NORSOK STANDARD Z-013

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Risk and emergency preparedness analysis

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Foreword

The NORSOK standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for existing and future petroleum industry developments.

The NORSOK standards are prepared to complement available international standards and to fill the broad needs of the Norwegian petroleum industry. Where relevant NORSOK standards will be used to provide the Norwegian industry input to the international standardisation process. Subject to development and publication of International Standard, the relevant NORSOK standard will be withdrawn.

The NORSOK standards are developed according to the consensus principle generally applicable for most standards work and according to established procedures defined in NORSOK standard A-001.

The preparation and publication of the NORSOK standards is supported by OLF (The Norwegian Oil Industry Association) and TBL (Federation of Norwegian Manufacturing Industries). NORSOK standards are administered and issued by NTS (Norwegian Technology Centre).

All annexes are informative.

Introduction

The purpose of this NORSOK standard is to establish requirements for effective planning, execution and use of risk and EPA. Also the use of RAC is covered, thus the standard covers some aspects of risk assessment. Guidelines are provided in the 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 NORSOK 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 EPA, with an emphasis on providing insight into the process and concise definitions.

This NORSOK standard is structured around the following main elements:

- Establishment of risk acceptance criteria prior to execution of the risk analysis.
- The relation between the risk and EPA, especially the integration of the two types of analysis into one overall analysis process.
- Planning and execution of analyses.
- Further requirements to use of risk and EPA for different activities and life cycle phases.
- Establishment of requirements based on risk and EPA.

This NORSOK standard covers EPA, establishment of emergency preparedness, while maintenance and further development of emergency preparedness are not covered by the standard.

This NORSOK 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.

This NORSOK standard does not cover onshore facilities.

Analysis of occupational fatality risk is covered in this NORSOK standard. It does not cover a number of occupational health risk aspects, including physical and psychological working environment, working environment mapping and analysis, and the use of risk acceptance criteria. Occupational injuries are not part of this NORSOK standard.

2 Normative references

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

IEC 61508	Functional safety of electrical/electronic/programmable electronic safety related systems(all parts)
IEC 61511	Functional safety instrumented systems for the process industry sector (all parts) (under development)
ISO 13702	Petroleum and natural gas industries - Offshore production installations - Control and Mitigation of Fires and Explosions - Requirements and guidelines.
ISO 17776	Petroleum and natural gas industries - Offshore production installations – Guidelines on tools and techniques for identification and assessment of hazards.
ISO 15544	Petroleum and natural gas industries - Offshore production installations – Requirements and guidelines for emergency response.

“OLF- Veiledning for gjennomføring av miljøriskoanalyser for petroleumsaktiviteter på norsk sokkel - Metode for Miljørettet Risiko Analyse (MIRA)” (OLF Recommended method for environmental risk analysis, MIRA, Norwegian only) Rev.1 OLF, November 1999

OLF Guidelines for Area-based Emergency Preparedness, 30.6.2000

OLF Guidelines for the application of IEC 61508 and IEC 61511 in the petroleum activities on the Norwegian continental shelf, 1.2.2001, OLF Guideline 66, Rev 1

NORSOK standard N-001 Structural design, Rev. 3, August 2000

NORSOK standard S-001	Technical safety
NORSOK standard S-002	Working environment
NORSOK standard Z-008	Criticality classification method
NORSOK standard Z-016	Regularity management & reliability technology

“Risikoanalysen som beslutningsstøtte under design av normalt ubemannede installasjoner” (Risk analysis as decision support for design of normally unmanned installations, Norwegian only), Aker report 58357, 21.9.1999

NPD	Regulation for management of HES

European Commission: Model Evaluation Group, report of the Second Open Meeting, Cadarache France, 19 May 1994, Report EUR 15990 EN, ISBN 92-826-9549-2, 1995

"Design of Offshore Facilities to Resist Gas Explosion Hazard Engineering Handbook."

3 Definitions and abbreviations

3.1 Definitions

For the purpose of this NORSOK standard the following terms and definitions apply.

3.1.1
accidental event (AE)
event or chain of events that may cause loss of life, or damage to health, the environment or assets

NOTE 1 - The events that are considered in a risk analysis are acute, unwanted and unplanned. For instance; planned operational exposure that may be hazardous to health or to the environment, are usually not included in a risk analysis.

NOTE 2 - 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.

3.1.2
as low as reasonably practicable (ALARP)
ALARP expresses that the risk level is reduced (through a documented and systematic process) so far that no further cost effective measure is identified

NOTE - The requirement to establish a cost effective solution implies that risk reduction is implemented until the cost of further risk reduction is grossly disproportional to the risk reducing effect.

3.1.3
can
verbal form used for statements of possibility and capability, whether material, physical or casual

3.1.4
defined situations of hazard and accident (DSHA)
selection of hazardous and AEs that will be used for the dimensioning of the emergency preparedness for the activity

NOTE 1 - The selection will be representative for possible hazards and AEs for the facilities and activities, and includes DAEs, hazardous and accidental situations associated with a temporary increase of risk and less extensive AEs, e.g.man overboard situations, limited oil spills exceeding the stipulated discharge limits, occupational accidents, etc.

NOTE 2 - 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.

3.1.5
dimensioning accidental event (DAE)
AEs that serve as the basis for layout, dimensioning and use of installations and the activity at large, in order to meet the defined RAC

3.1.6
dimensioning accidental load (DAL)
load (action) that is sufficient in order to meet the RAC

NOTE - It may be difficult to define the accidental load in relation to some types of AEs, 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 DAEs.

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 has to 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 has to be functional, i.e. minor damage may be acceptable provided that the planned function is maintained. This may be relevant for ESVs, deluge systems, escape ways, main structural support system, etc.
- The equipment has to be gas tight. This may be relevant for hydrocarbon containing equipment.

3.1.7
effectiveness analysis
analysis which documents the fulfilment of performance standards for safety and emergency preparedness

NOTE - Effectiveness analyses in relation to technical performance standards for essential 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 has to be traceable and will normally - though not necessarily - be quantitative.

3.1.8
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

NOTE - The definition focuses on the distinction between dimensioning of emergency preparedness and dimensioning of essential safety systems (see also the definition of EPA and establishment of emergency preparedness). Dimensioning of essential safety systems is done in connection with the use of risk analysis, and minimum requirements by authority regulations, established practice, recognised norms, etc.

3.1.9
emergency preparedness analysis (EPA)
analysis which includes establishment of DSHA, including major DAEs, establishment of performance standards for emergency preparedness and their fulfilment and identification of emergency preparedness measures

3.1.10
establishment of emergency preparedness
systematic process which involves planning and implementation of suitable emergency preparedness measures on the basis of risk and EPA

3.1.11
emergency preparedness organisation
organisation which is planned, established, trained and exercised in order to handle occurrences of hazardous or accidental situations

NOTE - The emergency preparedness organisation includes personnel on the installation as well as onshore, and includes all personnel resources that will be activated during any occurred situation of hazard or accident.

3.1.12
essential safety system
system which has a major role in the control and mitigation of accidents and in any subsequent EER activities

3.1.13
informative reference
reference used informative in the application of NORSOK standards

3.1.14
main safety function
safety functions that need to be intact in order to ensure that pollution is controlled and 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

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

EXAMPLES - Main support structure, escape ways, control centre, shelter area (temporary refuge) and evacuation means.

3.1.15
may
verbal form used to indicate a course of action permissible within the limits of the standard

3.1.16
performance standards for safety and emergency preparedness
requirements to the performance of safety and emergency preparedness measures which ensure that safety objectives, RAC, authority minimum requirements and established norms are satisfied during design and operation

NOTE - The term 'performance' is to be interpreted in a wide sense and include availability, reliability, capacity, mobilisation time, functionality, vulnerability, personnel competence, expressed as far as possible in a verifiable manner.

3.1.17
risk
combination of the probability of occurrence of harm and the severity of that harm

NOTE - Risk may be expressed qualitatively as well as quantitatively. Probability may be expressed as a probability value (0-1, dimensionless) or as a frequency, with the inverse of time as dimension.

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) should not be included in the quantitative 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.

The implication of the definition is further that perceived risk (i.e. subjectively evaluated risk performed by individuals) should not be included in the expression of risk.

3.1.18
risk acceptance criteria (RAC)
criteria that are used to express a risk level that is considered tolerable for the activity in question

NOTE - RAC are used in relation to risk analysis and express the level of risk which will be tolerable for the activity, and is the starting point for further risk reduction according to the ALARP-principle, see also 3.1.2. Risk acceptance criteria may be qualitative or quantitative.

3.1.19
risk analysis
use of available information to identify hazards and to estimate the risk

NOTE 1 - The risk analysis term covers several types of analyses that will all assess causes for and consequences of AEs, with respect to risk to personnel, environment and assets. Examples of the simpler analyses are SJA, FMEA, preliminary hazard analysis, HAZOP, etc.

NOTE 2 - Quantitative analysis may be the most relevant in many cases, involving a quantification of the probability and the consequences of AEs, in a manner which allows comparison with quantitative RAC.

3.1.20
risk assessment
overall process of risk analysis and risk evaluation

NOTE - See Figure 2.

3.1.21
safety objective
objective for the safety of personnel, environment and assets towards which the management of the activity will be aimed

NOTE - Safety objectives will imply short or long term objectives that have been established for the activity, while the RAC express the level of risk (in relation to the risk analysis) that is currently acceptable.

3.1.22
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

3.1.23
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

AE	accidental event
AFFF	aqueous film forming foam
AIR	average individual risk
ALARP	as low as reasonably practicable
ALS	accidental collapse limit state
BDV	blowdown valve
BOP	blow out preventer
CBA	cost benefit analysis
CFD	computational fluid dynamics
CRA	concept risk analysis
DSHA	defined situations of hazard and accident
DAE	dimensioning accidental event
DAL	dimensioning accidental load
DNV	Det Norske Veritas
DP	dynamic positioning
EER	escape, evacuation and rescue
E&P	exploration and production
EPA	emergency preparedness analysis
EPCI	engineering, procurement, construction and installation
ERA	early risk analysis
ESD	emergency shutdown
ESV	emergency shutdown valve
F&G	fire and gas
FAR	fatal accident rate
FMEA	failure mode and effect analysis
GBS	gravity base structure
HAZID	hazard identification

HAZOP	hazard and operability study
HC	hydrocarbons
HCLIP	hydrocarbon leak and ignition project
HES	health, environment and safety
HIPPS	high integrity pressure protection system
HMSO	Her Majesty's Stationary Office
HRA	health risk assessment
HSE	health and safety executive
IR	individual risk
IRPA	individual risk per annum
JIP	Joint Industry Project
LCC	life cycle cost
LEL	lower explosive limit
LQ	living quarter
NCS	Norwegian Continental Shelf
NLFEM	non-linear finite element method
NMD	Norwegian Maritime Directorate
NPV	net present value
MODU	mobile offshore drilling unit
NPD	Norwegian Petroleum Directorate
NTS	Norwegian Technology Centre
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
PLL	potential loss of life
QRA	quantitative risk analysis
RAC	risk acceptance criteria
RBI	risk based inspection
RCM	reliability centred maintenance
RRM	risk reduction measure
RV	relief valve
SAR	search and rescue
SBSD	scenario based system design
SDOF	single degree of freedom
SIL	safety integrity level
SINTEF	The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology
SJA	safe job analysis
TBL	Federation of Norwegian Manufacturing Industries
TRA	total risk analysis
TREPA	total risk and emergency preparedness analysis

UEL upper explosive limit

4 Establishment and use of risk acceptance criteria (RAC)

4.1 General

Establishment and use of RAC are elements of HES management, which is not covered in full in this NORSOK standard. The E&P Forum document "Guidelines for Development and Application of Health, Safety and Environmental Management Systems" gives guidance for HES management.

4.2 Basis for RAC

Risk acceptance criteria illustrate the overall risk level which is determined as tolerable, 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 RAC.

The RAC 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 RAC should as far as possible reflect the safety objectives and the particularities of the activity in question.

The evaluations that form the basis for the statement of the RAC shall be documented. Distinct limitations for the use of the RAC shall be formulated. Data used during the formulation of quantitative RAC 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.

