

NORSOK STANDARD

RISK AND EMERGENCY PREPAREDNESS ANALYSIS

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FOREWORD

NORSOK (The competitive standing of the Norwegian offshore sector) is the industry initiative to add value, reduce cost and lead time and eliminate unnecessary activities in offshore field developments and operations.

The NORSOK standards are developed by the Norwegian petroleum industry as a part of the NORSOK initiative and supported by OLF (The Norwegian Oil Industry Association) and TBL (Federation of Norwegian Engineering Industries). NORSOK standards are administered and issued by NTS (Norwegian Technology Standards Institution).

The purpose of NORSOK standards is to contribute to meet the NORSOK goals, e.g. by replacing individual oil company specifications and other industry guidelines and documents for use in existing and future petroleum industry developments.

The NORSOK standards make extensive references to international standards. Where relevant, the contents of a NORSOK standard will be used to provide input to the international standardisation process. Subject to implementation into international standards, the NORSOK standard will be withdrawn.

All annexes are informative.

INTRODUCTION

The purpose of this standard is to establish requirements for effective planning, execution and use of risk and emergency preparedness analysis. Guidelines are provided in informative Annexes.

These Annexes are provided as supplementary information and check lists which may be used by personnel in charge of evaluation and analysis of risk and emergency preparedness. The emphasis has therefore been to provide useful information, rather than to reduce the volume of these Annexes.

This NORSOK standard includes a number of requirements from which no deviation is normally permitted ('shall' statements). A preferred action is recommended in other cases ('should' statements).

When this standard is used in a way which implies deviation from a recommended course of action ('should' statements), the reasons for choosing this course shall always be stated.

1 SCOPE

This NORSOK standard presents requirements to planning, execution and use of risk and emergency preparedness analysis, with an emphasis on providing insight into the process and concise definitions.

The standard is structured around the following main elements:

- Establishment of risk acceptance criteria prior to execution of the risk analysis.
- The connection between the risk and emergency preparedness analyses, especially the integration of the two types of analysis into one overall analysis.
- Planning, establishment of requirements and execution of analyses.
- Further requirements to use of risk and emergency preparedness analyses for different activities and life cycle phases.

The use of risk acceptance criteria and risk analyses in relation to working environment factors is not covered by this standard. The standard covers emergency preparedness analyses, establishment of emergency preparedness as well as organising for emergency preparedness, while maintenance of emergency preparedness and further development are not covered by the standard.

This standard covers analysis of risk and emergency preparedness associated with exploration drilling, exploitation, production and transport of petroleum resources as well as all installations and vessels that take part in the activity. Operations and modifications of installations as well as decommissioning and disposal of these are also covered. The standard does not cover plants and pipelines onshore.

2 NORMATIVE REFERENCES

The following standards include provisions which, through references in this text, constitute provisions of this NORSOK standard. The latest issue of the references shall be used unless otherwise agreed. Other recognised standards may be used provided it can be shown that they meet or exceed the requirements of the standards referred to below.

ISO 13702	Petroleum and natural gas industries - Offshore production installations - Control and Mitigation of Fires and Explosions - Requirements and guidelines.
E&P Forum	Guidelines for the Development and Application of Health, Safety and Environmental Management Systems.
HSE SI 1992/2885	A guide to the Offshore Installations (Safety Case) Regulations, UK Health and safety Executive, 1992.

HSE SI 1995/743	Prevention of fire and explosion and emergency response on offshore installations (PFEER) Regulations, UK Health and Safety Executive, 1995.
NSA	Guidelines for application of risk and emergency preparedness assessment for Mobile Offshore Drilling Units (Is being updated in 1998, and will in the future be issued as a DNV Recommended Practice)

3 DEFINITIONS AND ABBREVIATIONS

3.1 Definitions

The list of definitions gives supplementary comments to selected terms. These comments present premises, amplifications, elaborations, etc. The list is arranged alphabetically and numbered. Further elaboration is given in informative Annexes A, C, D and E.

3.1.1	Acceptance Criteria for risk	Criteria that are used to express a risk level that is considered acceptable for the activity in question, limited to the high level expressions of risk.
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Risk acceptance criteria are used in relation to risk analysis and express the level of risk which the operator or owner will accept in the activity. The term is related to the high level expressions of risk. Requirements on lower levels are also relevant, see for instance Definition 3.1.14, relating to functional requirements to safety and emergency preparedness. In some studies on a lower level, general decision criteria relating to HES management are used.

3.1.2	Accidental event	Event or chain of events that may cause loss of life, health, or damage to environment or assets.
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The events that are considered in a risk analysis are acute, unwanted and unplanned. Planned operational discharges, such as to external environment, are usually not included in a risk analysis.

The term 'event' will have to be defined explicitly in relation to each analysis, in order to be consistent with the availability analysis, that is with production regularity.

3.1.3	ALARP (As Low as Reasonably Practicable)	ALARP expresses that the risk level is reduced - through a documented and systematic process - so far that no further cost effective measure may be identified.
3.1.4	Can	Verbal form used for statements of possibility and capability, whether material, physical or casual.
3.1.5	Defined situations of hazard and accident (DFU)	A selection of possible events that the emergency preparedness in the activity should be able to handle, based on the activity's dimensioning accidental events, and hazardous and accidental situations associated with a temporary increase of risk and less extensive accidental events.

Examples of less extensive accidental events may be man overboard situations, limited oil spills exceeding the stipulated discharge limits, occupational accidents etc.

Situations associated with a temporary increase of risk, may involve drifting objects, work over open sea, unstable well in connection with well intervention, «hot» work, jacking up and down of jack-up installations, special operations and environmental conditions etc.

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| 3.1.6 | Dimensioning accidental events (DUH) | Accidental events that serve as the basis for layout, dimensioning and use of installations and the activity at large, in order to meet the defined risk acceptance criteria. |
| 3.1.7 | Dimensioning accidental load (DUL) | The most severe accidental load that the function or system shall be able to withstand during a required period of time, in order to meet the defined risk acceptance criteria. |

It may be difficult to define the accidental load in relation to some types of accidental events, for instance in relation to filling of buoyancy compartments that may lead to capsizing or loss of buoyancy. In these cases, the basis of dimensioning is given by the dimensioning accidental events.

Dimensioning accidental events and dimensioning accidental loads are closely related. The establishment shall start with the completion of a risk analysis and the comparison of estimated risk with risk acceptance criteria. It must be assumed that the risk analysis has established alternative accidental events and associated accidental loads, and possibly also associated probability.

Tolerable damage or required functionality have to be defined in such a way that the criteria for dimensioning are unambiguous. The term "withstand" in the definition may be explained as the ability to function as required during and after the influence of an accidental load, and may involve aspects such as:

- The equipment shall be in place, i.e. it may be tolerable that some equipment is damaged and does not function and that minor pipes and cables may be ruptured. This may be relevant for electrical motors and mechanical equipment.
- The equipment shall be functional, i.e. minor damage may be acceptable provided that the planned function is maintained. This may be relevant for ESD valves, deluge systems, escape ways, main structural support system, etc.
- The equipment shall be gas tight. This may be relevant for hydrocarbon containing equipment.

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|--------------|---|--|
| 3.1.8 | Effectiveness analysis of safety and emergency preparedness measures | Analysis which shall document the fulfilment of functional requirements to safety and emergency preparedness. |
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Effectiveness analyses in relation to technical functional requirements for safety systems are carried out in relation to risk analyses. It is therefore a prerequisite that quantitative risk analyses in relation to design include quantitative analyses of escape, evacuation and rescue. Similarly, effectiveness analyses of emergency preparedness measures are done in connection with emergency preparedness analyses. The analysis shall be traceable and will normally - though not necessarily - be quantitative.

3.1.9	Emergency Preparedness	Technical, operational and organisational measures that are planned to be implemented under the management of the emergency organisation in case hazardous or accidental situations occur, in order to protect human and environmental resources and assets.
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The definition focuses on the distinction between dimensioning of emergency preparedness and dimensioning of process (technical) safety systems (see also the definition of emergency preparedness analysis and establishment of emergency preparedness, as well as Annex D). Dimensioning of process safety systems is done in connection with the use of risk analysis, and minimum requirements by authority regulations, established practice, recognised norms, etc.

3.1.10	Emergency preparedness analysis	Analysis which includes establishment of defined situations of hazard and accident, including dimensioning accidental events, establishment of functional requirements to emergency preparedness, and identification of emergency preparedness measures.
3.1.11	Environmental resource	Includes a stock or a habitat, defined as:
	Stock	A group of individuals of a stock present in a defined geographical area in a defined period of time. <i>Alternatively:</i> The sum of individuals within a species which are reproductively isolated within a defined geographical area.
	Habitat	A limited area where several species are present and interact. Example: a beach.

For further discussion, see Annex C.

3.1.12	Establishment of emergency preparedness	Systematic process which involves planning and implementation of suitable emergency preparedness measures on the basis of risk and emergency preparedness analysis.
3.1.13	Emergency preparedness organisation	The organisation which is planned, established, trained and exercised in order to handle occurrences of hazardous or accidental situations.

The emergency preparedness organisation includes personnel on the installation as well as onshore, and includes all personnel resources that the operator will activate during any occurred situation of hazard or accident. The emergency organisation is organised independently of the normal, operational organisation.

3.1.14	Functional requirements to safety and emergency preparedness	Verifiable requirements to the effectiveness of safety and emergency preparedness measures which shall ensure that safety objectives, risk acceptance criteria, authority minimum requirements and established norms are satisfied during design and operation.
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The term 'effectiveness' in relation to these functional requirements shall be interpreted in a wide sense and include availability, reliability, capacity, mobilisation time, functionality, vulnerability, personnel competence. For further discussion, see Annex D.

3.1.15 Informative references Shall mean informative in the application of NORSOK Standards.

3.1.16 Main safety function Safety functions that need to be intact in order to ensure that personnel that are not directly and immediately exposed, may reach a place of safety in an organised manner, either on the installation or through controlled evacuation.

The main safety functions, including their required functionality, shall be defined for each installation individually in an unambiguous way.

Examples of main safety functions are main support structure, escape ways, control centre, shelter area (temporary refuge) and evacuation means.

3.1.17 May Verbal form used to indicate a course of action permissible within the limits the standard.

3.1.18 Normative references Shall mean normative (a requirement) in the application of NORSOK Standards.

3.1.19 NORSOK Norsk Søkkel Konkurranseseposisjon, the Competitive standing of the Norwegian Offshore Sector, the Norwegian initiative to reduce cost on offshore projects.

3.1.20 Risk Expression of probability for and consequence of one or several accidental events.

Risk may be expressed qualitatively as well as quantitatively.

The definition implies that risk aversion (i.e. an evaluation of risk which places more importance on certain accidental consequences than on others, where risk acceptance is concerned) shall not be included in the expression of risk. It may be relevant to consider on a qualitative basis certain aspects of risk aversion in relation to assessment of risk and its tolerability.

3.1.21 Risk analysis Analysis which includes a systematic identification and description of risk to personnel, environment and assets.

The risk analysis term covers several types of analyses that will all assess causes for accidents and consequences of accidental events. Examples of the simpler analyses are Safe Job Analysis, FMEA, Preliminary Hazard Analysis, HAZOP, etc.

Quantitative analysis may be the most relevant in many cases, involving a quantification of the probability for and the consequences of accidental events, in a manner which allows comparison with quantitative risk acceptance criteria.

3.1.22 Safety objective Objective for the safety of personnel, environment and assets towards which the activity shall be aimed.

Safety objectives will imply short or long term objectives that the operator/owner has established for his activity, while the risk acceptance criteria express the level of risk (in relation to the risk analysis) that is currently acceptable to the operator/owner.

The safety objectives shall as far as possible be expressed in a way which allows verification of fulfilment through an ALARP evaluation. Long and short term safety objectives form the basis for further development of the safety level and the tightening of the risk acceptance criteria as an element of the continuous improvement process and the HES management.

3.1.23 Shall Verbal form used to indicate requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted, unless accepted by all involved parties.

3.1.24 Should Verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required.

3.2 Abbreviations

AIR	Average Individual Risk
ALARP	As Low As Reasonably Practicable
DFU	Defined situations of hazard and accident
DUH	Dimensioning accidental event
DUL	Dimensioning accidental load
FAR	Fatal Accident Rate
FMEA	Failure Mode and Effect Analysis
HAZID	Hazard Identification
HAZOP	Hazard And Operability Study
HES	Health, Environment and Safety
IR	Individual Risk
IRPA	Individual Risk Per Annum
LEL	Lower Explosive Limit
MIRA	Environmental risk analysis
MODU	Mobile Drilling Unit
NPD	Norwegian Petroleum Directorate.
NSA	Norwegian Shipowners' Association
NTS	Norwegian Technology Standards Institution.
OLF	The Norwegian Oil Industry Association.
PDO	Plan for Development and Operation
PFD	Process Flow Diagram
PFEER	Prevention of Fire and Explosion and Emergency Response
QRA	Quantitative Risk Assessment
RAC	Risk Acceptance Criteria
SJA	Safe Job Analysis

TBL	Federation of Norwegian Engineering Industries.
TRA	Total Risk Analysis
UEL	Upper Explosive Limit
VEC	Valued Ecological Component

4 ESTABLISHMENT AND USE OF RISK ACCEPTANCE CRITERIA

4.1 General Requirements for Formulation of Risk Acceptance Criteria

Risk acceptance criteria illustrate the overall risk level which is determined as acceptable by the operator/owner, with respect to a defined period of time or a phase of the activity. Annex A presents a comprehensive discussion of aspects related to defining and using risk acceptance criteria.

The acceptance criteria for risk constitute a reference for the evaluation of the need for risk reducing measures and shall therefore be available prior to starting the risk analysis. The risk acceptance criteria shall as far as possible reflect the safety objectives and the particularities of the activity in question. The safety objectives are often ideal and thereby difficult to reflect explicitly.

The evaluations that form the basis for the statement of the risk acceptance criteria shall be documented by the operator/owner. Distinct limitations for the use of the risk acceptance criteria shall be formulated. Data that are used during the formulation of quantitative risk acceptance criteria shall be documented. The manner in which the criteria are to be used shall also be specified, particularly with respect to the uncertainty that is inherent in quantitative risk estimates.

The need for updating of risk acceptance criteria shall be evaluated on a regular basis, as an element of further development and continuous improvement of safety.

In order for the risk acceptance criteria to be adequate as support for HES management decisions, they shall have the following qualities:

- be suitable for decisions regarding risk reducing measures.
- be suitable for communication.
- be unambiguous in their formulation.
- be independent of concepts in relation to what is favoured by the risk acceptance criteria.

Unambiguous in the present context implies that they shall be formulated in such a way that they do not give unreasonable or unintentional effects with respect to evaluating or expressing of the risk to the activity. Possible problems with ambiguity may be associated with:

- imprecise formulation of the risk acceptance criteria,
- definition of system limits to what shall be analysed, or
- various ways of averaging the risk.

Another possible problem is that criteria that are principally different may be aimed at the same type of risk (for example risk to personnel expressed by means of FAR versus impairment risk for main safety functions) may not always give the same ranking of risk in relation to different alternatives. More in-depth discussion of these aspects is presented in Annex A.

Transport between installations shall be included in the risk levels when this is included in the operations of the installations.

The results of risk assessments will always be associated with some uncertainty, which may be linked to the relevance of the data basis, the models used in the estimation, the assumptions, simplifications or expert judgements that are made.

Considerable uncertainty will always be attached to whether certain events will occur or not, what will be the immediate effects of such events, and what the consequences will be. This uncertainty is linked to the knowledge and information that is available at the time of the analysis. This uncertainty will be reduced as the development work progresses.

The way in which uncertainty in risk estimates shall be treated, shall be defined prior to performing the risk analysis. It is not common to perform a quantitative uncertainty analysis, it will often be impossible. Sensitivity studies are often preferred, whereby the effects on the results from changes to important assumptions and aspects are quantified.

The risk estimates shall as far as possible be considered on a 'best estimate' basis, when considered in relation to the risk acceptance criteria, rather than on an optimistic or pessimistic ('worst case') basis. The approach towards the best estimate shall however, be from the conservative side, in particular when the data basis is scarce.

4.1.1 Verification of Risk Acceptance Criteria

Risk acceptance criteria may normally not be verified through direct observations, as the events are rare would require unrealistically long observation periods. Therefore, the risk acceptance criteria have to be verified in the following manner:

- Through verification that organisational, operational and technical assumptions that form part of the studies are in compliance with actual operating parameters.
- By monitoring trends for risk indicators as explained in Annex A.

Possible deviations between risk acceptance criteria and registered parameter values shall be handled in accordance with the company's procedures for deviations. A possible action is to update the assumptions in the quantitative risk analysis, in order to identify the extent of the influence on overall risk.

Compliance with risk acceptance criteria through risk indicators or similar shall as a minimum be verified once a year.

4.2 Decision Criteria

Risk acceptance criteria are related to high level expressions of risk. Criteria are also required in relation to more limited analyses, quantitative and qualitative, in order that decisions may be made about actions and implementation of risk reducing measures. Such decision criteria shall be formulated on the basis of the purpose of the analysis, reflecting also the HES management system established by the operator or owner and the general principles for giving priority to risk reducing measures, see Section 5.1.4.

5 PLANNING, EXECUTION AND USE OF RISK AND EMERGENCY PREPAREDNESS ANALYSIS

The requirements in this section are general and not connected to any particular life cycle phase. The phase specific requirements are given in Section 7. The description in Section 5 is mainly dealing with integrated risk and emergency preparedness analysis. Sections 6 and 7 present the conditions under which this is most relevant.

The E&P Forum document "Guidelines for Development and Application of Health, Safety and Environmental Management Systems" gives guidance for HES management. Figure 5.1 shows how risk and emergency preparedness analyses may be integrated into an HES management context.

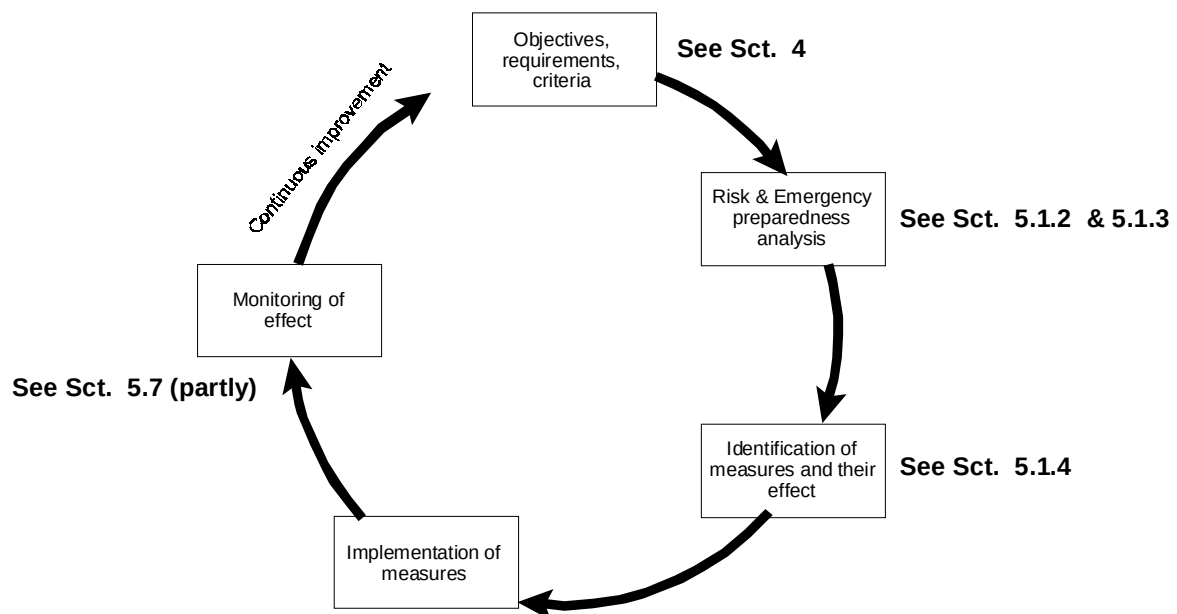


Figure 5.1 Management feedback loop for use of risk and emergency preparedness analysis in HES management

5.1 General Requirements

5.1.1 Purpose and Responsibility

The main purpose of using risk and emergency preparedness analyses is to formulate a decision-making basis that may contribute to selecting safety-wise optimum solutions and risk reducing measures on a sound technical and organisational basis. In order to achieve these objectives, the following general requirements to risk analyses apply:

- Assumptions must be identified, made visible and communicated to the users of the analysis results.
- The analyses must be targeted and carried out in a systematic way.
- They must be focused on identification of and insight into the aspects and mechanisms that cause risk.

- They must be carried out at an appropriate time, in order that the results of the studies can be timely taken into account in the relevant decision-making process.
- It is required not to use the results in a decision-making context that goes beyond the limitations that apply to quantitative risk analysis in particular (see Section 5.3.3).
- The operator's or owner's responsibility shall be clearly defined (may be important for instance when operator is not involved in concept definition phase) with respect to the execution of the analyses and the implementation of their results.
- Experience has shown that users need to be actively involved in the risk evaluation in order for it to be effective.
- The quality of the decision-making basis needs to be ensured, including insight into and knowledge about its use and limitations. Risk acceptance criteria need to be developed to ensure that the activity is carried out in a justifiable way.
- Knowledge must be accumulated about aspects that contribute to risk, in order to ensure that the risk level remains low and that accidental events are avoided.

5.1.2 Planning and Execution of Risk Analyses

Risk analyses shall be planned in accordance with the development of the activity, ensuring that the risk studies are used actively in the design and execution of the activity:

- Risk analyses shall be carried out as an integrated part of the field development project work, so that these studies form part of the decision-making basis for i.a. design of safe technical, operational and organisational solutions for the activity in question.
- Risk analyses shall be carried out in connection with major modifications, change of area of application, or decommissioning and disposal of installations, as well as in connection with major changes in organisation and manning level. See Section 7.6.

Requirements to execution and use of risk assessment shall be formulated in a way which ensures that the quality of the decision-making basis is maintained. This implies that a number of aspects needs to be clarified before a risk analysis is started:

- a) The purpose of the risk analysis has to be clearly defined and in accordance with the needs of the activity. The target groups for the results of the analysis have to be identified and described.
- b) The risk acceptance criteria for the activity have to be defined, see Section 4.1.
- c) The decision criteria for studies of limited extent need to be defined, see Section 4.2.
- d) The scope of the study and its limitations need to be clearly defined. The appropriate method is chosen partly on this basis.
- e) Preliminary statement on the types of analysis and the use of their results is made.
- f) Operational personnel shall be included in the work to the extent necessary.
- g) A listing shall also be made of relevant regulations, possible classification society rules and applicable standards and specifications that the operator/owner will use. This applies particularly to the building of new mobile units and floating production installations.

5.1.3 Planning of Emergency Preparedness Analyses

It is important to place focus on emergency preparedness as an integrated part of the work at an early stage in a field development project, in order to avoid major and costly changes at a later stage. (See also Section 7.2)

Therefore, when a risk analysis is carried out as a basis for emergency preparedness analysis, the following aspects shall be focused on:

- a) DUH shall be identified and extensively described.
- b) assumptions, premises and suppositions shall be identified and documented as a basis for establishing functional requirements to emergency preparedness.

The following aspects shall be clarified prior to starting the emergency preparedness analysis:

- a) The purpose of the analysis shall be clearly defined and shall correspond to the identified needs of the activity. The target groups for the analyses and their results must be defined.
- b) The scope of the analysis and its limitations must be clearly defined. The method is chosen on this basis.
- c) When quantitative analyses are used, the data basis in the planning phase has to be as adapted as possible to the purpose of the study.
- d) Operating personnel shall participate in the work to the extent necessary.
- e) The format of reporting and the documentation shall be suitable for ensuring an effective follow-up, control and development of the emergency preparedness.

All emergency preparedness requirements shall be satisfied for the DFU.

5.1.4 Risk Reducing Measures

Factors which may cause an accidental event shall as far as possible be removed and that risk reducing measures shall be evaluated for possible implementation in order to reduce each identified risk element.

Risk reducing measures include both probability reducing and consequence reducing measures, including emergency preparedness measures. The risk reducing measures may be of a technical, operational and/or organisational nature. The choice of types of measures will normally be based on a broad evaluation, where risk aspects are in focus. Emphasis shall be put on an integrated evaluation of the total effect that risk reducing measures may have on risk. Possible coupling between risk reducing measures shall be communicated explicitly to the decision-makers, if alternative measures are proposed.

General principles for setting up priorities for risk reducing measures:

- Probability reducing measures shall be given priority over consequence reducing measures whenever possible.
- Layout and system design shall be suitable for the operations and minimises the exposure of personnel to accidental effects.

The choice of risk reducing measures shall furthermore take into account the reliability and the vulnerability of the risk reducing measures and the possibility of documenting and verifying the estimated extent of risk reduction. Consequence reducing measures (especially passive measures such as passive fire protection) will often have a higher reliability than probability reducing measures, especially the operational ones.

The possibility of implementing certain risk reducing measures is dependent on factors such as available technology, the current phase in the activity and the results of cost benefit analysis. The choice of risk reducing measures shall therefore be explained in relation to such aspects.

Operational or organisational measures may, in the operational phase, compensate for the limited possibilities that exist for making major technical modifications.

5.2 Specific Requirements to Qualitative Risk Analysis

Examples of qualitative risk analyses are Safe Job Analysis, Failure Mode and Effect Analysis, HAZOP, "Driller's HAZOP", Preliminary Hazard Analysis, and simple comparative studies, etc. The steps of a qualitative risk analysis are:

- a) Planning of the analysis
- b) System description
- c) Identification of hazards
- d) Assessment of each hazard
- e) Identification of possible risk reducing measures

Fault Tree Analysis is sometimes carried out as qualitative analysis, i.e. without probability analysis. This is, however, an exception, and the applicable requirements are nevertheless presented in Section 5.3.

5.2.1 Planning of the Analysis

General requirements to the planning of risk analyses are presented in sections 5.1.1. and 5.1.2. Qualitative studies are usually carried out by a group of persons. Broad representation in the analysis group is important when several technical disciplines are affected by the analysis.

5.2.2 System Description

There is less emphasis on formal system description in a qualitative risk analysis than in a quantitative risk analysis, see also Section 5.3.4. It is nevertheless important to ensure that the group has a common understanding of the technical system being considered, including relevant operations.

5.2.3 Identification of Hazards

In a qualitative risk analysis, the identification of hazards shall be based on a broad review of potential causes of accidents, in order to ensure that the maximum number of hazards are identified.

5.2.4 Assessment of each Hazard

Assessment of each hazard is either done in combination with the identification of hazards, or separately in the next step. Again, it is important to stimulate the use of the total experience of the group members. Experience from accidents and incidents from the company's own files and data bases and, from public data bases such as Synergi, shall be put to use. Possible causes of accidents shall as far as possible be identified, as a basis for identification of risk reducing measures.

5.2.5 Identification of possible risk reducing measures

Any qualitative risk analysis shall seek to identify possible risk reducing measures as a basis for ranking and decision. The principles for giving priorities stated in Section 5.1.4 shall as far as possible be followed.

5.3 Specific Requirements to Quantitative Risk Analysis

5.3.1 Steps in a Quantitative Risk Analysis

The elements in a quantitative risk analysis are presented in Figure 5.2, which shows four levels:

Inner level: risk estimation

Second level: risk analysis

Third level: risk evaluation

Outer level: HES management

Requirements to the risk analysis and the risk estimation are presented in the following text, sections 5.3.2 - 5.3.13. The formulation of the risk acceptance criteria will determine which of the requirements in sections 5.3.9 - 5.3.12 that are applicable.

