts</th>
<th>Process leaks — leaks of gas and/or oil from:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blowout in drilling</td>
<td>• Wellhead equipment</td>
</tr>
<tr>
<td>Blowout in completion</td>
<td>• Separators and other process equipment</td>
</tr>
<tr>
<td>Blowout in production (including wirelining, etc)</td>
<td>• Compressors and other gas treatment equipment</td>
</tr>
<tr>
<td>Blowout during workover</td>
<td>• Process pipes, flanges, valves, pumps, etc</td>
</tr>
<tr>
<td>Blowout during abandonment</td>
<td>• Topsides flowlines</td>
</tr>
<tr>
<td>Underground blowout</td>
<td>• Pig launchers/receivers</td>
</tr>
<tr>
<td>Also covered under blowouts are:</td>
<td>• Flare/vent system</td>
</tr>
<tr>
<td>• Well control incidents (less severe than blowouts)</td>
<td>• Storage tanks</td>
</tr>
</tbody>
</table>
• Fires in drilling system (e.g. mud pits, shale shaker, etc)  
• Loading/unloading system  
• Turret swivel system

Riser/pipeline leaks — leaks of gas and/or oil from:
• Import flow-lines
• Export risers
• Sub-sea pipelines
• Sub-sea wellhead manifolds

Marine events
• Anchor loss/dragging (including winch failure)
• Capsize (due to ballast error or extreme weather)
• Incorrect weight distribution (due to ballast or cargo shift)
• Icing
• Collision in transit
• Grounding in transit
• Lost tow in transit

Non-process fires
• Fuel gas fires
• Electrical fires
• Accommodation fires
• Methanol/diesel/aviation fuel fires
• Generator/turbine fires
• Heating system fires
• Machinery fires
• Workshop fires

Non-process spills
• Chemical spills
• Methanol/diesel/aviation fuel spills
• Bottled gas leaks
• Radioactive material releases
• Accidental explosive detonation

Dropped objects — objects dropped during:
• Construction
• Crane operations
• Cargo transfer
• Drilling
• Rigging-up derricks

Marine collisions — impacts from:
• Supply vessels
• Stand-by vessels
• Other support vessels (diving vessels, barges, etc)
• Passing merchant vessels
• Fishing vessels
• Naval vessels (including submarines)
• Flotel
• Drilling rig
• Drilling support vessel (jack-up or barge)
• Offshore loading tankers

Transport accidents — involving crew-change or in-field transfers
• Helicopter crash into sea/ platform/ashore
• Fire during helicopter refuelling
• Aircraft crash on platform (including military)
• Capsize of crew boats during transfer
• Personal accident during transfer to boat
• Crash of fixed-wing aircraft during staged transfer offshore
• Road traffic accident during mobilisation
Drifting offshore vessels (semi-sub, barges, storage vessels)  
Icebergs  
(For each vessel category, different speeds of events, such as powered and drifting may be separated.)

**Personal (or occupational) accidents**

**Construction accidents** — accidents occurring during:  
- Construction onshore  
- Marine installation  
- Construction offshore  
- Hook-up and commissioning  
- Pipe laying

**Structural events**  
- Structural failure due to fatigue, design error, scour, subsidence, etc  
- Extreme weather  
- Earthquakes  
- Foundation failure (including punch-through)  
- Bridge collapse  
- Derrick collapse  
- Crane collapse  
- Mast collapse  
- Disintegration of rotating equipment

**Attendant vessel accidents**

**Diving accidents**

4.1.5. **Issues of concern**  
What are the issues of concern?  
The major issues of concern in an offshore QRA are events that may cause fatalities or injuries to personnel, impairment of defined safety functions, damage to the environment or damage to the installation. In addition, events with potential to cause disruption of production may be included.

4.1.6. **Identification of relevant hazards**  
In which way do you include likelihood considerations in identifying potentially relevant hazards?  
During the process of hazard identification, a wide range of hazards may be suggested. Many of these may be rejected and not subject to further assessment. The three most important reasons for rejection of a hazard are:

- That the hazard concerns derives from installations/equipment not covered by the study or that the hazard threatens only personnel categories not covered by the study (e.g. accidents during installation and abandonment, hazards involving only supply/standby boat crew, hazards involving only helicopter pilots, fixed wing transport and other means of transport to heliport or port).
The exact boundary for which hazards to include is therefore highly dependent on the study scope.

- That the likely consequences of a hazard are found to be negligible or too small to be covered by the study (e.g. collisions with fishing vessels).
- That the likelihood of occurrence of a hazard is found to be too remote (e.g. earthquakes, in an area normally considered safe of earthquakes).

It is important that the reasons for rejection are recorded and documented. Whether the exclusion of a hazard from further assessment is due to negligible consequences or negligible probability, the decision should preferably be supported by experience and/or statistics. At this stage in the risk assessment process, conclusions should be based on conservative assumptions and evaluations.

4.1.7. Completeness

How do you assure completeness of your results in this step of risk assessment?

For “standard” offshore installations, the use of comprehensive checklists and accident databases ensures retention of previous experience. For novel concepts, the use of checklists and databases combined with other techniques as listed in Section 4.1.1, as well as close co-operation with designers and operational staff is considered the best possible approach to prevent relevant hazards to be overseen.

4.1.8. Regulatory authorities

How, if at all, are regulatory authorities involved in this step of risk assessment?

In NPD’s guidelines for safety evaluation of platform conceptual design (Norwegian Petroleum Directorate, 1981) it was required that the following types of events should at least be included to the extent relevant for the installation which was analysed:

- blow-out;
- fire;
- explosion and similar incidents;
- falling objects;
- ship and helicopter collisions;
- earthquakes;
- other possible relevant types of accidents;
- extreme weather conditions; and
- relevant combinations of these accidents.