4.3 Qualities of RAC

In order for the RAC to be adequate as support for HES management decisions, they should represent a compromise where the following qualities are satisfied as far as possible:

- Be suitable for decisions regarding risk reducing measures.
- Be suitable for communication.

a) Be unambiguous in their formulation (such that they do not require extensive interpretation or adaptation for a specific application).

- Not favour any particular concept solution explicitly nor implicitly through the way in which risk is expressed. (But the application of RAC in risk evaluation will usually imply that one concept (or concepts) is (are) preferred over others, due to lowest risk).

More in-depth discussion of these aspects is presented in annex A.

The RAC shall be consistent with the risk elements as outlined in 5.2.5.

If average fatality risk or AIR is used in the formulation of RAC, also criteria for areas or groups within the platform personnel shall be formulated. It is not sufficient just to have a platform average value as criterion. See also § 6 (Risk acceptance criteria for major hazard and environmental damage risk) in NPD *Regulations for management of HES*.

The risk estimates shall be considered on a 'best estimate' basis, when considered in relation to the RAC, 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.

4.4 Updating of RAC

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

4.5 Uncertainties

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. This uncertainty will be reduced as the development work progresses.

Uncertainties are usually most extensive in early concept study phases. This shall be reflected in these phases when RAC are used to judge the results of a QRA. The requirement may be satisfied in either of two possible ways:

- Apply more conservatism in the risk analysis.
- Make sure that RAC are satisfied with some margin.

5 Planning, execution and use of risk and emergency preparedness analysis (EPA)

5.1 General

The requirements in this clause are general and not connected to any particular life cycle phase. The phase specific requirements are given in clause 7. The description in clause 5 is mainly dealing with integrated risk and EPA. Specific requirements to QRA are presented in clause 6.

5.2 General requirements

5.2.1 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.

The main results of any risk analysis shall be:

- Input to management of risk.
- Presentation of risk for the activity in question, in accordance with the structure of the RAC and for the relevant risk elements, see 5.2.5.
- Input to selection of development concepts, projects, construction and operation of facilities and installations to minimise risks, in accordance with what is relevant for the decisions to be taken.
- Ranking of risk contributors as basis for HES management.
- Identification of potential risk reducing measures, in accordance with what is relevant for the decisions to be taken.
- Important operational assumptions/measures in order to meet RAC.
- It is required to follow up results, recommendations and assumptions from the analysis. The documentation of these shall facilitate such follow-up.

The main results of a TRA (or other detailed risk analysis of similar nature) should in addition offer:

- The basis for establishment of performance standards.
- Establishment of requirements to emergency preparedness.
- Input to selection of development concepts, projects, construction and operation of facilities and installations to minimise risks.
- Identification of DALs.

The TRA will also be used for establishing performance standards for essential safety systems.

The main results of an EPA shall be:

- Basis for establishing emergency preparedness, including emergency preparedness plans and training and exercise plans.
- Selecting optimum solutions between available alternatives.

A number of aspects shall be clarified before an analysis is started:

a) The purpose of the 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 RAC for the activity shall be defined, see clause 4.
c) The decision criteria for studies of limited extent need to be defined.
d) The scope of the study and its limitations shall 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 inclusive of workers representatives, onshore and offshore, shall be involved in the work to the extent necessary.
g) Relevant regulations, possible classification society rules and applicable standards and specifications that shall be the basis for design and operation. This applies particularly to the building of new mobile units and floating production installations.

Requirements f) and g) may not be fully achievable when a floating unit is built on speculation, without a specific operation nor continental shelf decided.

5.2.2 Planning and execution of risk analyses

Risk analyses shall be planned in accordance with the development and operation 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 7.4 and C.6.

In order to achieve the overall objectives, the following general requirements to risk analyses shall apply:

- Planning of risk analyses:
  - The analyses shall be targeted and carried out in a systematic way as an integral part of HES management.
  - The studies shall be focused on identification of and insight into the aspects and mechanisms that cause risk.
  - The analyses 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.
  - The results from the studies shall not be used in a decision-making context that goes beyond the limitations that apply to QRA in particular (see 6.3).

- Execution of risk analyses:
  - The responsibility of the operator, owner, contractor/subcontractor shall be clearly defined (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.
  - Assumptions shall be identified, made visible and communicated to the users of the analysis results.
  - Experience has shown that the users of the analysis results need to be actively involved in the risk evaluation in order for it to be effective.

See also requirements for risk analysis as basis for EPA in 5.2.3.

5.2.3 Planning and execution of emergency preparedness analyses

It is important to 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 C.2.

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

a) DAEs (as part of the DSHAs) shall be identified and sufficiently described.
b) Assumptions, premises and suppositions shall be identified and documented as a basis for establishing performance standards for emergency preparedness.

The following aspects shall be clarified prior to starting the EPA, in addition to the general requirements of 5.2.1:

When quantitative analyses are used, the data basis in the planning phase shall be adapted as far as possible to the purpose of the study.

5.2.4 Competence of analysis personnel

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

5.2.5 Risk elements

The following risk elements shall as a minimum be considered in a TRA, to the extent they are applicable:

- Blowouts, including shallow gas and reservoir zones, unignited and ignited.
- Process leaks, unignited and ignited.
- Utility areas and systems fires and explosions.
- Fire in accommodation areas.
- Falling/swinging objects.
- Transportation accidents:
  - Transport of personnel between installations shall be included in the risk levels when this is an integral part of the operations of the installations.
  - Transport of personnel from shore to the installation shall be included if required by the RAC.
  - Helicopter crash on the installation.
- Collisions, including fields related traffic, and external traffic, drifting and under power.
- Riser and pipeline accidents.
- Accidents from subsea production systems.
- Occupational accidents.
- Escape, evacuation and rescue accidents, i.e. until a so-called ‘safe place’ has been reached.
- Structural collapse, including collapse of bridges between fixed and/or floating installations.
- Foundation failure.
- Loss of stability/position.

The list above shall apply explicitly for a detailed risk analysis ,to the extent they are applicable. For a less detailed analysis the entire list may not be applicable in detail, but it should be considered as a guidance for which risk elements that are addressed. An explicit list of the relevant risk elements to be considered shall be prepared as part of the definition of scope of work. The list may need to be updated through the HAZID.

5.2.6 Risk reducing measures

Risk reducing measures shall be identified as part of any risk or EPA.

Risk reducing measures involve probability-reducing measures, including inherently safe solutions, and consequence-reducing measures, including emergency preparedness measures. Further details on requirements are given in NPD Regulation for management of HES §§ 1 (risk reduction) and 2 (barriers). See also A.3.5.

Dependencies between risk reducing measures should be documented explicitly, if alternative measures are proposed. The choice of risk reducing measures should 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. The possibility of implementing certain risk reducing measures is dependent on factors such as available technology, the current phase of the activity and the results of cost benefit analysis. (see also annex E).

The choice of risk reducing measures shall be documented in relation to all relevant aspects.

5.3 Specific requirements to qualitative risk analysis

Examples of qualitative risk analyses are SJA, preliminary hazard analysis, coarse risk analysis with risk matrix presentation, 'Driller's HAZOP' and simple comparative studies. General requirements to the planning of risk analyses are presented in 5.2.1 and 5.2.2. Qualitative studies are usually carried out by a broad group of persons in order to reflect the relevant competencies, reference is made to 5.2.

The steps of a qualitative risk analysis depending on the level of detail, are:

a) Planning of the analysis.
b) System/Job description and limitation.
c) Identification of hazards.
d) Analysis of causes and potential consequences.
e) Risk evaluation.
f) Identification of possible risk reducing measures.

See annex A for discussion of qualitative RAC.

Experience from accidents and incidents from the company's own files and data bases and from public data bases, shall be available for the analysis team.

This revision of this NORSOK standard has placed the main emphasis on quantitive risk analysis. Hence, no specific requirements are formulated for qualitative risk analysis. The general requirements of 5.2 do apply.

5.4 Specific requirements to EPA

5.4.1 Scope of analysis

An EPA shall define the basis for DSHAs and document the choice of DSHA's. A systematic review of a possible development of a DSHA shall define and dimension required emergency preparedness measures to fulfil the established performance standards for safety and emergency preparedness. The effect of the emergency response measure shall be evaluated.

Emergency preparedness analysis should be an integral part of development and modification projects.

Emergency preparedness measures include measures directed at containing spills of oil and other pollutants, from minor or major releases. Dimensioning of medical preparedness is also part of the EPA.

Operational limitations will be taken into account when operational and environmental conditions are defined. Assumptions may have to be established, 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 EPA

Figure 1 presents the steps of EPA and establishment of emergency preparedness, in relation to input from the QRA. The starting point of the presentation is the integrated risk and EPA, and it shows how the work may be carried out step by step in a field development project. This applicability is limited to DAEs.

The steps of the EPA are briefly described in 5.4.3 to 5.4.7.

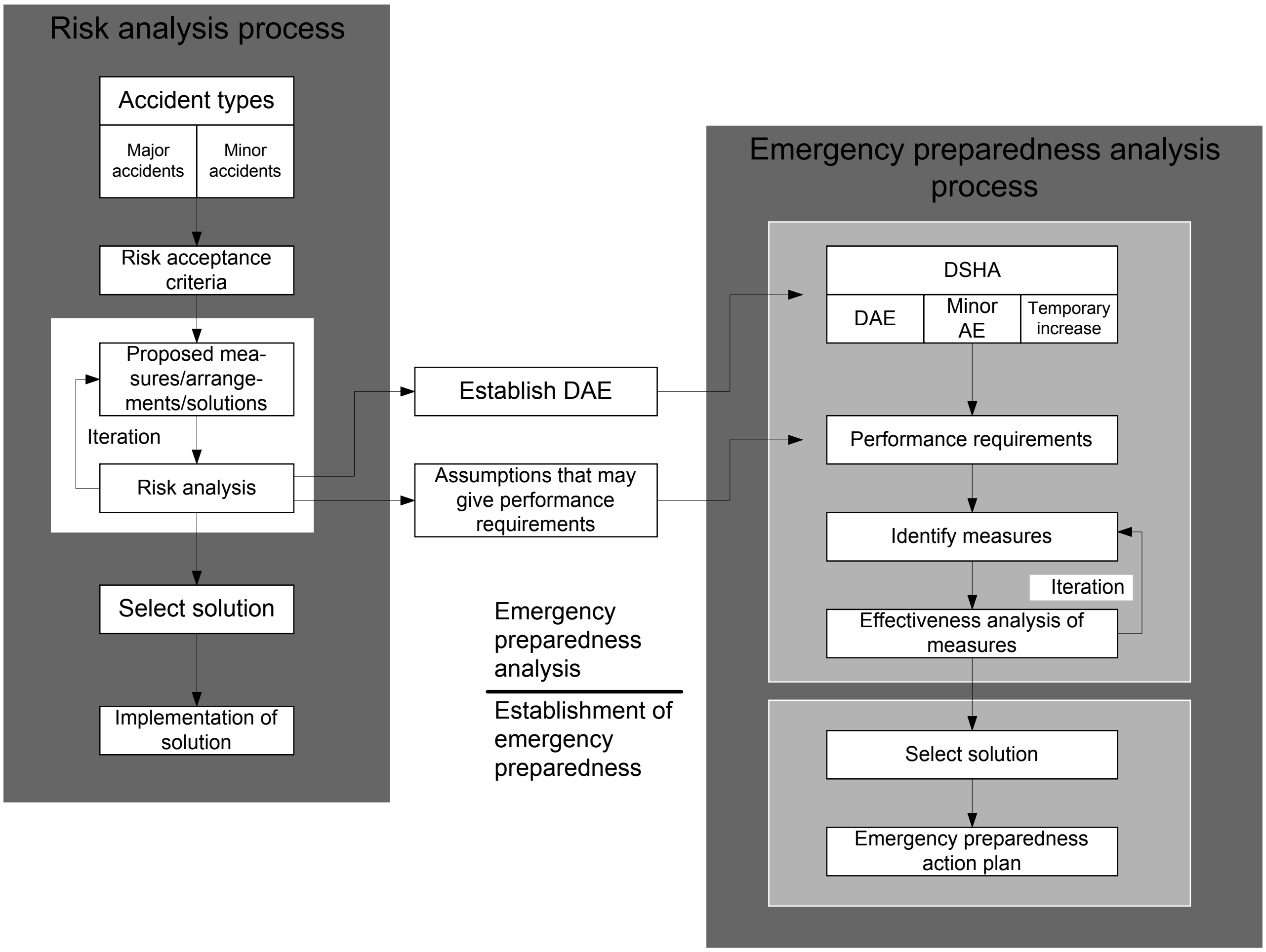


Figure 1 - Risk and EPA

Guidance to establish emergency preparedness plans is found in ISO 15544.