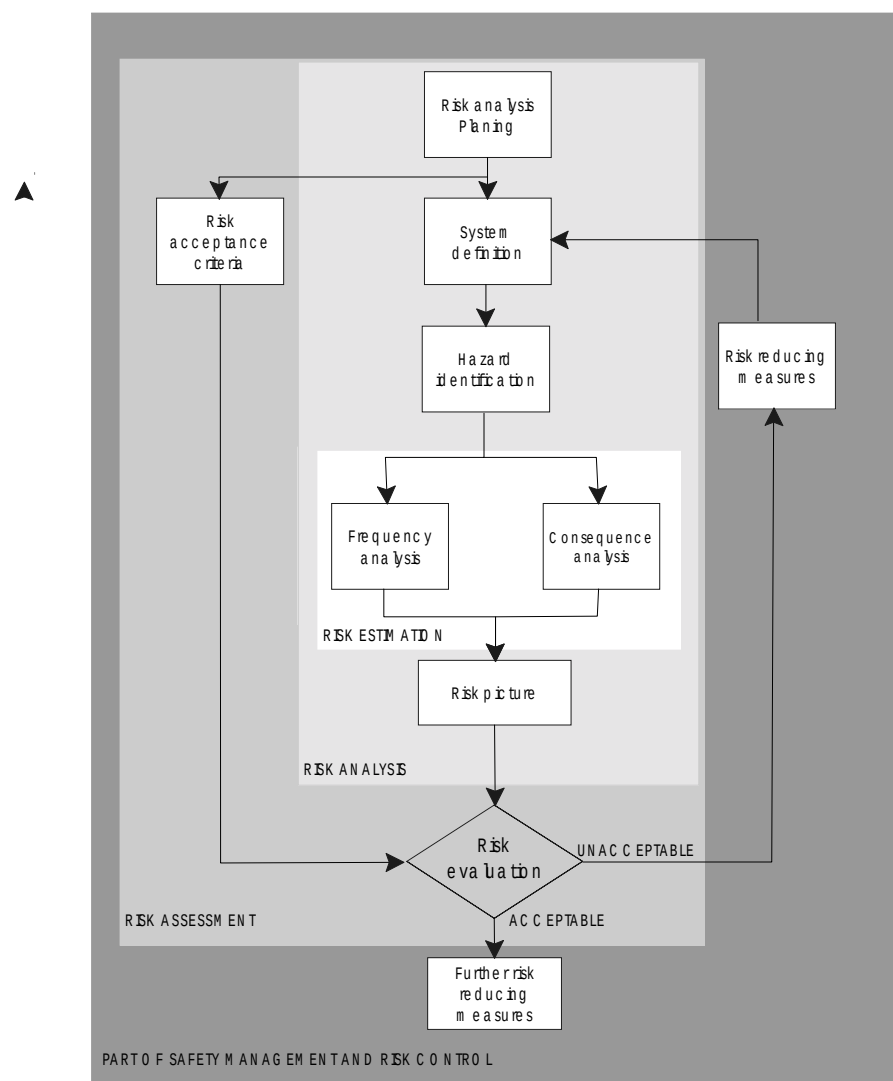


Figure 5.2 - Risk estimation, analysis and evaluation

5.3.2 Planning of Quantitative Risk Analysis

General requirements to the planning of risk analysis are stated in Section 5.1.1. Additional requirements to the planning of quantitative risk analysis are as follows:

- a) When quantitative risk analysis is carried out, the data basis needs to be adapted as far as possible to the purpose of the study. Data bases (local, national and international) need to be considered in this context, as well as use of relevant experience (internal and external).
- b) Prior to a decision to start a quantitative risk analysis, a careful consideration should be given to whether the data basis is sufficiently extensive to produce reliable conclusions.
- c) Simple comparative studies may sometimes be carried out without an extensive data basis.

5.3.3 Limitations of Risk Analysis

Quantitative risk analysis has certain limitations that need to be observed during the planning of such studies. The limitations of a risk analysis should usually be stated explicitly.

Limitations on the use of risk analysis will result from the way the general requirements, such as presented in this NORSOK standard, are adhered to. The following are general aspects that usually imply limitations:

- There has to be sufficiently broad basis of relevant data for the quantification of accident frequency or accident causes.
- The data usually refers to distinct phases and operations, which imply that the use of the data should not be made for other phases and operations.
- The depth of the analysis in the consequence and escalation modelling determines how detailed considerations that may be made for the systems and functions that are involved in the analysis.

The level of precision in the results shall not be more extensive than what is justifiable on the basis of the calculations, data and models which are available for the quantification of probability and consequence. This may imply that risk can not be expressed on a continuous scale when the estimation of either probability or consequence (or both) is based on categories.

5.3.4 System Description

The system description shall include:

- Description of the technical system, including the relevant operations and phases.
- Statement of the period of time to which the analysis relates.
- Statement of the personnel groups, the external environment and the assets to which the risk assessment relates.
- Capabilities of the system in relation to its ability to tolerate failures and its vulnerability to accidental effects.

5.3.5 Identification of Hazard

Hazard identification shall include:

- A broad review of possible hazards and sources of accidents, with particular emphasis on ensuring that relevant hazards are not overlooked.

- A rough classification into critical hazards (as opposed to non- critical) for subsequent analysis.
- Explicit statement of the criteria used in the screening of the hazards.
- Explicit documentation of the evaluations made for the classification of the non-critical hazards.

Possible tools for the hazard identification may be:

- Use of check lists and accident statistics,
- performance of HAZOP studies, HAZID, or similar,
- experience from previous analyses.

The participation of operational personnel, offshore and onshore, is particularly important.

5.3.6 Analysis of Causes and Frequency of Initiating Events

Analysis of possible causes of initiating events should be preferred to assessment of initiating event frequency based on accident and failure statistics. The cause analysis gives the best basis for identifying measures that may prevent occurrence of these events and thus prevent accidents.

Possible tools that may be used for the analysis of causes of initiating events are:

- Fault Tree Analysis
- Failure Mode and Effect Analysis

Cause analysis and/or frequency data for initiating events should include contributions from human and operational factors. 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.

The following requirements should apply when a frequency analysis has to be used:

- Data that are used have to be consistent with relevant operations and phases.
- The robustness of the data used shall be considered.
- Both the data and the models into which the data are applied, shall be suitable in relation to the context of the study.
- The extent of the data basis has to be sufficiently broad to produce robust conclusions.
- The use of data should take account of possible trends if they can be substantiated.

Analytical models and computer codes used, have to be suitable for the purpose and have a resolution which is adapted to the objectives of the analysis. The models must also comply with the operator's/owner's requirements to input data, assumptions, etc.

5.3.7 Consequence and Escalation Analysis

This term is used in a wide sense, including both consequence modelling (i.e. estimation of accidental loads), modelling of escalation and estimation of response to accidental loads. The distinction between cause analysis and consequence analysis may vary somewhat according to the purpose and the nature of the analysis.

A detailed consequence analysis usually consists of the following sub-studies:

- Leakage of inflammable substances

- calculation of release (amounts, rates, duration, etc.)
- calculation of spreading of leakages
- calculation of ignition potential
- fire load calculation
- explosion load calculation
- response calculation (sometimes this may be separate studies)
- Well blowouts (with respect to environmental loads)
 - calculation of releases
 - calculation of release duration
 - spill drifting calculation
 - calculation of 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
 - calculation of load distribution
 - calculation of impulse distribution
 - response calculation (may also be separate studies)
- 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.

Further details are presented in Annex B and C.

Relevant tools for consequence modelling in relation to fire and explosion are:

- CFD-methods (Computational Fluid Dynamics)
- analytical methods
- simulation methods (based on CFD or analytical methods)

Non-linear structural analyses are often used for external impacts, thereby making it possible to reflect structural reserve capacity beyond yield.

Qualified methods should be used, applying to analytical models, computer codes and data, which should be qualified by the operator/owner or by recognised institutions on his behalf. This may for instance be achieved through use of the "Model Evaluation Protocol" established by the "Model Evaluation Group" under the EU Commission.

Escalation analysis is closely integrated with consequence modelling and response calculation. Analysis or evaluation of safety systems forms part of the escalation analysis (see Section 5.3.8), in

order to assess the possibility or the premises for maintaining control of the sequence of accidental events.

As far as possible, contribution to failure from human and organisational factors shall be explicitly analysed, together with the contribution from such failures to dependent failures.

The following analysis methods are the most relevant ones for the escalation analysis:

- Event Tree Analysis
- Fault Tree Analysis
- Simulation/ probabilistic analysis

5.3.8 Assessment of Safety Critical Systems

Analysis or evaluation of safety critical systems is an important part of the escalation analysis, and are also carried out as an assurance activity for these systems.

An escalation analysis should as a minimum include a classification of the safety critical systems based on vulnerability to accidental events. A comprehensive analysis shall include identification and analysis of mechanisms of failure of these systems and their dependencies, in relation to relevant accidental events. Emphasis shall be given to analysis of the total system and dependent failures shall be integrated in the analysis of the safety critical systems.

5.3.9 Loss of Main Safety Functions

The analysis shall include evaluations of possible loss of main safety functions due to accidental loads, possibly by carrying out separate response studies. Main safety functions are discussed in Annex A, Sections A1.1, A2.8 and A4.1.2.

5.3.10 Estimate Risk to Personnel

The risk to personnel is often expressed as fatality risk, sometimes also as risk in relation to personal injury. The following fatality risk contributions are often estimated separately:

- immediate fatalities
- escape fatalities
- evacuation and rescue fatalities

It may also be considered to split the fatality risk contributions into areas according to where the fatalities occur. Fatality calculations may include:

- response of personnel to accidental loads
 - heat radiation
 - toxic gas, smoke, etc.
 - blast/impulse loads
- probabilistic simulation of evacuation and rescue operations

An estimate of the number of personnel injured in accidents is often required as input to emergency preparedness analysis. This may imply that the consequence analysis for personnel is extended to include injuries.

5.3.11 Estimate Environmental Risk

The following steps form part of an environmental risk assessment:

- Establish the distribution of release duration.
- Simulation of the drifting of oil spill for relevant scenarios.
- Estimate the effects on environmental resources.
- Estimate restoration times.

The risk to the environment shall be expressed as follows:

- For each Valued Ecological Component separately
- On an annual basis for continuous activities
- For activities that have a duration shorter than a year, the basis of the risk calculation shall be the duration of the activity.

Further discussion is presented in Annex C.

5.3.12 Estimate Risk for Asset Damage/Production Disruption

The following additional steps are carried out in order to estimate the risk for asset damage and deferred production:

- Establish the distribution for duration of accidental events (often an extension beyond the period of exposure of personnel)
- Calculate response in the form of equipment and structures.

Further details are presented in Annex E.

5.3.13 Documentation

The documentation of a quantitative risk analysis should include the following:

- 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 make them useful to all relevant target groups, including the work force. This may imply that different result presentations may be required for different groups.

5.4 Specific Requirements to Emergency Preparedness Analysis

5.4.1 Scope of Analysis

Emergency preparedness measures include measures directed at containing spills from minor or major releases. The basis for establishing the oil spill contingency including technical, organisational and operative measures (such as amount of booms and their storage location, dispersants, etc.) forms part of the emergency preparedness analysis efforts.

Dimensioning of the installation's capacity (including external vessels' capacities) for treatment of injured personnel is also part of the emergency preparedness analysis.

Operational limitations, to the extent that they are documented in procedures, instructions, etc. are taken into account when operational and environmental conditions are defined. Assumptions may have to be done, if the analysis is carried out prior to the formulation of such procedures. Any assumptions made in this respect shall be verified at the earliest possible convenience.

5.4.2 Steps in Emergency Preparedness Analysis

Figure 5.3 presents the steps of emergency preparedness analysis and establishment of emergency preparedness, in relation to input from the quantitative risk analysis. The starting point of the presentation is the integrated risk and emergency preparedness analysis, and it shows how the work may be carried out step by step in a field development project. This applicability is limited to dimensioning accidental events.

The steps of the emergency preparedness analysis are briefly described in sections 5.4.3 - 5.4.7.

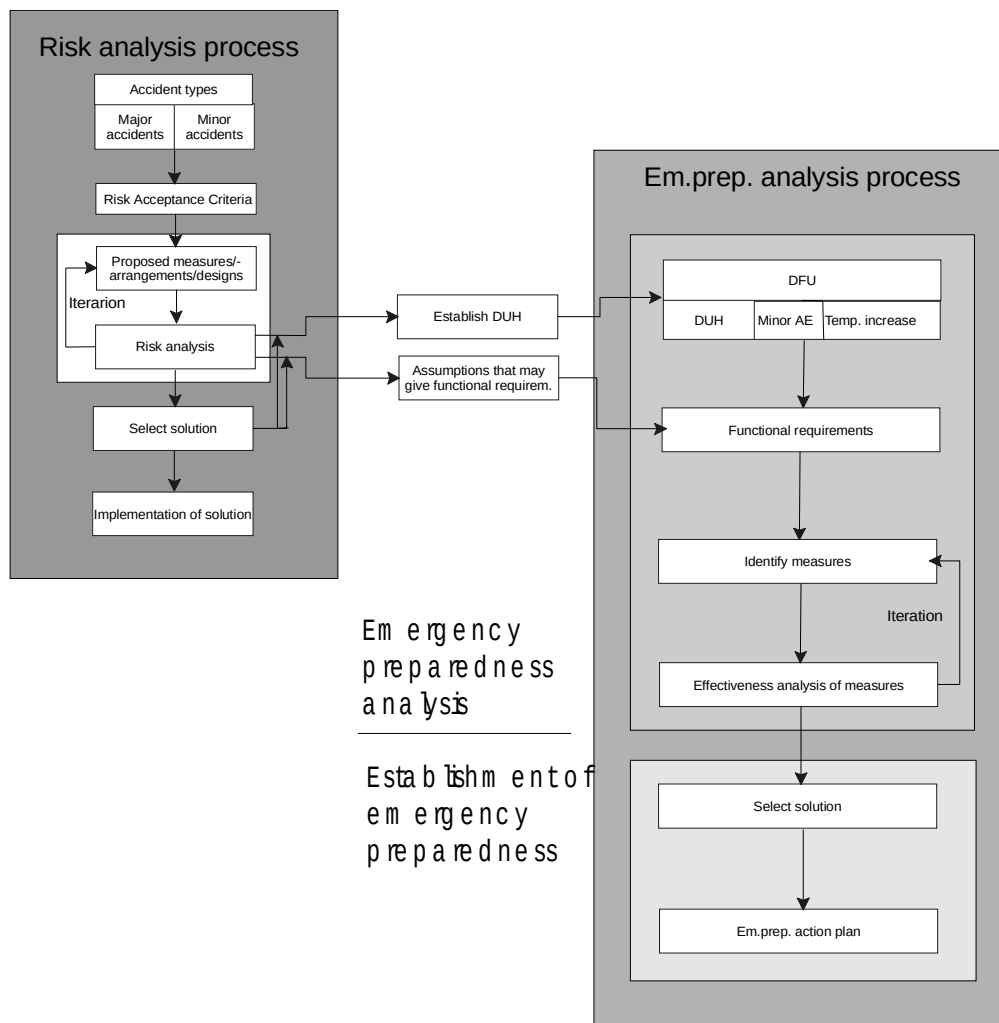


Figure 5.3 - Risk and emergency preparedness analysis

5.4.3 Identification of DFU

Defined situations of hazard and accident include the following event categories:

- Dimensioning accidental events (DUH), defined through quantitative risk analysis,
- Situations associated with temporary increase of risk,
- Less extensive accidental events, including acute cases of illness.

Dimensioning accidental events shall be defined through quantitative risk analysis as shown in Figure 5.3. The other event categories shall be established on the basis of:

- Events that have been experienced in comparable activities.
- Accidental events that appear in quantitative risk analysis without being identified as dimensioning accidental events, as long as they represent separate challenges to the emergency preparedness.
- Events for which emergency preparedness exists according to normal practice.

When defined situations of hazard and accident are being established, it will be important to include events that may mainly cause damage to assets without risk to personnel, such as damage to pipelines and subsea production systems.

The description of dimensioning accidental events from the quantitative risk analysis shall be detailed. In the description of situations associated with temporary increase of risk, or less extensive accidental events, the following shall be included:

- A general description of the situation in terms of duration and extent.
- The number of persons that may be threatened or injured, as well as environmental resources and assets that may be threatened or damaged.
- Operational and environmental conditions that may be present when these accidental events occur.

When dealing with not normally manned installation, distinctions also have to be made between those DFU that relate to personnel being present and those that relate to the installation being unmanned.

It is always possible to imagine combinations of circumstances that may have very unfortunate consequences. Quite different emergency preparedness requirements may be needed if such extremely remote combinations shall be taken into account. The most unlikely combinations of operational and environmental conditions will consequently be disregarded with respect to definition of defined situations of hazard and accident. The events to be included in the defined situations of hazard and accident are those that may reasonably be foreseen.

Choice of DFU shall be documented, in particular in relation to why they are considered to make a representative selection, and also those events that may have been omitted.

Further discussion in Annex D.

5.4.4 Information from Quantitative Risk Analysis

Information and results from quantitative risk analysis shall form part of the emergency preparedness analysis. Such information shall include:

- Description of those DUH for which organisational and operational measures shall be established.
- Time requirements that have to be satisfied.
- Required capacity, effectiveness and protection of systems that form part of the emergency preparedness.
- Assumptions on the success or suitability of emergency preparedness measures (such as assumptions on the possibility of assisting injured personnel on the installation or after initial escape).

Further details are included in Annex D.

5.4.5 Establish Functional Requirements

Functional requirements to emergency preparedness measures shall be:

- Easy to understand
- Explicit and measurable
- Realistic

The basis for establishment of the functional requirements is indicated by Figure 5.3, and includes results and premises from risk analysis, Design Accidental Events and Loads.

Functional requirements shall be established in relation to competence of personnel and the following emergency phases:

- Alert
- Danger Limitation
- Rescue
- Evacuation
- Normalisation

The functional requirements must be specified in a way which will allow them to be validated.

5.4.6 Identification of Measures and Solutions

Measures and solutions to be considered in an emergency preparedness analysis are:

- Organisational and operational measures related to dimensioning accidental events, possibly also technical measures not included in the risk analysis.
- Technical, organisational and operational measures related to less extensive accidental events as well as to temporary increase of risk.

The principles stated in Section 5.1.4 shall be used for giving priority to the risk reducing measures.

The basis for the identification of possible measures and solutions is i.a. knowledge about internal and external emergency preparedness resources, which therefore shall be described or referred to. All relevant resources within the following categories should be considered:

- Unit resources
- Area resources
- External resources

5.4.7 Effectiveness Analysis

The effectiveness of technical emergency preparedness measures may usually be documented through reliability or vulnerability studies. For the organisational or operational measures, the following methods may be applicable:

- Results of training
- Experience from exercises
- Calculation of capacities, response times, or similar.

It may be relevant to optimise the effectiveness on the basis of documented results. This is discussed in Annex E.

5.5 Competence of Analysis Personnel

Requirements as to the competence of personnel carrying out and evaluating the risk and emergency preparedness analysis shall be defined.

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.

For emergency preparedness analysis, personnel having competence in emergency preparedness analysis as well as in project and operational work shall be included in the analysis team. Risk analysts should also participate, in order to facilitate the integration of risk and emergency preparedness analyses.

5.6 Use of Results of Risk and Emergency Preparedness Analysis

Documentation of risk shall be formulated in the following manner:

- The information shall be understandable to all involved, decision-makers as well as operating personnel. The results and associated assumptions are to be presented in such a way that the decision-makers get a correct and balanced overview of the basis for the decisions to be made.
- Important assumptions and premises shall be stated explicitly, so that they may be evaluated and accepted.

When an analysis is carried out by external consultants, the operator or owner shall prepare his own assessment of the study's conclusions and recommendations. This document shall include plans for implementation of risk reducing measures, including emergency preparedness measures.

Assumptions and premises stated in the overall risk analyses (those that are carried out in order to compare results against risk acceptance criteria, see Definition 3.1.1) at an early stage of the design, shall be included as functional requirements for safety and emergency preparedness measures for later phases of the design project.

Documentation from risk and emergency preparedness analysis shall specify such functional requirements, in a way that makes them suitable for being used as dimensioning requirements.

Results of emergency preparedness analyses are primarily used for establishment of emergency preparedness, including emergency preparedness plans and training and exercise plans.

In addition, the results of the risk and emergency preparedness analysis shall be used for:

- Selecting optimum solutions between available alternatives.
- Designing risk reducing measures, including emergency preparedness measures.
- Documenting risk acceptability of the chosen solution.
- Designing basis for preventive safety measures.
- Carrying out cost benefit studies relating to improvement of safety and emergency preparedness.
- Preparing procedures for operations having critical importance for safety.

The format of the risk acceptance criteria will influence strongly the presentation of risk results. The presentation of result of a quantitative risk analysis shall further be comprehensive, allowing good insight into the mechanisms of risk causation.

The following documentation shall be available prior to start-up or operation of the installation/operation:

- Documentation of the measures that have been or will be implemented as a consequence of the analysis.
- Description of the risk and emergency preparedness analyses that are planned to be carried out or updated for the installation in the subsequent life cycle phase, as part of the overall HES management documentation.
- Description of plans for the verification of studies.

5.7 Verification of Functional Requirements and Risk Acceptance Criteria

Verification that functional requirements to safety and emergency preparedness systems are met in the operational phase may be achieved through monitoring trends for risk indicators as explained in Annex A, which should be monitored as a minimum once per year.

Possible deviations between functional requirements and registered parameter values shall be handled in accordance with the company's procedures for deviations. A possible action is to update the assumptions in the quantitative risk analysis, in order to identify the extent of the influence on overall risk.

6 RISK AND EMERGENCY PREPAREDNESS ANALYSIS FOR MOBILE UNITS

6.1 General

This phase includes drilling of exploration, appraisal and production wells from mobile drilling unit (MODU) as well as interventions and operations in subsea production systems. The purpose of the analyses is:

- Risk analysis
 - To evaluate if risk levels are in accordance with risk acceptance criteria for the operations in question, and in relation to the installation involved on the specific location and to the specific well conditions.
 - Optimisation of drilling and well intervention programs and activities.
 - Decisions as to the need for and extent of further risk reducing measures.
- Emergency preparedness analysis
 - Establishment of emergency preparedness, including updating of emergency preparedness analysis for the actual installation in relation to location and well specific conditions.

The target groups for the studies are the operational onshore organisation having the responsibility for the planning and management of drilling and well operations, possibly including the rig owner's

onshore organisation, as well as management and workforce on the installation and personnel having emergency preparedness planning responsibility.

The studies will normally be limited to the mobile installation involved in the operations, possibly including nearby vessels and installations, if the distance is such that accidental effects may affect them (or vice versa). Experience has shown that the personnel conducting the study must have extensive knowledge about relevant systems and operations.

6.2 Requirements to Risk and Emergency Preparedness Analysis

The operator or owner shall ensure that risk and emergency preparedness analyses for mobile installations meet the requirements to production installations, as stated in Section 6 and in Sections 7.1 - 7.5 of this NORSOK Standard. The studies shall be conducted in a manner that would satisfy the requirements stated by NPD as well as in the UK Safety Case and PFFER regulations.

The following studies shall normally be available for any drilling and well intervention operation:

- Risk analysis for the mobile installation, updated in accordance with the technical and operational status of the installation.
- Environmental risk analysis (either as separate study or integrated into overall risk analysis) in relation to relevant operations and exposed environmental resources.
- Emergency preparedness analysis for the installation with similar status with respect to operations and preparedness, including oil spill contingency.
- Vulnerability analysis for safety critical systems.
- Overall risk and emergency preparedness analysis focusing on specific aspects for the equipment to be used, planned operations and location specific conditions.
- Detailed blowout risk studies reflecting actual reservoir conditions, operational procedures and equipment to be used.
- Detailed risk studies of operations [other than possible blowout scenarios] and equipment to be used.

Studies of mobile installations may be conducted according to the revised "Guidelines for application of risk and emergency preparedness assessment for Mobile Offshore Units" issued by the Norwegian Shipowners' Association (*these Guidelines will be issued in an updated version in 1998 as a DNV RP - Recommended Practice*), or in another way as long as the requirements of the present NORSOK standard are satisfied.

7 RISK AND EMERGENCY PREPAREDNESS ANALYSIS IN LIFE CYCLE PHASES

This section is based on the general requirements outlined in the previous section and defines their implications for risk and emergency preparedness analysis in each life cycle phase. The use of risk acceptance criteria in the various life cycle phases is not discussed, this is presented in Annex A.

7.1 Analyses in Development and Operations

The table below presents an overview of the main analyses to be conducted during development and operations, including their timing and main objectives.

The requirements to analyses related to life cycle phases are discussed in the subsequent sections. A precise definition of each life cycle phase has not been made. The contents of each phase has undergone changes lately, and general definitions hardly exist. The phases which may overlap, are grouped together for the sake of argument, without any attempt to make clear distinctions. A brief statement of the objectives of the studies are included in the beginning of each section. This is included in order to state what contexts the studies are intended for, thus giving the background to the requirements stated.

Table 7.1 - Summary of main risk and emergency preparedness analyses

Analysis	Timing	Main purpose
Early risk analysis	Early planning phase Before decision to proceed	Comparisons of alternatives, assessment of compliance with overall risk acceptance criteria. Identification of concept features which can be cost driving if the risk acceptance criteria are to be met.
Concept risk analysis	When layout drawings and PFD's have been made. After decision to proceed, before submission of PDO	Assessment of compliance with acceptance and design criteria. Establishment of design accidental loads (to the extent possible).
Analyses in connection with design change proposals and the detailing of the concept	After concept risk analysis	Evaluate how changes etc. affect risk. As for concept risk analysis.
Total risk analysis (TRA) (reflects all the design change analyses)	When layout drawings, P&ID's for process and safety systems have been made. Before approval of project's budget frames, after submission of PDO. Verify and confirm DULs.	Verification of design and check of compliance with overall risk acceptance criteria (provide the assumptions for safe operation). Establish effectiveness requirements from assumptions and premises in analysis.
TRA updates	Operation	Update due to experience, modifications etc.
Risk analysis of critical operations, including Safe Job Analysis (SJA)	Planning of the operations (covers all phases, the analyses can be included in concept risk analysis or TRA)	Identification of hazards and possible risk reducing measures, to achieve safe job performance.
Emergency preparedness analysis including effectiveness analyses of emergency preparedness measures	In relation to all preceding studies.	Basis for design of the emergency preparedness.

ISO 13702 "Petroleum and natural gas industries - Offshore production installations - Control and Mitigation of Fires and Explosions - Requirements and guidelines" states requirements to risk assessment and implementation of measures in order to control risk in relation to fire and explosion on offshore installations. These requirements are relevant for development and operation.

7.2 Feasibility Study and Conceptual Design Phases

This section covers phases of feasibility studies and conceptual design work. Risk and emergency preparedness analysis are usually carried out separately in these phases. The main objectives of these studies are:

- Risk analysis
 - Comparison and ranking of field development concepts, possibly also including qualitative evaluations.
 - Optimisation of chosen concepts.
 - Identification of potential for achieving an acceptable solution or extra costs required to do so.
 - Assess whether the risk level of a given concept is in accordance with risk acceptance criteria, or whether the concept has the potential to meet these criteria.
 - Identify all major hazards.
- Emergency preparedness analysis
 - Identification of possible emergency preparedness aspects linked to the field development that may require extra costs to achieve an acceptable solution, or which may affect or imply special design requirements.