In 1990, the guidelines were replaced by Regulations relating to implementation and use of risk analyses in the petroleum activities (Norwegian Petroleum Directorate, 1990). These regulations do not include the above or any similar listing of hazards. However, there is no reason to believe that any of the listed hazards should
be left out. In the forthcoming NPD regulations reference will be made to the NORSOK standard for risk and emergency preparedness analysis (NORSOK, 1998), which includes a somewhat more detailed list.

4.1.9. Standards/guidelines

Which underlying standards/guidelines are you using in this step of risk assessment?

In DNV, the hazard identification is done in accordance with internal procedures and guidelines. These cover the requirements of both The Norwegian Standard — Requirements for risk analyses (Norwegian Standards Association, 1991) and the NORSOK standard for risk and emergency preparedness analysis (NORSOK, 1998) as well as regulatory requirements.

In addition, DNV’s clients may have company specific requirements or standards.

4.1.10. Standardisation

How much standardisation is currently available for this step of risk assessment?

Based on experience gained through more than 20 years with quantitative risk assessments in the offshore industry, some tradition have been established and quite comprehensive hazard checklists have been developed. It is, however, important to emphasise that no limited list of hazards can be exhaustive. In DNV, internal procedures and guidelines, as well as requirements specified by the client are the basis for the hazard identification.

4.1.11. Quality assurance

Do you have specific Quality Assurance (QA) procedures that you follow? If yes, what recommendations can you make in regards to QA requirements and standardisation?

Compliance with internal procedures is assured by self-check by the risk analyst and verified internally by a dedicated senior risk analyst, before approval by DNV’s project manager/project responsible. It is required that the internal verifier shall be involved throughout the whole project, and identification and selection of hazards and failure cases for further assessment as well as selection of methodology are considered some of the most important issues with regard to verification.

An offshore QRA will normally be subject to review by several stakeholders (including field operator/oil company, yard/contractor, designers/engineering company, regulatory authorities, etc.) and possibly also independent third party verification.

4.1.12. Uncertainties

How do you address and/or quantify the impact of uncertainties in this step?

At this stage no thorough evaluation of uncertainty is normally included. Unless a coarse conservative evaluation clearly indicates a negligible risk contribution from an identified hazard, further analysis of probability and consequences should be performed.
4.1.13. “Qualitative” or “quantitative”?

Is the overall approach to this step “qualitative” or “quantitative”? How do you relate this to actuarial data, including generic and process/system specific aspects?

In general, the hazard identification is qualitative. However, a coarse quantification may be done during selection of failure cases for further assessment.


How do you utilise and view “subjective expert judgement”? How crucial is the use of expert judgement in this step of the analysis?

During the initial phase of the hazard identification, it is important to identify all possible hazards. This may take form as a brain storming, and here “subjective expert judgement” may represent an extremely valuable contribution. Also, techniques as HAZOP, SWIFT and FMECA require participation of experts. At this stage of the risk assessment process “subjectivity” will have no negative impact on the quality of the final results, provided that the subjective judgement is conservative.

4.2. Step II: event scenario assessment

Identification of the initiators and sequences of events that can lead to the realisation of the hazard.

4.2.1. Overall approach

Please describe briefly the overall approach used in this step for your applications.

Definition of accident scenarios is closely linked to the consequence modelling. This is particularly true for hydrocarbon events, and especially where escalation may occur. The selection of accident scenarios to model is always a compromise between representing the variety of possible accidents on the installation, and not spending a disproportionate amount of time analysing different scenarios with insignificant differences with regard to the overall risks. The “right” number has been achieved when further splitting of the scenarios has no significant effect on the risk.

In some very simple QRAs a failure case such as, for example, “small gas leak in separation module” may be represented by a single scenario with the most likely, or alternatively the most conservative, cases of ESD (Emergency Shut Down), blow-down/depressurisation, ignition, fire type, orientation, etc. This approach is unlikely to be adequate for a full QRA.

Many QRAs combine accident scenarios, so as to obtain a single average consequence for each failure case. For example, if a failure case under certain circumstances, estimated to occur 10% of the time, gave 10 fatalities whereas it otherwise gave none, the result would be recorded as one fatality. This approach is commonly used in evacuation modelling, where fatality rates are used that are averages over all sea states. This approach is desirable because it reduces the number of scenarios to consider. However, it conceals the true causes of the risks, and may give misleading results on the fN curve, although the total number of fatalities would be correct.

A systematic approach to accident scenario generation involves defining the parameters that may influence the risk, and considering each combination of
each parameter in turn. The combinations are normally defined using event trees. The advantages of this are that it is systematic and hence easy to understand and likely to be comprehensive. The disadvantages are that it tends to generate large event trees with many scenarios needing to be modelled. Knowing which branches can be neglected and which will turn out to be important requires considerable experience from the analyst.

The parameters to take into account during analysis of hydrocarbon releases from the topside process system on an offshore installation comprise:

- leak frequency;
- leak type/material (e.g. gas/oil/wellfluid);
- leak location;
- leak rate/size;
- duration of leak/volume;
- reliability of shutdown system, effect of shutdown system on leak volume;
- effect of blowdown system;
- probability of ignition, time of ignition;
- probability of explosion in the event of ignition, effect of explosion;
- effect of fire-fighting systems, reduced heat loads;
- impact of initial accident;
- further escalation of the accident; and
- wind patterns.

Typically, separate event trees are established for each leak rate, location, and released material. For example, on an offshore installation with two wellhead

Fig. 4. General process layout for an offshore installation, example.
modules (C12 and C22) and three process modules (C13, C23 and C33) as shown in Fig. 4, hydrocarbon releases were modelled by 27 event trees as listed in Table 2. Allowing for all possible combinations of parameters, this leaves several thousand possible scenarios to be modelled. If escalation is possible, many further scenarios might be considered. There are also numerous possible ways in which an event tree might be constructed to present these alternatives.