5.4.3 Establish DSHA

DSHA shall include the following event categories:

- DAEs, usually defined on the basis of DALs through QRA.
- Situations associated with temporary increase of risk.
- Less extensive AEs, including acute cases of illness.

DSHAs shall in addition be established on the basis of:

- Events that have been experienced in comparable activities.
- Accidental events that appear in QRA without being identified as DAEs, as long as they represent separate challenges to the emergency preparedness.
- DSHAs according to OLF *Guidelines for Area-based Emergency Preparedness (30. 6. 2000)*.
- Events for which emergency preparedness exists according to normal practice.

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

When DSHA are established, it is 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 need for description of DAEs (amongst DSHAs) is addressed in 5.2.3. In the description of situations associated with temporary increase of risk, or less extensive AEs, 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 AEs occur.

When dealing with normally unmanned installations, distinctions also have to be made between those DSHA that relate to personnel being present and those that relate to the installation being unmanned.

For normally unmanned installations, some DSHAs based upon DAEs which are commonly defined as DSHAs for manned installations, may be disregarded as DSHAs, if a low exposure (activity level) implies that the probability of occurrence is remote. This may be considered on a case by case basis.

5.4.4 Information from QRA

All relevant information and results from QRA shall form part of the EPA. Such information shall include:

- Description of those DAE for which organisational and operational measures shall be established.
- Time requirements that have to be satisfied.
- Required performance 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).

5.4.5 Establish performance standards

Performance standards for emergency preparedness measures should be:

- Express a functionality, not a solution.
- Easy to understand.
- Explicit and measurable.
- Realistic.

The basis for establishment of the performance standards is indicated by Figure 1, and includes results and premises from risk analysis, DAEs and loads.

Performance standards shall be established in relation to competence of personnel and the following emergency phases:

- Alert
- Danger limitation
- Rescue
- Evacuation
- Normalisation

The performance standards shall be specified in a way which will allow those that are relevant to be validated and used as risk indicators during the operational phase, reference is made to 5.5.

5.4.6 Identification of measures and solutions

Measures and solutions to be considered in an EPA are:

- Organisational and operational measures related to DAEs, and technical measures not included in the risk analysis.
- Technical, organisational and operational measures related to less extensive AEs as well as to temporary increase of risk.

The principles stated in 5.2.4 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:

- Installation’s own resources.
- Resources in the area.
- External resources.

5.4.7 Effectiveness analysis

The performance 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 performance on the basis of documented results. This is discussed in annex E.

5.4.8 Documentation of EPA

Suitable information shall be provided in an understandable way for all relevant personnel, decision-makers as well as operating personnel.

The documentation and results of the EPA shall be used for:

- Stating the objectives, scope and limitations.
- Describing the object/installation in question, inclusive all phases.
- Identifying assumptions and premises, in particular those derived from the QRA.
- Giving detailed description of all relevant DSHA.

The presentation of results of an EPA shall be sufficiently comprehensive in order to allow good insight into the basis for the analysis.

The following documentation shall be available in addition to an updated version of the analysis and known to the operating personnel 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 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.

5.5 Verification of performance standards

Verification that performance standards for 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.

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 the risk level in relation to the RAC. Examples of such indicators may be:

- Hydrocarbon leak frequencies.
- Extent of hot work.
- Availability of essential safety systems (see Figure 3).
- Mobilisation time for emergency personnel/teams.

- Aspects related to safety culture.

Site specific risk indicators should be defined for each installation or field, based upon these general recommendations.
The intention is therefore to get an early warning of any trends, which may result in inability to meet RAC.
The risk indicators shall be monitored regularly, in order to identify unwanted development at an early stage.

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

5.6 Involvement of operation personnel

The involvement of the workforce in performance of quantified risk assessment should be as follows:

- During HAZID.
- In the review of system descriptions, assumptions and premises.
- In the review of the documentation from the analysis, including results and evaluation of risk reducing measures.

See also 5.2.1 and 6.16.

It may be required to prepare separate presentations of the results and conclusions from TRA studies, in order to communicate these to the entire workforce in an instructive and useful manner.

The involvement of operational personnel in performance of EPA offshore should be as follows:

- During HAZID.
- During evaluation of hazards.
- In the review of risk reducing measures.

6 Specific requirements to quantitative risk analysis (QRA)

6.1 Steps in a QRA

The elements in a QRA are presented in Figure 2, which shows four levels:

- Inner level: Risk estimation
- Second level: Risk analysis
- Third level: Risk assessment
- Outer level: HES management

Please note that these four levels do not reflect the sequence in which the tasks are carried out. The sequence starts at the top in Figure 2 and continues downwards.

Requirements to the risk analysis and the risk estimation are presented in the following text, 6.2 to 6.17. The formulation of the RAC will determine which of the requirements in 6.11 to 6.14 that are applicable.

This NORSOK standard covers the risk estimation, risk analysis, and risk assessment. HES management is not covered.

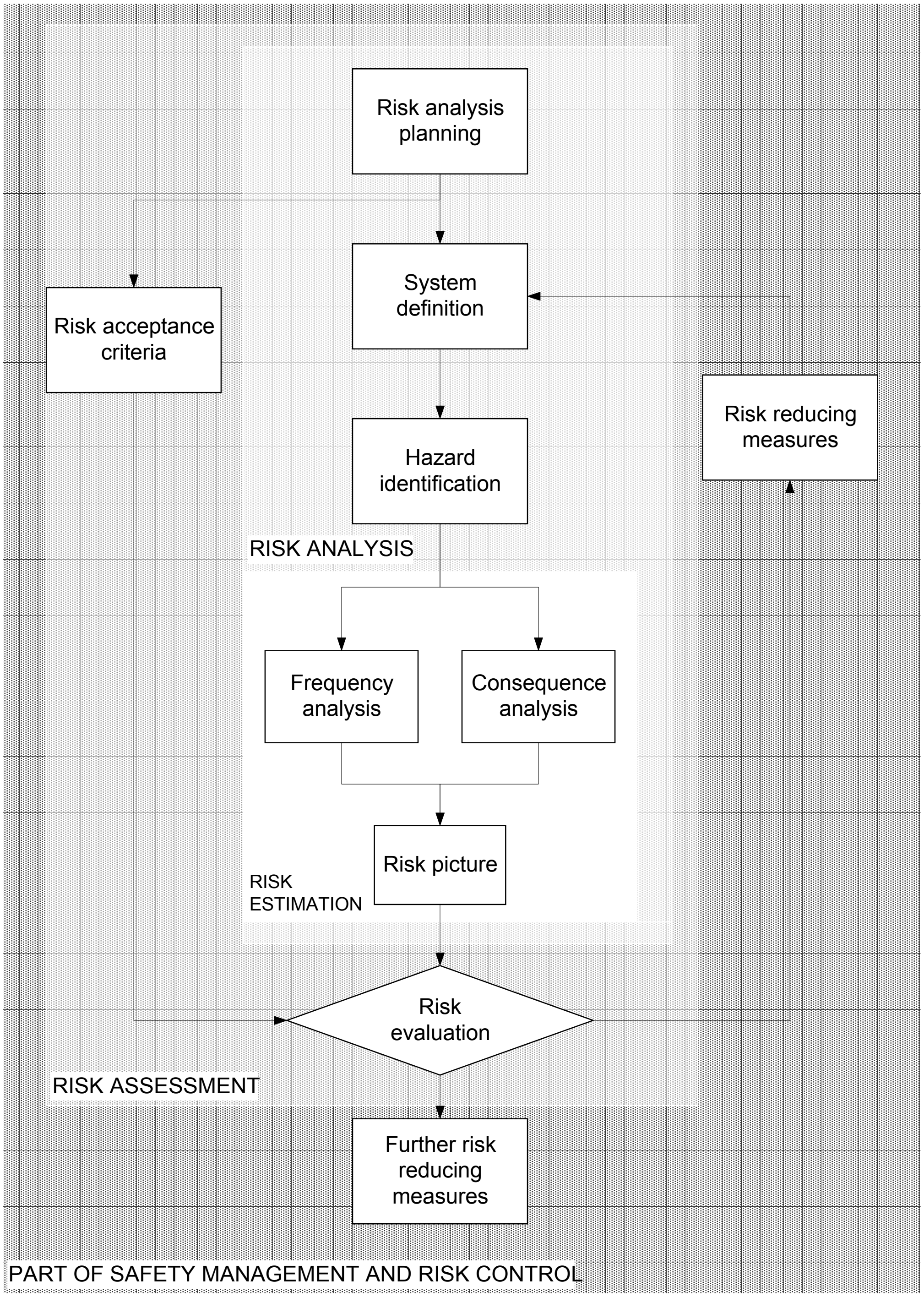


Figure 2 – Risk estimation, analysis and evaluation

6.2 Planning

General requirements to the planning of risk analysis are stated in 5.2.2. Additional requirements to the planning of QRA in relation to the use of data basis and models, are presented in 6.7.

6.3 Limitations

The limitations of a risk analysis shall be stated explicitly. They should be observed during planning of the studies.

Limitations on the use of risk analysis will result from the way the general requirements, as presented in this NORSOK standard, are adhered to. The general aspects for data basis and models shall be considered regarding limitations as detailed in 6.7.

The adequate level of precision in the results shall be evaluated explicitly, on the basis of the calculations, data and models which are available for the quantification of probability and consequence. Sometimes, it is required to express results with somewhat higher precision than what could be considered justifiable, based upon precision in calculations, data and models. This should be considered in the evaluation of uncertainties.

6.4 System definition

The system definition (or description) shall include:

- Description of the object of the analysis, i.e. the technical system (process, structure, utility, safety, emergency preparedness systems), including the relevant operations and phases.
- Statement of the period of time to which the analysis relates.
- Statement of current condition (in relation to possible degradation) for essential safety systems and safety functions (applies in particular to analyses in operations phase).
- Statement of the personnel groups, the external environment and the assets to which the risk assessment relates.

The system description should for a QRA in addition to the general requirements above, include capabilities of the system in relation to its ability to tolerate failures and its vulnerability to accidental effects.

6.5 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.
- Internal/external incident reports that are applicable.
- 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 HAZID may be:

- Use of check lists and accident statistics, e.g. use of lists in ISO 17776, annex D, or similar, se.g. as outlined in ISO 17776, annex C.

b) Experience from previous analyses, safety inspections and audits.

6.6 Analysis of causes and frequency of initiating events

Explicit 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.

- FMEA

Cause analysis and frequency data for initiating events shall contain an evaluation of the need to include evaluations of human and organisational factors. This is particularly important where accidents may be caused directly by human or organisational errors.

For the analysis of causes/frequency of initiating events in a QRA, an explicit human reliability analysis should as far as possible be carried out.

Reference is made to the NPD Regulation for management of HES, §15 (QRAs and EPAs).

6.7 Data basis and models

The following requirements apply:

- Both the data and the models into which the data are applied, shall be suitable in relation to the context of the study.
- Data that are used should be consistent with relevant operations and phases.
- If trends in data are used, they will need to be substantiated.

Analytical models and computer codes 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 requirements to input data, assumptions, etc. see also 6.15 on sensitivity studies and annex D for further details.

The modelling of the potential incident/accident sequence shall be detailed enough in order to suit the purpose of the analysis, e.g.:

- Estimate the risk picture.
- Estimate the performance of the barriers.
- Establish performance standards for the essential safety systems.
- Show the dependency between the physical barriers.
- Reflect explicitly common cause and mode failures.

As the risk analysis forms an important part of the basis for the decision-making process, the input data, models and assumptions shall be considered in relation to the need for verification. See also annex D and NORSOK standard Z-016, clause 6.
Qualified methods should as far as possible 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.
When unqualified methods are used, the effects on the uncertainties in the results shall be considered.

6.8 Consequence and escalation analysis in TRA

The term consequence analysis 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.

The requirements of this subclause shall apply explicitly for a detailed risk analysis .For a less detailed analysis the entire list is not applicable in detail, but it should be considered as a guidance for which risk elements that are addressed.