The target groups for the studies are decision-makers in relation to the field development concept.

A special case occurs when a pipeline system is being developed, or if alternative transportation means are considered, such as export by pipeline or tanker. Such projects require their own evaluations in relation to feasibility of the project and concept design. The purpose of the analysis are in this case:

- Risk analysis
 - Comparison and ranking of alternative transportation alternatives or routing alternatives for pipelines.
 - Comparison of alternative locations for riser or compressor platforms.
 - Optimisation of chosen transportation system, including pipeline routing.
 - Identification of potential for or extra costs that may be required in order to achieve an acceptable solution.
 - Assess whether the risk level of the concept is in accordance with risk acceptance criteria, or whether the concept has the potential in order to meet these.
- Emergency preparedness analysis
 - Identification of possible emergency preparedness aspects relating to the field development that may require extra costs in order to achieve an acceptable solution, or which may affect or imply special design requirements.

All relevant installations that are part of the production system, including mobile units and vessels that are involved in the operations, are comprised by the studies. It is particularly important at this stage to focus on non-traditional safety and emergency preparedness aspects. If relevant the need for

manned underwater operations in all phases of the activities, shall be evaluated and consequently be comprised by the studies.

The need for data as a basis for quantitative studies is not particularly extensive in these phases.

The following applies with respect to timing of the studies:

- Quantification of risk to personnel should be done at the earliest possible stage.
- Dimensioning accidental events shall be identified at the earliest possible stage, preferably in the concept design phase.
- Initial emergency preparedness analysis shall be carried out in the conceptual design phase.

Assumptions and premises on which the studies are based have to be documented extensively, as input to subsequent detailed risk and emergency preparedness analyses.

7.3 Engineering Phases

Pre-engineering and detailed engineering phases (or combinations) are included in this section. Risk and emergency preparedness analysis should to the largest possible extent be carried out as an integrated analysis, with the following objectives.

- Assess the risk level of the selected concept and its accordance with risk acceptance criteria.
- Identify dimensioning accidental events as basis for design of safety and emergency preparedness systems.
- Verify assumptions made in studies conducted in previous phases.
- Identify assumptions and premises as well as updated dimensioning accidental events as input to the establishment of emergency preparedness.
- Decide about the need for and the extent of further risk reducing measures.
- Initial establishment of technical, operational and organisational emergency preparedness for the part of DFU that is outside the dimensioning accidental events.
- Initial establishment of operational and organisational emergency preparedness for dimensioning accidental events.

The target groups for the studies are the decision-makers related to the field development, engineering management, engineering disciplines, relevant representatives of the workforce, as well as personnel being responsible for the planning and implementation of emergency preparedness.

The risk and emergency preparedness analyses cover relevant installations that form part of the production system, including mobile units and vessels that are involved in the operations, possibly also nearby vessels and installations if they are close enough to be affected by accidental effects. Further the need for manned underwater operations during all phases of the activities shall be evaluated. Emphasis should be set to make an assessment to what manned underwater operations the concept entails and to whether suitable technical solutions exists for the implementation of the concept in conjunction with contingency aspects.

In these phases, the need for data as a basis for quantitative studies will be quite extensive and cover a wide range of systems, reflecting the wide need for studies of vital systems and equipment. The requirements are equally comprehensive to the competence of personnel involved in the execution

as well as the review of the studies. Finally, the requirements to analytical models and software are correspondingly extensive. The general requirements are stated in Sections 5.1 and 5.2. Meeting these requirements is of great importance during the engineering phases, due to the extensive analytical work.

Qualitative studies like FMEA and HAZOP, etc. are often more extensive than quantitative studies.

The following applies with respect to timing of the studies:

- Quantification of personnel risk from feasibility study or concept design phases is updated and continued throughout the engineering phases.
- After completion of the conceptual design phase possibilities for improving the risk level significantly are limited. Therefore, acceptable solutions have to be found at this stage. However, the possibilities for increasing the risk are numerous also after the concept design phase.
- Updated emergency preparedness analysis shall be carried out in the detailed engineering phase.
- The final updating of risk and emergency preparedness analysis shall be carried out towards the end of these phases:
 - Update quantitative risk analysis reflecting the chosen solutions and systems.
 - Carry out the final emergency preparedness analysis.
 - Document the results from the emergency preparedness analysis in a suitable way, for all dimensioning accidental events and DFU, possible causes and effects of accidents for use in the operational phase.
- Qualitative studies shall be conducted continuously during these phases.

It is essential that assumptions and premises for the studies are clearly documented for the following purposes:

- Basis for subsequent updating of emergency preparedness analysis and establishment of emergency preparedness.
- Basis for establishment of emergency preparedness information.
- Basis for follow-up in subsequent fabrication and installation phases.
- Basis for follow-up in the operational phase.

The presentation of results from HAZOP studies shall include an overview of the responsibilities and a time schedule for the implementation of recommendations from the studies.

The requirements to result presentations are quite extensive and detailed in these phases, reflecting the extensive and varied contexts in which the result documentation is used. The quality of the studies will largely depend on close communication with all relevant disciplines in the project.

7.4 Fabrication and Installation Phase

This phase covers the fabrication of equipment and structures, hooking up, towing of modules, installation, commissioning and start-up preparations.

The risk and emergency preparedness analysis should as far as possible be an integrated one, with the following objective:

- Analyse particular aspects of the fabrication and installation that may entail loss of or severe damage to the entire installation and/or risk to personnel.
- Determine the emergency preparedness level for the fabrication and installation work.

The target groups for the studies are operational personnel having responsibility for the installation work, management and workforce on the installation, as well as personnel being responsible for the planning and implementation of emergency preparedness.

The studies will not be limited to the production installations, but will include all installations and vessels engaged in the installation and hook- up operations. They may also include nearby installations and vessels, if they are close enough to be affected by accidental effects.

The data basis for any quantitative risk analysis in these phases is often limited, since many of these operations are unique for the current project . Qualitative analyses will often be predominant, quantitative analysis may be done when sufficient data basis exists.

It may be a necessary to update the risk and emergency preparedness analysis made during the engineering phases, if the installations have been significantly changed during fabrication and installation.

7.5 Operational Phase

This phase includes normal operation, inspection, maintenance and limited modifications. The need for integrated risk and emergency preparedness analysis is determined by the extent of modifications. The objective of the studies is:

- To update risk and emergency preparedness analysis in order to ensure that they reflect relevant technical and operational aspects.
- To ensure that the risk level is kept under control.
- To ensure that operational personnel are familiar with the most important risk factors and their importance for an acceptable risk and emergency preparedness.
- To ensure that risk aspects in connection with ongoing operations and work tasks are being assessed and that necessary risk reducing measures are implemented.
- To ensure that the risk level is monitored according to updated risk analysis data bases, tools, methods and experience.

Qualitative studies shall be carried out when planning and preparing for work tasks that have vital importance for the operational safety.

The target groups for the studies are operative onshore organisation having responsibility for the planning and management of the operations, management and workforce on the installation, as well as personnel being responsible for the maintenance of the emergency preparedness.

The studies will not only be limited to the production installation, but will also cover nearby vessels and installations, if they are close enough to be affected by accidental effects.

The data basis for quantitative studies will in general be the same as for the engineering phases, but will in addition include data generated during the operation of the installation as well as new and

updated knowledge and experience. Risk indicators as outlined in Annex A are of particular importance in this context.

Requirements to the competence of the personnel who carry out and evaluate the quantitative risk and emergency preparedness analysis, their underlying assumptions, analytical models and computer codes, as well as result presentations, are the same as for the engineering phases. There are few specific formal requirements to the use of Safe Job Analysis, but it is important that the workforce and other operational personnel are actively involved in the work.

Updating of risk and emergency preparedness analyses shall identify needs for further risk reducing measures such as emergency preparedness measures, or in order to identify new areas for particular attention in the safety and emergency preparedness work of the activity.

Studies shall be updated in connection with major modifications or changes to area of application and also on the basis of:

- Experience from accidents that have occurred,
- Organisational changes,
- Changes to regulations.

The updating of analyses includes i.a. updating of:

- The installation and operations in accordance with the development of the activity .
- Assumptions and premises that the earlier analysis has been based on, and possibly further development (of these).
- Whether risk associated with special operations or new equipment that are being planned, has been assessed at an earlier stage.
- The data basis in the light of to new experience, new knowledge or changes in the data bases that have been used, including revision of experience data from own operations.
- The methodology which is used.
- The analysis results in the light of possible changes to the operator's/owner's risk acceptance criteria for the installation or operations.

The operator/owner shall formulate minimum requirements to the frequency of updating of the quantitative risk analyses and emergency preparedness analysis, unless technical or operational circumstances in the meantime have necessitated more frequent updating.

7.6 Modification and Reuse

A modification project will normally include the following phases, study phase, engineering, fabrication, installation, completion and operation. If the modification is very large compared to the existing use of the installation (reuse) the project should be treated as a new building project. Risks, risk acceptance and emergency preparedness shall address all phases involved.

The target groups for the studies are decision-makers in relation to the modifications, engineering personnel as well as operational management personnel and the workforce, in addition to personnel being responsible for updating and maintenance of emergency preparedness.

The studies will include all relevant installations engaged in the production system, including mobile units and vessels that may be involved in operations, possibly also nearby vessels and installations, if they are close enough to be affected by accidental effects.

During the study phase the feasibility of the planned modifications shall be assessed with respect to safety and risk acceptance. For smaller modifications this may be a qualitative risk analysis, while for larger modifications quantitative concept risk analysis as described in Section 7.1 and 7.2 may be required. For modification of process systems a HAZOP is required.

During engineering phases an integrated risk and emergency preparedness analysis shall be carried out as described in Section 7.3. However, it is sufficient to update only the parts of the existing analysis for the installation that is affected by the modification.

A separate integrated risk and emergency preparedness analysis shall be made for the time period when the modification work takes place on the installation.

In both of these analyses the additional risks from the modification work shall be added to the existing risk level on the installation and be compared to the risk acceptance criteria for the installation in question. DFU, DUH and DUL for the installations shall be updated and be applied for further design of safety systems and emergency preparedness for the modified installation.

For smaller modifications when it is obvious that the risk acceptance criteria will be met a qualitative risk and emergency preparedness analysis is sufficient also in engineering. The quantitative effect of the modification on the risk level may then be calculated at the regular updating of the quantitative risk and emergency analysis for the installation.

The analyses should identify operations where Safe Job Analysis should be carried out. The following special aspects shall be considered if they are relevant:

- increased number of personnel onboard during modification work
- increased number of personnel in hazardous areas
- risks associated with simultaneous operations during installation, modification and commissioning
- use of hot-work during modification work offshore contra use of flanges
- effect of habitats for hot-work
- dropped objects
- temporary unavailability of safety systems for modification work
- effect of modifications on ESD-system and process safety
- increase in number of leak sources and explosion loads due to more equipment
- human error

Otherwise the studies shall satisfy the general requirements to risk and emergency preparedness analysis given in this standard. An environmental risk assessment shall be included, if oil spill risk is involved.

7.7 Decommissioning and Disposal

This phase includes preparations for and execution of decommissioning and disposal activities in relation to production installations. The contents of this phase corresponds to the work in the fabrication and installation phases, see Section 7.4. When preparing for decommissioning and

disposal, there will usually be more emphasis on deliberations and comparison of alternative solutions. The following aspect shall therefore be emphasised in addition to what is mentioned in Section 7.2:

- Studies that compare alternative solutions with respect to risk and emergency preparedness.

There is often a so-called "cold" phase, without hydrocarbons, between decommissioning and disposal, often entailing considerable deviations from regulations, as equipment and systems are removed or deactivated. The most important risk aspects are often connected to the following preparations for the 'cold phase':

- use of divers,
- use of underwater cutting devices,
- manned operations in relation to heavy lifts and cutting operations.

Emergency preparedness in this period shall be determined according to a separate emergency preparedness analysis, where the following DFU shall be addressed as a minimum:

- Helicopter crash on the helideck or within the installation's safety zone
- Acute medical case
- Ship collision
- Man-over-board
- Occupational accidents

Further requirements are described in Section 7.4.

ANNEX A RISK ACCEPTANCE CRITERIA (INFORMATIVE)

A.1 High level risk acceptance criteria for Quantitative Analyses

This type of risk acceptance criteria is most commonly used in relation to overall risk studies in the conceptual design phase (previously known as 10^{-4} criteria), in engineering phases and in the operations phase. It will be required that relevant and quantifiable experience data are available for the analysis in order to enable comparison with quantitative risk acceptance criteria.

Requirements stipulated in standards, specifications, procedures etc. which are necessary to achieve acceptable safety, shall not be interpreted as risk acceptance criteria. However, such requirements will be important premises in relation to the risk analysis in order to achieve an acceptable level of risk.

The basis for the formulation of risk acceptance criteria shall include:

- a) the regulations that control safety within the activities,
- b) recognised norms for the activity,
- c) requirements for risk reducing measures,
- d) knowledge about accidents, incidents and consequences of these,
- e) experience from own or similar activity.

Section 4.2 in the normative text presents an overview of the high level expressions of risk to which risk acceptance criteria may be tied. Section 5.2 outlines briefly the use of decision criteria for more limited risk analysis.

The decision context (in relation to phase, activity or system) and the need for decision support are aspects that need to be considered when choosing the risk acceptance criteria. In addition, the criteria have to reflect the approach to risk analysis, and finally be consistent with previous use within the company.

Some petroleum examples of decision support contexts into which risk analysis may play a role can illustrate the choice of risk acceptance criteria:

- a. In relation to decisions regarding the overall operations of an installation, the total risk potential has to be considered. The risk acceptance criteria that are relevant will usually be quantitative (for example FAR values) or semi-quantitative (such as risk matrix). These criteria enable the reflection of many different scenarios and the aggregation of these into one or a few characteristic values.
- b. One overall risk value is preferable for instance for the comparison of two alternative field development concepts, with respect to risk for personnel. PLL may in these circumstances be suitable, as this criterion also allows for different manning levels for the options being considered.

- c. Risk analysis or safety evaluation is often performed as one of the inputs for design development within an engineering project. Changes to the design will usually imply changes to the risk picture. The risk acceptance criteria should be formulated in such a way that these changes may be registered. Use of criteria related to impairment of safety functions will enable calculation of how the impairment frequency is changed according to design changes (e.g. in connection with relocation of equipment).

The risk acceptance criteria may be subdivided in categories according i.a. to the purpose and the level of detail of the analysis:

- High level risk acceptance criteria for quantitative studies
- Risk matrixes and the ALARP principle
- Risk comparison criteria

A.1.1 Risk acceptance criteria related to Main Safety Functions

The probability of defined main safety functions being impaired (damaged) is calculated in order to ensure that the platform design does not imply unacceptably high risk, and to provide input to the definition of dimensioning accidental loads. This has often been done within the concept risk analysis.

Example:

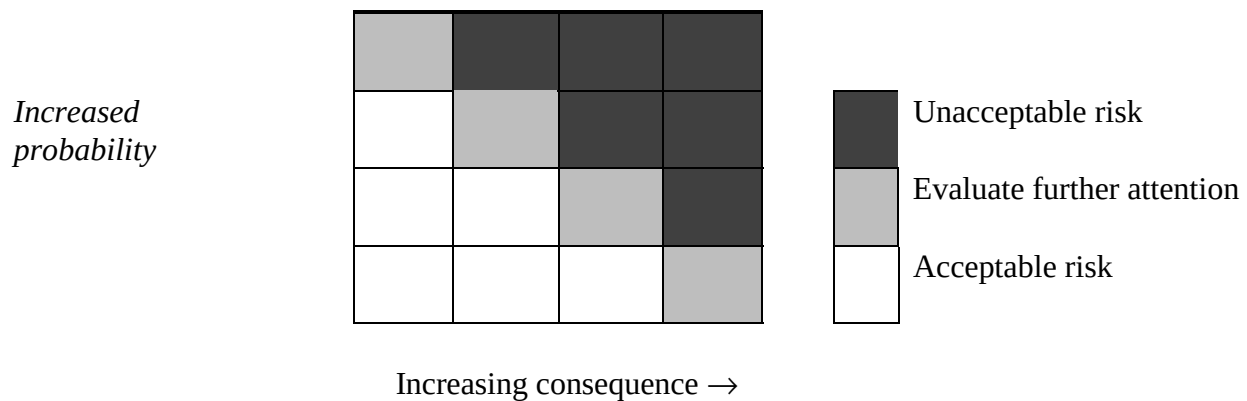
- The frequency 1×10^{-4} per year for each type of accidental load has been used frequently as the limit of acceptability for the impairment of each main safety function. Sometimes one prefers an overall frequency summing up all accidental load types. For these purposes an overall frequency of 5×10^{-4} per year has been used as the impairment frequency limit.

The main safety functions and their required functionality have to be defined separately for each installation. The exposed areas that are defined in relation to these criteria are often those separated by H-0 fire partitions. Sometimes such an area may be quite extensive and a further subdivision may be done. Such a subdivision within a fire area will be based on possible accidental effects and their extension. The exposed area may in these cases vary according to the type and the magnitude of the accidental events.

A.1.2 Risk Matrixes

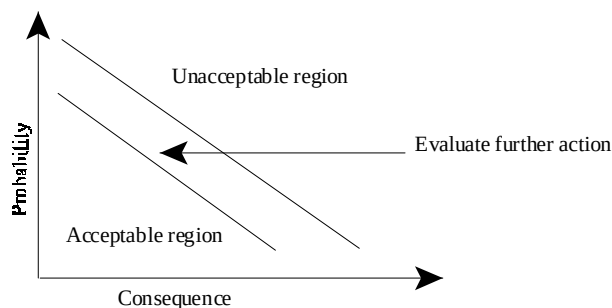
The arrangement of accident probability and corresponding consequence in a matrix (see figure A1) may be a suitable expression of risk in cases where many accidental events are involved or where single value calculation is difficult. The matrix is separated into three regions as follows:

- Unacceptable risk
- Acceptable risk
- A region between acceptable and unacceptable risk, where evaluations have to be carried out in order to determine whether further risk reduction is required or whether more detailed studies should be done first of all.

**Figure A1. - Risk matrix**

The limit of acceptability is set by defining the regions in the matrix which represent unacceptable and acceptable risk. The risk matrix may be used for qualitative as well as quantitative studies. If probability is classified in broad categories such as «rare» and «frequent» and consequences in «small», «medium» and «catastrophic», the results from a qualitative study may be shown in the risk matrix. The definition of the categories is particularly important in case of qualitative use.

The categories and the boxes in the risk matrix may be replaced by continuous variables, implying a full quantification. An illustration of this is shown in figure A2.

**Figure A2. - Risk matrix like presentation with continuous variables**

The following are examples of situations where the use of risk matrix is natural:

- Evaluation of personnel risk for different solutions such as integrated versus separate quarters platform
- Evaluation of risk in relation to operations such as exploration drilling
- Evaluation of risk in relation to a particular system such as mechanical pipe handling
- Evaluation of environmental risk.

A.1.3 f-N Curves

The f-N curve (f = frequency, N = number, i.e. measurement of consequence) expresses the acceptable risk level according to a curve where the frequency is dependent on the extent of

consequences (such as number of fatalities per accident). The acceptance limit may be adjusted according to the resource which is exposed. The f-N curve used as an acceptance limit may reflect aversion to major accidents (with multiple fatalities), if the curvature is different from an "iso-risk" line (along which the product of f and N is constant). The calculation of values for the f-N curve is cumulative, i.e. a particular frequency relates to "N or more" fatalities. Figure A3 presents an illustration.

The f-N curve may be used in relation to risk acceptance for personnel, environment and assets.

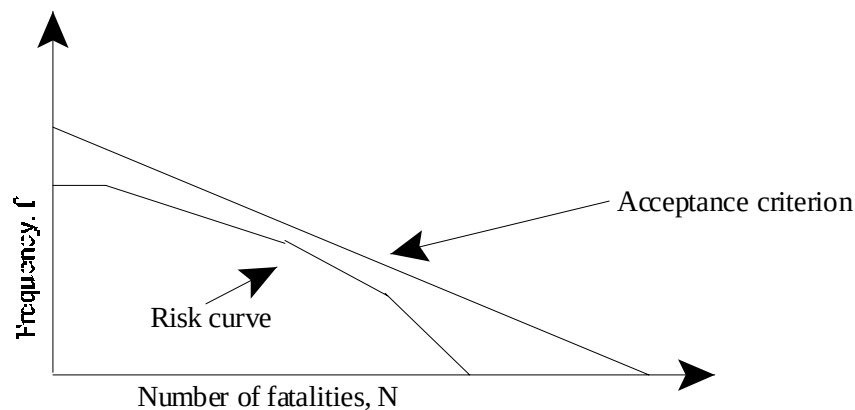


Figure A3. f-N curve

A.1.4 ALARP-principle

The ALARP ("As Low As Reasonably Practicable", see fig. A4) principle is sometimes in the industry used as the only acceptance principle and sometimes in addition to other risk acceptance criteria.

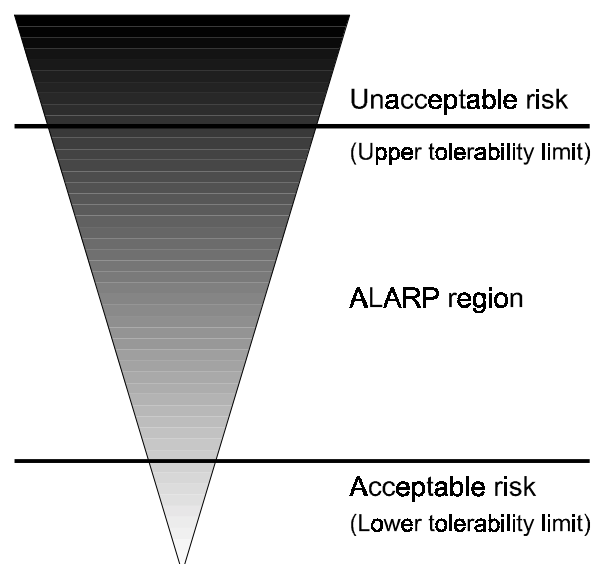


Figure A.4. The ALARP-principle

The use of the ALARP principle may be interpreted as satisfying a requirement to keep the risk level "as low as possible", provided that the ALARP evaluations are extensively documented.

The risk level shall be reduced as far as possible in the interval between acceptable and unacceptable risk. The common way to determine what is possible is to use cost-benefit evaluations as basis for decision on whether to implement certain risk reducing measures.

The upper tolerability limit (see fig. A4) is almost always defined, whereas the lower tolerability limit may sometimes be left undefined. This will not prohibit effective use of the approach, as it implies that ALARP evaluations of risk reducing measures will always be required.

The ALARP principle used for risk acceptance is applicable to risk to personnel, environment and assets.

A.1.5 Comparison Criteria

This type of criteria is suitable in more limited studies which aim at comparing certain concepts or solutions for a particular purpose with established or accepted practice. Often our risk studies for such purposes are relatively limited, implying that this type of risk acceptance criteria will be the most suitable. The criteria are suitable in relation to operations which are often repeated such as drilling and well interventions, heavy lift operations, diving etc. The use of the comparison criteria requires that the basis of the comparison is expressed relatively precisely.

The formulation of the acceptance criterion in this context may be that the new solution shall not represent any increase in risk in relation to current practice.

Examples of comparison criteria are:

- Alternative design (or use of new technology) for fire water system shall be at least as safe as conventional technology.
- The risk level for the environment shall not be higher compared to existing solution.
- Alternative solution shall be at least as cost effective as the established practice.

This type of risk acceptance criteria is also suitable for risk to personnel, environment and assets.

A.2. Aspects in relation to choice of high level Risk Acceptance Criteria

A.2.1 Overview

The use of the risk acceptance criteria will always influence strongly the selection of the type of criteria. Quite often conflicting interests are involved. On one hand the risk acceptance criteria may be needed as basis for decisions on risk reducing measures both in engineering and operational phases. On the other, the criteria should enable comparison of the risk level with other types of risk.

The following table illustrates some of the important aspects in choosing risk acceptance criteria and how these may be in conflict:

Aspect	Advantages and disadvantages of particular criteria
Suitability for decision support	Risk acceptance criteria that are simple to use in a decision-making process are often precise and associated with particular features of an installation or an activity. Such risk acceptance criteria are suitable for measuring the effect of risk reducing actions and other changes to design or operations.
Adaptability to communication • easy to understand for non experts • comparison of risk with other activities	Adaptability to communication implies how the risk acceptance is interpreted and understood among all involved parties: those that are exposed to the risk, the management of the company, authorities, the public etc. A message may be transmitted easily if the risk acceptance criteria are easy to understand. On the other hand, acceptance criteria which appear easy to understand may represent an oversimplification if the decision problem is very complicated or difficult to understand. Risk acceptance criteria that are easy to understand may be ambiguous due to a low level of precision. Risk acceptance criteria that express a societal dimension will often enable comparison with other activities in the society. Such risk acceptance criteria are often related to parameters that belong far out in the event sequence (such as fatalities).
Unambiguity • precision • system limits • averaging	Unambiguous risk acceptance criteria are often precisely defined with respect to calculation of risk and to the applicable system limits. They are usually not subject to extensive averaging and will therefore rarely be misunderstood.
Concept independence	Risk acceptance criteria that are concept independent will not favour one particular concept solution but be neutral in relation to such a choice.
Uncertainty	Risk parameters that are far out in the event sequence will often involve the highest degree of uncertainty. Estimates will have to be made for each element in the event sequence, implying the most extensive computational uncertainty for the last elements. On the other hand, these risk parameters express the highest level of detail and will therefore often give the best basis for decisions.

The parameters most commonly used as risk acceptance criteria are discussed in the following subsections in relation to the quality parameters outlined in the table above. First of all some of these quality criteria are discussed a more detail.

A.2.1.1 Suitability for decision support

The most important requirement to a risk acceptance criterion is its ability to provide basis for decision on the implementation of risk reducing measures. Therefore they have to express the effect of risk reducing measures.

The ALARP principle may be used in this context to decide on the implementation of risk reducing measures, provided that the risk level is below the upper tolerability limit. The ALARP principle implies that decisions are based on cost-benefit evaluations (see definition 3.1.3 as well as Annex

E). The cost-benefit ratio is in a wide context the sum of all resources employed compared to all the effects gained.

A.2.1.2 Adaptability to communication

This implies that non experts shall be able to understand the risk acceptance criteria . The risk acceptance criteria should also enable comparison of risk from other activities.

In order to achieve an effective HES management there is a clear need for communicating risk acceptance criteria as well as risk analysis results to non experts. Such non experts will include operational management, work force representatives, other engineering disciplines' work force, the society/public at large or other third parties.

A.2.1.3 Unambiguity

Ambiguity problems may be associated with:

- Imprecise (inaccurate) formulation of the risk acceptance criteria
- definition of system limits for the object of the analysis
- different ways of averaging the risk

Precision

If for example acceptance is related to loss of main safety functions or escalation, this requires explicit definitions of the implications in relation to accidental effects.

System limits

The limits for the activity will have to be defined in relation to what the risk acceptance criteria shall be valid for. Examples may include one single installation or all installations that are operated by the same crew. Different system limits for an installation and for the risk acceptance criteria may sometimes cause doubt about the application.

Problems may also arise in relation to manned or not normally manned installations, development of a field with one large or several smaller installations, subsea production systems versus platform based systems, full processing offshore compared to partial processing onshore, etc. All these aspect may affect the choice of the system limits.