It is not feasible to model so many and, in practice, the analyst simplifies the event tree using judgement to discard branches that are not expected to affect the results significantly. In a typical full QRA of an offshore process system, the total number of accident scenarios may be several hundreds. This number may be too great to model in detail or to document in full unless an advanced computer-based technique is used. Grouping or categorising of scenarios, in order to limit the number of scenarios to consider, is common.

<table>
<thead>
<tr>
<th>Area</th>
<th>Fluid</th>
<th>Leakage category</th>
<th>Event tree code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wellhead, Level 1</td>
<td>Wellfluid</td>
<td>Small</td>
<td>SWW1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>MWW1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>LWW1</td>
</tr>
<tr>
<td>Wellhead, Level 2</td>
<td>Gas</td>
<td>Small</td>
<td>SGW1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>MGW1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>LGW1</td>
</tr>
<tr>
<td></td>
<td>Wellfluid</td>
<td>Small</td>
<td>SWW2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>MWW2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>LWW2</td>
</tr>
<tr>
<td>Process, Level 1</td>
<td>Gas</td>
<td>Small</td>
<td>SGP1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>MGP1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>LGP1</td>
</tr>
<tr>
<td></td>
<td>Oil</td>
<td>Small</td>
<td>SOP1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>MOP1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>LOP1</td>
</tr>
<tr>
<td>Process, Level 2</td>
<td>Gas</td>
<td>Small</td>
<td>SGP2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>MGP2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>LGP2</td>
</tr>
<tr>
<td></td>
<td>Oil</td>
<td>Small</td>
<td>SOP2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>MOP2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>LOP2</td>
</tr>
<tr>
<td>Process, Level 3</td>
<td>Gas</td>
<td>Small</td>
<td>SGP3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>MGP3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
<td>LGP3</td>
</tr>
<tr>
<td></td>
<td>Oil</td>
<td>Small</td>
<td>SOP3</td>
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<td></td>
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<td>Medium</td>
<td>MOP3</td>
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<td></td>
<td></td>
<td>Large</td>
<td>LOP3</td>
</tr>
</tbody>
</table>
For the example above, an event tree as shown in Fig. 5 was developed. This tree was applied for all process releases of hydrocarbons (blowouts and riser accidents were modelled separately), even though some branches were considered irrelevant for several failure cases. When scenarios (i.e. end events) considered to have no probability to occur were excluded, the number of scenarios was of the order of 300. Based on a grouping of scenarios with similar outcomes, the number of finally considered scenarios was approximately 150.

Quite similar processes are run for assessment of scenarios related to blowouts and riser and pipeline accidents as the process described for hydrocarbon releases from the process system described above.

Also, for accidental events like ship collisions, helicopter crashes, dropped loads/objects and other fires (i.e. non-process related), possible accident scenarios must be considered. To the extent relevant it may also be necessary to consider scenarios related to accidents related to electrical power (e.g. battery explosion), fragments from turbines/rotary equipment, water penetration in dry shafts, loss of buoyancy, excess weight, displaced ballast, earthquake, structural failure and extreme weather.

4.2.2. Identification of the sequences of events (scenarios)

How do you identify the sequences of events (scenarios) that describe or predict the course of events that may lead to an undesired outcome or subsequent effect?

As described earlier, the scenario development is normally predicted by use of the even tree technique, based on identified hazards and parameters that are expected to influence the outcome and hence the total risk.

4.2.3. Domain and boundaries

By which criteria do you define the domain and its boundaries into which the undesired outcomes enter?

With regard to personnel safety, the domain for an offshore QRA is normally defined to include the installation and the immediate vicinity, e.g. related activities within a safety zone of a few hundreds of metres off the installation.
For environmental damage, the domain may extend much further, may be to coastal areas several hundreds of kilometres away.

4.2.4. Completeness

**How do you assure completeness of your results in this step of risk assessment?**

DNV have quite detailed internal guidelines for assessment of accident development. These are considered to cover the aspects relevant to event scenario assessment in the NORSOK standard (NORSOK, 1998, section 5.3.7 and Annex B). Application of these is believed to give a reasonable completeness of the event scenario assessment.

4.2.5. Regulatory authorities

**How, if at all, are regulatory authorities involved in this step of risk assessment?**

There is no direct involvement by regulatory authorities in the event scenario assessment. It is, however, important to assess the scenarios to a level of detail sufficient to estimate risk on a format comparable to the risk acceptance criteria. When the new Regulation for Management in the Petroleum Activities in the Norwegian Sector of the North Sea enter into force (Norwegian Petroleum Directorate, 2000) compliance with the NORSOK standard will probably be required (see Section 4.2.6).

4.2.6. Standards/guidelines

**Which underlying standards/guidelines are you using in this step of risk assessment?**

Section 5.3.7 and Annex B of the NORSOK standard for risk and emergency preparedness analysis (NORSOK, 1998) have several requirements relevant for event scenario assessment.

In DNV, the event scenario assessment is done in accordance with internal procedures and guidelines, which cover the requirements in the NORSOK standard. In addition, DNV’s clients may have company specific requirements or standards

4.2.7. Standardisation

**How much standardisation is currently available for this step of risk assessment?**

The use of event trees in the assessment of accident development has to a large extent become the standard methodology for assessment of complex scenarios in offshore QRA. To some extent simulation tools and probabilistic analysis is applied, but often combined with event trees.