For a TRA, the consequence analysis shall include but not be limited to the following sub-studies (either as part of the TRA or through separate studies), when the hazards are relevant:

- Leakage of inflammable substances:
  - Calculation of release (amounts, rates, duration, etc.).
    d) Calculation of spreading of leakage and gas dispersion.
  - Calculation of ignition potential.
  - Fire load calculation.
  - Explosion load calculation.
  - Response calculation.

- Blowouts (with respect to environmental loads):
    e) Calculation of release rate, duration, etc.
  - Spill drifting calculation.

- Blowouts (non environmental effects):
  - Consequences related to ignition and subsequent effects are calculated as for leakages of inflammable substances.

- External impact (collision, falling/swinging load, helicopter crash on installation):
    f) Calculation of energy distribution.
  - Calculation of load distribution.
  - Calculation of impulse distribution.
  - Response calculation.

- Falling loads on subsea installations and pipelines:
  - Consequence calculations as for external impacts in general.

- Loss of stability and buoyancy, catastrophic loss of anchor lines:
  - Calculation of residual buoyancy and stability in damaged condition.
  - Calculation of load distribution in damaged condition.
  - Response calculations.

The stability and buoyancy 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.

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

CFD-methods
- Analytical methods, reference is made to industry procedure, see annex G.
- 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.

Escalation analysis includes consequence modelling and response calculation. Analysis or evaluation of essential safety systems forms part of the escalation analysis (see 6.9), in order to assess the possibility or the premises for maintaining control of the sequence of AEs.

As far as possible, contribution to escalation from human and organisational factors should be explicitly analysed, together with the contribution from such failures to dependent failures, reference is made to 6.6.

The most important barriers shall be explicitly modelled in an event tree (or corresponding). This does not necessarily require that all barriers are modelled as nodes in the event tree, but the models will need to be available for analysis of dependencies.

6.9 Essential safety systems

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

When required/requested by relevant authority or contract requirements an escalation analysis shall be made and shall as a minimum include a classification of the essential safety systems based on vulnerability to AEs. A comprehensive analysis shall include identification and analysis of mechanisms of failure of these systems and their dependencies, in relation to relevant AEs. Emphasis shall be given to analysis of the total system and dependent failures shall be integrated in the analysis of the essential safety systems.

This is further discussed in 8.7 and 8.9.

6.10 Risk analysis of well and drilling activities

Blowouts represent a major risk contributor to installation risk, but detailed evaluation is also required for a specific well program.

On an overall level, risk evaluations for planned drilling and well activities shall be performed such that the effect of the activities is determined as part of the total risk on the installation.

The remainder of this subclause applies to detailed analyses of well activities for specific wells or groups of wells, and can only be carried out when detailed programs, equipment specifications and procedures have been proposed. The risk analysis shall provide the basis for:

- Operational planning.
- Planning of well control activities.
- Selection of and requirements to barriers.
- Requirements for training and organisation of the activities.
- Restrictions (if any) applicable to simultaneous operations.

The detailed risk analysis of well activities should usually include:

- Probability of blowout and its consequence in terms of appropriate categories according to what is relevant and what is required by RAC.
- Probabilities of occupational accidents and their consequences.
- Probabilities of different amounts of oil spilled, as input to the environmental risk analysis (see 8.2).

The risk analysis can cover several drilling and well activities as long as presumptions and basis are the same. Regardless, an evaluation of the activity shall be done to ensure a consistent basis.

6.11 Estimation of fatality risk

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:

h) Immediate fatalities.
- Transportation fatalities including shuttling.
- Escape fatalities.
- Evacuation and rescue fatalities.

The fatality risk contributions shall be split into areas or exposed personnel groups according to where the fatalities occur.

In a TRA, the fatality calculations shall include:

- Response of personnel to accidental loads:
  - Heat radiation.
  - Toxic gas, smoke, etc.
  - Primary and secondary (usually most important) effects of blast/impulse loads.
- Analysis of evacuation and rescue operations (preferably with a probabilistic modeling).

An estimate of the number of personnel injured in accidents is often required as input to EPA. This may imply that the consequence analysis for personnel is extended to include injuries. The analysis may also be used for dimensioning of evacuation and rescue capacity, as outlined in B.9.

Fatality risk results should be subjected to extensive validation, due to the absence of experience data for judgement of realism. Presentation of intermediate results may be used for this purpose, as outlined in B.9.

6.12 Loss of main safety functions

When required/requested by relevant authority or contract requirements, the analysis shall include evaluations of possible loss or impairment of main safety functions, such as main support structure, escape ways, shelter area, control room function and evacuation means, due to accidental loads. This may be achieved by carrying out separate response studies, as outlined in 6.7 or in other ways. Main safety functions are discussed in A.1.2, A.2.8 and A.4.2.2.

6.13 Establishment of DALs

Accidental events and DALs are closely related. The establishment shall start with the completion of a risk analysis and the comparison of estimated risk with RAC.

The risk analysis will have to establish sets of AEs and associated accidental loads, and possibly also associated probability. The DALs are chosen from these sets, such that the RAC are complied with.

6.14 Estimate risk for asset damage/production disruption

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

- Establish the distribution for duration of AEs (often an extension beyond the period of exposure of personnel).
- Calculate responses for equipment and structures.
- Estimate required man hours and duration of restoration work.
- Estimate cost of restoration and duration of operations shut down including possible temporary solutions, as by-pass, temporary equipment, substitution, etc.

Further details are presented in annex E and NORSOK standard Z-016.

6.15 Sensitivity analysis

The need for sensitivity studies shall always be considered. Uncertainties shall be evaluated on this basis.

Sensitivity analysis presents robustness (i.e. to what extent the conclusions depend on variability in the input values and assumptions) in the results based on variances in:

- Risk modelling data.
- Design parameters.
- Operational parameters.

Sensitivity analysis will be particularly important if the data basis has an in sufficient number of occurrences. Sensitivities will then have to be considered in order to limit the uncertainties and produce robust conclusions.

6.16 Documentation

The information shall be understandable to all relevant personnel, decision-makers as well as operating personnel. The list below shall be considered relevant for the analysis in question and level of detail.

The documentation of a QRA shall as a minimum include the following:

- Statement of objectives, scope and limitations.
- Description of the object (or system) of the analysis, the phases and operations that the analysis is valid for, the categories of defined accidental hazards/events that are covered and the dimension of risk. The descriptions should preferably be accompanied by drawings or similar.
- Statement of the assumptions, presumptions and premises on which the study is based, so that they may be evaluated and accepted.
- Data basis.
- Description of the analytical approach used.
- Quality assurance, including personnel competence.
- Presentation of conclusions from the study.
- Presentation of possible measures that may be used for reduction of risk and their risk reducing effect.

The documentation for a TRA shall in addition to the general requirements presented in 5.2.1 as a minimum include the following:

- 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.
- i) Specify performance standards, in a way that makes them suitable for being used as dimensioning requirements.
- Description of DAEs and DALs.

Assumptions and premises stated in the overall risk analyses (those that are carried out in order to compare results against RAC, see 3.1.18 at an early stage of the design), shall be included as performance standards for safety and emergency preparedness measures for later phases of the design project.

A plan for follow-up of the analysis shall be prepared, containing an assessment of the study's conclusions and recommendations as well as plans for implementation of risk reducing measures, including emergency preparedness measures.

6.17 Update of analysis

Studies shall be updated in connection with major modifications or changes to area of application. Further the effect on the risk levels of following aspects shall be considered and the studies updated when relevant:

- Experience from accidents that have occurred, in particular with respect to analysis of causes.
- Organisational changes.
- Changes to regulations.
- Changes in data basis, models or risk estimating methods.
- Minor modifications, which in sum does represent a major modification.

The updating of analyses shall include updating of the following when relevant:

- The description 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 RAC for the installation or operations.

The operator/owner shall formulate minimum requirements to the frequency of updating of the QRA and EPA, unless technical or operational circumstances in the meantime have necessitated more frequent updating.

7 Risk and emergency preparedness analysis (EPA) in life cycle phases

7.1 General

This clause is based on the general requirements outlined in the previous clause and defines their implications for risk and EPA in each life cycle phase. The use of RAC in the various life cycle phases is not discussed, this is presented in annex A. See also ISO 17776, annex C.

An existing mobile unit that is brought into the Norwegian sector, will usually have applicable risk analyses prepared under foreign legislation. The specific and itemised studies of the tables in clause 7 may be departed from for a mobile unit, as long as the available studies cover the requirements of clause 5, clause 6 and clause 7.

7.2 Analyses during concept development

Table 1 presents an overview of the main analyses which shall be conducted during concept development phases, including their timing, main purpose and focus. Further details are provided in annex C.

Table 1 – Summary of main risk analyses during field development phase

Analysis	Timing	Main purpose	Main focus
ERA	Selection of main concept, pre-conceptual phase	• Comparison and ranking of field development concepts • Optimisation of chosen concepts • Identify all major hazards.	• All installations that are part of production system, including mobile units and vessels that are involved in the operations • HAZID of all risk aspects • Non-traditional safety aspects • Identification of potentially extra costs for achieving an acceptable solution
Concept TRA	When layout drawings and PFD's have been made. Before issue of invitation to tender. Before submission of PDO	• Assessment of compliance with acceptance and design criteria • Identify functional requirements as input to design specification • Establish dimensioning accidental loads	• HAZID • Identify aspect which need detailed analysis • Identify design or operational challenges • Identify design or operational assumptions • Establishment of DALs • Give recommendations to design
Design TRA	When layout drawings, P&ID's for process and essential safety systems have been made.	• Verification of design • Check of compliance with overall RAC (assumptions for safe operation) • Establish performance standards and requirements from assumptions and premises in analysis	• Update DALs • Decide about the need for and the extent of further risk reducing measures • Analysis of performance of safety barriers • Identify risk indicators and their importance • Review and update assumptions made • Verify and confirm DALs • Detailing of the analysis for achieving more accurate results
As-built TRA	When final design of systems	• Update TRA with as-built information and reflect any changes to risk levels • Provide input to operations	• As for design TRA

Table 2 presents an overview of the additional analyses which should be considered during development phases. When performed their timing, main purpose and focus shall be as given in Table 2. Further details are provided in annex C.

Table 2 – Summary of optional additional risk analyses during field development or operational phase

Analysis	Timing	Main purpose	Main focus
Detailed risk analysis and analyses in connection with design change pro-posals, handling of deviations and project phases (TRA extension)	After concept risk analysis	• Evaluate special risk aspects on the basis of performed risk analysis in order to give design input • Evaluate how changes etc. affect risk • Evaluate effects of deviations from statutory requirements	• HAZID • Reflect design details/specifications • Reflect detailed/special analysis performed • Provide operational recommendations • Update DAL (if required) • Assessment of compliance with acceptance and design criteria • Input to DSHA (when required/requested)
Quantitative/ Qualitative studies (FMEA, HAZOP, etc)	When appropriate or requested during engineering phases, in order to evaluate systems designs	• Identification of requi-red improvements in system design	• Processing systems • Utility systems • Drilling fluid systems • Essential safety systems • Loss of barriers • Human factors
Integrated risk and EPA of fabrication and instal-lation	Prior to decision on concepts for fabri-cation and installation	• Provide input to concept and methods for fabrication and installation • Identify operational limitation and environmental envelops to be observed during fabrication and installation	• Fabrication of equipment and structures, hooking up, towing of modules, installation, commissi-oning and start-up preparations • All installations and vessels engaged in the installation and hook-up operations • Nearby installations and vessels, if they are close enough to be affected by accidental effects • Aspects of the fabrication and installation that may severely affect the entire installation and/or risk to personnel • Determine the emergency preparedness level for the fabrication, installation and commissioning work

7.3 Use of SBSD

During development of special concepts, such as normally unmanned installations, it may be required to adopt SBSD as a means to fulfil the intentions of applicable requirements through non-traditional solutions, which may depart from the detailed requirements in regulations and standards. Annex F describes how this may be carried out in practice.

The use of SBSD shall meet the following main requirements:

- Quantitative risk analysis shall always be carried out in relation to RAC.
- High level RAC shall be complemented by decision criteria relating to performance of barriers.
- The barriers gas detection, fire detection and HC potential limitation/isolation should always satisfy a set of basic functional requirements, even when SBSD is used.