The formulation of the risk acceptance criteria may in some cases favour certain concept solutions, due to the way in which the risk levels are calculated. Risk acceptance criteria for personnel may for instance be aimed both at personnel being directly exposed and at personnel outside the area where accidents may occur. Such criteria may favour large integrated installations rather than smaller and simpler installations, or vice versa.

Averaging of risk

There must be some flexibility involved in the application of risk acceptance criteria, therefore certain forms of averaging will be required.

Risk may be averaged for example over:

- time (such as averaging over time of the year, one typical year in the entire lifecycle, the duration of a particular operation or the entire operations phase)

- installations (such as averaging over installations that are bridge connected or otherwise operated as one unit)
- areas on one installation (such as averaging over all areas or all process areas)
- groups of personnel (such as averaging over all drilling personnel, all process operators or other groups onboard).

This implies that a higher level of risk may be acceptable if the exposure is limited to a short duration or limited to a small part of the installation or that only a small group of all people onboard are exposed. The choice of averaging may influence the results of the risk analysis, for example the same drilling program with the same number of wells will still yield different blow-out risks if the drilling is carried out in periods with different duration.

It would be unsuitable to give too prescriptive rules for how the averaging may be done. Peaks in the risk levels that are eliminated through averaging should not be too high in relation to the average value and they should have a short duration compared to the period over which the averaging occurs. In any case, peaks in the risk level should be analysed and presented separately. It will be important to decide whether risk acceptance criteria shall apply to an average period, the most exposed period, the most exposed personnel etc. Most often an average year is used but expression of risk for the worst year and for the most exposed personnel will always give a more differentiated presentation.

A.2.1.4 Uncertainty

Results of a risk analysis will always involve some uncertainty, which may be attributed to the relevance of the data basis, the calculation models or the assumptions, premises and expert evaluations that are done.

There will always be considerable uncertainty as to whether certain events will occur or not, what the immediate effects will be and what consequences may be caused for personnel, environment or assets. This uncertainty reflects the insufficiency of the information and knowledge available for the analysis at an early stage, in relation to technical solutions, operations and maintenance philosophies, logistic premises etc. The uncertainty will be reduced as the field development project progresses.

The calculation of events sequences for risk from an initiating event may be illustrated as follows:

Causes $\Rightarrow$ Event $\Rightarrow$ Physical accidental loads $\Rightarrow$ Physical consequences $\Rightarrow$ Damage

One example of risk calculations relating to event sequence:

Event		Physical accidental loads		Physical consequence		Damage
Leak	$\Rightarrow$	Fire load, x kW	$\Rightarrow$	Fire loads on escape way	$\Rightarrow$	Fatalities

(The causes of events are often omitted in an analysis, causes of a leak may for example not be addressed particularly).

The amount of assumptions that have to be made will usually increase as one gets further down the accident sequence and more and more uncertainty is introduced. Risk expressions related to physical accidental loads or physical consequences are therefore somewhat less uncertain than risk expressions related to fatality risk. This should also be considered when choosing the risk parameters for which acceptance limits will be established.

The way to treat uncertainties in the analysis should be defined prior to performing this evaluation. Full quantification is usually not performed (and is often impracticable), more often sensitivity studies are carried out in relation to critical assumptions and factors in the analysis.

The comparison to risk acceptance criteria should usually be made in relation to «best estimate» from the risk analysis rather than to an optimistic or pessimistic result of the studies.

The evaluation of risk also depends on the knowledge and the information available to the analyst as well as to the decision makers. The evaluation of the uncertainty in the results will therefore vary according to the different persons involved.

A.2.2 Potential Loss of Life (PLL)

The *PLL* value is the statistically expected number of fatalities within a specified population during a specified period of time.

Aspect	Advantages and disadvantages of <i>PLL</i>
Suitability for decision support	<i>PLL</i> is well suited for comparing alternative solutions for the same development objective.
Adaptability to communication • easy to understand for non experts • comparison of risk with other activities	<i>PLL</i> is relatively easy to understand for non experts due to its calculation of an absolute level of fatalities. However, this acceptance limit does not consider the number of individuals in the population. This has to be observed carefully when comparing with other activities, especially if the number of individuals is different.
Unambiguity • precision • system limits • averaging	It is usually possible to define the <i>PLL</i> unambiguously <i>PLL</i> is not well suited for averaging differences between personnel groups etc.
Concept independence	The <i>PLL</i> value will often favour the development concept that has the lowest manning level implying that a lower number of individuals are exposed to risk.
Uncertainty	The <i>PLL</i> value is, calculation wise, at the far end of the event chain and has therefore the highest level of uncertainty, more so than frequency of <i>impairment of main safety functions</i> and <i>frequency of escalation</i> . <i>PLL</i> is less uncertain than <i>FAR</i> values due to the omission of the averaging over persons.

A.2.3 *f*-N curves

The *f*-N curves are usually a graphic representation of the cumulative frequency distribution for the number of fatalities in the risk calculations that have been performed, see also section A1.3.

Aspect	Advantages and disadvantages of <i>f</i> -N curves
Suitability for decision support	The <i>f</i> -N curves may be difficult to use in relation to risk acceptance if the limit is exceeded in one area but otherwise well below.
Adaptability to communication • easy to understand for non experts • comparison of risk with other activities	The cumulative expression of the <i>f</i>-N curve makes it somewhat difficult to comprehend. The <i>f</i>-N-curves may to some extent be suitable for comparison as long as corresponding curves can be expressed for other activities. They lack however, in the same way as <i>PLL</i>, the ability to relate the risk to the number of exposed individuals.
Unambiguity • precision • system limits • averaging	Unambiguous definition should be possible.
Concept independence	Acceptance criteria based on <i>f</i> -N curves may be formulated in a way that favours e.g. concepts with low risk potential to major accidents. However, such criteria may also be defined so as to be concept independent.
Uncertainty	As for <i>PLL</i> .

A.2.4 Fatal Accident Rate (FAR)

The FAR value expresses the number of fatalities per 100 million exposed hours for a defined group of personnel.

The FAR is often used as a risk parameter. Several variants are used, mainly reflecting how the averaging of the risk level is done.

A.2.4.1 FAR for an entire Installation

The FAR value for an entire installation is the number of expected fatalities per 100 million exposed hours for one or several specified installations. The risk level is averaged over all positions onboard.

Aspect	Advantages and disadvantages of <i>FAR for an entire installation</i>
Suitability for decision support	The <i>FAR value for an entire installation</i> is not very suitable for decision support with respect to reflection of the effect of risk reducing measures. This is due to the averaging over all exposed personnel, which means that limited effects usually will disappear almost entirely. (<i>Area FAR</i> is more suitable in this context).
Adaptability to communication • easy to understand for non experts • comparison of risk with other activities	The <i>FAR value</i> is relatively easy to comprehend for non experts. The <i>FAR value</i> is the easiest of all parameters for comparison with risk for other activities.
Unambiguity • precision • system limits • averaging	The <i>FAR for an entire installation</i> is unambiguously defined, but the averaging over the entire installation may imply a somewhat inaccurate reflection of the risk picture.
Concept independence	<i>FAR for an entire installation</i> will favour a concept with high manning level in a low risk area, thereby implying that the risk level may be high in some smaller areas without necessarily showing an effect on <i>the FAR for an entire installation</i> .
Uncertainty	The calculations required to establish the <i>FAR for an entire installation</i> include calculation all through the event chain, in addition to averaging over all exposed personnel onboard. The uncertainties in the results are therefore relatively high.

A.2.4.2 FAR for a group with uniformed risk exposure

The *Group-FAR* is the expected number of fatalities per 100 million exposed hours for the group in question.

Aspect	Advantages and disadvantages of group FAR
Suitability for decision support	More suitable than <i>FAR for an entire installation</i> (see section A2.4.1), because the <i>group FAR</i> averages over a smaller number of positions.
Adaptability to communication • easy to understand for non experts • comparison of risk with other activities	Similar to <i>FAR for an entire installation</i> , however this value and the <i>group FAR</i> are often mixed together unintentionally.
Unambiguity • precision • system limits • averaging	As <i>FAR for an entire installation</i> but with a higher precision level than the former as to the averaging.
Concept independence	Less concept dependent compared to the <i>FAR for an entire installation</i> , <i>PLL</i> and <i>f-N curves</i> due to its focusing on a smaller group of personnel.
Uncertainty	Uncertainty is relatively high as all <i>FAR</i> calculations apply far out in the event sequence. The <i>group FAR</i> is better than the <i>FAR for an entire installation</i> due to its averaging over a smaller group.

A.2.4.3 FAR for a physically bounded area

The *area-FAR* is the expected number of fatalities per 100 million exposed hours in a physically bounded area.

Aspect	Advantages and disadvantages of area FAR
Suitability for decision support	Better suited than <i>PLL</i> , <i>f-N curves</i> , <i>IR</i> , <i>FAR for an entire installation</i> and <i>group FAR</i> due to its focusing on one specific area on the installation.
Adaptability to communication • easy to understand for non experts • comparison of risk with other activities	Difficult to compare with other activities because area definitions will vary. Alternatively a comparison will have to be done area by area.
Unambiguity • precision • system limits • averaging	As <i>FAR for an entire installation</i> in relation to precision and system limits. Considerably better than the <i>FAR for an entire installation</i> as to averaging of the risk.
Concept independence	As for <i>group FAR</i> .
Uncertainty	As for <i>group FAR</i> except that the averaging is different.

A.2.5 Individual Risk (IR)

Individual Risk (IR) is the probability that a specific individual (for example the most exposed individual in the population) shall suffer a fatal accident during the period over which the averaging is carried out (usually a 12 month period).

It is often difficult in practice to calculate the risk level for a specific individual and the calculations are therefore often carried out for an «average individual». *IR* will then be proportional to the *group FAR*.

Aspect	Advantages and disadvantages of IR
Suitability for decision support	<i>IR</i> for a single individual (average individual) is relatively well suited for decisions relating to actions that may affect such an individual, because the effects will be explicitly reflected.
Adaptability to communication • easy to understand for non experts • comparison of risk with other activities	Relatively simple to comprehend for non experts and relatively easy to compare with risk for other activities as long as the risk level is expressed for a single individual.
Unambiguity • precision • system limits • averaging	There may be problems involved in defining the precise exposure for a certain individual. <i>IR</i> implies limited averaging corresponding to that of area <i>FAR</i> .
Concept independence	Less dependent on the actual concept compared to the <i>FAR for an entire installation, PLL</i> and <i>f-N curves</i> .
Uncertainty	Like the other risk parameters relating to personnel <i>IR</i> will be associated with relatively high uncertainty as the entire accident sequence needs to be quantified.

A.2.6 Risk Matrix

The risk matrix usually has consequence categories along one of the axes and probability or frequency along the other axis. The consequences may be defined in relation to personnel, environment or assets, or to a combination of these.

Aspect	Advantages and disadvantages of risk matrix
Suitability for decision support	Not particularly suitable for decision-making because the risk is expressed on a coarse scale and often subjectively expressed. Thus several risk reducing actions may be taken without having any effect on the risk matrix.
Adaptability to communication • easy to understand for non experts • comparison of risk with other activities	Easy to comprehend for non experts. Implies a visual representation of the risk. Not necessarily suited for comparison with other activities as the risk matrix is often tailored specifically to the actual study. Often used in relation to limited problems.
Unambiguity • precision • system limits • averaging	Should be possible to formulate unambiguously, but has often a low level of precision due to the risk matrix' relatively coarse categorisation into groups and the absence of detailed calculations.
Concept independence	Definition of the consequence categories and the distinction between unacceptable and acceptable risk will determine whether the <i>risk matrix</i> favours any particular concept.
Uncertainty	The <i>risk matrix</i> is relatively insensitive to uncertainty as the separation into categories is relatively coarse and the possibility of ending up in the wrong cell is relatively low.

A.2.7 Escalation Frequency

The *escalation frequency* is the frequency of events implying that an accident escalates, e.g. from one area into the neighbouring area. One example may be the frequency of gas leaks in an area which may entail impairment of the fire division between these two areas. It may be useful to relate the frequency to a time period such as escalation into a neighbouring area within two hours after initiation of a fire.

Aspect	Advantages and disadvantages of the escalation frequency
Suitability for decision support	This is a typical design related criterion . Well suited for representation of improvement due to technical design changes, but less suitable for representation of the effect of procedural and organisational measures. Not particularly suitable in the operations phase, because technical systems at that stage are fixed.
Adaptability to communication • easy to understand for non experts • comparison of risk with other activities	The <i>escalation frequency</i> is easy to understand, but is not very suitable for comparison with risk in other activities.
Unambiguity • precision • system limits • averaging	The <i>escalation frequency</i> in relation to well defined and well separated areas is unambiguous but with regard to escalation within one single area, between process segments etc., it may be less clear.
Concept independence	In principle independent of concept, but will naturally contribute to solutions that will reduce the escalation frequency, dependent on how the areas are defined.
Uncertainty	The uncertainty is more limited as compared to the personnel risk parameters as it is determined earlier in the event sequence. May however, to some extent, depend on how escalation is defined.

A.2.8 Loss of Main Safety Function

The frequency of *loss of the main safety functions* is the frequency of accidental events that lead to impairment of the main safety functions. Typical main safety functions are escape ways, evacuation means, the main support structure and the control room function.

Aspect	Advantages and disadvantages of the ' <i>loss of main safety functions</i> '
Suitability for decision support	Represents a typical design related criterion which is well suited for decision-making on technical measures. Better than the escalation frequency criterion in the operations phase because non technical measures may also influence the frequency of <i>loss of main safety functions</i> , probably with a higher uncertainty than for technical measures.
Adaptability to communication • easy to understand for non experts • comparison of risk with other activities	The term <i>loss of main safety functions</i> is relatively easy to understand for non experts, but requires a good definition of how the main safety functions may be impaired. Is not suitable for comparison of risk with other activities.
Unambiguity • precision • system limits • averaging	Should be possible to formulate this in an unambiguous way.
Concept independence	In principle independent of the concept but will obviously contribute to solutions that will minimise the frequency of loss of the defined main safety functions.
Uncertainty	The defined <i>main safety functions</i> will have to be accurately determined, in relation to which circumstances and loads that will imply loss of the function. Uncertainty is otherwise comparable to escalation frequency.

A.3 Other Aspects

A.3.1 Establishment of an Acceptable Level

There is a general requirement to document the basis for establishment of risk acceptance criteria. This will also simplify a future updating of the criteria.

The level of precision in the formulation of the risk acceptance criteria will depend on the need for input to decision-making. Risk analyses will be carried out on different levels of detail and in different lifecycle phases, for limited specific decisions and for complete installations. The

acceptance criteria must be suited for covering such a variation. Risk acceptance criteria will have to be used in a consistent way for all activities within an operating company.

The risk acceptance criteria should be at a level where there is a reasonable balance between ambitions as to continuous improvement, defined safety objectives and technology improvements on one hand and what is realistic to achieve on the other.

The guidelines in this informative annex will not provide any indications as to what level may be considered acceptable for the Norwegian offshore operations.

A.3.2 Handling of deviations from Risk Acceptance Criteria

The operator's management is responsible for establishing management systems including establishment and use of risk acceptance criteria and studies as a means to establishing, implementing and furthering a fully satisfactory safety level.

Active involvement by the management is necessary in order to place the risk analysis in an appropriate context in relation to the HES management. It is also vital that the work force is involved in the process.

Possible deviations from the risk acceptance criteria will have to be handled in the same way through the same process. Usually such deviations will be dealt with according to normal procedures for deviation handling.

Old installations that were designed before the use of risk analysis became general may be treated as deviations from the risk acceptance criteria if necessary, or it may be more appropriate to develop separate risk acceptance criteria for such old installations.

A.3.3 Updating of Risk Acceptance Criteria

It is required that the risk acceptance criteria be updated according to the development of the activity as a whole, in order that these criteria remain an effective means to achieve the overall safety objectives. Whenever the safety objectives are changed, it must be considered if the risk acceptance criteria shall also be judged. It may also be necessary to update the risk acceptance criteria according to the development in analysis methodology, data bases and technology. The risk acceptance criteria will therefore change over time and through the different lifecycle phases.

If the safety objectives are reached, this may represent a significant reduction of the risk in the activity and may therefore call for revision of the risk acceptance criteria. Such a revision may imply that accidental events that initially were not classified as dimensioning, may be re-classified at a later stage as being dimensioning for the activity in question.

A3.4 Prioritising of Risk Reducing Measures

The overall principles for prioritising risk reducing measures imply that reducing probability of accidents shall be favoured over reduction of consequence whenever this is technically,

operationally and economically feasible . This implies that the choice of technical, operational and organisational risk reducing measures should be given the following priorities:

- a) Probability reducing measures, in the following order of priority:
 - aa) measures which reduce the probability for a hazardous situation to occur,
 - ab) measures which reduce the probability for a hazardous situation to develop into an accidental event.
- b) Consequence reducing measures, in the following order of priority:
 - ba) measures related to the design of the installation, to low bearing structures and passive fire protection,
 - bb) measures related to safety and support systems, and active fire protection,
 - bc) measures related to contingency equipment and contingency organisation.

A.4 Use of risk Acceptance Criteria in lifecycle phases

The petroleum activity may be divided into different lifecycle phases. The use of risk acceptance criteria and risk analyses will naturally vary according to which phase of the activity is being considered. The approach to evaluation of an entire platform is, for example, quite different from the approach to evaluation of a single operation.

An overview of the lifecycle phases is presented in the normative text in section 7.2. The same structure is applied in the following presentation in that section, except that exploration drilling is discussed at the end of section A.4.

A.4.1 Conceptual design and engineering phases

A.4.1.1 General

Use of risk analysis and associated risk acceptance criteria is an important tool for establishing design criteria and making related decisions during the design process. It is important to establish design criteria as early as possible in these phases. These aspect are discussed in the report «Methods for establishment of dimensioning criteria» (see Annex F) which describes the following three main elements in this process.

- Technical requirements and specifications (i.e. product specifications, economic premises and requirements, technical specifications, operational premises)
- Environmental loads and assumptions regarding external environment as well as working environment (i.e. loads related to wind, waves, earth cracks, lighting, rust, erosion etc.)
- Accidental loads and safety requirements (i.e. risk acceptance criteria in relation to personnel, environment and assets, loads from dimensioning accidental events, functional requirements related to safety and emergency preparedness including vulnerability and reliability)

The following three approaches are used in order to establish design criteria with respect to accidental loads and safety requirements:

- explicit interpretation from risk acceptance criteria based on risk analysis
- qualitative (semi-quantitative) analysis
- experience data and standards

The following sub-sections are focused on overall risk acceptance criteria.

A.4.1.2 Feasibility Studies and Concept Evaluation

The concept evaluation phase requires that quantitative risk acceptance criteria have been established. Coarse risk assessments are often performed during the feasibility study phase in relation to technical and economic potentials and limitations. Detailed quantitative risk analyses are usually not expected during the feasibility studies, but at least a qualitative assessment of safety aspects should be part of the feasibility studies.

Relatively detailed quantitative risk analysis is thereafter required in relation to quantitative risk acceptance criteria for personnel, environment and assets. These studies will consider the alternative concepts and conclude on their potential to meet the risk acceptance criteria. Critical aspects (operationally or technically) should be identified to the extent possible in order to estimate necessary cost in relation to meeting the risk acceptance criteria or to have realistic basis of comparison.

The risk acceptance criteria to be used shall apply for the installations in normal operation. The uncertainties arising from assumptions about operational conditions as well as from calculations and experience data will have to be considered in relation to the risk acceptance criteria (see also discussion on uncertainty in section A2.1.4)

An example of the use of main safety functions as acceptance criteria may be as follows:

The evacuation system shall be intact and accessible during 90 minutes in order to enable a controlled evacuation from the shelter area on the installation. Total frequency of accidental events implying loss of this safety function shall be equal to or less than 5×10^{-4} per year.

Other main safety functions for which criteria may be established are as follows:

- Main support structure/buoyancy and stability
- Escape ways
- Shelter area (safe area)
- Evacuation means (location and shielding of lifeboats)
- Escalation (fire and explosion barriers)
- Control room function (i.e. required extent of control, monitoring and communication)

A concept risk analysis may be carried out without all details about safety systems onboard being known. Usually one will assume standard safety systems and the resulting risk picture will present the different contributions and pinpoint where measures have to be taken in order to meet the risk acceptance criteria. Advantages and disadvantages of the different types of criteria are outlined in the sections A2.2 to A2.8.

A.4.1.3 Pre- and detailed Engineering Phases.

The same quantitative risk acceptance criteria are normally used in the engineering phases as in the concept study phase. All dimensioning accidental loads have to be defined through the engineering phases. These loads together with assumptions and premises in the risk assessment shall be formulated as design requirements (reliability, availability, vulnerability etc.) This has to take place at the earliest possible stage of the project.

Generally through the engineering process and in particular during the definition of design requirements, detailed risk analysis may be used in relation to personnel in order to determine the ability to meet the design specifications (such as fire and explosion over pressure studies as well as studies of falling objects). The results of the detailed studies should be used during the decision process in the engineering phases and will finally be integrated into the detailed updating of the conceptual risk analysis, often called a Total Risk Analysis. It is recommended to carry out such a detailed risk analysis for personnel, environment and assets as part of the detailed engineering phase in order that this analysis may be used actively in the decision-making process in this phase.

This means that the de-composition of the safety and emergency preparedness requirements down to area system and component level has to be carried out during the engineering phases. Comparison with risk acceptance criteria (on a high level of risk) should still be used in order to ensure that measures are adopted in those areas where they are most efficient. ALARP evaluations should also be used during this decision-making process.

A.4.2 Construction and Installation Phases

A.4.2.1 Construction Phase

This phase implies construction of a fixed or floating structure, modules and other parts of the installation. The majority of this work is done at shore or inshore. However, some work will often have to be done offshore.

a) Construction work at shore/inshore:

These activities are usually carried out under the management of a construction yard outside the jurisdiction of the petroleum law, and risk acceptance criteria have normally not been established. Particular aspects relating to escape and evacuation from modules have to be considered in each case, and it may sometimes be necessary to carry out risk analyses in order to ensure that personnel may be protected from accidental effects and be able to escape from an accident (e.g. during hook-up in a fjord). In such studies, risk aspects are usually identified and assessed qualitatively against risk acceptance criteria. Qualitative criteria are briefly outlined in section A4.2.2.

b) Offshore construction work:

The risk acceptance criteria pertaining to the operations phase will normally apply to offshore construction if the work is carried out at the installation's location. It may be necessary to give particular consideration to special aspects such as use of flotel, high manning level, high level of

construction work, manned underwater operations, start-up of hydrocarbon processing systems, helicopter shuttling activities and high drilling activities.

A.4.2.2 Installation Phase

This phase includes the installation of subsea facilities, pipelines and surface facilities including modules and structure at the field location. Sometimes this phase will also include inshore hooking-up of modules and structures. The work in this phase often requires use of several types of vessels which may or may not operate simultaneously in the fjord.

As of today, there is no industry-accepted practice with respect to how risk acceptance criteria for temporary phases should be formulated. This is due to the following:

- each installation activity is often unique and is normally done only once.
- experience data from other installation activities may not be applicable, thus preventing the establishment of a robust data base.
- the duration of each installation sequence is usually quite short and each step may also vary quite significantly in extent and risk exposure.

Consequently, it has been found difficult to establish quantitative risk acceptance criteria for this phase. Any risk quantification will have quite extensive uncertainty, reflecting a lot of assumptions and simplifications which may be difficult or impossible to verify or eliminate. Quantitative risk acceptance criteria are therefore often judged not to be useful in relation to the efforts needed to carry out a quantitative analysis. Therefore qualitative risk acceptance criteria and risk analysis have often been used.

A.4.3 Operations Phase

A.4.3.1 Normal Operation

Regular activities which are required in order to operate an installation are all considered as normal operation. This will usually include maintenance and inspection and the implied activity level.

The risk level in the operations phase is usually a function of the design and the technical, operational and organisational premises that were established for the operation. The same applies to the risk acceptance criteria against which the risk results were measured.

The design of the installation will normally limit the extent to which risk reduction in the operations phase may be achieved, even though a program for continuous risk reduction is required. Such limitations will usually not exist to the same extent for the design of new installations. Risk acceptance criteria for new installations may therefore not automatically be valid for existing installations (see also the discussion about handling of deviations in section A3.2.)

Risk Indicators

It is required that the risk level in the operations phase is monitored in order to identify how the risk level develops. The risk analyses should therefore be capable of identifying the parameters or

indicators which have a strong impact on the risk level and also the effect that changes will have on the risk level. This will enable an effective monitoring of changes of the risk level in relation to the risk acceptance criteria. Examples of such indicators may be:

- Manning level and distribution
- Hydrocarbon leak frequencies
- Extent of hot work
- Availability of critical safety systems
- Production rates for each well

The starting point for the acceptance of the risk level is that these indicators have a certain value as presumed or established in the risk analysis. Changes in these values will imply change of the risk level. The intention is therefore to get an early warning of any trends which finally may result in inability to meet risk acceptance criteria. The trends for the risk indicators must be monitored relatively continuously, which requires that the indicators are suitable for identification of changes within a relatively short time span.

Monitoring of risk indicators will focus the attention on factors that are crucial for the risk level and provide a tool for identifying and rectifying deviations from the assumptions made in the risk analysis.

Data bases

The risk level as analysed for the normal operation is initially based on data from recognised data bases and calculations tools and is not particularly related to the actual installation. As soon as installation-specific experience data are available, they should also be used in the updating of the risk level in relation to the risk acceptance criteria. Therefore, requirements must be established both to the amount of installation-specific data and to their quality, so that the reliability of these data is acceptable.

It is important to fully understand that safe operation will always be strongly dependent on adherence to recognised standards and practices for operations and activities. Risk analysis and risk acceptance criteria can never and should never replace the use of recognised standards and practices.

A.4.3.2 Special Operations

These are operations that are not covered by the base case risk analysis as they are usually carried out during limited periods in the operations phase. Such operations may be special lifting operations, drilling or other well activities, manned underwater operations, shut down periods for maintenance purposes etc.

The risk acceptance criteria are usually based on an average level through one year, and are therefore not suited for evaluation of risk associated with short duration operations during which the risk levels may be higher globally or locally. Risk acceptance for such conditions will have to reflect:

- The duration of the period with increased risk.
- The peak level of risk during this operation.

- Whether the risk increase is local or global for the installation.
- Whether the risk increase affects the different personnel groups in the same way or differently.

The conditions of such periods may be quite different from one operation to another and it has not been possible to give general recommendations as to risk acceptance. The ALARP principle should always be used as a minimum in order to reduce the risk as far as practically possible.

Some categories of special operations are indicated below.

Intervention on not normally manned installations

Such an intervention is by nature a special operation although usually part of the normal operation of that particular installation. Interventions are done regularly and would usually need to be analysed only once. Such an analysis should include the activity to be carried out on the installation as well as the transport to and from that installation. The risk acceptance will normally include individual risk, PLL or FAR either associated with each particular operation or with the operation of the installation as such.

Drilling, completion and other well operations

Risk associated with these well operations is normally part of the risk analysis for the installation and therefore included in the overall risk picture. Separate studies may be required if the conditions are different from those analysed, e.g. changes to the drilling and completion program, special well interventions being required, or because reservoir conditions are different etc. Driller's HAZOP is a possible tool to use for most of these operations. Risk acceptance may be evaluated in relation to the installation's risk acceptance criteria or by comparison with normally accepted well operations and their standards.