4.2.8. QA

**Do you have specific Quality Assurance (QA) procedures that you follow? If yes, what recommendations can you make in regards to QA requirements and standardisation?**

Compliance with internal procedures is assured by self-check by the risk analyst and verified internally by a dedicated senior risk analyst, before approval by DNV’s project manager/project responsible.
An offshore QRA will normally be subject to review by several stakeholders (including field operator/oil company, yard/contractor, designers/engineering company, regulatory authorities, etc.) and possibly also independent third party verification.

4.2.9. Uncertainties

How do you address and/or quantify the impact of uncertainties in this step?

At this stage of the QRA, the aim is to establish a sufficient variety of scenarios to represent possible accident scenarios, but still not making the analysis unnecessarily complex. The “right” level of details has been achieved when further development of the scenarios has no significant effect on the risk, nor improves the accuracy of the risk estimates.

The development of an accident scenario may depend on the numerous possible combinations of input parameters. If the uncertainties in the inputs can be expressed as distributions, then the uncertainties in the outputs can be estimated by specialised techniques of uncertainty analysis. The most widely used technique for combining uncertainties in many parameters is Monte Carlo simulation, which enables modelling complex interactions in a simple way. Several such models have been developed to account for uncertainties in fire and explosion escalation.

By comparative analysis or sensitivities the relative differences in risk levels may often be estimated with a sufficient degree of accuracy for making the right decisions, even if there is significant uncertainty in the absolute risk estimates or the assessment of the scenario development is incomplete.

4.2.10. “Qualitative” or “quantitative”?

Is the overall approach to this step “qualitative” or “quantitative”? How do you relate this to actuarial data/experience, including generic and process/system specific aspects?

The initial assessment of event scenario development, e.g. establishment of event tree structure, is mainly a qualitative process. It is, however, closely linked to consequence calculations in order to estimate conditional probabilities for different developments (e.g. branch probabilities in event tree analysis).

4.2.11. Expert judgement

How do you utilise and view “subjective expert judgement”? How crucial is the use of expert judgement in this step of the analysis?

The main benefit of expert judgement in the event scenario assessment, is the possibility to select a limited, but still completely representative, number of scenarios to assess, thus allowing an efficient use of available resources on assessment of scenarios which are significant with regard to the overall risks.

If scenarios representing a significant contribution to the overall risks are left out, the risk will probably be underestimated. Spending a disproportionate amount of time analysing different scenarios with insignificant differences with regard to the overall risks is also likely to reduce the quality of the final results.
4.2.12. Human factor aspects

How do you consider the “human” factor aspects in event/scenario modelling?

Contributions from human and operational factors should be included, with regard to initiating events, scenario development as well as contribution from such failures to dependent failures. Sometimes this may only be complied with indirectly (implicitly included in the experience data), but shall as far as possible be explicitly considered in a cause analysis. This is in line with the requirements in the NORSOK standard for risk and emergency preparedness analysis (NORSOK, 1998).

4.3. Step III: consequence assessment

Identification and assessment of the consequences of the realised hazard.

4.3.1. Overall approach

How do you perform the consequence assessment? Please describe briefly the overall approach used in this step for your applications.

Consequence assessments are carried out in order to estimate the impact of the final accident scenario with regard to the risk acceptance criteria, e.g. expected values for number of fatalities, amount of oil spill and/or cost of material damage.

But consequence assessments are also performed in order to estimate the development of an accident, such as calculating fire size and duration or explosion pressure as basis estimation of escalation potential.

The consequence assessment in an offshore QRA may typically address the following types of accidents:

- process accidents;
- risers and pipeline accidents;
- blowouts;
- dropped objects;
- ship collisions; and
- extreme weather and earthquake.

For the first three, the consequences are related to release and possible ignition of hydrocarbons, while the next three are related to mechanical impacts and structural integrity. For dropped objects, however, the more severe accidents are normally those causing damage to hydrocarbon containing equipment.

The field of consequence modelling for hydrocarbon releases is highly developed, and there are several commercially-available computer programs to model the discharge, dispersion, fire and explosion of gases and liquids. Some of the techniques are relatively simple, and are suitable for manual analysis, and have commonly been implemented in customised spreadsheets. More complex models may be available in stand-alone format, or as part of integrated QRA software.

Modelling of hydrocarbon releases that are strongly influenced by the presence of obstacles or confinement may require more sophisticated approaches such as the use of computational fluid dynamics (CFD) models. CFD models provide numerical
representations of fluid flow, which can represent the effects of obstacles and confining structure. They are quite expensive, but are still beginning to be used for critical explosion and fire scenarios in QRAs of the detailed design. CFD modelling gives probably the best available accuracy for a well specified scenario, but not necessarily a good representation of other slightly different scenarios. Hence, numerous runs may be necessary.

4.3.2. Exposure

*By which criteria do you define the intensity, time and mode of contact?*

The results from the consequence calculations must be expressed in a way enabling evaluation with regard to the risk acceptance criteria.

For fires, the effects will be related to heat load (radiation, convection or elevated temperatures), inhalation of smoke and loss of visibility. Often it will be necessary to know the duration or time-dependency of the exposure in order to estimate the total effect.

Other types of exposure that will be assessed in an offshore QRA include:

- explosion overpressures (pressure, drag forces, impulse/duration);
- gas concentrations;
- spill to the environment (rate and duration);
- mechanical impacts (energy, impact area, stiffness, etc.);
- falling loads directly hitting personnel; and
- helicopter collisions (injuries/fatalities to passengers and crew, impact to installation).

4.3.3. Completeness

*How do you assure completeness of your results in this step of risk assessment?*

Completeness of the consequence assessment is a function of both the scope for the risk assessment and of the risk acceptance criteria. For all identified and relevant hazards, consequences must be assessed with regard to their contribution to all risk measures for which acceptance criteria have been defined.