7.4 Analyses in operations

Table 3 presents an overview of the main analyses which shall be conducted during the operations phase, including their timing, main objectives and focal points. Further details are provided in annex C.

Table 3 – Summary of main risk analyses during operations phase

Analysis	Timing	Main purpose	Main focus
TRA updates	During operations phase	• Update of risk levels due to experience, modifications, model improvements, changes in criteria, operational mode, manning level, maintenance philosophy, etc	• Update design TRA • Eliminate assumptions • Reflect operational experience • Reflect modifications • Reflect new knowledge • Establish basis for risk communication with operational personnel • Present a detailed risk picture • Present input to scenarios for DSHA
Risk analysis of critical operations, including SJA	Planning of the operations	• Identification of hazards • Identification of risk reducing measures, in order to achieve safe job performance	• Necessary risk reducing measures shall be implemented
TRA adaptation for operations phase	Regularly during operations phase	• Ensure that the risk level is kept under control. • Ensure that operational personnel are familiar with the most important risk factors and their importance • Identify and follow up of assumptions made in earlier phases • Update DSHA	• Follow up of TRA during operations phase • Status and condition of critical safety aspects
Integrated TREPA of modifications	Prior to deciding on details of modifications	• Evaluate the operational phase with the modifications implemented • Identification of hazards • Identification of possible risk reducing measures	• As for engineering phases to the extent relevant
Integrated TREPA of modification work	Prior to deciding on the way in which the modification shall be implemented	• Evaluate the operational phase during modification work • Identification of hazards • Identification of possible risk reducing measures	• Simultaneous activities • Increase in risk level during modifications work • Need for additional emergency actions during modifications work • Establish emergency preparedness requirements for the modifications work

7.5 Analyses of emergency preparedness

Table 4 presents an overview of the main analyses which shall be conducted during the development phase, including their timing, main objectives and focal points. Further details are provided in annex C.

Table 4 – Summary of main emergency preparedness analyses

Analysis	Timing	Main purpose	Main focus
Early EPA	Before decision to start preparations of PDO.	• Comparison and ranking of field development concepts • Optimization of chosen concepts • Identification of initial performance standard for emergency preparedness	• Possible emergency preparedness aspects that may require extra costs in order to achieve an acceptable solution • Non-traditional emergency preparedness aspects • Escape and evacuation aspects
Concept EPA	When layout drawings, P&ID's for process and essential safety systems have been made. Before submission of PDO.	• Assessment of compliance with acceptance and design criteria. • Provide input to design and operational procedures • Establish performance standards for technical, operational and organisational emergency preparedness.	• Identify aspects which need detailed analysis • Identify design or operational assumptions • Give recommendations to design • Relevant installations that are part of the production system, including mobile units and vessels that are involved in the operations, nearby vessels and installations
As-built EPA	When final design has been made	• Update EPA with as-built information and reflect changes to risk levels • Establish performance standards	• As for concept EPA • Input to emergency preparedness plans, procedures and emergency organisation.

It should be emphasised that the main emphasis should be placed on the aspects listed above, which analysis that they are included into, are of less importance.

8 Interfaces

8.1 General

Several assessments will affect risk analysis or vice versa. This clause gives an overview of studies, which may provide input to or require results from the risk analysis.

8.2 Relations to other NORSOK standards

Analyses for safety, reliability and maintenance are related. Three NORSOK standards deal with these issues.

- Z-CR-008 Criticality classification method
- Z-013 Risk and emergency preparedness analysis
- Z-016 Regularity management and reliability technology

The relations between the standards in terms of exchange of information are depicted in Figure 3.

Reference is also made to NORSOK standard N-001 and NORSOK standard S-001.

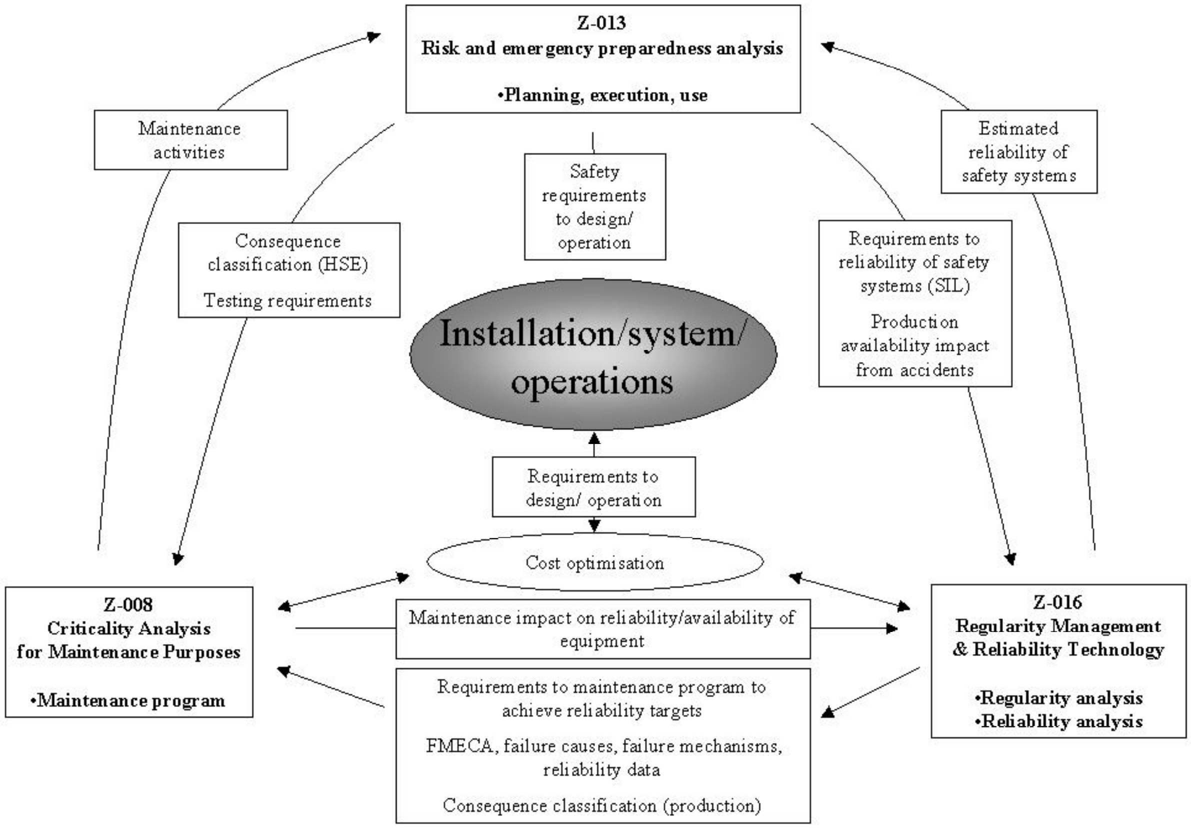


Figure 3 – Relations between NORSOK standards Z-CR-008, Z-013 and Z-016

8.3 Estimate environmental risk

The MIRA method is established by OLF and has several interfaces with a risk analysis. 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 main inputs from risk analysis are:

- Frequency of blowouts.
- Release scenarios, including rates, duration, dispersion, etc.

The main output from MIRA to a risk analysis is basis for an EPA.

Reference is made to OLF Recommended method for environmental risk analysis, MIRA.

8.4 Regularity analysis

Reference is made to NORSOK standard Z-016 where regularity, availability and reliability analysis functions of any type of systems and operations are outlined. Risk and emergency preparedness analyses link many aspects of regularity and reliability analysis. NORSOK standard Z-016, clause 5, outlines important interface issues between these two types of analyses, such as summarised below:

- The risk and EPA may impose reliability requirements on certain equipment, typically essential safety systems.
- The risk and EPA may impose requirements to equipment configuration that will affect regularity.
- Production unavailability due to catastrophic events.
- Assumptions and premises in the risk and emergency preparedness analyses may influence the regularity analysis and its operational and maintenance strategies. Examples are manning levels, logistics and equipment test strategies.
- Study assumptions and data in reliability analyses and risk and emergency preparedness analyses shall be consistent.

8.5 Reliability centred maintenance (RCM)

The purpose of an RCM analysis is to establish the (preventive) maintenance programme in a systematic and optimal way. This is described in NORSOK standard Z-016, 8.4.2 from which the following text has been summarised.

The interfaces between RCM analysis and risk and emergency preparedness analyses are:

- Input to RCM analysis in terms of reliability requirements for essential safety systems (fire water system, F&G detection system, ESD system), based on assumptions used in the QRA studies.
- Input to RCM analysis in terms of manning requirements (or prohibited manning), based on assumptions used in the QRA studies.
- Study assumptions and data in risk and emergency preparedness analyses and RCM analyses shall be consistent.

8.6 Reliability/risk based testing

For dormant systems testing, intervals can be established on the basis of reliability/risk methodology, as described in NORSOK standard Z-016, 8.4.4.
From the safety acceptance criteria or the risk and EPA there may be requirements to on-demand availability for essential safety systems. Such systems, e.g RV, ESV or BDV, shall be tested at regular intervals and the test results recorded. The results shall be compared with the reliability requirements to see whether the requirements are met. Based on the results, the test intervals can be adjusted to achieve the required on-demand availability at minimum cost.

8.7 Risk based inspection (RBI)

RBI is a methodology which aims at establishing an inspection programme based on failure mechanisms which may be subject to inspection (corrosion, vibration, etc.). Interactions between RBI and other analysis functions are described in NORSOK standard Z-016, 8.4.5, from which the following text has been summarised.

The methodology combines availability and risk analysis work and is typically applied for static process equipment (e.g. piping, pressure vessels and valve bodies). The failure mode of concern is normally loss of containment. The input to a risk analysis is probability of leak and consequence to assets.

Interactions between RBI, RCM, regularity, availability and risk analyses are important to ensure consistency in relevant failure rates and associated downtime pattern for equipment covered in these analyses.

RBI in operations phase will provide information about failure mechanisms and frequencies, which may be included in risk analysis, especially in the analysis of causes for accidents.

Risk analysis will correspondingly give input to optimisation of inspection programs, in relation to which equipment and pipe systems that have the highest contribution to risk to life and assets.

8.8 Criticality ranking

Criticality analysis should be co-ordinated with RCM as described in NORSOK standard Z-016. The ranking of criticality should be based on the effect of errors/faults and on the time from the occurrence (of the error/fault) until the effect occurs on the installation. The main interfaces with risk analysis is to provide input to:

- Effects of failure of essential safety systems.
- Ranking of safety systems.
- Criticality classification of essential safety systems.

Reference is also made to NORSOK standard Z-008.

8.9 Risk and EPA for mobile units

Risk and EPA is required for mobile units (i.e. mobile drilling units and mobile accommodation units) according to statutory requirements, in relation to:

- Construction of new mobile units.
- Operation of mobile units.
- Major modifications of mobile units.
- Interfaces with fixed installations when connected by bridge, cantilevered, etc.

The planning and execution of risk and emergency preparedness analyses shall in principle meet the requirements of clause 1 to clause 6 of this NORSOK standard. The documentation may be based on accepted safety cases (UK legislation) or analyses according to NMD's risk analysis regulations.

8.10 Safety integrity level (SIL)

IEC 61508 shall provide a SIL for the electric, electronic and programmable part of a number of essential safety systems/functions such as ESD, F&G, shut down of ignition sources. It establishes an expression of required availability of the system.

To compare SIL against overall RAC is not relevant, as the RAC are too coarse. The SIL risk analysis is rather on a detailed level, which must be defined. As the SIL is an expression of availability figures for the system, it should be established and used as a 'barriers level' to be met. Hence, SILs might be relevant when applying SBSD, see annex F.

The availability of barriers is reflected in event trees and the SIL may provide an indirect input to the event tree. The risk analysis can be used for sensitivity studies related to the defined SILs, whether to maintain the level or relax this and still meet the performance standards.

Guidance on how to establish SILs is found in the OLF guidelines for the application of IEC 61508 and IEC 61511, see clause 2. See also NORSOK standard Z-016.

8.11 Health risk assessments (HRAs)

Occupational HRAs are not normally part of a risk analysis scope, but may be included as part of the analysis of occupational accidents.

There may be input from QRA to working environment analyses, in relation to what hazards that may lead to injuries. See NORSOK standard S-002.