Manned underwater operations

Risk associated with manned underwater operations is usually independent on the installation's risk analysis. The following should be considered in relation to manned underwater operations from vessels and installations:

- access for vessels, installations, divers
- evacuation means
- possible temporary blockage of the installation's other evacuation means (lifeboats, liferafts, escape chutes, etc.)
- lifting operations
- fishery
- release of chemicals, barite, cement
- dumping of cuttings
- scaffolding over open sea
- flaring
- water jet, sandblasting
- sea-water intake, including fire water
- cooling water discharge

Particular attention should be paid to hyperbaric evacuation of divers, if manned underwater operations are carried out from the installation.

Safe job analysis and/or risk matrixes are normally utilised, as well as comparison with established and recognised standards with regard to acceptance of risk. Manned underwater operations from or close to an installation may have implications for its emergency plans and operational modus.

Work on critical equipment

Safe job analysis is the most commonly used approach to risk analysis. Risk acceptance criteria do not usually exist, and more general decision criteria may be used. Safe job analyses are commonly focused on occupational accidents and do not normally reflect the potential for major accidents.

Heavy lifting

Safe job analysis is the most commonly used approach in this context. Risk acceptance is most frequently related to general decision criteria for HES management, e.g. that procedures are in place, that these are complied with etc. Specific risk acceptance criteria are usually not formulated.

Marine operations

Normal marine activities with supply vessels and stand-by vessel are usually covered in the installation's overall risk analysis as regards any threats to the installation itself. Special operations with mobile units and other installation vessels may require separate studies. Risk matrix may be a suitable tool in relation to risk acceptance provided that criteria for acceptance of risk are formulated in the matrix.

A.4.3.3 Inspection and maintenance

Inspection and maintenance form an integrated part of normal operations, including preventive and corrective maintenance as well as routines for condition monitoring and inspection program.

Separate risk analyses are usually not conducted for regular inspection and maintenance, neither will particular risk acceptance criteria apply. These activities are implicitly part of the overall risk analysis, usually based on compliance with established procedures and standards for such activities. If manned underwater inspection or maintenance shall be carried out, see paragraph regarding "Manned underwater operations" in A.4.3.2 above.

Therefore, the *execution* of maintenance and inspection shall normally not be subject to risk analysis. Such studies should however be used in the *establishment of programs* for inspection and maintenance, in order to achieve a cost effective program for these activities and to ensure priority to risk critical equipment (risk based inspection). Identification of critical equipment may be performed in relation to high level risk acceptance criteria for the installation, but risk analyses are usually not suited for establishing the criteria for choosing inspection and/or maintenance program.

Change of program for inspection or maintenance should be analysed in relation to the assumptions made with respect to inspection and maintenance in the overall risk analysis, to ensure that such changes do not affect the risk level in an unacceptable way.

A system is also needed to ensure experience transfer from the inspection and maintenance work, to evaluate whether these data will change the assumptions on which the studies have been based.

A.4.3.4 Risk during Modification Work

Modifications are usually carried out while the installation is in normal operation and will therefore imply an increase of the activity level on or around the installation during a period which may be short or somewhat longer. Risk analysis should be used in order to ensure that the modification work does not in itself imply an unacceptable risk level.

The following parameters should be included in the evaluation of a temporary increase of risk in connection with modifications (see also fig. A5):

- The maximum increase of the risk level. Evaluations have to be made whether the peak level is acceptable even though the duration may be short. This may influence the decision whether to carry out the modification work as planned or whether e.g. compensating actions or restrictions in the normal operations should be implemented.
- The duration of activities implying increased risk level, and the implicit total exposure of personnel to increased risk in relation to the risk acceptance criteria.
- Whether the increase of risk is local, i.e. affects a particular area of the installation, or applies globally. A local increase of risk may be more easily acceptable or even compensated for, as opposed to a global increase of risk.
- It may also be relevant to consider what effect the modification will have on the normal operation, e.g. . whether a certain risk reduction is achieved. Some increase of risk during modification may be easier to accept if the resulting effect is a significant reduction of risk during normal operations.

The total risk exposure will depend on any possible increase of risk during modification and any possible reduction of risk resulting from that modification. Figure A5 shows two different situations with respect to the risk level without risk reducing measures (R1) and with implementation of risk reducing measures (R2) during which a temporary increase of risk occurs. The diagram shows both the instantaneous values of risk as well as the accumulated risk values for both alternatives. The accumulated curves show that quite some time will elapse before the accumulated risk for situation R2 is lower than for the situation R1.

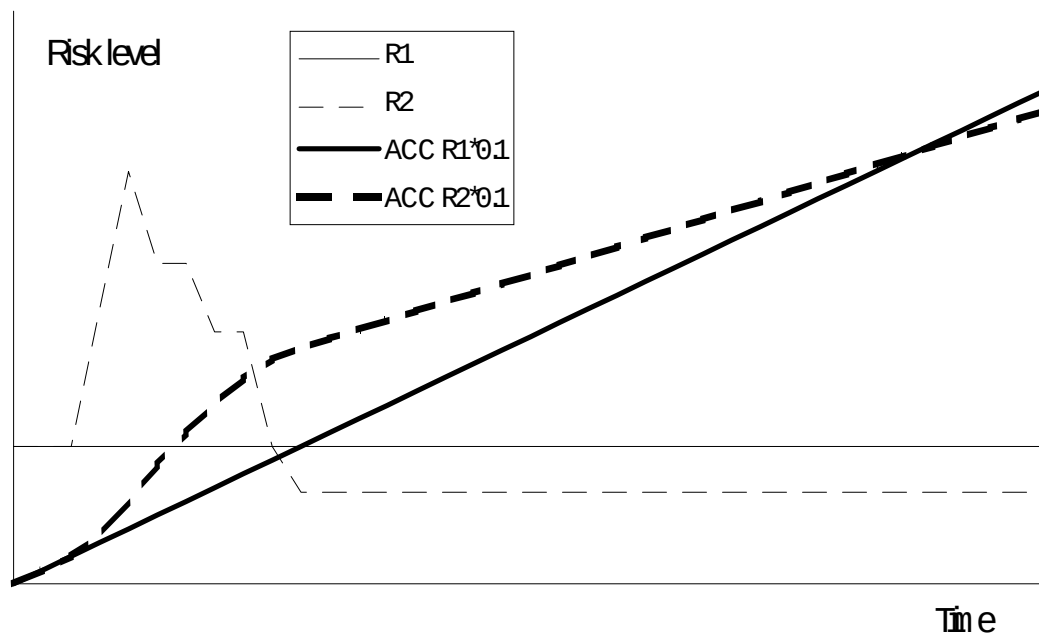


Figure A.5 - Example of variation of risk level during implementation of risk reducing measures, and effect on accumulated risk over time.

The final decision regarding acceptance will have to be based on an overall evaluation of all parameters. Lifecycle considerations should be used more in relation to modification works. There will often be trade-offs, e.g. in relation to welded piping connections as opposed to flanged piping connections (welded connections may imply higher risk during modification due to hot work, but lower risk in operation due to lower leak frequency).

Establishment of a routine for integrating risk analysis competence into the early phases of modifications planning, is as core element in HES management. This should ensure that risk analysis aspects are taken care of as an integrated element in the planning and execution of modifications.

A.4.4 Decommissioning and disposal

This phase of the field operation includes activities having the following objectives:

- shut down and secure the systems, equipment and the installation, i.e. making the installation cold,
- maintain and inspect a cold installation until final disposal is being carried out,
- carry out the final disposal.

Different analytical methods and different risk acceptance criteria will apply to the planning and the execution of these three categories of work, but they have a lot in common with other activities described previously.

A.4.4.1 Shut-down

The shut-down phase itself has a lot in common with work associated with hook-up and commissioning of a new installation (except being reverted). The principles for shut-down should therefore be the same as for hook-up and commissioning. The intention is to ensure that the work is completed in a safe manner and in a sequence which gives the best safety. The most critical operations from a risk analysis point of view will include removal of tubing in production and injection wells, permanent plugging of wells, as well as removal of hydrocarbon residuals in the process equipment. Reference is made to the well interventions in section A4.3.2.

A.4.4.2 Maintenance and inspection of cold installation

This phase is parallel to intervention on not normally manned installations (see section A4.3.2). The risk acceptance criteria and the risk analysis approach should be parallel even though the risk picture may be different. PLL and Individual Risk (IR) are suitable criteria.

A.4.4.3 Completion of final disposal

The alternatives for final disposal are quite varied. Risk analysis and risk acceptance criteria will therefore have to be chosen in relation to the alternative for final disposal which is being evaluated. HAZOP and Safe Job Analysis may be the most relevant risk analysis approaches as far as planning of disposal operations is concerned. Disposal of installations has many similarities with installation of new installations, implying that the principles for risk acceptance discussed in section A4.2.2 may also be applicable to the final disposal of an installation.

A.4.5 Risk Acceptance Criteria for mobile units

Mobile units in this context include drilling units, separate accommodation units and mobile units used for special maintenance tasks, whereas stand-by vessels, pipe-laying vessels, vessels for manned underwater operations and vessels engaged in seismic activities and supply vessels are not covered by this term. Floating (and thus mobile) production installations shall be considered as any other (or fixed) production installation. Authority regulations will usually define the scope of production installations requirements in contrast to requirements for mobile installations.

Taking on a mobile installation often demands special considerations with respect to risk acceptance criteria. The way in which the risk acceptance criteria are defined will usually determine the type of risk analysis that has to be conducted. Risk analyses based on other regulatory regimes may usually be used.

The risk acceptance criteria adopted in relation to taking on mobile installations shall as far as possible be in accordance with recognised and accepted models for risk analysis of such installations.

In addition, the operator should consider whether all relevant assumptions are valid in order to decide whether the risk acceptance criteria may be met for the planned operation. This may include aspects such as:

- well specific conditions (for example blow-out probability, blow-out release rate)

- location specific aspects (for example environmental conditions, location-specific shipping traffic)
- additional accidental events (for example in relation to neighbouring installations or operations on these)

Follow-up of recommendations concerning risk reducing measures required in order to meet the risk acceptance criteria should be verified by the operator before accepting the installation.

When a mobile installation shall be connected to a production installation, the risk acceptance criteria for the production installation will usually be adopted for the entire complex. This will imply that the risk acceptance criteria for the mobile unit must be in line with the risk acceptance criteria adopted by the operator for the production installation, and a quantitative risk analysis of the floating installation will usually be required.

In these cases, the operator will have to ensure that his risk acceptance criteria are suitable for the entire complex.

ANNEX B ANALYSIS OF CAUSES AND CONSEQUENCES OF VARIOUS ACCIDENTS (INFORMATIVE)

This Annex discusses causes and consequences of typical accidental events. A set of aspects to be covered by "qualified tools and models" are given. The guidelines and requirements apply to ERA (Early Risk Analysis), CRA (Concept Risk Analysis) and TRA (Total Risk Analysis).

Note that several techniques are available to identify hazards associated with an installation or an activity, e.g. HAZOP/FMEA, checklist, "Top Down" Approach, qualitative review, etc. The technique to be used depends on the type of risk analysis to be conducted and the type of operation or facility to be assessed. Hazard identification methodology is not described in this guideline, however, the accidents discussed in the following could be used as a first checklist to identify relevant accidents for the analysis.

The following are abbreviations which are special to this Annex:

ERA Early Risk Analysis
CRA Concept Risk Analysis
TRA Total Risk Analysis

B.1 Hydrocarbon Leak, Fire And Explosion

In order to quantify risk related to hydrocarbon leaks, and consider the importance of factors/measures, event tree models shall be used with "leak" being the undesired incident.

The following shall be taken into account:

- leak cause, source and location,
- leak rate, volume and duration,
- leak medium (e.g. gas/oil),
- effectiveness of shutdown system on leak volume,
- gas spreading/dispersion,
- probability of ignition, time of ignition,
- probability of explosion in the event of ignition, effect of explosion,
- effectiveness of fire-fighting system,
- effectiveness of blowdown system,
- accident escalation,
- escape possibilities and evacuation system,
- distribution of personnel.

The ERA and CRA may be based on assumptions on some of these factors, e.g. personnel distribution, effectiveness of safety systems and leak duration. Such assumptions shall be followed up in later phases. The TRA is to include studies of the effectiveness of safety systems.

B.1.1 Leak Frequency

The causes of leaks shall be identified as basis for leak frequency quantification and identification of possible probability reducing measures. Pipe and equipment (components) where leaks may occur shall be identified for each module/area. The components shall be grouped in component types, e.g.

- pipe (small diameter, large diameter),
- flanges (normal steel gasket, greylock),
- valves,
- pumps,
- compressors,
- vessels (pressure vessels, heat exchangers),
- instrument connections,
- pig receiver/launcher,
- risers, flowlines,
- pipelines.

Within each module/area the number of components (metres of pipe) of the various component types shall be estimated. Frequencies of leaks with given hole sizes shall be determined for each component type based on qualified data and models.

An initial leak rate shall be calculated for each hole size by using discharge calculation models, based on medium, pressure, temperature and density. It will be useful to define leak scenarios to reflect various physical properties, such as:

- the gas leak is not sufficient to give an explosion mixture of a size which give pressure effects, and thus explosion is unlikely and a local fire is a possible scenario,
- the leak gives sufficient time for manual intervention before large explosive mixtures are formed,
- the leak is too large for manual intervention to be realistic,
- the leak would quickly fill several areas with explosive gas,
- an ignited leak in the area would give a ventilation controlled fire.

Some typical leak scenarios shall be selected for further studies. Typical quantities/volumes in the various process sections shall be calculated on the basis of the sections the process is divided into by emergency shutdown valves (ESD). One must differentiate between various media (gas or oil).

In the ERA the equipment count for an area may be based on previous counting for similar areas (or even the leak frequencies may be quantified based on experiences from a similar area in operation). The number of accident scenarios studied shall be chosen based on the precision of the study, to reflect the risk picture. In the CRA the main components shall be counted, e.g. pumps, compressors, vessels, pig receiver/launcher, pipe segments), and data for similar main components used in the quantification of leaks with given hole sizes. The TRA in the operational phase shall be based on experiences of smaller leaks, and an evaluation of experiences versus the equipment counting for larger leaks.

B.1.2 Gas Concentrations, Shut Down And Isolation

Discharge amounts as a function of time shall be calculated (using qualified models) for the typical leak rates. Calculations shall also be made to describe concentration development of the discharge medium, i.e. of when/where a flammable mixture is obtained, including ventilation conditions. Often, special discharge assessments have to be made for risers, flowlines and pipelines.

Subsea leaks include a spread in water. The gas and oil concentrations at sea level shall be assessed, and further the possibility of ignitable gas clouds. The assessment shall include possible drift of the hydrocarbons, both in water and air, the vaporisation and the location of possible ignition sources. If there are subsea ESD valves, both the situations with successful closure and failure to isolate shall be evaluated.

B.1.3 Effectiveness of Shutdown Systems

A successful shutdown depends on:

- detection of the leak,
- automatic emergency shutdown system (panels, valves),
- operator intervention if automatic emergency shutdown is not achieved.

An effectiveness analysis of the shutdown system shall be conducted, covering the probability that the system operates and the response time. The following types of failures shall be covered:

1. unknown fault (sleeping fault) in the emergency shutdown system, also covering failure to respond on a leak,
2. known faults where emergency shutdown system is not operative and the production continues, e.g. due to:
 - detected faults (now under repair) causing unavailability of the safety function,
 - function testing of the emergency shutdown system is being done, and the system is out of function during test.

The leak and discharge calculations shall include some typical scenaria with shutdown faults. In the ERA it is normally sufficient to assume a reliability (based on typical results from previous studies) and response time of the safety systems. If a high reliability is required, the possibility to achieve this shall be evaluated.

In the CRA the risk reducing effect of subsea isolation barriers in import and export lines may be subject to evaluation. If found required the best location shall be studied.

B.1.4 Ignition

The probability of ignition depends on:

- the availability of a flammable mixture,
- the flammable mixture reaching an ignition source,
- the type of ignition source (energy etc).

An ignition probability that takes these into consideration shall be determined for each area (module), each leak category and each medium.

The following ignition sources shall be considered:

- hot work,
- faults in electrical equipment,
- faults in rotating equipment,
- ignition caused by turbines and combustion engines/hot surfaces,
- automatic ignition in the event of a fracture/rupture,
- static electricity,
- flare/open fire.

The time of ignition should be taken into consideration by defining "immediate ignition" and "delayed ignition".

In the ERA a less detailed model is sufficient, reflecting the area, leak category and medium. A subsea leak ignited on the installation is in the ERA and CRA counted as an escalated accident. In the TRA the possible consequences are considered for comparison with risk acceptance criteria. The possibility for a fire at sea scenario shall then be assessed.

B.1.5 Explosion

A probability distribution of pressure development for the various areas or modules and leak categories shall be established based on qualified models, taking into account :

- location of leak sources,
- gas concentrations (clouds),
- location and energy of ignition sources,
- area geometry,
- ventilation areas,
- equipment congestion.

Response analyses shall be performed for typical explosion pressures in order to assess the extent of the damage locally in the accident module as well as global for the installation's structural integrity. The analysis shall focus on the areas that have the highest explosion risk and where an explosion is considered to cause the most extensive damage.

In ERA and CRA the explosion calculations are used to establish design loads for the area dividers and equipment in the area, such that the risk meets the relevant acceptance criteria. The design loads from the ERA are mainly used for cost purposes, and thus the pressure consideration may aim at the level rather than a precise figure.

B.1.6 Fire fighting

A reliability and vulnerability analysis of the fire fighting system shall be conducted. The analysis shall include:

- the reliability of the automatic fire fighting system (fire water/AFFF etc),
- the probability of successful manual intervention,
- the probability of fire fighting preventing new leaks from occurring as a result of pipe rupture etc and thus enabling escalation of the fire,
- possible external fire fighting in case of larger fires, availability of vessels, response times and the effects on the scenario (water capacity, accessibility, interactions with people on board).

The analysis shall include possible damage to the system and its utilities from the accident scenario, e.g. explosion or fire loads, gas detection causing shut down of ventilation and air intakes.

This shall take into consideration the area, leak size, explosion pressure and whether a successful shutdown has been achieved. The effect of passive fire protection shall also be considered.

B.1.7 Blowdown -

An analysis of the blowdown system shall be conducted, including:

- the use of the pressure relief system, the probability of the pressure relief system being activated in specific situations,
- how efficient the blowdown system is in preventing the escalation of accidents.

The assessment shall take into consideration the area, leak rate, explosion pressure and whether a successful shutdown has been achieved.

B.1.8 Impact of Accident Scenario

Calculations shall be made to determine heat loads on various places on the installation (e.g. living quarters, lifeboat stations) for some typical accident scenarios at different wind conditions.

A distribution of loss of life in the accident area and in adjacent areas resulting from the initial accident shall be determined for each accident scenario. The distribution shall be based on the established distribution of personnel and on criteria for the heat load, explosion pressure etc that a human being can tolerate. Further the consequences from accident development and escape and evacuation shall be included in the risk picture.

B.1.9 Risk Calculations

Probability distribution of loss of life, discharge of substances harmful to the environment and economic losses with the loss categories defined, shall be determined for each accident scenario. The total risk contribution from hydrocarbon leaks shall be calculated on the basis of this distribution and the established frequencies. Also unignited HC leaks shall be included, and in particular leaks from pipelines in the safety zone or between installations covered by the risk acceptance criteria.

B.2 Blow-out

Event trees shall be used in order to analyse the risk related to blow-out. The following shall be taken into account:

- blow-out location,
- flow rate as a function of time and bridging possibilities,
- medium (e.g. gas or oil),
- operation (drilling, completion, maintenance, production, injection),
- reservoir conditions (e.g. shallow gas),
- probability of ignition, time of ignition,
- probability of explosion, impact of explosion,
- effect of fire fighting system, heat load,
- wind conditions,
- escalation of accident,
- escape and evacuation,
- simultaneous operations (drilling, production etc).

B.2.1 Frequency

A blow-out can occur during various work operations and in various locations, and these shall be identified, e.g.:

- work operations: drilling, completion, production, injection, workover,
- blow-out location: drill pipe/tubing, BOP, X-mas tree, wellhead and outside the casing.

Blow-out frequencies (given per well/well year/workover) shall be determined for the various operations, blow-out locations and media. The blow-out frequencies for the installation are then quantified on the basis of the number of wells and workovers. A set of "typical" blow-out rates shall be defined.

In the ERA all relevant information may not be available, and assumptions have to be made. The scenario may be defined based on comparisons with other installations. If blow-out is found to be a major contributor to the total risk, a thorough examination to reduce frequencies, consequences and duration of blowouts shall be performed as part of or basis for the CRA or TRA. In the operational phase the blow-out rate shall be updated based on best available data for the reservoir. The contingency for blow-out shall be checked in the TRA.

B.2.2 Ignition, Fire, Explosion, Safety Systems, Evacuation (Blow-out Scenarios)

An ignition probability shall be determined for each scenario type, based on blow-out location, medium, rate and possible ignition sources. The time of ignition shall be taken into consideration by defining "immediate ignition" and "delayed ignition". The ignition probability may be adjusted to reflect water content (water cut) of the well stream.

The possibility of fire at sea scenario shall be considered both for subsea blowouts and blowouts on the installation.

The further accidental development in the event of ignition shall be considered with the same principles as for HC fires and explosions, both for explosion probabilities and consequences based on safety system effectiveness. The escalation to other wells shall be studied, both failures to isolate and accidental loads damaging equipment causing secondary blowouts.

The CRA shall define design accidental loads from blowouts according to the risk acceptance criteria, considering wind conditions and shielding, in particular for LQ, main escape ways and life boat stations both from above and below. Both heat loads and smoke have to be assessed. The design load explosion pressures shall be used to establish requirements to area dividers, critical structural elements and critical equipment (supports and integrity).

B.3 Helicopter Crash on Installation

The risk related to a helicopter crash or other helicopter accidents on the helideck or the platform outside the helideck and inside the safety zone, shall be analysed.

The analysis shall consider the possibility/probability of the following:

- helicopter accident/crash (on the platform),
- personnel on the platform being hit by the helicopter or fragments,
- leak, fire of fuel,
- mechanical damage to process equipment with subsequent hydrocarbon leak
- damage to jet fuel tanks, leak and ignition,
- ineffective fire fighting, escalation of fire to surroundings such as living quarters.

For trips between shore and the offshore installation the risk related to personnel on board the helicopter shall be included in the comparison with risk acceptance criteria (RAC) for accidents within the safety zone. The total risk related to personnel on shuttle flights between offshore installations shall be included. This delimitation is set to give compatible results, and limit the study (general helicopter safety is discussed in separate studies).

In the ERA one may apply data for similar installations, and adjust for specific conditions. In the CRA the layout and exposed equipment shall be checked as well as the operational conditions for helicopters.

B.4 Collisions

The risk from two types of collisions shall be considered:

- ships / vessels ramming the installation (powered as well as drifting),
- collision between the installation and floating units located near by (flotels, crane vessels etc).

B.4.1 Ships/Vessels Ramming the Installation

An analysis of the risk related to collisions with other vessels will consist of two parts:

- a survey of the traffic in the area and a quantification of the probability of collisions (frequency analysis) and the associated loads,
- an analysis of the impact the various collision scenarios will have on the installation (consequence analysis).

The risk related to the colliding vessel shall not be included (loss of life on board the vessel etc).

B.4.1.1 Survey of Traffic

Vessel activities in the ocean area around the installation will normally be surveyed, and this shall be reflected in the analysis. The following types of vessels shall be included:

- fishing vessels,
- service vessels,
- supply and standby vessels,
- tankers,
- other passing surface ships / vessels
- ferries.

Supply and standby vessels may be omitted from the survey, if extensive statistics for these vessels are already available. Often are they nevertheless included in order to obtain verification of previous data. The traffic shall be presented the way it is anticipated to be during the relevant period of time. The following shall be taken into consideration for each vessel type:

- average number of calls/passings per year,
- categorising of the size and speed of vessels,
- ship routes,
- seasonal variations,
- weather routing,
- movement pattern in safety zone.

B.4.1.2 Collision Energy

Speed distributions shall be established for each vessel type to distinguish between vessels making headway and vessels adrift. Wind and wave conditions shall be taken into consideration for vessels adrift.

The calculations for collision energy shall differentiate between various ways the collision can occur (bow/stern or sideways and the point of impact on the installation).

B.4.1.3 Consequence Analysis

Consequence analysis of typical collision scenarios shall be conducted.

The integrity of the installation to the accidental loads shall be determined and compared with the collision energies calculated for typical collision scenarios above.

Both local and global overloading of the structure shall be considered. The impact on the installation, measured in loss of life, economic losses and discharges harmful to the environment

shall be assessed. The acceptance criterion for collision is related to catastrophic consequence, not damage to the structure.

The following effects shall also be taken into consideration:

- the superstructure of the vessel may (for large vessels) collide with the deck structure,
- the ship may sink and cause damage to pipelines and other subsea installations,
- anchor grapppling may damage pipelines or well templates,
- the ship may catch fire which can escalate to the installation or prevent evacuation.

B.4.1.4 Probability of Collision

If the impact calculations show that the collision scenario could cause a significant impact on the platform in terms of safety, the probability of the scenario shall be determined.

The following shall be taken into consideration when computing the probability:

- fairways,
- movement pattern within the safety zone,
- navigational errors,
- unsuccessful warning and/or assistance.

For vessels adrift the basis shall be what may cause the vessel to become adrift. In addition, the following shall be taken into account:

- wind and wave conditions,
- warning procedures,
- emergency procedures for assistance to vessels adrift.

B.4.2 Collision between Installation and Floating Unit

If the installation shall be connected to a flotel for the entire period or part of the period included in the TRA, the risk contribution from a collision with the flotel shall be calculated. Similarly the risk from other near by units (crane ships, service vessels, tendering vessels etc.) shall be considered.

The risk related to the flotel (loss of life on board and economic losses) shall be treated as a separate installation, and included in the total risk contribution for the installations (as specified in risk acceptance criteria).

The probability of the flotel colliding with the installation can be considered using an event tree.

The following shall be taken into account:

- anchor line break or dragging,
- faults in the DP system/thrusters,
- structure failure,
- weather conditions and wind direction,

- possibility of manoeuvring using own propulsion machinery,
- availability of towage vessels,
- successful assistance,
- procedures for emergency preparedness.

The consequence calculations correspond to those for collision between the installation and another vessel.

Various collision scenarios shall be described and collision energies shall be calculated. The values shall be compared with the accidental loads that the installation can withstand.

The ERA may use accident statistics to assess the risk related to flotel collisions. Qualified models shall be used to see if the location of the installation is acceptable relative to ship traffic lanes, and this analysis has to be performed early, either to decide location or to prepare for (expensive) measures to control ship collision risk.

In the TRA the operational measures shall be verified, e.g. to see the response times for emergency preparedness vessels or the effectiveness of surveillance systems.

B.5 Falling Loads

Falling loads causing damage to hydrocarboncarrying systems (leak) or significant structural damage shall be studied. Personnel risk connected with accidents caused by loads that injure people directly through falls, swinging, crushing etc is not covered by this section, but is included in work accidents.

The following accidental events shall be analysed:

- fall of crane, boom or load into sea,
- fall of crane, boom or load on board the installation.

Unlikely events with insignificant risk, e.g. crane fall onboard the installation, may be disregarded from detailed analysis. The systems/areas exposed to risk shall be identified. A differentiation shall be made between various types of loads, such as containers and various types of pipe. The probability of damage shall be assessed for the relevant systems by taking into account:

- the probability of the object hitting the system,
- the impact load on the system.