4.3.4. Regulatory authorities

*How, if at all, are regulatory authorities involved in this step of risk assessment?*

The Norwegian regulations for risk analysis (Norwegian Petroleum Directorate, 1990) give no detailed requirements for the consequence assessment. Several other regulations issued by the NPD, however, have a general requirement for risk analyses stating that “Risk analyses shall be carried out in order to disclose the consequences of single failures or sequential failures during operations, in order that risk reducing measures can be taken”.

4.3.5. Standards/guidelines

*Which underlying standards/guidelines are you using in this step of risk assessment?*

In addition to DNV internal procedures for consequence assessments and requirements specified by the actual client, the NORSOK standard for risk
and emergency preparedness analyses (NORSOK, 1998) have certain requirements for “consequence and escalation analysis”.

The NORSOK standard states that a detailed consequence analysis usually consists of the following sub-studies:

- Leakage of inflammable substances; calculation of release (amounts, rates, duration, etc.), spreading, ignition potential, fire- and explosion loads and responses.
- Well blowouts (with respect to environmental loads); calculation of release rates and duration, spill drifting and environmental effects.
- Well blowouts (non environmental effects); consequences related to ignition and subsequent effects are calculated as for leakages of inflammable substances.
- External impact (collision, falling load, helicopter crash on installation); calculation of energy distribution, load distribution, impulse distribution and responses.
- Falling loads on subsea installations and pipelines; consequence calculations as for external impacts in general.
- Extreme environmental loads; calculations are usually carried out by the relevant discipline as part of the analyses of structural design, and the results from these studies may be integrated into the risk analysis.
- Loss of stability and buoyancy, catastrophic loss of anchor lines; calculations are usually carried out by the relevant discipline as part of the marine studies, and the results from these studies may be integrated into the risk analysis.

The NORSOK standard presents further details for information in two annexes. It also states that CFD-methods (Computational Fluid Dynamics), analytical methods and simulation methods (based on CFD or analytical methods) are considered relevant tools for consequence modelling in relation to fire and explosion, and that non-linear structural analyses are often used for external impacts, thereby making it possible to reflect structural reserve capacity beyond yield.

4.3.6. Standardisation

How much standardisation is currently available for this step of risk assessment?

The standardisation of the consequence assessment is closely related to the use of standard, commercially available software for consequence calculations. Company internal standardisation by defining preferred tools and methodologies, manual as well as computerised, is quite common.

4.3.7. Uncertainties

How do you address and/or quantify the impact of uncertainties in this step?

In general, the available techniques are sufficiently accurate for risk assessment purposes. However, the quality of the results heavily depends on an appropriate selection and specification of scenarios to assess.

If there are several parameters influencing the consequences that may vary more or less independent, such as accident location and wind direction and speed, calculation
tools based on, e.g. Monte Carlo simulation may be applied to estimate the uncertainties in the outputs.

While complex situations may be impossible to model by simple tools, the selection of methodology for the consequence calculations may sometimes have insignificant impact on the results, e.g. for simple geometries.

In 1989, a risk assessment was performed in order to estimate the risk from large gas fires one installation with regard to evacuation possibilities on an adjacent platform. For a given release diameter, the release rate was estimated to 481 kg/s and the estimated corresponding jet fire dimensions were a height of 250 m and a diameter of 30 m. In a recently performed analysis, CFD calculations were performed for a similar situation with a release rate of 500 kg/s. These calculations gave a fire height of 230 m and an average diameter of approximately 30 m. But if the wind speed was increased from 2 m/s to 15 m/s, the CFD calculations gave a reduction of the maximum radiation level on the adjacent platform (22–45% for different scenarios), while the simplified tilting of the flame applied in 1989 indicated an increase by a factor of 2.5 (Fig. 6).

4.3.8. “Qualitative” or “quantitative”?

Is the overall approach to this step “qualitative” or “quantitative”? How do you relate this to actuarial data/experience, including generic aspects?

The consequence assessment in a QRA is quantitative. Quite detailed calculations are performed for a selection of scenarios. Provided an appropriate selection of

Fig. 6. Flame size calculation results — based on empirical correlation (left) and CFD.
scenarios, methodology and tools are used, the estimated consequences are believed to give a fair representation of the expected accident scenario. In general, the most commonly used tools have been validated and calibrated against experience and test results.

4.3.9. Expert judgement

How do you utilise and view “subjective expert judgement”? How crucial is the use of expert judgement in this step of the analysis?

Expert judgement is necessary for appropriate selection of methodology. If unnecessarily complex methods are applied, a lot of effort may be spent on issues with limited importance, and accordingly reducing the resources available for more important issues.

4.3.10. Mitigation measures

Do you include any consequence mitigation measures? If yes, what is the basis for this and do you follow established requirements or otherwise?

Detailed analysis of efficiency, availability, reliability and vulnerability of safety systems and mitigation measures are performed in order to estimate the conditional probability for the different accident scenarios and their outcomes.

4.4. Step IV: risk evaluation

4.4.1. Step IV-A: risk estimation

Assessing and expressing the likelihood of the consequences and describing the quality of such estimates.

4.4.1.1. Likelihood of effects. How do you express the likelihood of effects (qualitative/quantitative, etc.)?

In an offshore QRA the likelihood of the effects (i.e. those estimated/calculated in the consequence assessment) will normally be expressed in terms of expected frequency (e.g. expected number of large gas fires per year). The likelihood may also be expressed in terms of probability (e.g. probability per crane lift of pipeline damage due to loss of load).

4.4.1.2. Quality of estimates. What criteria do you use to describe the quality of estimated risk measures?

The results are normally presented as “best estimates”, sometimes with associated confidence intervals. Basis for the applied initial event frequencies as well as how the final scenario frequencies have been calculated should be documented or referred to.