Annex A
(informative)
Risk acceptance criteria

A.1 Risk acceptance criteria for quantitative analyses

A.1.1 General

This type of RAC is most commonly used in relation to overall risk studies in the conceptual design, 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 RAC.

Requirements stipulated in standards, specifications, procedures, etc. which are necessary to achieve acceptable safety, should not be interpreted as RAC. 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 RAC should 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.

Clause 4 in the normative text presents an overview of the high level expressions of risk to which RAC may be tied.

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 RAC. 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 RAC:

a) In relation to decisions regarding the overall operations of an installation, the total risk potential has to be considered. The RAC 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 RAC 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 RAC may be subdivided in categories according i.a. to the purpose and the level of detail of the analysis:

- Quantitative RAC for quantitative studies.
- Risk matrixes and the ALARP principle.
- Risk comparison criteria.

A.1.2 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 DALs. This has often been done within the concept risk analysis.

Example:

- The frequency 1 x 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 x 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 AEs.

A.1.3 Risk matrixes

The arrangement of accident probability and corresponding consequence in a matrix (see Figure A.1) may be a suitable expression of risk in cases where many AEs 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.

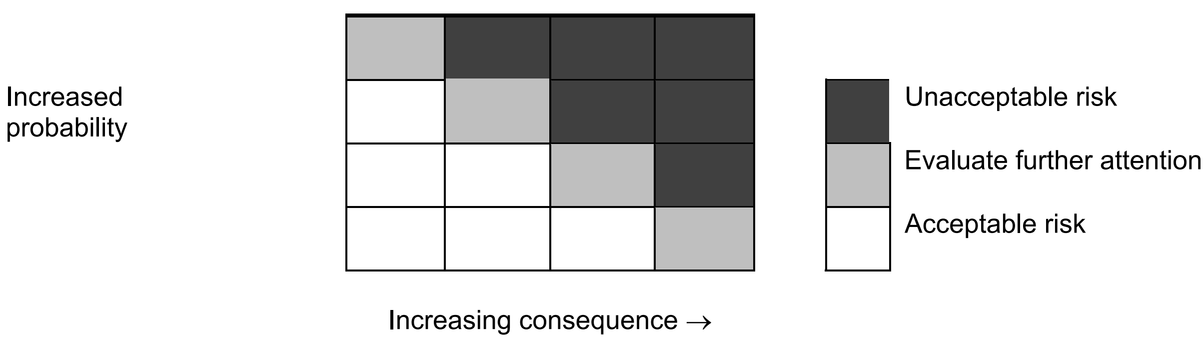


Figure A.1 – Risk matrix

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 continues variables, implying a full quantification. An illustration of this is shown in Figure A.2.

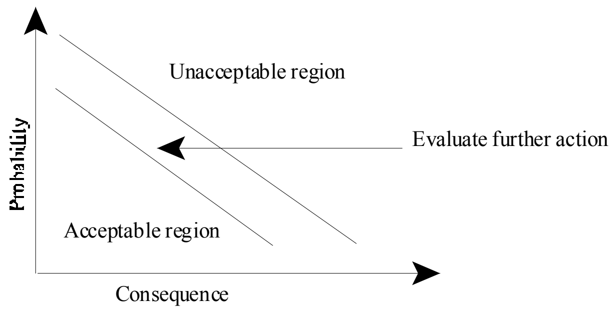


Figure A.2 – Risk matrix like presentation with continuous variables

The upper tolerability limit (Figures A.1 and A.2) is almost always defined, whereas the lower limit is individual to each individual risk reducing measure, depending on when the cost of implementing each measure becomes unreasonably disproportional to the risk reducing effect.

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.1.4 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 risk aversion to major accidents (with multiple fatalities), if the product of f and N is decreasing with increasing N. The calculation of values for the f-N curve is cumulative, i.e. a particular frequency relates to 'N or more' fatalities. Figure A.3 presents an illustration.

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

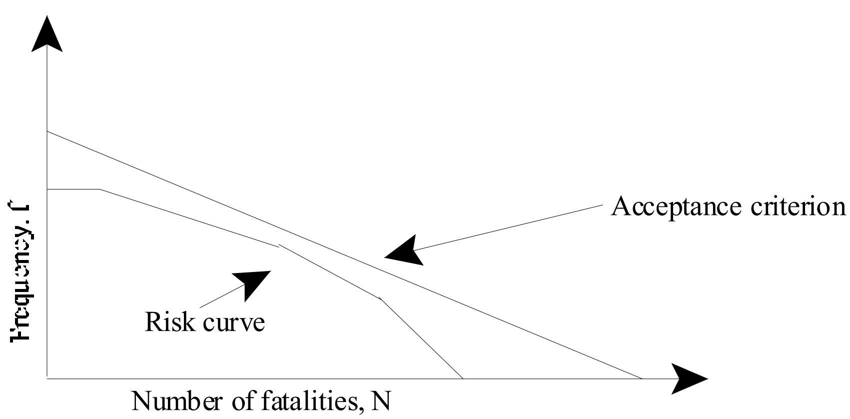


Figure A.3 – f-N curve

A.1.5 ALARP – principle

The ALARP (see Figure A.4) principle is sometimes in the industry used as the only acceptance principle and sometimes in addition to other RAC.

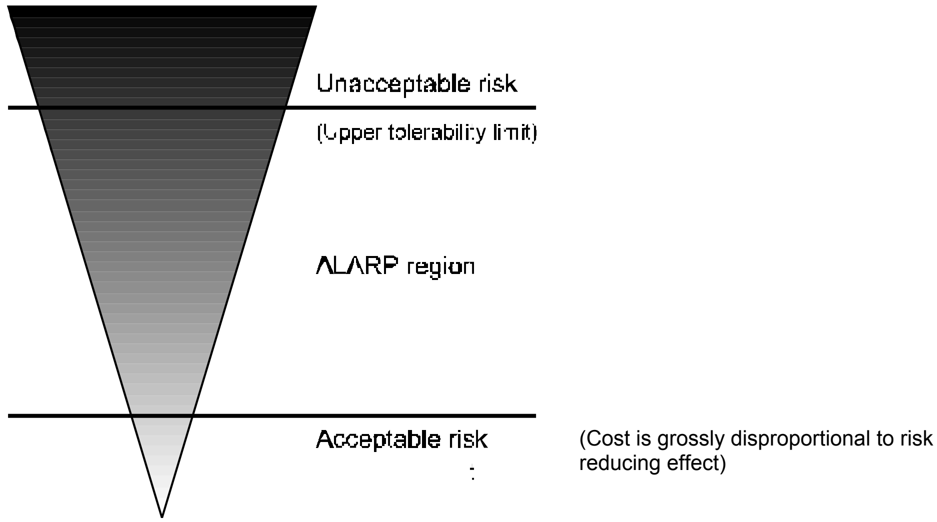


Figure A.4 – The ALARP – principle

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 should 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 Figure A.4) is almost always defined, whereas the lower tolerability limit is sometimes defined and is in other cases left undefined. The lower limit is individual to each individual risk reducing measure, depending on when the cost of implementing each measure becomes unreasonably disproportional to the risk reducing effect.

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

A.1.6 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 RAC 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 should 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 should be at least as safe as conventional technology.
- The risk level for the environment should not be higher compared to existing solution.
- Alternative solution should be at least as cost effective as the established practice.

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

A.2 Aspects in relation to choice of risk acceptance criteria (RAC)

A.2.1 Overview

A.2.1.1 General

The use of the RAC will always influence strongly the selection of the type of criteria. Quite often conflicting interests are involved. On one hand the RAC 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 RAC 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 RAC 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 RAC 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 RAC are often related to parameters that belong far out in the event sequence (such as fatalities).
Unambiguity • Precision • System limits • Averaging	Unambiguous RAC 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 RAC are discussed in the following subclauses 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.2.1.2 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 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.2.1.3 Adaptability to communication

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

In order to achieve an effective HES management there is a clear need for communicating RAC 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.2.1.4 Unambiguity

Ambiguity problems may be associated with:

- Imprecise (inaccurate) formulation of the RAC.
- 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 RAC are 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 RAC 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 aspects may affect the choice of the system limits.

The formulation of the RAC may in some cases favour certain concept solutions, due to the way in which the risk levels are calculated. RAC 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 RAC, 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 blowout 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 RAC should 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.2.1.5 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 ⇨ Event ⇨ Physical accidental loads ⇨ Physical consequences ⇨ Damage

One example of risk calculations relating to event sequence:

Event		**Physical accidental loads**		**Physical consequence**		**Damage**
Leak	⇨	Fire load, x kW	⇨	Fire loads on escape way	⇨	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 RAC 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 PLL
Suitability for decision support	PLL 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.	PLL 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 PLL unambiguously. PLL is not well suited for averaging differences between personnel groups etc.
Concept independence	The PLL 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 PLL 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 impairment of main safety functions and frequency of escalation. PLL is less uncertain than FAR 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 A.1.4.

Aspect	Advantages and disadvantages of ***f-N curves***
Suitability for decision support	The f-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 f-N curve makes it somewhat difficult to comprehend. The f-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 PLL, 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 f-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 PLL.

A.2.4 Fatal accident rate (FAR)

A.2.4.1 General

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.2.4.2 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 *FAR for an entire installation*
Suitability for decision support	The FAR value for an entire installation 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. (Area FAR is more suitable in this context).
Adaptability to communication • Easy to understand for non-experts. • Comparison of risk with other activities.	The FAR value is relatively easy to comprehend for non-experts. The FAR value is the easiest of all parameters for comparison with risk for other activities
Unambiguity • Precision • System limits • Averaging	The FAR for an entire installation is unambiguously defined, but the averaging over the entire installation may imply a somewhat inaccurate reflection of the risk picture.
Concept independence	FAR for an entire installation 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 the FAR for an entire installation.
Uncertainty	The calculations required to establish the FAR for an entire installation include calculation all through the event chain, in addition to averaging over all exposed personnel onboard. The uncertainties of the results are therefore relatively high.

A.2.4.3 FAR for a group with unformed 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 FAR for an entire installation (see A.2.4.2), because the group FAR averages over a smaller number of positions.
Adaptability to communication • Easy to understand for non-experts. • Comparison of risk with other activities.	Similar to FAR for an entire installation, however this value and the group FAR are often mixed together unintentionally.
Unambiguity • Precision • System limits • Averaging	As FAR for an entire installation but with a higher precision level than the former as to the averaging.
Concept independence	Less concept dependent compared to the FAR for an entire installation, PLL and f-N curves due to its focusing on a smaller group of personnel.
Uncertainty	Uncertainty is relatively high as all FAR calculations apply far out in the event sequence. The group FAR is better than the FAR for an entire installation due to its averaging over a smaller group.

A.2.4.4 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 PLL, f-N curves, IR, FAR for an entire installation and group FAR 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 FAR for an entire installation in relation to precision and system limits. Considerably better than the FAR for an entire installation as to averaging of the risk.
Concept independence	As for group FAR.
Uncertainty	As for group FAR except that the averaging is different.

A.2.5 Individual risk (IR)

IR is the probability that a specific individual (for example the most exposed individual in the population) should 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	IR 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. IR implies limited averaging corresponding to that of area FAR.
Concept independence	Less dependent on the actual concept compared to the FAR for an entire installation, PLL and f-N curves.
Uncertainty	Like the other risk parameters relating to personnel IR 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 risk matrix favours any particular concept.
Uncertainty	The risk matrix 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 2 h 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 escalation frequency is easy to understand, but is not very suitable for comparison with risk in other activities.
Unambiguity • Precision • System limits • Averaging	The escalation frequency 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 AEs 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 '*loss of main safety functions*'
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 loss of main safety functions, 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 loss of main safety functions 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 main safety functions 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 Safety objectives

The safety objectives should 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 RAC as an element of the continuous improvement process and the HES management.

A.3.2 Establishment of an acceptable level

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

The level of precision in the formulation of the RAC 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 RAC 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.3.3 Handling of deviations from RAC

The management is responsible for establishing management systems including establishment and use of RAC 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 RAC 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 RAC if necessary, or it may be more appropriate to develop separate RAC for such old installations.