If the energy from the falling load is sufficient to cause a leak, accident frequencies shall be quantified on the basis of relevant statistics. These scenarios shall be analysed further as described for HC leaks, including ignition probability to reflect the possibility that the fall itself is an ignition source. In cases where the falling load does not cause a leak, but structural damage, the possibility of progressive collapse shall be considered. The economic losses shall be determined.

In the ERA the falling object risk may be assessed based on simple geometrical considerations and rough evaluations of damage. In the CRA and TRA the operational pattern shall be examined, and distribution of loads established. The CRA shall, if required to meet risk acceptance criteria,

conclude design loads for subsea equipment, structural parts and protection of HC equipment.

In the frequency quantification for the TRA, the design of the crane shall be reflected, e.g. progressive collapse and brake systems.

B.6 Earthquake and Extreme Weather

The risk related to earthquakes and extreme weather shall be considered. Assessment of the structural integrity as well as equipment and supports shall be performed (when available, assumptions for later follow up is specified). In all cases a contribution from these types of accidents shall be included (e.g. assuming a failure frequency of 10^{-4} /year and 20% fatalities a FAR contribution of about 0.2 for each of the accident types is computed).

In the ERA one may assume that the installations will be designed for:

- no damages in the 100 year condition (probability of exceedance about 0.01 per year),
- survival of the main safety functions and installation integrity in the 10 000 year condition (probability of exceedance about 0.0001 per year).

In the CRA this assumption shall be verified and the risk contribution from such events assessed. If required, new design loads shall be identified.

The TRA shall include considerations of the risk related to personnel, environment and economics. Also less severe conditions than the 10 000 year situation have to be considered. In the operational TRA changes of the structural integrity shall be checked, and the equipment and equipment supports shall be evaluated for extreme conditions.

B.7 Occupational (Work) Accidents

Occupational accidents are defined as human accidents that are not caused by accidental events involving the platform/process. In practice this means all accidents not included in other accident types in the analysis, and will typically include:

- falls (to the same level, to a lower level, to the sea etc),
- falling objects, e.g. jolts, blows and crushing hitting personnel,
- poisoning, asphyxiation, radiation,
- electric shock,
- damage caused by tools, machinery.

Recreational accidents and social accidents (such as suicide) shall not be included.

B.7.1 Risk related to Occupational work Accidents

The frequency of fatal accidents and FAR values shall be quantified on the basis of relevant statistics, with differentiation between various functions (administration/production, drilling, catering, construction/maintenance) and type of accident (fall, falling objects etc). Basis for quantification can be found in NPD's annual reports, and the same personnel categories may be used. The fatality rate has to be derived from the injury statistics.

The following formula shall be used to calculate FAR values related to occupational work accidents in updating of TRA in the operational phase:

$$\text{FAR} = a \cdot b \quad \text{where}$$

a = ratio between death and injuries based on statistics from comprehensive data (many installations, long period of time, e.g. for the offshore installations on the Norwegian shelf).

b = registered number of injuries per 10^8 hours on the relevant installation.

The occupational work accident statistics shall be examined for differences from other installations, and these differences commented as basis for measures. When statistics indicate significant differences in ratios (a) for various types of work, this should be included in the calculation.

B.8 Other Accidental Events

Other types of accidental events shall be analysed if they are considered to be possible risk contributors, e.g.:

- fire (not HC) in
 - the drilling mud system,
 - methanol and glycol systems,
 - diesel and jet fuel systems,
 - drain system,
 - living quarters,
- accidents related to electrical power
 - short circuits/flashovers/arcs that lead to fire or other major damage,
 - explosion/blow-up of electrical apparatuses/transformers,
- fragments from turbines/rotating equipment
 - penetrations of walls, structures or equipment,
- loss of underpressure in cells,
- water penetration in dry shafts,
- loss of buoyancy,
- excess weight,
- displaced ballast.

Frequencies of such accidents may be assessed based on statistics, but with adjustments if the actual conditions deviates from normal. The analysis of fires shall be conducted analogously with ignited hydrocarbon leaks, with "fire" as the undesired event in the event trees being the usual (in certain

instances, e.g. for the methanol system, it may be more appropriate to let "leak" be the undesired event). The same degree of detail is not necessary.

In the ERA other fires may be considered purely based on statistics, unless major differences from other installations exist (e.g. major quantities of combustibles, materials in LQ that may produce poisonous gas during fires).

ANNEX C METHODOLOGY FOR ESTABLISHMENT AND USE OF ENVIRONMENTAL RISK ACCEPTANCE CRITERIA (INFORMATIVE)¹

C.1 Introduction

This informative Annex describes how risk acceptance criteria for the environment should be established and used in relation to accidental spills.

The methodology to be used when establishing the risk acceptance criteria is illustrated by means of quantitative examples.

The environmental risk is different from other types of risk in so far as the external environment is exposed to risk from different activities that fall under the responsibility of different operators. The risk acceptance criteria for environment should therefore take account of the fact that several fields during development or production may expose the same environmental resources. Also other activities, such as merchant shipping or onshore industry, may increase the environmental risk for the same environmental resources. The approach to establishment of risk acceptance criteria for the environment therefore needs to be more standardised compared to other types of risk.

Environmental risk is in the present context the combination of the probability for given accidents and the consequences thereof. Please note that the term 'acceptable environmental risk' as used in this Annex does not express that accidents which results in environmental damage are acceptable, as discussed in a broader context in Section 5 of the normative text.

C.2 Definitions in Relation to Environmental Risk

The following definitions are used in this informative Annex in addition to those stated in the normative text:

Accidental release - unplanned release resulting from accident.

Accidental oil spill - unplanned spill of liquid hydrocarbons (oil, condensate) affecting external environment, resulting from an accident.

Environment - external environment that may be subjected to accidental spills to sea, such as marine environment and the coast.

Influence area - area which with at least X% is affected by an oil spill, determined on the basis of oil spill drift simulations. (X is often taken as 5% or 10%, value must be defined by operator)

Analysis area - that part of the environment which is subjected to the analysis, based on assessment of the influence area, probability of release with a certain rate and duration distribution. The analysis area may be greater than, equal to or smaller than the influence area.

¹ Prepared by OLFs Working Group for Environmental Risk Analysis

Recovery (duration) - The time required before a resource has recovered to the population level or condition prior to the spill, considerations given to natural variations.

Environmental damage - Direct or indirect reduction of one or several resources resulting from an accidental spill. The recovery time for at least one of the affected resources must be at least 1 month for the effect to be classified as environmental damage.

Categories for environmental damage - Categorisation of environmental damage into one of the following **minor, moderate, significant, serious**, defined by its recovery. The examples below provide illustrations.

C.3 Establishment and Use of Risk Acceptance Criteria for the Environment

All petroleum activity may affect the environment, accidental spills may give serious environmental damage. Each operator has to decide what shall be his safety objectives for the environment. The evaluations will focus on to what extent the environment shall be as far as possibly undisturbed by the oil activities. It is recommended to adapt the following principle:

The duration of environmental damage shall be insignificant
in relation to the expected time between such damages.

This principles implies that each category of environmental damage may be associated with an acceptable frequency of occurrence. The following steps allow calculation of these risk acceptance criteria.

C.3.1 Offshore Activities

The offshore activities undertaken by the operators may in present context be divided into three levels: single operations; operation of an installation; operation of a field. These levels may be characterised as follows:

- **Operation** - A single operation with a limited duration, such a the drilling of an exploration well, i.e. all activities conducted by the mobile unit on location until the location is abandoned.
- **Installation** - An offshore facility from which drilling or production may be performed, such as an integrated production platform or an isolated subsea well template.
- **Field** - Several installations that together conduct drilling and production from one or more reservoirs.

The main principle stated above may be applied for all environmental risks that may subject the environmental resources, irrespective of the operator, the source of the spill or the location of the spill. The total environmental risk should be assessed as a part of the evaluation of whether a new activity could be carried out. An analysis may alternatively be carried out in order to determine the risk posed by existing installations or activities in order to allow new activities to be undertaken.

An assumed average activity level and average number of facilities per field and installation are proposed in the following to replace actual values, since the individual operator cannot influence

other operators' activities nor define environmental requirements for other operators. A quantitative illustration is presented at the end of this Annex.

C.3.2 Use of the Risk Acceptance Criteria for the Environment

The field related criteria should always be used for field development, irrespective of the field development concept.

The installation related criteria should be used for all activities considered together in relation to an installation. The use of criteria related to operations should be used for isolated operations, such as drilling of an exploration well.

The risk acceptance criteria cannot be considered definite limits. Risk reducing measures should always be considered when the estimated risk is in the ALARP interval, between upper and lower tolerability limits.

The risk acceptance criteria shall be satisfied for all environmental damage categories for the risk level to be acceptable.

Quantification of risk to the environment should be done both with respect to frequency and consequence. This may be illustrated as a risk matrix, or as a continuous function, see Annex A.

The acceptance limits are quantitatively different depending on whether a field, an installation or an operation is considered. It may not always be obvious on which level the acceptance should be considered, this has to be decided explicitly in each case. If in doubt, it is recommended that the highest level is used, i.e. field related before installation related, installation related before operational related.

C.4 Environmental Risk Analysis

An environmental risk analysis has to be carried out such that frequencies for each damage category is quantified, in order to use the risk acceptance criteria for the environment. It is assumed that a documented approach is chosen for the execution of the environmental risk assessment. There are several approaches that may be used, these are somewhat different with respect to the consequence categories used. There is work ongoing in order to harmonise these approaches. For the recommended approach, see Ref. 13 in Annex F.

The general steps of an environmental risk analysis are as follows:

1. Describe the activities.
2. Assess probabilities for accidental spills with different amount (rate) and duration. This is often done in a technical risk analysis.
3. Define the influence area (or the analysis area) based on oil spill drift simulations.
4. For each spill category defined in terms of amount and duration, the consequence for the resources are determined, based on factors such as:
 - probability that an oil spill shall expose vulnerable resources, according to:
 - oil drift simulations, natural dispersion, evaporation, etc.
 - effectiveness of the oil spill combatment (this is often initially disregarded)

- assessment of damage in the case of exposure of vulnerable resources:
 - amount of oil that affect the resources
 - characteristics of the oil
 - duration of the exposure
 - the vulnerability of the resources in the relevant period of the year (relevant stages, behaviour, etc.)
 - the proportion of resource present in the influence or analysis area being affected
5. Assess the environmental damage based on probability and consequence.
 6. Determine the effectiveness of possible risk reducing measures, including design changes and/or operational actions (oil spill combatment equipment).
 7. Compare risk results with the risk acceptance criteria and recommend risk reducing measures.
 8. Compare risk results with the risk acceptance criteria and recommend risk reducing measures. If necessary, repeat Steps 1-7 (shortcuts may be made)

C.5 Approach to Establishment of Environmental Risk Acceptance Criteria

It should be emphasised that the quantitative illustrations are merely examples. The main principle which is used is the following:

The recovery following environmental damage for the most vulnerable resource shall be insignificant in relation to the expected period between such damages.

The categories of environmental damage are defined as follows:

- **Minor** - environmental damage with recovery between 1 month and 1 year.
- **Moderate** - environmental damage with recovery between 1 and 3 years.
- **Significant** - environmental damage with recovery between 3 and 10 years.
- **Serious** - environmental damage with recovery in excess of 10 years.

The following average activity levels are assumed for the Norwegian continental shelf:

- An environmental resource may only be damaged if it is within the influence area of an installation.
- An environmental resource is assumed to be within the influence area of five oil/gas fields.
- There are two installations per field with the same influence area.
- Ten operations occur per year per installation.

The approach takes as its starting point the resources and their recoveries. Which installation that is the origin of the spill is without importance, seen from the resources' point of view. The principal basis is that a particular resource in total shall not be exposed to accidental spills for a longer proportion of time than can be considered 'insignificant'.

The overall principle as stated above implies that recovery following environmental damage shall have an 'insignificant' duration when compared to the expected period between such damages. Each operator has to choose the value to be interpreted as 'insignificant'. Examples for this value may be 0.5%, 1%, 2%, 5% or 10%. A 5% value is used in the following, as an illustration. Alternative interpretations 0.5% and 1% for 'insignificant' are also illustrated. The implication of the 5%

considered as 'insignificant' is that minor environmental damage with an average recovery of 0.5 years, may not occur more frequent than once every ten years.

Similar interpretations may be done for each environmental damage category, and the following table results, using the information above:

Table C1: Acceptable frequency limits, based on 'insignificant' interpreted as 5% (example).
Please note that 'average recovery' is a chosen mean value in each recovery category.

Environmental damage category	"Average" recovery	Acceptable frequency limit
Minor	1/2 year	< 1 event per 10 year
Moderate	2 year	< 1 event per 40 year
Significant	5 year	< 1 event per 100 year
Serious	20 year	< 1 event per 400 year

The following approach is used for the splitting up of these values into installations and operations:
If the environment in an area may survive a minor environmental damage with frequency once per 10 years, then this may be translated into the following:

- for a field with more than one installation: "1/5 of the frequency limit", i.e. 1 event per 50. year
- for one installation: "1/10 of the frequency limit ", i.e. 1 event per 100. year
- for one operation: "1/100 of the frequency limit ", i.e. 1 event per 1000. year

Combined with Table C1, the following results:

Table C2: Acceptable frequency limits for environmental damage categories for fields, installations and operations, based on 'insignificant' interpreted as 5% (example).

Environmental damage	Acceptable frequency limit	Field specific risk:	Installation specific risk:	Operational specific risk (per operation)
Minor	< 1 event per 10 year	< 1 event per 50 year	< 1 event per 100 year	< 1 event per 1 000 year
Moderate	< 1 event per 40 year	< 1 event per 200 year	< 1 event per 400 year	< 1 event per 4 000 year
Significant	< 1 event per 100 year	< 1 event per 500 year	< 1 event per 1 000 year	< 1 event per 10 000 year
Serious	< 1 event per 400 year	< 1 event per 2 000 year	< 1 event per 4 000 year	< 1 event per 40 000 year

Table C2 may be interpreted as annual probabilities, as they are low values implying that frequency and probability are the same values.

Table C3: Acceptable frequency limits for environmental risk, based on 'insignificant' interpreted as 5% (example).

Environmental damage	Field specific frequency limits per year:	Installation specific frequency limits per year:	Operational specific frequency limits per operation:
Minor	$< 2 \times 10^{-2}$	$< 1 \times 10^{-2}$	$< 1 \times 10^{-3}$
Moderate	$< 5 \times 10^{-3}$	$< 2.5 \times 10^{-3}$	$< 2.5 \times 10^{-4}$
Significant	$< 2 \times 10^{-3}$	$< 1 \times 10^{-3}$	$< 1 \times 10^{-4}$
Serious	$< 5 \times 10^{-4}$	$< 2.5 \times 10^{-4}$	$< 2.5 \times 10^{-5}$

The ALARP zone may for instance be defined in the range 10% to 100% of the acceptance limit. These limits must be defined by the operator.

Example: The following limits may be derived for 'minor' environmental damage on an installation:

- Acceptable environmental risk. Risk reducing measures may be evaluated, but are not required: $< 0.1 \times 10^{-2}$
- Acceptable environmental risk. Risk reducing measures shall be evaluated. $0.1 - 1 \times 10^{-2}$
- Unacceptable environmental risk. Risk reducing measures should be implemented, and environmental risk reanalysed: $\geq 1 \times 10^{-2}$

Table C3 is based on 'insignificant' interpreted as 5%. If 'insignificant' is interpreted as 0.5% or 1%, would the following risk acceptance limits result, as illustrated in Tables C4 and C5.

Table C4: Acceptable frequency limits for environmental risk, based on 'insignificant' interpreted as 0.5% (example).

Environmental damage	Field specific frequency limits per year:	Installation specific frequency limits per year:	Operational specific frequency limits per operation:
Minor	$< 2 \times 10^{-3}$	$< 1 \times 10^{-3}$	$< 1 \times 10^{-4}$
Moderate	$< 5 \times 10^{-4}$	$< 2.5 \times 10^{-4}$	$< 2.5 \times 10^{-5}$
Significant	$< 2 \times 10^{-4}$	$< 1 \times 10^{-4}$	$< 1 \times 10^{-5}$
Serious	$< 5 \times 10^{-5}$	$< 2.5 \times 10^{-5}$	$< 2.5 \times 10^{-6}$

Table C5: Risk acceptance criteria for environmental risk, based on 'insignificant' interpreted as = 1% (example).

Environmental damage	Field specific frequency limits per year:	Installation specific frequency limits per year:	Operational specific frequency limits per operation:
Minor	$< 4 \times 10^{-3}$	$< 2 \times 10^{-3}$	$< 2 \times 10^{-4}$
Moderate	$< 1 \times 10^{-3}$	$< 5 \times 10^{-4}$	$< 5 \times 10^{-5}$
Significant	$< 4 \times 10^{-4}$	$< 2 \times 10^{-4}$	$< 2 \times 10^{-5}$
Serious	$< 1 \times 10^{-4}$	$< 5 \times 10^{-5}$	$< 5 \times 10^{-6}$

ANNEX D RELATIONSHIP BETWEEN RISK AND EMERGENCY PREPAREDNESS ANALYSIS (INFORMATIVE)

D.1 What is Emergency Preparedness?

D.1.1 Emergency Preparedness in relation to Normal Operations

The definition of "emergency preparedness" (see normative text, definition 3.1.3) underlines that all technical, operational and organisational measures that are planned to be implemented under the management of the emergency preparedness organisation in relation to occurrences of hazardous or accidental events are part of the term "emergency preparedness".

The primary objective of this limitation is to separate dimensioning of emergency preparedness measures from dimensioning of technical safety systems, which main are dimensioned in relation to risk analysis. Some definitions in the past have included the safety systems as part of the emergency preparedness, but these are left outside with the present definition.

The definition shall further separate operational emergency preparedness measures from actions and operations taken as part of normal operation, and does this by reference to the emergency preparedness organisation. Normal operation will always include responses to abnormal conditions and events. If these responses are successful in gaining control over the situation, then no emergency preparedness situation arises. Only when the operational responses and measures are not successful, will an emergency preparedness situation arise.

The distinction between normal operation, activation of safety systems and emergency preparedness measures may be illustrated along several axes:

- Timewise, when does the transition from normal operation into an emergency preparedness situation occur?
- Mobilisation and activation, automatic or manual
- Which organisation is in charge, the normal operational organisation or the emergency preparedness organisation?

It is not possible to find a unique distinction between normal operations and emergency preparedness. A distinction has to be expressed simultaneously along all these axes. This is to some extent outlined in the following.

D.1.2 Emergency Preparedness in relation to Safety Systems

The starting point for the distinction between normal operation and associated activation of safety and emergency preparedness is that the latter shall not include dimensioning of safety systems.

Systems that are automatically activated are the installation's safety systems which usually are activated on the basis of input from detection systems for fire, gas, smoke, etc. The activation may require in some few cases, either as an option or as a requirement, that a certain manual initiation action is performed, but the system may otherwise perform as an automatic system. A flare system

which require manual activation, upon which the system performs sequential or simultaneous depressurisation of gas containing pressure systems, may be the typical example of the special case.

There are usually several technical, operational or organisational barriers that upon detection and/or warning shall prevent a threat from developing into an accidental situation, or that are intended to limit the consequences if an accident occurs. These measures will to a certain extent be automatic, the extent to which they are will usually depend on the type of hazard involved. Automatic safety systems will work in parallel with manual emergency preparedness measures for a certain period. These manual actions are mobilised by the installation's emergency preparedness organisation. The timing of transfer from safety systems to emergency preparedness systems is therefore not a unique time. The diagram below attempts to illustrate some of these aspects.

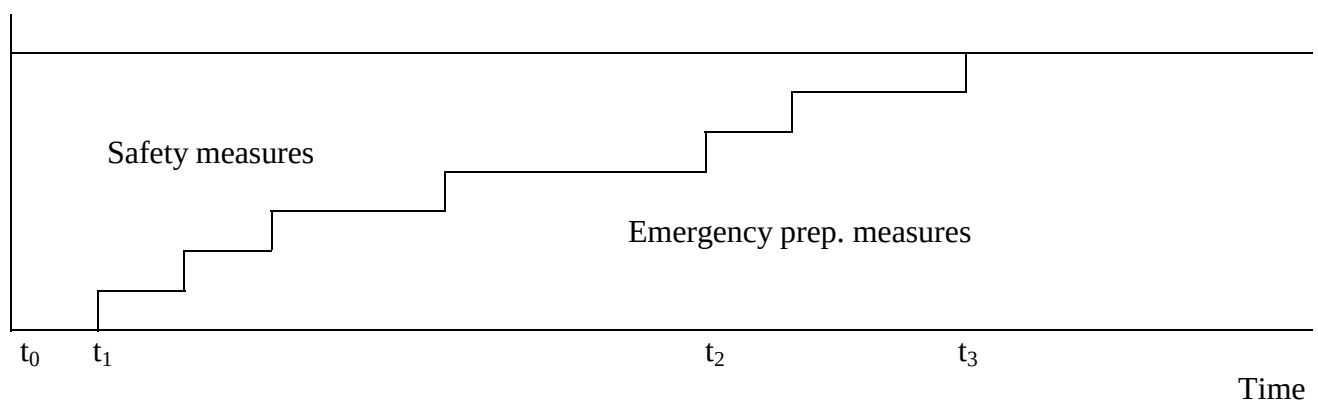


Figure D1. Timewise development of an accidental situation. Transition from a "safety" domain to an "emergency preparedness" domain

The diagram may be illustrated as follows for an ignited case of gas leak:

- A limited gas leak occurs at time t_0 . Gas alarm is triggered in the control room, following automatic detection of 15% LEL. Production supervisor notifies a process operator in the area of the alarm, and asks him with great caution to approach the place where the leak has been detected, and if possible inspect the location and determine the cause and extent of the problem. *This action is considered part of normal operation.*
- The process operator reports back to the control room at time t_1 that there is a small gas leak from a flange on a gas dehydration unit, he is able to see the exact location of the leak, but the leak cannot be isolated manually. He has retreated to behind a fire wall. At this time the following could occur:
 - Mobilisation of the installation's emergency preparedness organisation, by whom the platform manager is the first to be notified. *This is the time of the first mobilisation of an emergency preparedness action.*
 - Emergency shutdown and depressurisation is initiated manually, after which these systems perform automatically. They are considered automatic safety systems, *not part of the emergency preparedness.*

- Gas alarm is initiated on the installation, all personnel onboard will secure their workplace, then leave in order to report to their muster stations (for instance in the shelter area). This is an *emergency preparedness action*.
- Notification of onshore emergency preparedness organisation is initiated according to the relevant action plans (*emergency preparedness action*).
- A limited gas explosion occurs after approximately 15 seconds, followed by fire. The damage from the explosion is limited.
- Fire fighting and cooling of process equipment is initiated automatically by the fire detection, all systems are essentially undamaged from the blast loads. (*safety system*)
- The installation's emergency preparedness organisation ensures that all personnel have reported to their stations successfully, and then monitors the development of the situation, and maintain communication with the onshore emergency preparedness organisation. (*emergency preparedness action*).
- The fire water system is successful in controlling the fire without secondary leaks or escalation of the fire (*safety system*).
- The pressure inside the gas segment is considerably reduced after approximately 20 minutes and the fire intensity is correspondingly reduced.
- The fire is extinguished at time t_2 . Cooling of equipment and structures continues. Personnel on the installation as well as onshore is informed about the progress.
- The fire water system is stopped at time t_3 , reflecting the absence of any further fire hazard. *This is the first time when the installation's emergency preparedness organisation has full control with all system*. The normalisation phase starts.

Safety systems and emergency preparedness measures are working in parallel in the interval t_1 to t_3 . From time t_1 the situation is regarded as an emergency preparedness situation, when it is confirmed that the normal operating organisation can not handle the situation and the emergency preparedness organisation therefore is mobilised. The onshore emergency preparedness organisation also has to be considered in this context, as in the example above.

Finally, it could be noted that the oil spill preparedness as well as preparedness with respect to cases of illness are included in the emergency preparedness context. The emergency preparedness work has the following phases; notification, combatment, rescue, evacuation and normalisation.

D.1.3 Safety and Emergency Preparedness Measures

Safety and emergency preparedness measures are the two general terms used in order to illustrate potential actions that principally may be taken. Measures will include technical systems and equipment as well as manual or organisational steps and procedures. In the following the general term measures is used most frequently, systems and equipment are used when the intention is to put emphasis on measures being of a technical nature.

Dimensioning of safety systems is done on the basis of risk analysis, in addition to minimum requirements stipulated by the relevant authorities, established practice, recognised standards, etc. Such systems may be:

- Depressurisation system, including flare system
- Automatic system for fire fighting
- Fire and gas detection and warning systems

Some of the systems and equipment that will be mobilised under the management of the emergency preparedness organisation are also dimensioned on the basis of results and/or premises in risk assessments. Typical examples in this context are:

- Escape ways (on the installation)
- Evacuation means (in order to abandon the installation)
- Rescue means (from the sea)

There are also measures that similarly will be mobilised by the emergency preparedness organisation that are dimensioned on the basis of results and/or premises in emergency analysis. Typical examples of such measures are:

- Actions intended to assist injured personnel on the installation
- Actions intended to rescue personnel who fall in the sea.

D.2 Defined Situations of Hazard and Accident (DFU)

There are two main categories of DFU:

- Dimensioning accidental events, these are identified through risk analysis
- Those types of accidental events that usually are not part of a detailed risk analysis, but usually subject to emergency preparedness analysis:
 - Hazardous and accidental situations associated with temporary increase of risk
 - Less extensive accidental events

Some of the less extensive accidental events are often included in the estimation of total risk, such as occupational accidents. This analysis is usually limited to an overall estimate of the numerical contribution from these events to frequency of fatal accidents, without analysis of which particular accidents that may occur. The accidental events that are analysed in detail are usually limited to those that may lead to dimensioning accidental events.

The following is recommended with respect to the level of details that should be addressed in the definition of DFU:

- Dimensioning accidental events are defined in detail through risk analysis, including their pertaining operational situation as well as relevant environmental conditions. These descriptions should also be used for the emergency preparedness analysis.
- Those DFU that are not analysed in detail in the risk analysis are in the emergency preparedness analysis given a more broad description, without detailed statement of operating and environmental conditions. The detailed development of applicable operating and environmental conditions is done as part of the emergency preparedness analysis.

D.3 Risk Analysis, Emergency Preparedness Analysis and Establishment of Emergency Preparedness

D.3.1 Defined Situations of Hazard and Accident

The relationship between quantitative risk analysis, emergency preparedness analysis establishment of emergency preparedness is in the following discussed in relation to three diagrams that express different aspects of the relationship.

Figure D2 is intended to demonstrate how the basis of the establishment of emergency preparedness is done. The basis starts with the two main categories of accidental events as described in Section D2 above.

Figure D2 shows that a major part of the basis fore establishment of emergency preparedness is the dimensioning accidental events. The circle is divided in three areas reflecting the categories (and sub-categories) of accidental events that constitute the DFU. There is an indication of a radial time scale in the diagram, implying that risk and emergency preparedness analysis start at the periphery of the circle, and are executed as the movement is towards the centre of the circle, which implies the completion of the work.