4.4.1.3. Completeness. How do you assure the overall completeness of the estimated risk measures?

The contribution to all risk measures for which acceptance criteria have been established, from all identified hazards with related accident scenarios shall be compiled. In complex analyses this may facilitated by use of integrated risk assessment
software. The completeness is further assured through self check (by the analyst/-s) and internal verification.

4.4.1.4. Regulatory authorities. How, if at all, are regulatory authorities involved in this step of risk assessment?

Some initiatives have been taken by regulatory authorities to collect accident information in databases, thus providing a better basis for frequency estimation. Otherwise, the regulatory authorities are not directly involved in the risk estimation. They may, however, require additional documentation if the presented material is considered insufficient.

4.4.1.5. Risk presentation. How do you display the estimated risk measures? Do you also show the impact of various uncertainties? Please elaborate.

The expression of the estimated risk should be in a way comparable with the acceptance criteria (see Section 4.4.2.1.1). Hence, human risk may for example be expressed in terms of “expected number of fatalities per year”, “FAR” (Fatal Accident Rate — expected number of fatalities per 100 million exposed hours) or “fN curves” (frequency of accidents with $N$ or more fatalities).

Risk in terms of loss of safety functions is expressed by the frequency of accidents causing impairment.

Risk results from a QRA of an integrated platform (PDQ) is shown in Figs. 7–9.

4.4.1.6. “Risk-outliers or vulnerabilities”. Do you identify various “risk-outliers or vulnerabilities”? How do you define “risk-outliers or vulnerabilities”?

“Risk-outliers or vulnerabilities” are normally not identified specifically, but the main risk contributors are. A variety of scenarios, including extremes, are assessed and included in the overall risk picture, and hence, the outliers may be said to be taken into account.

Fig. 7. Personnel risk, fN curve.
4.4.1.7. Sensitivity to model assumptions. Do you show the sensitivity of the estimated risk measures to the various model assumptions? If yes, how do you address and justify the “sensitive” and “uncertain” contributors in the context of overall risk assessment process?

Sensitivity analyses are often performed as an integrated part of offshore QRAs, but not always, and more often with regard to specifications and configuration (such as different technical solutions, manning levels and operational mode) than with regard to the mathematical modelling. When the modelling as such is considered, this will normally be a qualitative evaluation of the limitations and applicability of the applied model, or the risk is estimated by application of different models and different results presented for comparison.
4.4.2. Step IV-B: risk comparison

Comparing derived risk estimates to specified guidelines/criteria/goals and describing the dependence of these estimates on explicitly specified assumptions.

4.4.2.1. Regarding comparison of estimates

4.4.2.1.1. Risk comparison. How and with what do you compare derived estimates of likelihood/risk

Risk estimates may be compared, e.g. to company specified risk acceptance criteria, risk estimates for comparable or alternative solutions, established risk levels for other industry activities or authority requirements.

According to the Regulations for implementation and use of risk analyses (Norwegian Petroleum Directorate, 1990) the offshore field operators in Norwegian waters have to define safety objectives and risk acceptance criteria before a risk analysis is carried out. In the guidelines to the regulations it is stated that “the acceptance criteria may be defined both in quantitative and in qualitative terms, depending inter alia on the mode of expression of risk”. Further, the operator shall document the assessments that have led to the definition of the acceptance criteria, and clearly defined limits and conditions for their application must be stipulated. The way these acceptance criteria are to be used should also be specified, particularly with regard to the inherent uncertainty in expressing risk in quantitative terms.

If the operator has not yet defined risk acceptance criteria directly applicable for the actual analysis, such criteria should be established, preferably before the risk is calculated/estimated.

In quantitative risk assessments, the risk results should be compared with quantitative risk acceptance criteria. Hence, if the operators have qualitative criteria, an interpretation suitable for the present study should be agreed upon.

4.4.2.1.2. Quality of estimates. What criteria do you use to describe the quality of such estimates?

The quality of the risk estimates is related to the quality of the consequence assessment (see Section 4.3.7), and the quality of the likelihood estimation (see Section 4.4.1.2). The acceptance criteria, to which the risk results are compared, are normally the responsibility of the client/offshore field operator.

4.4.2.1.3. Regulatory authorities. How, if at all, are regulatory authorities involved in the comparison?

As it is required in the regulations that the operator must establish risk acceptance criteria, it should be considered a Norwegian authority requirement to implement all necessary risk reducing measures to achieve compliance with the acceptance criteria.

4.4.2.1.4. Standards/guidelines. Which underlying standards/guidelines are you using for the comparison?

Annex A to the NORSOK standard (NORSOK, 1998) gives informative guidelines for establishment of risk acceptance criteria. The Norwegian Oil Industry
Association (OLF) has published “Guidelines for the establishment of acceptance criteria for environmental risks caused by acute spills”.

4.4.2.1.5. Standardisation. How much standardisation is currently available for the comparison?

To the extent that risk acceptance criteria are established, they normally cover criteria for fatality risk. This may, however, be expressed in several different way, such as individual risk (e.g. FAR-value), average risk for a group or category of personnel, annual average for all personnel on board or as fN curves.

Criteria for availability of safety functions, such as escape routes, evacuation means and structural integrity, expressed as maximum acceptable frequencies of impairment, are also quite common.

Depending of the scope for the actual study, acceptance criteria for environmental and economical risks may also be included.

Often, the risk acceptance criteria are presented in terms of three regions. A first one where the risk is minimal, is thus considered acceptable.

A second region where risk reducing measures, or safeguards, should be considered, and implemented unless the cost is disproportionate to the effect. This is the so called “ALARP-region” (Fig. 10).

For even higher levels, the risk is considered so high that risk reducing measures must be implemented or are strongly recommended to achieve an acceptable level of risk. If such risk level applies to human safety or to the environment, the project should not be considered feasible without successful implementation of risk reducing measures. If such risk level has cost consequences only, a cost-benefit analysis can support the determination of the level of risk reducing measures to be implemented.