A.3.4 Updating of RAC

It is required that the RAC 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 RAC should also be judged. It may also be necessary to update the RAC according to the development in analysis methodology, data bases and technology. The RAC 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 RAC. Such a revision may imply that AEs that initially were not classified as dimensioning, may be re-classified at a later stage as being dimensioning for the activity in question.

A.3.5 Prioritising of risk reducing measures

The overall principles for prioritising risk reducing measures imply that reducing probability of accidents should 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:

    1) Measures which reduce the probability for a hazardous situation to occur.
    2) Measures which reduce the probability for a hazardous situation to develop into an AE.

b) Consequence reducing measures, in the following order of priority:

    1) Measures related to the design of the installation, to load bearing structures and passive fire protection.
    2) Measures related to safety and support systems, and active fire protection.
    3) Measures related to contingency equipment and contingency organisation.

A.4 Use of risk acceptance criteria (RAC) in lifecycle phases

A.4.1 General

The petroleum activity may be divided into different lifecycle phases. The use of RAC 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 clause 6. The same structure is applied in the following presentation in that clause, except that exploration drilling is discussed at the end of A.4.

A.4.2 Conceptual design and engineering phases

A.4.2.1 General

Use of risk analysis and associated RAC 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 aspects 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. RAC in relation to personnel, environment and assets, loads from DAEs, 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 RAC based on risk analysis.
- Qualitative (semi-quantitative) analysis.
- Experience data and standards.

The following subclauses are focused on overall RAC.

A.4.2.2 Feasibility studies and concept evaluation

The concept evaluation phase requires that quantitative RAC have been established. Coarse risk assessments are often performed during the feasibility study phase in relation to technical and economic potentials and limitations. Detailed QRA 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 QRA is thereafter required in relation to quantitative RAC for personnel, environment and assets. These studies will consider the alternative concepts and conclude on their potential to meet the RAC. Critical aspects (operationally or technically) should be identified to the extent possible in order to estimate necessary cost in relation to meeting the RAC or to have realistic basis of comparison.

The RAC to be used should 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 RAC (see also discussion on uncertainty in A.2.1.5)

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 min in order to enable a controlled evacuation from the shelter area on the installation. Total frequency of AEs 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 RAC. Advantages and disadvantages of the different types of criteria are outlined in A.2.2 to A.2.8.

A.4.2.3 Pre- and detailed engineering phases

The same quantitative RAC are normally used in the engineering phases as in the concept study phase. All DALs have to be defined through the engineering phases. These loads together with assumptions and premises in the risk assessment should 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 TRA. 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 RAC 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.4.3 Construction and installation phases

A.4.3.1 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 RAC have normally not been established. Particular aspects relating to escape and evacuation from modules have to be considered in each case. 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 RAC. Qualitative criteria are briefly outlined in A.4.3.2.

b) Offshore construction work:
The RAC 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.4.3.2 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 RAC 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 RAC 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 RAC are therefore often judged not to be useful, when compared to the efforts needed to carry out a quantitative analysis. Therefore qualitative RAC and risk analysis have often been used.

A.4.4 Operations phase

A.4.4.1 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 RAC 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 A.3.2).

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 RAC. Examples of such indicators may be:

- Hydrocarbon leak frequencies.
- Extent of hot work.
- Availability of critical safety systems.
- Mobilisation time for emergency personnel/teams.

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 RAC. The trends for the risk indicators must be monitored regularly

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 RAC. 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.

A.4.4.2 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 RAC 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 RAC 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.

SJA 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
SJA 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
SJA 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 RAC 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.4.4.3 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 RAC 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 should be carried out, see paragraph regarding "Manned underwater operations" in A.4.4.2. Therefore, the execution of maintenance and inspection should 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. Identification of critical equipment may be performed in relation to RAC 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.4.4.4 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 Figure A.5):

- 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 RAC.
- 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 A.5 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.

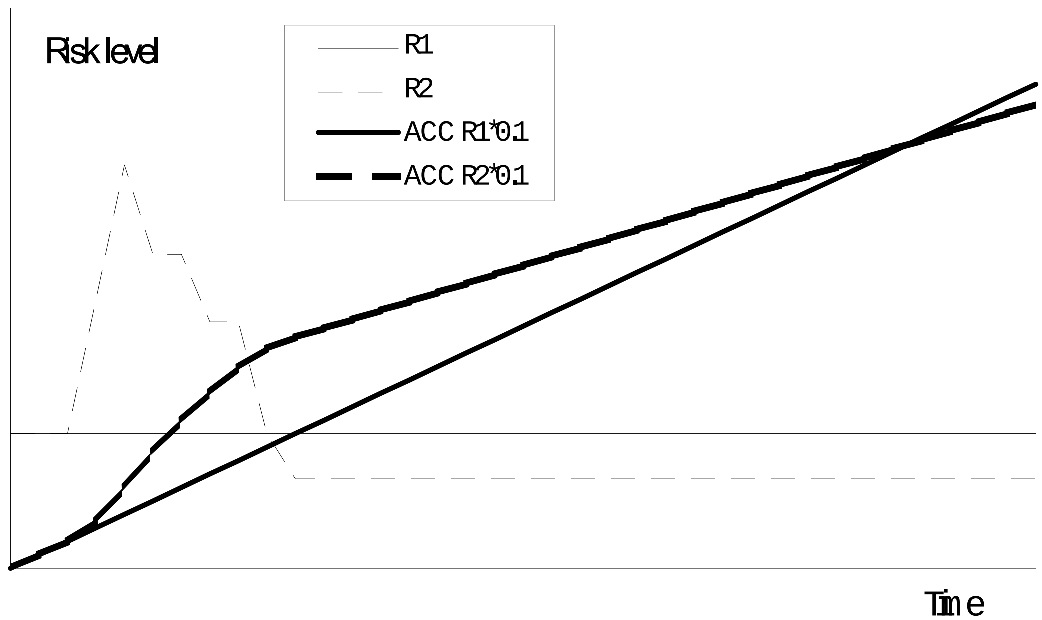


Figure A.5 – Example of variation of risk level during implementation of risk reducing measures, and effect on accumulated risk over time

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 a 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.4.5 Decommissioning and disposal

A.4.5.1 General

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 RAC 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.4.5.2 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 A.4.4.2.

A.4.5.3 Maintenance and inspection of cold installation

This phase is parallel to intervention on not normally manned installations (see A.4.4.2). The RAC and the risk analysis approach should be parallel even though the risk picture may be different. PLL and IR are suitable criteria.

A.4.5.4 Completion of final disposal

The alternatives for final disposal are quite varied. Risk analysis and RAC will therefore have to be chosen in relation to the alternative for final disposal which is being evaluated. HAZOP and SJA 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 A.4.3.2 may also be applicable to the final disposal of an installation.

A.4.6 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 should 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 for exploration drilling often demands special considerations with respect to RAC. The way in which the RAC 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 RAC adopted in relation to taking on mobile installations should 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 RAC may be met for the planned operation. This may include aspects such as:

- Well specific conditions (for example blowout probability, blowout release rate).
- Location specific aspects (for example environmental conditions, location-specific shipping traffic).
- Additional AEs (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 RAC should be verified by the operator before accepting the installation.

When a mobile installation should be connected to a production installation, the RAC for the production installation will usually be adopted for the entire complex. This will imply that the RAC for the mobile unit must be in line with the RAC adopted by the operator for the production installation, and a QRA of the floating installation will usually be required.

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

Annex B (informative) Analysis of causes and consequences of various accidents

B.1 General

This annex discusses causes and consequences of typical AEs. A set of aspects to be covered by 'qualified tools and models' are given. The guidelines and requirements apply to ERA,CRA and TRA.

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.

B.2 Hydrocarbon leak, fire and explosion

B.2.1 General

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

The following should 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 should be followed up in later phases. The TRA is to include studies of the effectiveness of safety systems.

B.2.2 Leak frequency

The causes of leaks should be identified as basis for leak frequency quantification and identification of possible probability reducing measures. Pipe and equipment (components) where leaks may occur should be identified for each module/area. The components should 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 should be estimated. Frequencies of leaks with given hole sizes should be determined for each component type based on qualified data and models.

An initial leak rate should 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 should be selected for further studies. Typical quantities/volumes in the various process sections should be calculated on the basis of the sections the process is divided into by ESVs) or equivalent valves. 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 should be chosen based on the precision of the study, to reflect the risk picture. In the CRA the main components should 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 should be based on experiences of smaller leaks, and an evaluation of experiences versus the equipment counting for larger leaks.

B.2.3 Gas concentrations, shut down and isolation

Discharge amounts as a function of time should be calculated (using qualified models) for the typical leak rates. Calculations should 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 should be assessed, and further the possibility of ignitable gas clouds. The assessment should include possible drift of the hydrocarbons, both in water and air, the vaporisation and the location of possible ignition sources. If there are subsea ESVs, both the situations with successful closure and failure to isolate should be evaluated.

B.2.4 Effectiveness of shutdown systems

A successful shutdown depends on:

- Detection of the leak.
- Automatic ESD system (panels, valves).
- Operator intervention if automatic ESD is not achieved.

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

- Unknown fault (sleeping fault) in the ESD system, also covering failure to respond on a leak.
- Known faults where ESD 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 ESD system is being done, and the system is out of function during test.

The leak and discharge calculations should 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 should 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 should be studied.

B.2.5 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 should be determined for each area (module), each leak category and each medium.

The following ignition sources should 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 RAC. The possibility for a fire at sea scenario should then be assessed.

B.2.6 Explosion

A probability distribution of pressure development for the various areas or modules and leak categories should 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 should 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 should 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.

See information procedure described in annex F.

B.2.7 Fire fighting

A reliability and vulnerability analysis of the fire fighting system should be conducted. The analysis should 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 should 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 should take into consideration the area, leak size, explosion pressure and whether a successful shutdown has been achieved. The effect of passive fire protection should also be considered.

B.2.8 Blowdown

An analysis of the blowdown system should 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 should take into consideration the area, leak rate, explosion pressure and whether a successful shutdown has been achieved.

B.2.9 Impact of accident scenario

Calculations should 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 should be determined for each accident scenario. The distribution should 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 should be included in the risk picture.

B.2.10 Risk calculation

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

B.3 Blowout

B.3.1 General

Event trees should be used in order to analyse the risk related to blowout. The following should be taken into account:

- Blowout 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.3.2 Frequency

A blowout can occur during various work operations and in various locations, and these should be identified, e.g.:

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

Blowout frequencies (given per well/well year/workover) should be determined for the various operations, blowout locations and media. The blowout frequencies for the installation are then quantified on the basis of the number of wells and workovers. A set of ‘typical’ blowout rates are recommended to be defined.

The assumptions and prerequisites should be based on:

- Type of installation.
- Where the activity is performed.
- Available equipment (barriers).
- Working procedures.
- Crew size and experience.
- Weather conditions(summer vs winter).
- Water depth and total depth of well.
- Pressure and temperature.

The risk analysis should show sensitivities to the following parameters:

- Changes in procedures.
- Riser margins.
- Well stability problems.
- New or modified equipment.
- Requirements for training.
- High pressure high temperature conditions in the well.
- Cold climate.
- Water depth.
- Pressure balanced operations.
- Acid stimulation.
- Use of dynamic positioning.

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 blowout is found to be a major contributor to the total risk, a thorough examination to reduce frequencies, consequences and duration of blowouts should be performed as part of or basis for the CRA or TRA. In the operational phase the blowout rate should be updated based on best available data for the reservoir. The contingency for blowout should be checked in the TRA.

B.3.3 Ignition, fire, explosion, safety systems, evacuation (blowout scenarios)

An ignition probability should be determined for each scenario type, based on blowout location, medium, rate and possible ignition sources. The time of ignition should 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 should be considered both for subsea blowouts and blowouts on the installation.

The further accidental development in the event of ignition should 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 should be studied, both failures to isolate and accidental loads damaging equipment causing secondary blowouts.

The CRA should define design accidental loads from blowouts according to the RAC, 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 should be used to establish requirements to area dividers, critical structural elements and critical equipment (supports and integrity).

B.4 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, should be analysed.

The analysis should 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 should be included in the comparison with RAC for accidents within the safety zone. The total risk related to personnel on shuttle flights between offshore installations should 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 should be checked as well as the operational conditions for helicopters.