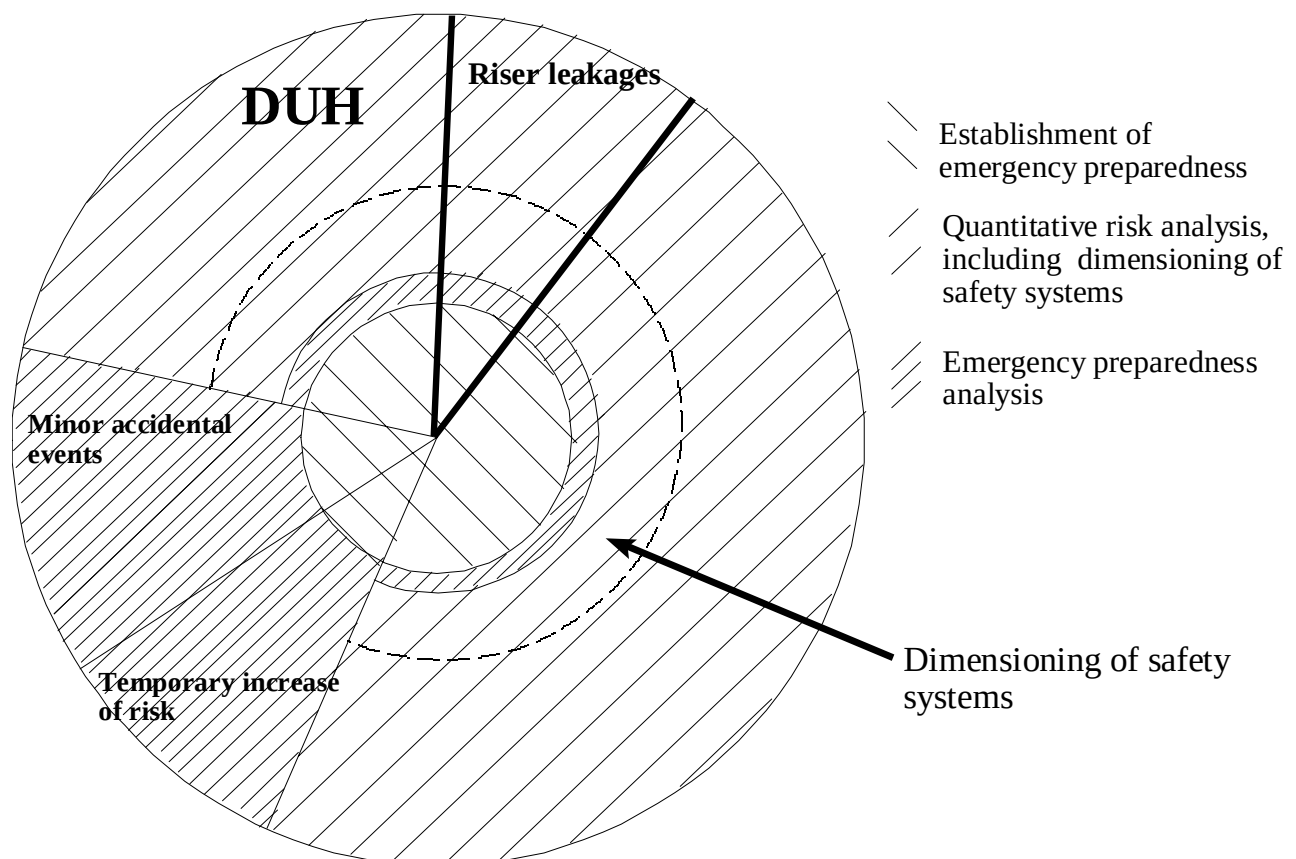


Figure D2. Relationship between risk and emergency preparedness analysis, establishment of emergency preparedness

There is a considerable effort devoted to those accidental events that are part of detailed risk analysis, in order to dimensioning of safety systems. This is indicated in the diagram for the dimensioning accidental events. Similar activity is also associated with emergency preparedness measures, mainly in relation to technical systems and equipment for evacuation. There is still a small portion of aspects in relation to dimensioning accidental events that are not handled in the quantitative risk analysis which need to be analysed with respect to emergency preparedness. These are implied by the thin ring relating to emergency preparedness analysis also for the dimensioning accidental events, relating to:

- analysis of measures for notification
- analysis of measures for rescue
- analysis of measures for normalisation
- analysis of organisational and personnel related measures for combatment and evacuation

It should be emphasised that the 'emergency preparedness analysis ring' in Figure D2 covers the full circle, implying that emergency preparedness analysis is carried out for all categories of accidental events being part of DFU. For instance is the analysis of organisational and personnel related measures also relevant for all categories of accidental events.

The diagram in Figure D2 should not be interpreted to imply that there is a static relationship between the extent of risk analysis, emergency preparedness analysis and establishment of emergency preparedness. It is emphasised that the type of accidental events considered will influence considerably the extent of these activities. The quantitative risk analysis and the subsequent dimensioning of safety and emergency preparedness systems will be the main effort, in relation to a limited fire in the process area. The emergency preparedness analysis in this context will usually be limited to dimensioning of the different emergency response teams for assistance to possibly injured personnel and normalisation.

Possible passing vessel collision may illustrate a different emphasis, even though it is still a type of accidental event that is part of the quantitative risk analysis. The only safety system that may be applied is automatic anti-collision radar. Some of the relevant emergency preparedness measures will be addressed in the quantitative risk analysis, but it will nevertheless be several measures that commonly are not addressed within the risk analysis, and therefore need to be addressed in the emergency preparedness analysis.

Further illustration of the relationship between DUH and DFU is indicated in Figure D3.

The "residual accidental events" in Figure D3 are those accidental events that have such a low probability that the risk associated with them is negligible. Some of the DFU are found in this category.

The area in the diagram marked "dimensioning accidental events" shall be interpreted to include potential DUH (accidental events which may form the basis of design accidental loads), from which the actual dimensioning accidental events are selected. The actual DUH selected (those that form input to design) are represented by small circles in the diagram. Some of these will be DFU.

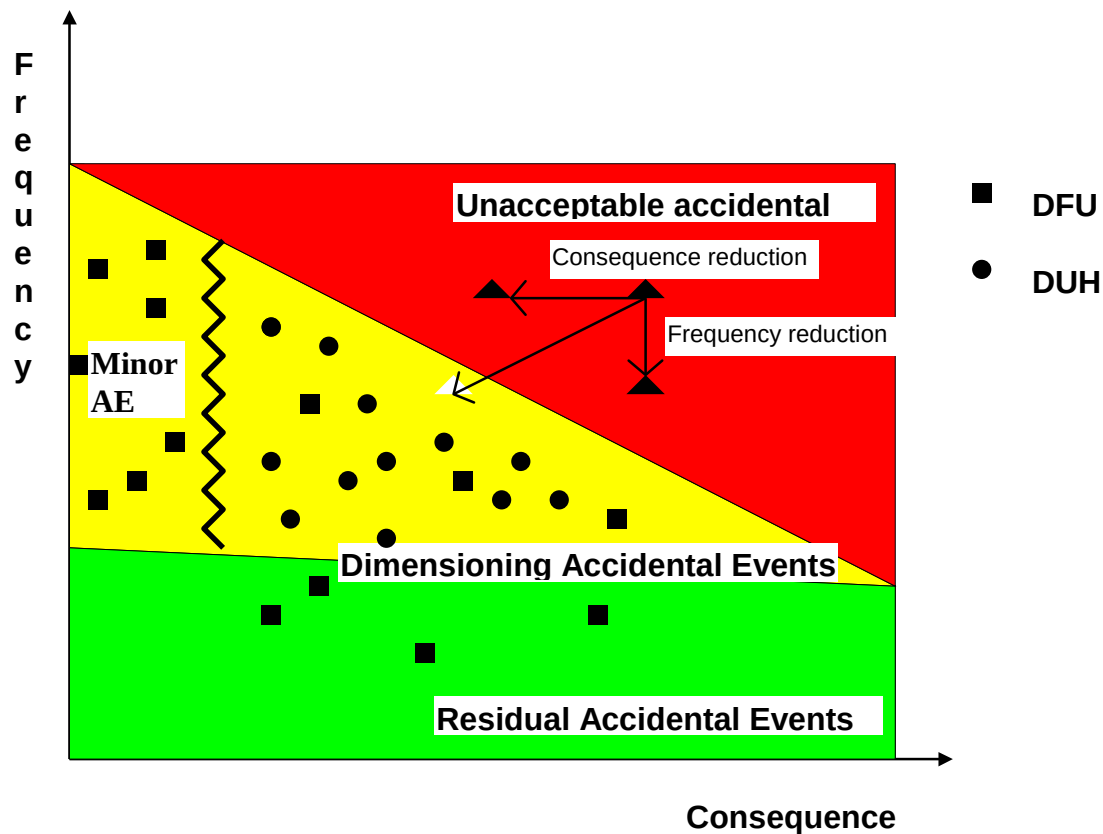


Figure D3. Dimensioning accidental events, defined situations of hazard and accident and residual accidental events

There is a diffuse separation indicated in the diagram between less extensive accidental events and dimensioning accidental events. This shall indicate that such a separation often is rather vague.

D.3.2 Emergency Preparedness Analysis

Integrated risk and emergency preparedness analysis is presented in Section 4.3 of the normative text. The following takes a limited view and presents the part of the integrated analysis which is the emergency preparedness analysis. The next diagram has the following objectives:

- Present the distinction between emergency preparedness analysis and establishment of emergency preparedness.
- Present the context of functional requirements to safety and emergency preparedness systems.
- Present the optimisation usually involved in identification of measures and performance of effectiveness analysis.

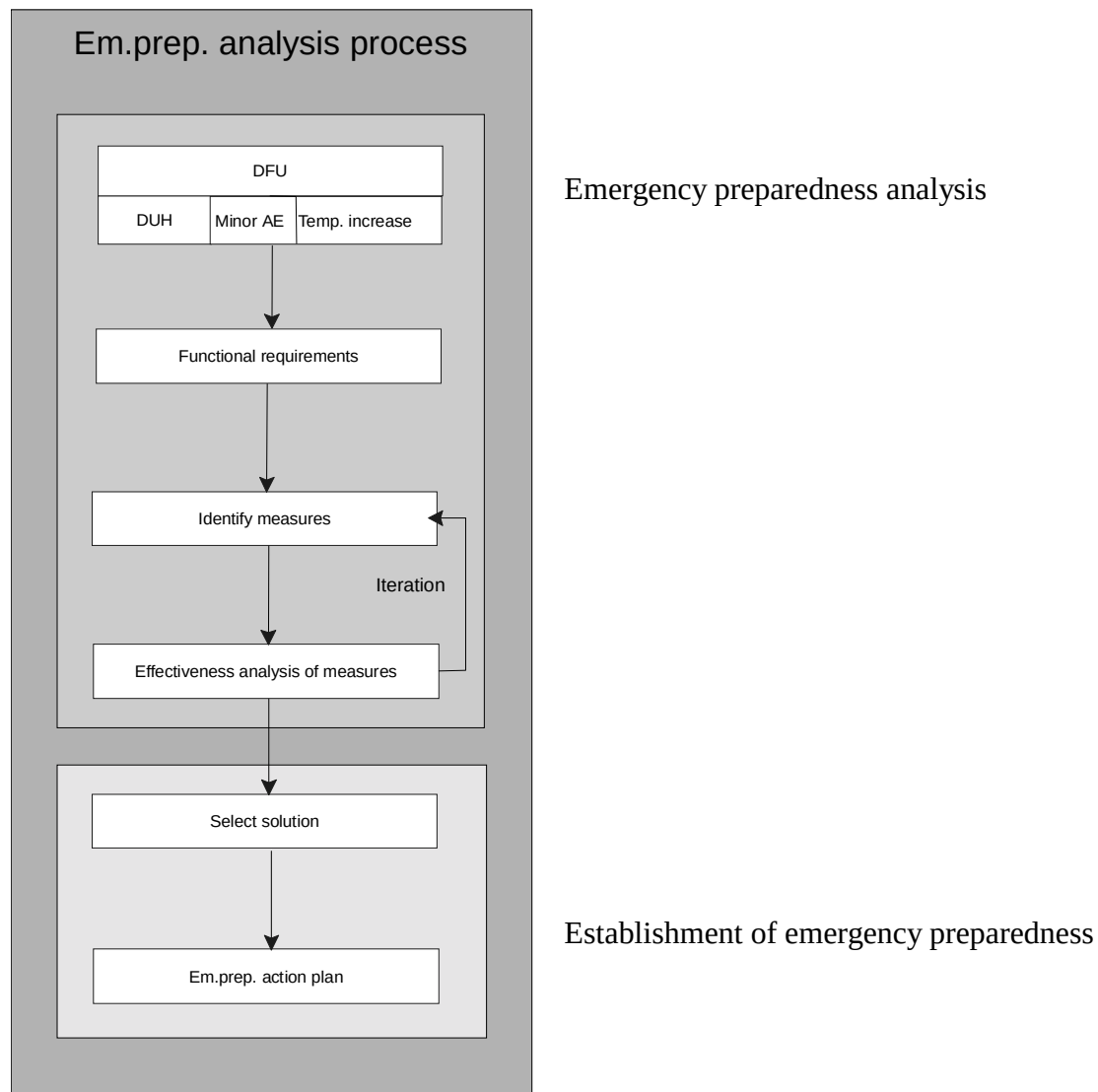


Figure D4. Emergency preparedness analysis and establishment of emergency preparedness

Figure D4 shows the emergency preparedness analysis to have the following steps:

- Establishment of DFU
- Establishment of functional requirements
- Identify relevant measures
- Effectiveness analysis of measures

The establishment of emergency preparedness follows the emergency preparedness analysis, consisting of the following steps:

- Choice of technical, operational and organisational solution
- Preparation of the emergency preparedness (or action) plan

The following resources should be considered when the measures are being established:

- Unit resources
 - Installation with its equipment and organisation
 - Helicopters
 - Standby Vessel
 - Oil-Spill emergency preparedness equipment
 - Shuttle Tanker
- Area resources
 - Sector club
 - Neighbour installations or other petroleum activity
 - Helicopters
 - Vessels in the area
 - Oil-Spill emergency preparedness equipment
- External resources
 - The Rescue Co-ordination Centres (RCC)
 - Helicopters
 - Aircraft
 - Navy (Coast Guard, marine) and other vessels
 - The public health services
 - Oil-Spill emergency preparedness system

The emergency preparedness analysis has distinct parallelism with quantitative risk analysis, but also its dissimilarities, the most important being that the quantitative risk analysis does not include the step of establishing the risk acceptance criteria, which is part of the emergency preparedness analysis through statement of functional requirements.

Iterations are used in both the emergency preparedness analysis as well as the quantitative risk analysis in order to achieve an optimum solution.

The coupling of the quantitative risk analysis and the emergency preparedness analysis in relation to the dimensioning accidental events is shown in the normative text, Section 5.4.2.

D.4 Functional Requirements to Safety and Emergency Preparedness

The general term which expresses the specific requirements to safety and emergency preparedness measures is in the normative text defined (Definition 3.1.14) as "Functional requirements to safety and emergency preparedness". These functional requirements must be specified in a way which will allow them to be validated.

The basis on which to determine what functional requirements that are needed, is as follows:

- Assumptions, premises and detailed results from quantitative risk analysis.
- General safety and emergency preparedness requirements formulated by the operator.
- Recognised norms for emergency preparedness.
- Experience relating to similar or parallel concepts and conditions.

Aspects for which it may be relevant to define functional requirements are as follows:

- a) availability of safe (sheltered) areas and evacuation and rescue means,
- b) reliability of emergency shutdown systems,
- c) availability of fire water system,
- d) reliability of the communication systems,
- e) extent of preparedness with respect to handling of spills including:
 - ea.) capacity of the oil spill handling equipment,
 - eb) response time for the oil spill combatment system,
 - ec) storage capacity for oil which is collected,
 - ed) competence of the personnel who form the oil spill combatment organisation,
 - ee) durability of the oil spill combatment equipment and organisation,
- f) requirements for maximum acceptable time to transport of injured or ill person to onshore treatment,
- g) capacity of the hospital on the installation or on a vessel,
- h) competence of the personnel who form the emergency preparedness organisation,
- h) maximum acceptable muster time for personnel who do not have assignments in the emergency preparedness organisation,
- i) maximum acceptable response time in a man-over-board situation from notification until the person has been retrieved from the sea,
- k) maximum acceptable mobilisation time for helicopters that participate in the SAR activities.

Conditions of sales agreements for petroleum products may sometimes be relevant for definition of functional requirements to emergency preparedness. There may further be particular emphasis on production regularity aspects for an installation which is part of a comprehensive production and transport network, in order that the negative effects on the total network may be minimised. There may be cases where some functional requirements for an installation is determined by consideration of other installations, say in case of a vulnerable connection to a pipeline transportation system.

D.5 Establishment of Emergency Preparedness

Establishment of emergency preparedness will have to be done in relation to the same categories as were stated in Section D2. The basis for the establishment of emergency preparedness is the following:

- Events for which detailed Quantitative risk analysis is carried out:
 - Quantitative risk analysis, the part of this which is devoted to dimensioning of emergency preparedness systems.
 - Emergency preparedness analysis for DUH, pertaining to those emergency preparedness measures that are not part of the risk analysis:
- Events that are not subject to detailed Quantitative risk analysis:
 - Emergency preparedness analysis these events in relation to technical, operational and organisation measures.

Establishment of emergency preparedness is discussed separately for major accidents, after which the establishment of emergency preparedness is discussed for the remaining events.

D.5.1 Major Accidents

It is assumed that quantitative risk analysis always is carried out for major accidents (i.e. accidental events that may potentially imply several fatalities per accident). This analysis is principally assumed to be an integrated risk and emergency preparedness analysis (see Section 4.3 in the normative text) for safety and emergency preparedness measures. This implies that the following is carried out in parallel:

- a) Effectiveness requirements for safety and emergency preparedness measures are extracted or interpreted from assumptions, premises and results of the quantitative risk analysis.
- b) Effectiveness analyses are carried out to the extent necessary in order to determine the implied effectiveness in the alternative solutions.

The establishment of effectiveness requirements from quantitative risk analysis is focused on dimensioning accidental events. These accidental events represent binding areas of action for all emergency preparedness work. All emergency preparedness requirements shall be met in full for these events.

When the integrated risk and emergency preparedness analysis is carried out, the results will partly be used for dimensioning of safety measures (typically for new installations) and also partly for establishment of emergency preparedness.

Risk analyses will principally never be capable of expressing a 'real' risk picture in the sense that true value of risk contribution from all possible hazards are known in full. This will always be impossible, due to the rare nature of the events involved. It should therefore never be ruled out completely that more severe accidental events may occur, and the establishment of emergency preparedness should take this aspect into some consideration.

D.5.2 Less Extensive Accidental Events, Temporary Increase of Risk

A detailed risk analysis is usually not carried out for less extensive accidental events as well as situations that imply temporary increase of risk. Therefor, the main analytical effort in order to generate a basis for establishment of emergency preparedness is the emergency preparedness analysis, as indicated in Section D.3.2.

The defined situations of hazard and accident represent binding areas of action for all emergency preparedness work. All emergency preparedness requirements shall be met in full for these events.

D.6 Checklist for possible DFU

The section presents an overview of possible DFU that should be considered prior to deciding on actual DFU for an installation. Dimensioning accidental events which are established through quantitative risk analysis are not included in the listing, which is limited to less extensive accidental events as well as situations that imply temporary increase of risk.

It should be noted that several of the events that are to be considered are part of normal operation, to the extent that operational procedures often will exist in order to manage the risk. Nevertheless, emergency preparedness measures may have to be established and be in place as a backup in the

case that the operational controls are unsuccessful in controlling the risk. There may for instance be plans to perform precautionary evacuation of personnel in the case of a drifting vessel close to the installation.

Some of these events are included in the checklist partly to remind that these situations may require establishment of emergency preparedness. This applies in particular to situations which represent a temporary increase of risk.

D.6.1 Temporary Increase of Risk

- Work over open sea
- 'Hot work'
- Extreme weather conditions
- Truck driving
- Drifting object/vessel
- Unstable well
- Jacking up and down of jack-ups
- Special operations during regular production, such as:
 - shut down due to failure of safety systems
 - maintenance period with abnormally high manning level
 - Temporary bridge connected flotel etc.

D.6.2 Less Extensive Accidental Events

- Liquid carry-over from flare
- Fire in auxiliary systems
- Fire in accommodation
- Helicopter accident on the installation (crash on helideck or other place)
- Helicopter accident (or incident) in the sea close to installation
- Acute medical case
 - Occupational accident
 - Injuries to personnel in relation to fire or explosion
 - Injuries to personnel in relation to escape, evacuation and rescue
 - Acute illness
 - Food poisoning, etc.
- Man-over-board
- Radioactive radiation
- Acute chemical spill
- Limited oil spill (on deck or on water)
- Failure of power generation
- Limited structural damage
- Limited loss of buoyancy (floating installation)
- Limited loss of stability (floating installation)
- Loss of the control room function (i.e. partial or total loss or degradation of detection, warning, alarm, communication)
- Terrorism
- Sabotage
- Positioning failure (floating installation)
- Failure of inert gas system (storage and/or production tanker)

- Failure of control systems for subsea production systems
- Hydrocarbon leak from subsea production systems
- Hydrocarbon leak from pipeline system

ANNEX E GUIDELINES FOR COST BENEFIT ANALYSIS (INFORMATIVE)

This Annex provides a recommended approach to the use of Cost Benefit Analysis (CBA) for Health, Environment and Safety (HES) issues in the offshore petroleum industry, in order to determine the optimum choice or solution. The use of this approach is well established in several areas, especially in the transportation sector. Also in the petroleum sector, the use has increased considerably in the last few years, and it is important that consistent approaches are developed and used. The consistent use of Cost Benefit Analysis is also an important prerequisite for successful use of scenario based analysis.

E.1 Purpose of Cost Benefit Analysis

E.1.1 Overall Objectives

The application of CBA in relation to risk aspects is somewhat special in the sense that there is a mix between deterministic and low probability cost elements. (See also discussion in Section E2.3.)

There may be somewhat different objectives for the performance of Cost Benefit Analysis:

- Determine optimum level of safety protection when risk acceptance criteria have been satisfied through prior risk assessment. Usually this will imply that risk acceptance criteria for personnel (possibly also environment) have been satisfied, and that the CBA is used in order to find the optimum level of protection against material damage risk. (Type I)
- Determine what is acceptable risk level without prior satisfaction of risk acceptance criteria. If this is the case, usually the same approach is then applied to risk to personnel, risk to environment and risk to assets, which all then are evaluated within an ALARP context. (Type II)
- Determine optimum level of emergency preparedness when risk acceptance criteria and functional requirements to emergency preparedness have been satisfied through prior risk assessment and emergency preparedness analysis. (Type III)

These contexts relate to the definition of the term 'risk' in Section 3 of the Normative text of this NORSOK standard. The application of the CBA approach in relation to Health, Safety and Environment aspects may also be wider than what is defined within the term 'risk'. This implies for instance that aspects related to health issues, working environment aspects, non acute spills and emergency repair capacities may be analysed.

Costs and benefits have to be interpreted in the widest possible context, when the CBA approach is utilised. This implies that all benefits and drawbacks have to be included in the analysis. Only some of these aspects may be candidates for quantification, which implies that qualitative evaluations have to be paired with quantitative analysis. For example will the benefits have to include the feeling of safety and protection that personnel may have in relation to a particular risk reduction measure. There may also be drawbacks that are impossible to quantify, such as the implicit setting of precedents [by adopting a certain measure] that may have far reaching implications in the future.

How the process is carried out is somewhat dependent on whether the main objective of the evaluation is risk to personnel or risk to assets. Two flow diagrams are therefore presented in the following sections.

E.1.2 ALARP Demonstration for Risk to Personnel

The use of CBA in an ALARP evaluation for personnel is considered to be of Type II as stated in Section E1.1. This implies that risk to personnel, environment and assets are integrated in the assessment, but usually the decisions are made with respect to risk to personnel. The evaluation process is presented in the diagram below. Brief comments to the steps of the process are also given.

Risk level in Unacceptable region?

If the risk level determined by QRA is in the 'Unacceptable' region, i.e. above the Upper Limit of Tolerability, implementation of necessary Risk Reduction Measures (RRMs) is mandatory, according to the ALARP principles.

Risk level in Acceptable region?

If the risk level is in the 'Acceptable' region, i.e. below the Lower Limit of Tolerability, no further implementation of RRMs is required, according to the ALARP principles (see Definition 3.13 in the Normative text, and Annex A, Section A1.4, and the evaluation may stop.

If the risk level is in neither of these categories, it falls in the so-called 'ALARP' region between the Lower and Upper Limits of Tolerability, and possible implementation of RRMs shall be considered.

Identify possible RRMs

The first step of the RRM evaluation is to identify all possible RRMs that may be considered. It is important to ensure that a broad experience basis is used in the identification of RRMs, especially important is to obtain participation of the workforce and operational experience.

Evaluate RRMs qualitatively

Each RRM should first of all be evaluated qualitatively for the effect on safety of personnel, environment and assets, based on:

- Compliance with regulations, guidelines, standards, accepted practice
- Qualitative evaluation of risk reducing potential

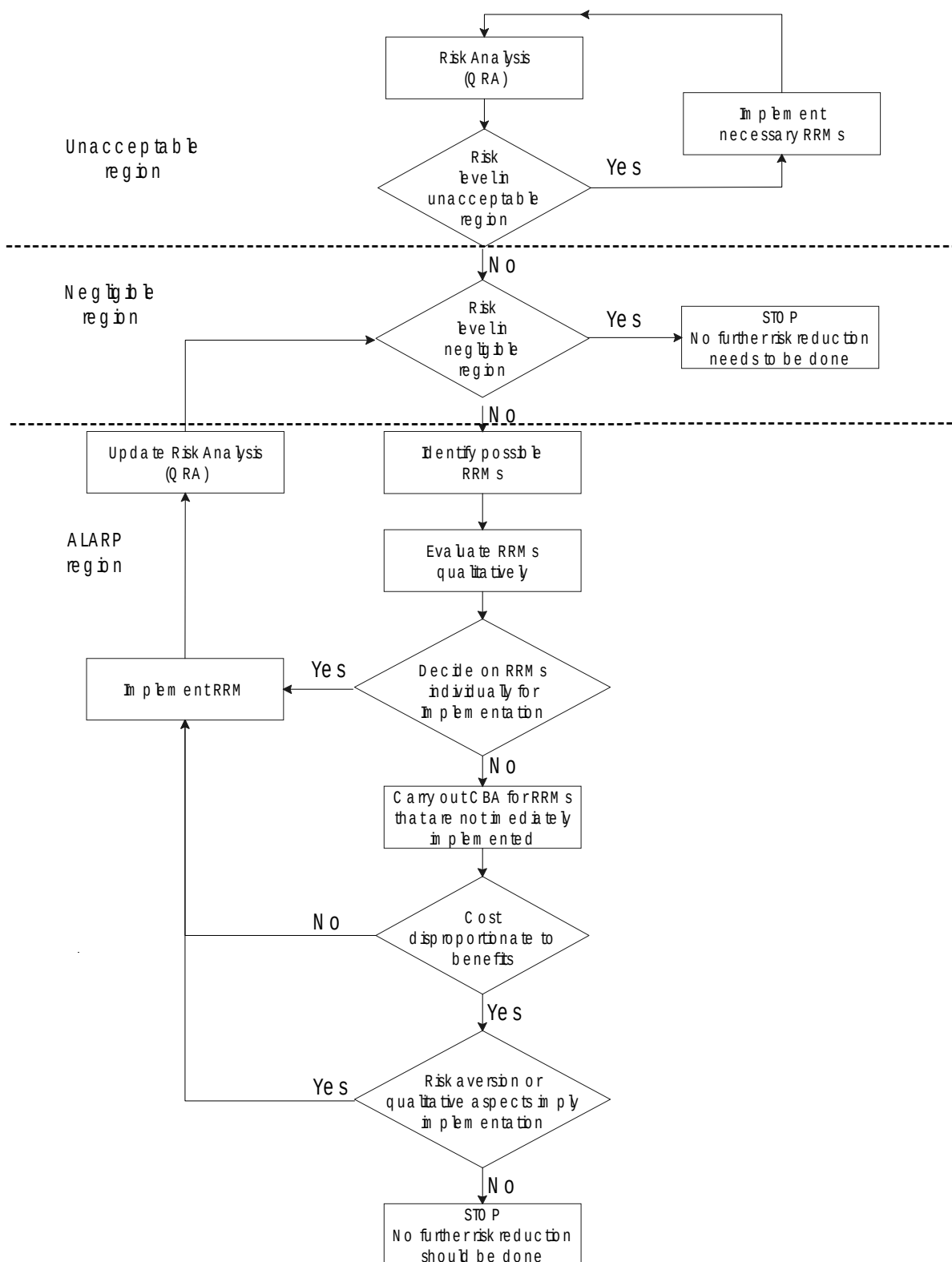


Figure E.1.1 ALARP demonstration for risk to personnel

Decide on RRM individually for implementation

The first iteration for the implementation of RRM is based on the qualitative evaluation. Some of the RRM will be obvious candidates for implementation, and no further analysis or evaluation should be done for these.