4.4.2.2. Regarding dependence on assumptions

4.4.2.2.1. Dependence on the modelling assumptions? How do you analyse the dependence of these estimates on the modelling assumptions?

The dependence of the risk estimates on the modelling assumptions are to some extent analysed by “sensitivity analysis”. For a development project, all assumptions used as basis for a QRA are normally registered, and a system is established

![ALARP-region diagram](image-url)

Fig. 10. As low as reasonably practicable (ALARP)-principle.
for follow-up the assumptions through the different phases of the project. If, for example, the risk analysis in an early phase has been based on one assumption regarding capacity and location of lifeboats and another one regarding manning level, the first one may be signed out when confirmed by “frozen design” or actually installed, while the latter would require reanalysis if the actual manning level differs from the assumption.

4.4.2.2. Regulatory authorities. How, if at all, are regulatory authorities involved in the dependence analysis?

The Norwegian Regulations for implementation and use of risk analyses (Norwegian Petroleum Directorate, 1990) requires that “implementation of the risk reducing measures and of the basic assumptions made in the risk analysis shall be systematically followed up in order to ensure that safety in the activities is maintained within the defined acceptance criteria for risk”.

The guidelines to the regulations further states that the assumptions on which the risk analysis is based are to be assessed, accepted and clearly set out, so that the results of the risk analysis are interpreted correctly and so that these assumptions can be implemented more easily in the operational phase.

4.4.2.2.3. Standards/guidelines. Which underlying standards/guidelines are you using for the dependence description?

The NORSOK standard (NORSOK, 1998) requires that assumptions must be identified, made visible and communicated to the users of the analysis results. The documentation of a QRA should include a statement of assumptions and premises on which the study is based and a presentation of the sensitivity in the results with respect to variations in input data and crucial premises.

4.4.2.2.4. Standardisation. How much standardisation is currently available for the dependence description?

For most offshore projects, a system for follow up of assumptions is established. Such a system is often a company specific application of standard database software. This will normally include a thorough description of the assumptions as well as a description of the impact of the assumption.

4.5. Step V: decision making

Deciding on actions based on risk evaluation.

4.5.1. How are the results used for industry-internal purposes?

As it is required by authorities to perform risk analyses, it may be regarded as a prerequisite for offshore operations. And initially, offshore risk analyses were performed primarily to achieve compliance with authority regulations and to document an acceptable level of safety.

Through risk assessment, the main risk contributors, and thereby focal areas for the risk management are identified. QRAs are now actively used by the offshore
industry during definition of design accidental loads/scenarios. Further, risk assessment provides a part of the basis for selection between alternative solutions, and is the main tool for identifying possible needs for risk reducing measures. Risk assessments are also used to increase the efficiency of inspection and maintenance, e.g. through risk based inspection (RBI).

4.5.2. How are the results used for regulatory purposes?

Risk assessments are required by the authorities as part of the risk management. From the authorities point of view, the purpose of the risk analyses is their contribution to establishing and maintaining a fully satisfactory level of safety for people, the environment and for assets and financial interests. Risk analyses also provide an important basis for appropriate supervision of the petroleum activities by the authorities.

Through requirements for risk analyses and compliance with risk acceptance criteria, the operators have to see beyond compliance with prescriptive technical requirements and seek a solutions with due regard to the overall safety.

5. Legal/policy issues

5.1. Legal/regulatory risk assessment

Are there any specific legal/regulatory requirements for performance of risk assessments? If so, are these requirements “prescriptive” or “non-prescriptive”? Please comment on the merits and detriments of the existing approach/requirements?

For offshore installations/operations in the North Sea, performance of risk assessments is required. In Norwegian waters, this is covered by regulations issued by NPD (for fixed installations, Norwegian Petroleum Directorate, 1990) and NMD (for mobile units, Norwegian Maritime Directorate, 1993), and in UK waters by HSE’s safety case regulations (UK Health and Safety Executive, 1992). The regulatory requirements for performance of risk assessments are in general “non-prescriptive”, even though there are some specific requirements regarding what to include and to some extent regarding recommended methodologies.

In other areas of the world there may be more or less similar regulations, the developments may be made by international oil companies according to their own internal safety standards or the offshore developments are regulated by detailed prescriptive requirements rather than requirements for safety management.

5.2. Risk goals and/or risk criteria

Are risk goals and/or risk criteria used? If so, are they qualitative or quantitative and are there any compliance requirements? Please elaborate.

According to Sections 10 and 11 of NPD’s regulations for implementation and use of risk analyses it is the operators responsibility to define both safety objectives and risk acceptance criteria.
The safety objectives shall express an ideal safety level and reflect the overall requirements of the applicable legislation with regard to fully satisfactory safety for people, the environment, assets and financial interests. They shall be used actively to initiate preventive safety measures based on knowledge obtained through a risk analysis. This is believed to contribute to a further enhancement of safety in the activities and shall form the basis for revision of the operator’s acceptance criteria when appropriate.

Risk acceptance criteria express a standpoint with regard to risk connected to loss of human lives, to personal injury, damage to the environment and to assets and financial interests. The need for risk reducing measures is assessed with reference to the acceptance criteria, which must consequently be defined before the implementation of a risk analysis.

In principle, risk acceptance criteria may be qualitative or quantitative. However, if the risk is quantified, it should preferably be compared to quantitative criteria. If the operator have qualitative criteria, an interpretation suitable for the present study should therefore be agreed upon prior to commencement of a quantitative assessment.

5.2.1. Cost/benefit analysis

*Is cost/benefit analysis required? If so, what are legal and policy implications?*

There are no specific requirements for cost/benefit analysis. To some extent it may, however, be a part of the risk acceptance criteria, especially with regard to material damage (see Section 4.4.2.1.5). Cost/benefit analysis may also be used to demonstrate whether or not the cost related to implementation of risk reducing measures is disproportionate to the effect, thereby demonstrating whether or not the risks are ALARP.

6. Impact of the generic standard

6.1. Possible merits

*What would be the merits of a generic standard for risk-based decision making for your specific technical area?*

As there are already regulations requiring risk assessments as part of the safety management, an established practice for performance of risk assessments and an applicable standard available (NORSOK, 1998), the merits of a generic standard may be quite limited with regard to offshore activities in the North Sea.

Introducing a more widely accepted international standard on risk based decision making may facilitate and promote the use of risk assessment and systematic risk management in areas of the world where there is not yet a tradition for applying such techniques.

Standardising risk assessments and related terminology across all industries will hopefully improve the general knowledge and understanding of risk; risk to whom,
risk of what and where? Thereby the introduction of a generic standard may facil-
itate communication of risk assessment results, not only to the decisions makers, but
also to the public in general.

6.2. Implications

*Which implications of its use do you expect (legal obligations, status, liability,
compulsory nature, scientific relevance)?*

Presently, risk assessments performed for the offshore industry in the North Sea
are “tailor made” to a high degree, based on a close interaction between designers,
risk analysts and decision-makers. This interaction is considered very valuable.

If a generic standard is developed and it becomes mandatory, it is therefore of
utmost importance that it will promote rather than hamper this interaction as well
as the possibilities for adaptation to a specific purpose.

For industries such as the offshore industry, where there is already an extensive
use of risk based decision making, detailed and/or prescriptive requirements might
represent a limitation to the use as well as the development of risk assessments.

6.3. Required scope

*How would you define its required scope?*

If a generic standard on risk based decision making is to be developed, the
development should be done with due attention to the existing ISO/IEC Guide 51,
Safety aspects — Guideline for their inclusion in standards (ISO/IEC, 1999) and
the guide on risk management terminology presently being developed (ISO/TMB
WG, 1999).

A standard should cover the whole process. Further reference is made to Section
3.3.

Early definition of risk acceptance criteria suitable for the purpose of the study is
believed to provide the best basis for later decisions. The management responsible
for the operations, should also be responsible for defining risk acceptance criteria on
basis of requirements stipulated by or in pursuance of law or regulations, including
requirements with regard to risk reducing measures, and the operator’s own safety
objectives for the activities. By making operators take greater responsibility for the
safety of their own operations, they are expected to use risk-based decision making
to greater effect.

It is important to encourage the focus on the overall risk, rather than sub-
optimisation on certain specified aspects.

If details or prescriptive requirements regarding selection of methodology are
included, they should be included as guidance and not be mandatory, in order not to
limit the use and development of new technology and methodology.

The standard should include requirements for the documentation and presenta-
tion of results, ensuring that the decision-makers form an accurate and comprehen-
sive picture of the basis for their decisions.
6.4. Potential users

Who would be its potential users?
A generic standard may be referred by regulations, etc. thus limiting the need for inclusion of requirements for risk based decision making, possibly divergent, in numerous documents. Regulatory authorities may then use the standard as basis for their review and acceptance of risk assessments.

Provided it suits their industry and company specific needs with an appropriate level of details, oil companies and offshore operators may apply a generic standard both for internally performed risk assessments and as part of the specifications when risk assessments are done on their behalf by consultants, engineering companies or others. Similarly, the consultants, engineering companies, etc. may use it as a tool during actual performance of risk assessments, but also as a reference when offering risk assessments.

7. Risk Perception

7.1. Public risk perception

In your view, how is the risk specific for your technical area perceived and assessed by the public? Please use the risk perception criteria in Table 3 and mark them as appropriate.

Table 3

<table>
<thead>
<tr>
<th>Risk perception criteria</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Not sure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability of occurrence</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Extent of potential damage</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incertitude of risk estimate</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ubiquity of potential damage</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Persistency of potential damage</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Reversibility of post-damage</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delay between initial event and impact</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Potential of mobilisation</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

These criteria are to be understood, as follows:

- **Icertitude** (related to statistical uncertainty, fuzzy uncertainty, and ignorance).
- **Ubiquity** defines the geographic dispersion of potential damages (intragenerational justice).
- **Persistency** defines the temporal extension of potential damages (intergenerational justice).
- **Reversibility** describes the possibility to restore the situation to the state before the damage occurred (possible restoration are e.g. reforestation and cleaning of water).
- **Delay effect** characterises a long time of latency between the initial event and the actual impact of damage. The time of latency could be of physical, chemical or biological nature.
- **Potential of mobilisation** is understood as violation of individual, social or cultural interests and values generating social conflicts and psychological reactions by individuals or groups who feel inflicted by the risk consequences.
Brief questions to several colleagues indicated that there in no uniform public perception of risk in the offshore industry, except that the extent of potential damage is high. For probability of occurrence and incertitude of risk estimate perception ranged from low to medium, whereas for all other criteria the perception ranged from low to high. Ubiquity of potential damage was considered quite high with regard to environmental risk, but with regard to other risk categories it was considered low, i.e. limited to the offshore installation itself.

The marking in Table 3 shows approximate “averages” of the responses received.

References

Norwegian Maritime Directorate, 22 December 1993, Regulations No. 1239 concerning risk analyses for mobile offshore units (with amendments of 8.1.80, 10.10.96 and 2.3.99).
Norwegian Petroleum Directorate, 1.9.81, Guidelines for safety evaluation of platform conceptual design.
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Norwegian Standards Association (NSF), August 1991, Norwegian Standard NS 5814, Requirements for risk analyses.
UK Health & Safety Executive, 1992, Offshore Installations (Safety Case) Regulations.