Carry out CBA for RRM that are rejected

For those RRM that are not immediately implemented in the first iteration, the CBA should be carried out, as specified in this Annex.

Costs in Gross Disproportion to Benefits?

For those RRM that have costs that are less than disproportionate to the benefits, implementation should be decided. The result will in most cases be quite dependent on how consequences of accidents are valued (for instance what is the value of human life, or an averted fatality). How this may be treated is discussed in Section E5 below.

Risk Aversion or qualitative aspects imply implementation?

Other 'non-quantitative' aspects may sometimes imply that an RRM should be implemented in spite of costs being in gross disproportion to benefits.

E.1.3 ALARP Demonstration for Risk to Assets

The use of CBA in an ALARP evaluation for risk to assets is considered to be of Type I as stated in Section E1.1. This implies that the consideration is limited to an economical optimisation. The evaluation process is presented in Figure E1.2 below. This diagram is with one exception identical with Figure E1.1. Brief comments are given to that element which is different in the two approaches.

This diagram assumes that there are tolerability limits also defined for risk to assets. This is perhaps most commonly **not** the case, and the two first decision boxes in the top of the diagram relating to ALARP regions may be disregarded.

Positive Life Cycle Cost?

For those RRM that have a positive net present value according to Equation (1) in Section E2.1 below, implementation is obvious. The result will in most cases be quite dependent on how consequences of accidents are valued. How this may be treated is discussed in Section E5 below.

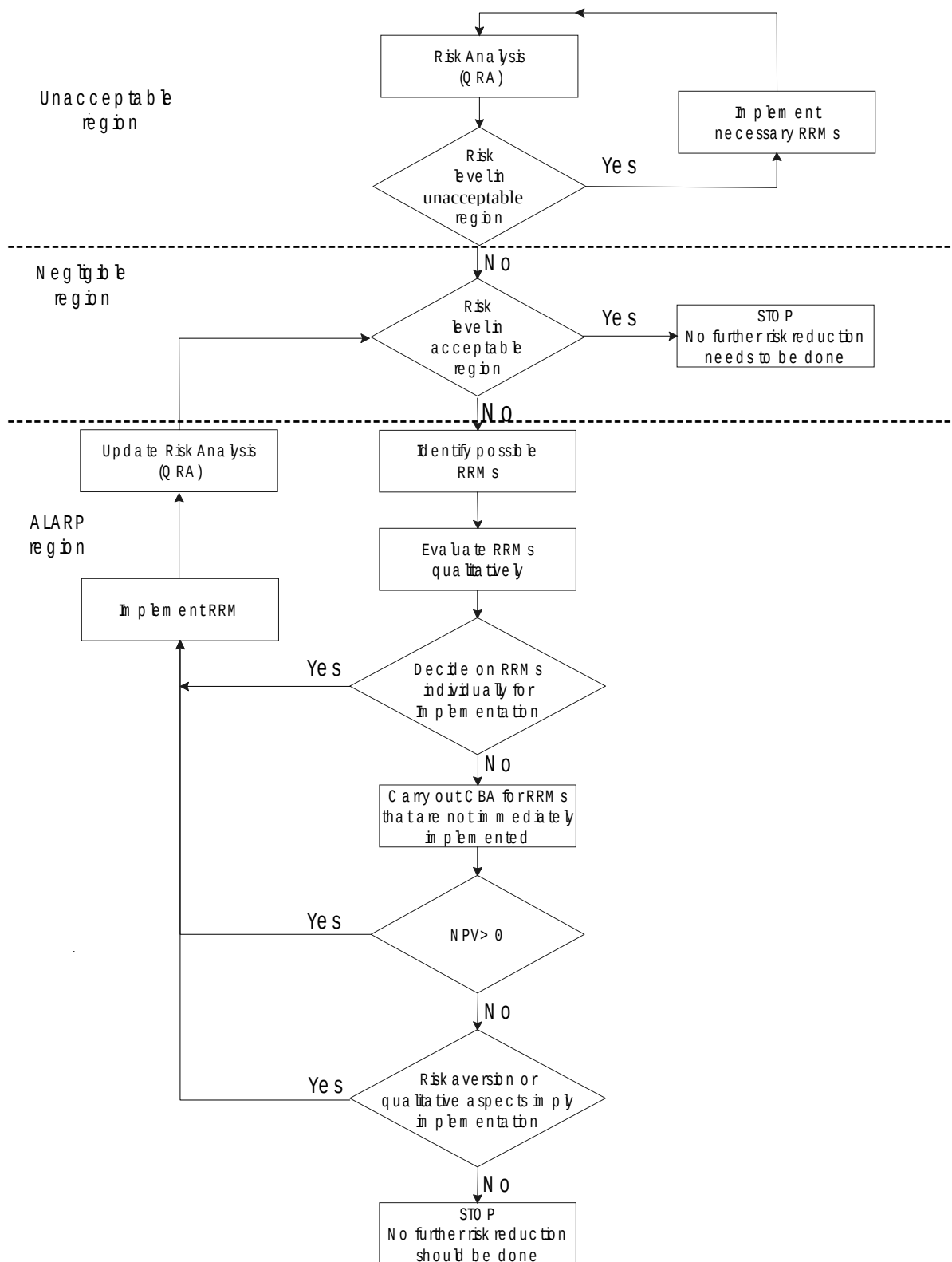


Figure E.1.2 ALARP demonstration for risk to assets

E.1.4 Optimisation of Emergency Preparedness

The use of CBA in the ALARP consideration for Emergency Preparedness is categorised as Type III as outlined in Section E1.1. The evaluations are carried out in the same manner as for risk to personnel, and basically follow the same approach as in Figure E1.1. ALARP limits do not apply however, and the simplified approach is shown in Figure E1.3.

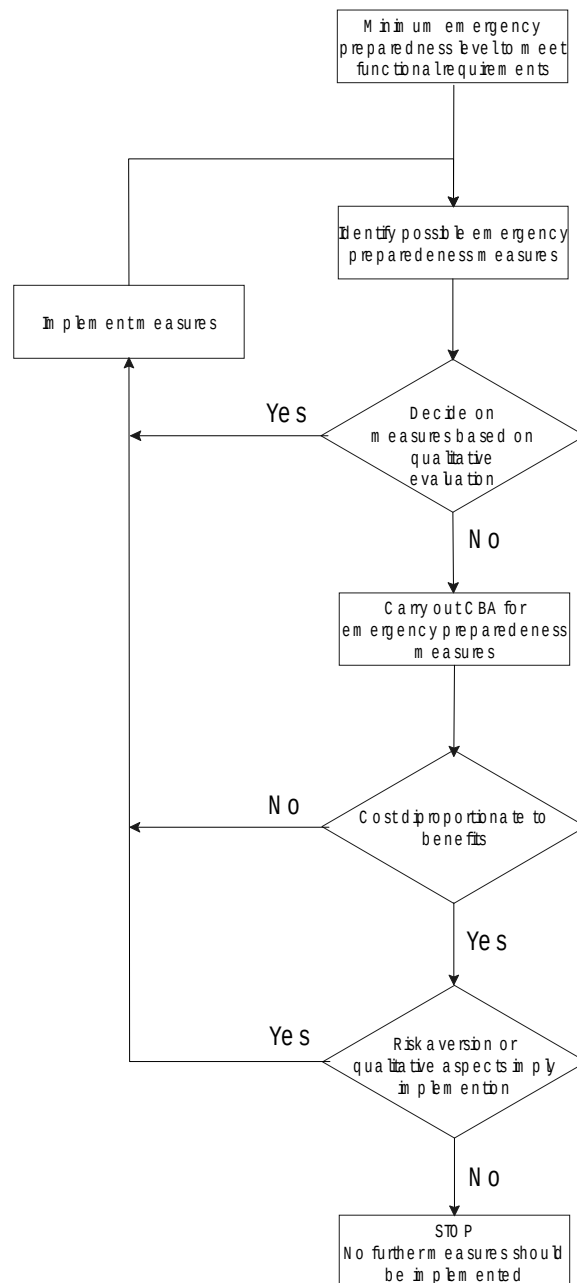


Figure E.1.3 Cost Benefit Analysis for emergency preparedness measures

E.2 Approach to Quantitative Comparison of Benefit and Cost

E.2.1 General Model

The main principle of quantitative comparison of benefit and cost in a HES context is that reduction of HES loss (i.e. benefits) should exceed costs when considered in a life cycle perspective.

Mathematically, this may expressed as follows:

$$LCC = \sum_{n=1}^N 1,0p^{-n} \left[\sum_{j=1}^3 \Delta C_{nj} \cdot V_j(C) - RC_n - IC_n \right] > 0 \quad (1)$$

where

- LCC = Life cycle cost (Net Present Value) for a particular risk reduction measure from year 0 until year 'N'
- N = Last year of field life time
- $1,0p^{-n}$ = Depreciation factor for year 'n', based upon interest 'p' %
- ΔC_{nj} = difference in expected accident consequence in year n, risk dimension j
 - j = 1 dimension: risk to personnel
 - j = 2 dimension: risk to environment
 - j = 3 dimension: risk to assets
- $V_j(C)$ = valuation of risk dimension j as a function of the accident consequence C
- RC_n = running costs (operating, maintenance, etc.) in year n
- IC_n = investment costs in year n

A special case is when LCC based on risk to assets alone, is negative and there is a significant improvement of risk to personnel. Then it is often useful to eliminate risk to personnel from Equation (1), and calculate the cost per statistically averted life. Alternatively, risk to personnel is retained in Equation (1), and the valuation $V_j(C)$ is chosen to reflect the willingness to pay to avert a statistical fatality.

The equation shows clearly that all costs during operation are to be depreciated according to an interest which should be the same as is usually used for investment analysis.

The depreciation is discussed in Section E2.4. Quantification of costs (RC_n and IC_0 in Equation (1)) is discussed in Section E3, whereas quantification of benefits (f_{nij} , C_{nij}) is discussed in Section E4. The potential problems of valuation - $V_j(C)$ - of personnel risk, risk to environment and risk to assets are discussed in Section E5.

In addition there are some contentious aspects of the overall approach that may be solved differently from time to time. The purpose of the discussion that follows in Sections E2.2 through E2.4 is to recommend how to treat these aspects, such that there should be a consistent use without significant variations in the approach chosen.

E.2.2 Company or Societal Consideration

There has over the years been considerable discussion about which perspective to adopt for the CBA, when it comes to costs and benefits. Costs and benefits are in the widest consideration seen in a societal context, whereas the most narrow consideration sees the economical aspects limited to that of the operator of the field, usually with a limited ownership share.

If the consideration of the company is chosen, then the cost of an accident may be very limited. Damage to equipment will in many cases be compensated with insurance, and lost income will often quite extensively be compensated by reduced taxation, due to reduced profit or deferred production. The drawback with this approach is that very few (if any) risk reducing measures would be cost effective to implement, because the cost of accidents are implicitly distributed to the entire industry and the society. This approach appeared to be more commonly chosen some years ago. In order to enable a comprehensive global optimisation, the societal consideration more suitable.

The societal consideration should be chosen, and thus the effect of insurance, tax and ownership shares is eliminated.

It could be argued that a societal consideration should imply that risk aversion should be included quantitatively in the analysis of benefits. It is acknowledged fully that risk aversion is a factor to be considered in the qualitative evaluation performed when the quantitative analysis has been completed. However, as argued in the relation to Definition 3.1.20 in the normative text, the consideration of risk aversion should **not** be included in the quantitative analysis, but be limited to the qualitative consideration. However, risk aversion should be one of the aspects that are considered when the value of the $V_j(C)$ factor in Equation (1) is determined.

E.2.3 Deterministic Costs vs. Probabilistic Benefits

A special case of the CBA for risk events is that benefit will usually occur rarely, in the sense realisation of the benefit will depend of the occurrence of the hazard from which prevention or protection is sought. This implies that the nature of the benefit is highly probabilistic.

Usually the costs are incurred initially as an investment, to some extent they may also occur as annual operational or maintenance costs. Only seldomly will the costs be dependent on occurrence of accidents and thus be probabilistic. One exception is reduced insurance fee.

The usual context is therefore that deterministic costs are made up front, possibly to be compensated with reduced losses, mainly associated with one (at most very few) potential accident, in the future. The amounts are such that either the final outcome over the life cycle will be either very negative or very positive. The expected cost or benefit is a mathematical calculation which never will occur in practice, at least not for a single installation. If the operator on the other hand has a high number of installations, then the sum of expected annual losses for the individual installations should come close to the average loss that the operator has for all his installations.

The final complication is that when an accident actually occurs, the benefit will seldomly be an amount which it is possible to calculate explicitly, due to the probabilistic nature. The benefit will usually have to be determined from the QRA as a distribution for possible benefits, and an expected value.

The CBA is carried out as outlined in the previous sections in spite of these theoretical complications. The implication is however, that the maximum loss should be considered in addition to expected values. If the operator has only one installation, then one needs to consider whether the company may survive a total loss of the installation, and how much the company is prepared to spend in order to reduce the likelihood that the total loss shall occur.

E.2.4 Depreciation of Future Losses

Costs due to material damage or production delay are usually depreciated using for instance the Net Present Value (NPV) approach. Also future running costs are depreciated in the same way, when the total cost of a risk reducing measure is calculated.

A difficult aspect is to what extent future fatalities or environmental damage shall be depreciated in the same way, which actually is according to a strict interpretation of Equation (1). Such depreciation implies that for instance an averted fatality some 10 years into the future has half the value of an averted immediate fatality, if an interest rate of 7% is used.

Fatalities have rarely been depreciated in this way. However, the use of this depreciation is recommended by HSE in their document "The tolerability of risk from nuclear power stations" (HMSO, 1992).

Depreciation of all future losses (including fatalities) is recommended to be the chosen approach, in order to maintain consistency.

E.3 Quantification of Costs

The costs that the benefits shall be evaluated against the benefits are:

- running costs (operating, maintenance, etc.)
- investment costs

Running costs are annual costs that shall be depreciated according to a defined interest rate. These costs shall be taken for the entire life time of the field.

Both running costs and investment costs shall be taken as incremental costs for the RRM in question or if applicable, combination of several RRMs. These costs are deterministic and shall be estimated according to normal cost estimation rules, however, best estimates should be used.

The running costs should mainly be restricted to direct costs, indirect costs should usually **not** be included with the following exceptions:

- when extra personnel are required because of the operations related to the RRM,
- existing personnel will require new skills to the extent that extra training (initial and refresher training) is necessary,
- additional transport by air or sea is required.

In accordance with the discussion above, the costs shall be taken as the cost before tax, and without consideration of the partners' shares.

E.4 Quantification of Benefit

E.4.1 General Quantitative Expression for Benefit

The general expression for quantification of benefits is as follows:

$$\Delta C_{nj} = \sum_{i=1}^I \left[f_{nij}^i \cdot C_{nij}^i - f_{nij}^{rrm} \cdot C_{nij}^{rrm} \right] \quad (2)$$

where

- ΔC_{nj} = difference in expected accident consequence in year n , risk dimension j for 'I' number of accident scenarios (total number of end events for all event trees)
- f_{nij} = accident frequency in year n , scenario i , risk dimension j (superscript 'i' denotes initial condition, whereas superscript 'rrm' denotes condition after RRM)
- C_{nij} = accident consequence in year n , scenario i , risk dimension j

Depending on the circumstances of the RRM either the accident frequency or the accident consequence (or both) may be changed, thus the general expression above.

E.4.2 Risk to Personnel

Reduction in risk to personnel will imply estimation of differences in all or some of the following:

- number of fatalities per accident
- conditional probabilities for fatal accidents
- frequency of accidents that may imply fatalities.

Injuries are sometimes also included in the assessment, if the RRM in question is mainly affecting risk relating to personnel injury.

E.4.3 Risk to Environment

Reduction in risk to the environment will imply estimation of differences in all or some of the following:

- size of spill per accident
- conditional probability for spill
- frequency of accidents that may imply spill

The quantification of risk to environment should be based on released amounts of hydrocarbon spills, rather than the recovery times for affected vulnerable resources, which is the usual parameter for quantification of risk to the environment.

There are two options for quantification of benefit in the risk to environment:

- amount of oil spilled from the installation (platform, subsea production facilities or pipeline)
- amount of stranded oil

Cost estimates for combatment of spills are found in the literature based on total amount spilled or just the amount which is stranded, the latter usually being just a small fraction of the former, in the case of an offshore spill far away from the coast.

E.4.4 Risk to Assets

Reduction in risk to assets will imply estimation of differences in all or some of the following:

- extent of damage per accident
- duration of production shutdown per accident
- conditional probability for equipment damage
- frequency of accidents that may imply asset damage

The quantification of difference in risk to assets will be based on difference with respect to:

- production delay costs
- costs related to damage to equipment and structures
- cost of temporary solutions

The costs of temporary solutions may be difficult to estimate, but should not be overlooked. In the case of the loss of the first GBS structure for the 'Sleipner A' platform, the cost of temporary solutions reached 80-85% of the replacement cost for the structure itself. This is probably an upper limit.

The risk to assets is for the CBA expressed in monetary terms. Sometimes risk to assets is expressed in the QRA as categories like 'system damage' - 'one module damage' - 'several module damage' - 'total loss'. If this is done for asset risk assessment, then these categories need to be translated into monetary terms.

E.5 Valuation Aspects

E.5.1 What constitutes 'Gross Disproportion'?

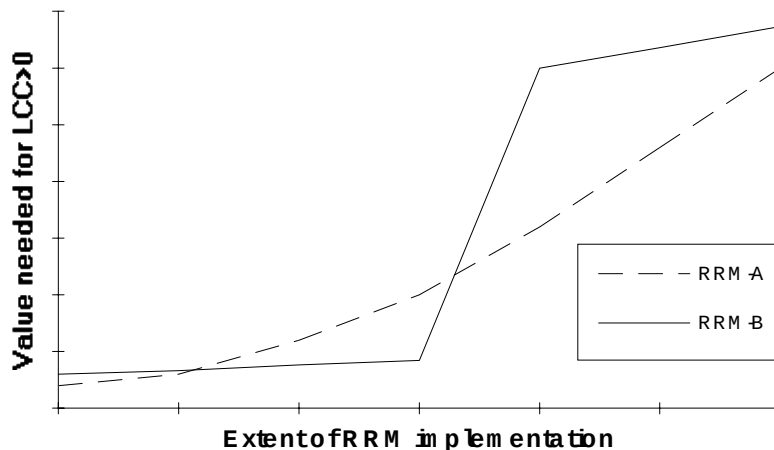


Figure E5.1 Illustration of 'Gross Disproportion'

continuous scale.

It is important to consider how to establish the limit between what is considered 'gross disproportion' and what is not. The diagram shows a theoretical example of two RRM's. The vertical axis shows the values considered for instance as cost of averting a statistical fatality in order to achieve $LCC > 0$ according to Equation (1). Two RRM's are considered, both capable of being implemented to a higher or lesser extent, on a

In the example diagram, RRM-A has a gradual increase, whereas RRM-B shows a significant step function. It is easier to define 'gross disproportion' for RRM-B than for RRM-A. 'Gross disproportion' for RRM-B will be to the right (above) the step value, which implies that RRM-B should be implemented up to the extent just before the step.

As noted earlier, risk aversion should also be considered in the determination of what is 'gross disproportion'.

It is sometimes argued that the risk level should also influence what is considered 'gross disproportion', i.e. that the willingness to spend should be higher if the risk level is close to the upper tolerability limit. This has not however, gained widespread support, but may need to be at least considered.

Some commonly used limits for what constitutes 'Gross Disproportion' are discussed separately below for personnel, environment and assets.

E.5.2 Risk to Personnel

There are two alternatives with respect to valuation of the benefit for personnel, these two alternatives may be expressed as:

- Assess cost of Human Life
- Assess willingness to pay for averting a statistical fatality

The determination of threshold values is a complicated issue, for which no exact definition or quantification can be given, irrespective of which of these two approaches that is chosen. Various studies have on the other hand, shown that our society implicitly uses such values, as decision

support related to investment in accident prevention measures in transportation, medical treatment, life insurance, etc.

A much cited value is £ 0.6 M (6-7 M NOK), which has been stated in the reference document on Tolerability of risk from nuclear facilities, published by HSE. Apparently this value has no particular offshore relevance, but it may be argued that there is sufficient similarity. An evaluation of societal loss of 'production capacity' for an average offshore worker comes up with a value in the same range.

An official Norwegian study on improvement of the Norwegian helicopter based SAR preparedness system has in 1996 used a value of 16.5 mill NOK per statistically saved life, in the CBA.

It could be argued that a typical value in Norway was 10-20 M NOK, which could only be seen as indication of an order of magnitude.

Considerably higher values often result when the 'willingness to pay' approach is used. This is obviously influenced by the search for gross disproportion as indicated in Figure E5.1 above. It is not uncommon that high level which indicates gross disproportion may be as high as 100 mill NOK or even higher.

Risk aversion, as discussed earlier, is primarily relevant for the valuation of risk to personnel.

E.5.3 Risk to Environment

Valuation of risk to environment may include many different aspects:

- Clean up cost
- Cost of lost oil
- Compensation to the fishing and fish farming industries, local communities, etc. for loss of income due to environmental damage.

These aspects are all tangible in the sense that monetary values may be defined relatively easily. There are also several intangible aspects, such as loss of reputation, being considered as an environmentally irresponsible organisation, etc.

The 'willingness to pay' approach should also be suitable for valuation of damage to the environment. On a purely qualitative basis, it appears that many people are prepared to pay substantial amounts in order to avoid damage to the environment, even in cases where the relationship between the measures taken and the positive effect is far from certain. It is not known that such assessments have been carried out in any extensive manner.

With respect to tangible aspects, the best researched spill is that from the oil tanker Exxon Valdez in the Prince William sound in Alaska in 1989. The following values may be cited for this spill:

- Approximately 440,000 NOK (1997 value) per ton oil spilled in clean-up cost.
- Approximately 1 million NOK (actual values paid) per ton oil spilled in compensation, fines, etc.

If one turns to more moderate spills (500 - 5,000 tons), a typical clean-up cost may be in the order of 150,000 NOK per ton oil that has stranded.

Sometimes also unignited gas releases are considered as risk to environment, however, this is not common. In such cases it appears virtually impossible to place a value on the release of gas, except the obvious loss of revenue from the lost volume of gas.

E.5.4 Risk to Assets

Damage to assets is the easiest aspect to quantify and would usually consist of the following components (not all of them relevant in all cases):

- Cost of replacement of structures and equipment due to material damage
- Value of Production Loss/Deferred Production

Cost of temporary solutions, insurance and tax aspects were discussed in Section E4.4. It could be noted that differences in the sales contracts for gas and oil imply that gas delivery is usually completely lost during production shut down (except for the short duration stops), whereas the oil production is deferred and may be produced later. The delay in the production of oil will depend on the circumstances, if production is at peak level (plateau level) and utilising the processing facilities fully, then the production delay is until the end of the plateau period. If the production at the time of the accident is below peak level, then the production delay is much shorter. This implies that the valuation of the production loss is different according to when the accident occurs, and a simulation may have to be performed whereby the time at which the accident occurs is simulated statistically.

In relation to production in the later phases of the field lifetime, the point after which recoverable reserves are too small to defend substantial reconstruction costs will also have to be defined.

In relation to production shutdown special emphasis must be placed on realistic estimates of the least serious accidents, for instance unignited gas leaks or unignited short duration blow-out. It is relatively common that quite extensive production shutdown periods result even after unignited hydrocarbon releases, for instance due to the need for thorough investigation, or because rectification of inherent weaknesses that have been revealed through an incident.

Assessment of loss of production should assess the actual impact on gas deliveries to the customers. For gas export, it will often be required to take into account relevant buffers such as storage, 'line pack' and 'substitution', i.e. delivery of the agreed amounts of gas, but from a different field.

A simulation approach may be quite an extensive analysis, and it may sometimes be appropriate to perform more simplified approach, if it is obvious that costs exceed benefits by far. The analysis is expected to be most detailed for the analysis of risk reducing measures that are possible candidates for implementation. If it is obvious that a measure is far from being feasible, then more simplified analysis may be appropriate.

ANNEX F NPD REQUIREMENTS THAT ARE NOT COMPLIED WITH (INFORMATIVE)

The NPD Guidelines to the Risk Analysis Regulations has explained the term 'accidental event' also to relate to a condition. In this NORSOK standard, condition is not included in the definition of 'accidental event', but the definition of 'defined situation of hazard and accident (DUL)' is defined in a way which includes accidental conditions.

The definition of 'emergency preparedness' has been modified, such that safety systems are not considered as emergency preparedness systems. This distinction also leads to other changes. The process involved in setting functional requirements are parallel. Dimensioning of escape ways, evacuation and rescue facilities are in relation to major accidents assumed to be done in the risk analysis.

The terms 'emergency preparedness analysis' and the 'establishment of emergency preparedness' are defined such that they do not overlap, which they partly are in NPD emergency preparedness regulations.

The term 'VSKTB' has been replaced by 'functional requirements to safety and emergency preparedness'.

The following is the priority list given for risk reducing measures in the Guidelines to §16 of the Risk Analysis regulations:

- a) Probability reducing measures, in the following order of priority:
 - aa) measures which reduce the probability for a hazardous situation to occur,
 - ab) measures which reduce the probability for a hazardous situation to develop into an accidental event.
- b) Consequence reducing measures, in the following order of priority:
 - ba) measures relating to the design of the installation, to loadbearing structures and passive fire protection,
 - bb) measures relating to safety and support systems, and active fire protection,
 - bc) measures relating to contingency equipment and contingency organization.

This has been replaced by the following more general priorities (see Section 5.1.4):

- Probability reducing measures shall be given priority over consequence reducing measures whenever possible.
- Layout and system design shall be suitable for the operations and minimises the exposure of personnel to accidental effects.

Risk acceptance criteria (see Definition 3.1.1) are limited to 'high level expressions of risk', which is not according to the definition of risk acceptance criteria as per NPD Risk Analysis Regulations. NPD's definition is covered by the two terms as used by this NORSOK standard, Risk Acceptance Criteria and Decision Criteria (see section A2).

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