B.5 Collisions

B.5.1 General

The risk from two types of collisions should 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.5.2 Ships/vessels ramming the installation

B.5.2.1 General

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 should not be included (loss of life on board the vessel, etc.).

B.5.2.2 Survey of traffic

Vessel activities in the ocean area around the installation will normally be surveyed, and this should be reflected in the analysis. The following types of vessels should 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 should be presented the way it is anticipated to be during the relevant period of time. The following should 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.5.2.3 Collision energy

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

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

B.5.2.4 Consequence analysis

Consequence analysis of typical collision scenarios should be conducted.

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

Both local and global overloading of the structure should be considered. The impact on the installation, measured in loss of life, economic losses and discharges harmful to the environment should be assessed. The acceptance criterion for collision is related to catastrophic consequence, not damage to the structure.

The following effects should 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 grappling may damage pipelines or well templates.
- The ship may catch fire which can escalate to the installation or prevent evacuation.

B.5.2.5 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 should be determined.

The following should 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 should be what may cause the vessel to become adrift. In addition, the following should be taken into account:

- Wind and wave conditions.
- Warning procedures.
- Emergency procedures for assistance to vessels adrift.

B.5.3 Collision between installation and floating unit

If the installation should 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 should be calculated. Similarly the risk from other near by units (crane ships, service vessels, tendering vessels, etc.) should be considered.

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

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

The following should 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 scenaria should be described and collision energies should be calculated. The values should 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 should 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 should be verified, e.g. to see the response times for emergency preparedness vessels or the effectiveness of surveillance systems.

B.6 Falling loads

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

The following AEs should be analysed:

- Fall of crane, boom or load into sea.
- Fall of crane, boom or load on board the installation.
- Swinging loads that may cause loss of containment or damage to essential safety systems.

Unlikely events with insignificant risk, e.g. crane fall onboard the installation, may be disregarded from detailed analysis. The systems/areas exposed to risk must be identified. A differentiation should be made between various types of loads, such as containers and various types of pipe. The probability of damage should 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 must be quantified on the basis of relevant statistics. These scenarios should 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 should be considered. The economic losses should 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 should be examined, and distribution of loads established. The CRA must, if required to meet RAC, 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 should be reflected, e.g. progressive collapse and brake systems.

B.7 Earthquake and extreme weather

The risk related to earthquakes and extreme weather should be considered. Assessment of the structural integrity as well as equipment and supports should be performed (when available, assumptions for later follow up is specified). In all cases a contribution from these types of accidents should be included. This should consider what a realistic failure frequency should be, in relations to the PLS criteria. Similarly a realistic extent of fatalities should be considered, based upon the opportunities for evacuation.

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 should be verified and the risk contribution from such events assessed. If required, new design loads should be identified.

The TRA should 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 should be checked, and the equipment and equipment supports should be evaluated for extreme conditions.

B.8 Occupational (work) accidents

B.8.1 General

Occupational accidents are defined as human accidents that are not caused by AEs 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) are not be included.

B.8.2 Risk related to occupational work accidents

The frequency of fatal accidents and FAR values should 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 should be used to calculate FAR values related to occupational work accidents in updating of TRA in the operational phase:

FAR = a • b 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 h on the relevant installation.

The occupational work accident statistics should 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.9 Loss buoyancy or stability

For floating installations the following AEs should be analysed if they are considered to be possible risk contributors, e.g.:

- Loss of buoyancy.
- Excess or displaced weight.
- Displaced ballast.
- Ballast system failure.
- Loss of stability in damaged condition.
- Mooring system failure.
- Turret turning system failure.

Frequencies of such accidents may be assessed based on statistics, but with adjustments if the actual conditions deviate from normal. The analysis of ballast system should usually include a fault tree analysis of contributions to system failure, including contributions from human and organisational factors where relevant.

B.10 Other accidental events (AEs)

Other types of AEs must 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.

Frequencies of such accidents may be assessed based on statistics, but with adjustments if the actual conditions deviate from normal. The analysis of fires should 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).

B.11 Fatality risk results

Fatality risk results are usually expressed according to how the RAC are formulated. It should normally in addition be presented main contributors to the overall fatality risk, in order to give an extensive presentation of the risk picture.

Results from detailed fatality risk estimation may be used as part of the input to dimensioning of capacities of the EER means. Some of these values are expressed explicitly within the models, others are not expressed at all, but may be inferred from other models or assumptions and premises. This implies that the following should be estimated for each scenario or categories of scenarios:

- Number of persons that according to assumptions or calculations do not reach the shelter are or main evacuation means.
- Number of persons that according to assumptions or calculations are considered to survive emergency evacuation and rescue, these values thus becoming critical premises for meeting RAC.
- Sometimes the quantitative analysis of success of emergency evacuation and rescue is performed within the risk analysis, taking into account the number of personnel who will be in the need for rapid rescue in order to survive.

For input to dimensioning of rescue capacity, it would often be useful to aggregate the results into a probability distribution for the number of persons in need of rapid rescue, due to one of the following circumstances:

- Persons who are injured in evacuation means.
- Persons in damaged evacuation means.
- Persons in liferafts.
- Persons in the sea.

Extensive presentation of fatality risk components should be made for the purpose of validation of the fatality risk estimations. The presentations outlined above will also serve this purpose, for the last phase of major accidents, the emergency evacuation and rescue. For the earlier phases of an accident, the following should be presented in order to serve the validation purposes:

- Hydrocarbon leaks:
  - Number of fatalities per instance of leak and per instance of ignited leak.
  - For modules separately and total for the installation.
  - Possibly also divided on different accident mechanisms, fire, explosion of varying severity, etc.

- Other leaks of inflammable substances or fire on the installation:
  - Number of fatalities per instance of leak of inflammable fluids and per instance of ignited leak.
  - For modules separately and total for the installation.

- External impacts, structural failure:
  - Number of fatalities per instance of initiating (top) event.

Annex C
(informative)
Analyses in development and operations

C.1 Feasibility study and conceptual design phases

This subclause covers phases of feasibility studies and conceptual design work. Risk and EPA are usually carried out separately in these phases.

It is important to consider which of the life cycle phases that are covered in the assessments, when studies such as optimisation studies, are carried out in this phase.

The main objectives of these studies should be:

- 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 RAC, 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 should be 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 and acceptable solution.
- Assess whether the risk level of the concept is in accordance with RAC, 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, should be comprised by the studies. It is particularly important at this stage to focus on non-traditional safety and emergency preparedness aspects, e.g. manned underwater operations.

The following should be applied with respect to timing of the studies:

- Quantification of risk to personnel should be done at the earliest possible stage.
- Dimensioning accidental loads must be identified at the earliest possible stage, preferably in the concept design phase.
- Initial EPA should be carried out in the conceptual design phase.

If deviations from statutory requirements are proposed a risk analysis should be made. For simpler installations guidance for risk analysis are found in annex F.

C.2 Engineering phases

Pre-engineering and detailed engineering phases (or combinations) are included in this subclause. Risk and EPA 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 RAC.
- Identify DALs 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 DALs 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 DSHA that is outside the major AEs.
- Initial establishment of operational and organisational emergency preparedness for major AEs.

The risk and emergency preparedness analyses must 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 should 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.

If deviations from statutory requirements are proposed a risk analysis should be made.

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

The following must be applied 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 EPA should be carried out in the detailed engineering phase.
- The final updating of risk and EPA must be carried out towards the end of these phases:
  - Update QRA reflecting the chosen solutions and systems.
  - Carry out the final EPA.
  - Document the results from the EPA in a suitable way, for all DSHA, possible causes and effects of accidents for use in the operational phase.
- Qualitative studies, including safety design reviews, should 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 EPA 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 should include an overview of the responsibilities and a time schedule for the implementation of recommendations from the studies.

C.3 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 work can be done onshore and offshore.

The risk and EPA 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, installation and commissioning work.

The studies must 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 following aspects have to be considered if they are relevant:

- Are there any hydrocarbons onboard or not.
- Increased number of personnel onboard.
- Increased number of personnel in hazardous areas.
- Risks associated with simultaneous operations.
- Use of hot-work offshore contra use of flanges.
- Effect of habitats for hot-work.
- Dropped objects.
- Temporary unavailability of safety systems for installation, commissioning work.
- Effect of commissioning and testing of ESD-system and process safety.
- Increase in number of leak sources and explosion loads due to more equipment.
- Human error.

The data basis for any QRA in these phases is often limited, since many of these operations are unique for the current project. Qualitative analyses will often be predominant, such as HAZOPs, safety assessments, emergency preparedness assessments, quantitative analysis may be done when sufficient data basis exists.

It should be required to update the risk and EPA made during the engineering phases, if the installations have been significantly changed during fabrication and installation.

C.4 Operational phase

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

- To update risk and EPA 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 should be carried out when planning and preparing for work tasks that have vital importance for the operational safety, such as concurrent operations.

The studies should not only be limited to the production installation, but 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.

Updating of risk and EPA must 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 should 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.
- Changes in data basis, models or risk estimating methods.
- Minor modifications, which in sum does represent a major modification.

The updating of analyses should include 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 RAC for the installation or operations.

The operator/owner must formulate minimum requirements to the frequency of updating of the QRA and EPA, unless technical or operational circumstances in the meantime have necessitated more frequent updating.

C.5 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 should address all phases involved.

The studies should 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 should 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 C.1 and C.2 may be required. For modification of process systems a HAZOP is required.

During engineering phases an integrated risk and EPA should be carried out as described in C.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 EPA should 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 should be added to the existing risk level on the installation and be compared to the RAC for the installation in question. DSHA, and DAL for the installations must 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 RAC will be met a qualitative risk and EPA 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 were SJA should be carried out. The following special aspects must 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 should satisfy the general requirements to risk and EPA given in this NORSOK standard. An environmental risk assessment should be included, if oil spill risk is involved.

C.6 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 C.4. When preparing for decommissioning and disposal, there will usually be more emphasis on deliberations and comparison of alternative solutions. Studies that compare alternative solutions with respect to risk and emergency preparedness should therefore be emphasised in addition to what is mentioned in C.2:
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 must be determined according to a separate EPA, where the following DSHA should 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 C.4.

Annex D
(informative)
Recognised data bases and computer software

Data sources

The following data sources should normally be used:

Hazard	Recommended data source
• Process leak	HSE Leak and Ignition Data base, Offshore Hydrocarbon Releases, 1992-99, OTO 1999 079, January 2000 HCLIP (for NCS, expected to be available from early 2001)
• Riser/pipeline leak	PARLOC 96, The update of loss of containment data for offshore pipelines, AME Ltd.
• Blowout	SINTEF Blowout database, Report SFT38 F00431
• Collision	COAST traffic database
• Dropped object	No source available
• Helicopter transportation	SINTEF Helicopter Safety Study, Rev. 2, 15.12.1999
• Occupational accidents	NPD Annual report 1999, May 2000
• Human tolerability limits	Scandpower/DNV report for Statoil, "Human resistance against thermal effects, explosion effects, toxic effects and obscuration of vision", dated 14.9.1993[1]
• Safety and production systems	OREDA, Offshore Reliability Data, SINTEF, Safety and reliability Department
• General	WOAD, Worldwide Offshore Accident Data, DNV

For an undated version of this annex, see the following internet address:
http://www.nts.no/norsok/z/Z01302/annexd.pdf

[1] Other sources should also be consulted, such as flare load limits, etc.

Annex E
(informative)
Guidelines for cost benefit analysis

E.1 General

This annex provides a recommended approach to the use of CBA for 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 CBA is also an important prerequisite for successful use of scenario based analysis.

E.2 Purpose of cost benefit analysis

E.2.1 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 E.3.3.

There may be somewhat different objectives for the performance of CBA:

- Determine optimum level of safety protection when RAC have been satisfied through prior risk assessment. Usually this will imply that RAC 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 RAC. 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 RAC and functional requirements to emergency preparedness have been satisfied through prior risk assessment and EPA. (Type III)

These contexts relate to the definition of the term ‘risk’ in clause 3. The application of the CBA approach in relation to HES 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 subclauses.

E.2.2 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 E.2.1. 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 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 3.1.2 , and A.1.5), and the evaluation may stop.

The upper tolerability limit is almost always defined, whereas the lower limit is individual to each individual risk reducing measure, depending on when the cost of implementing each measure becomes unreasonably disproportional to the risk reducing effect.

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 should 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.

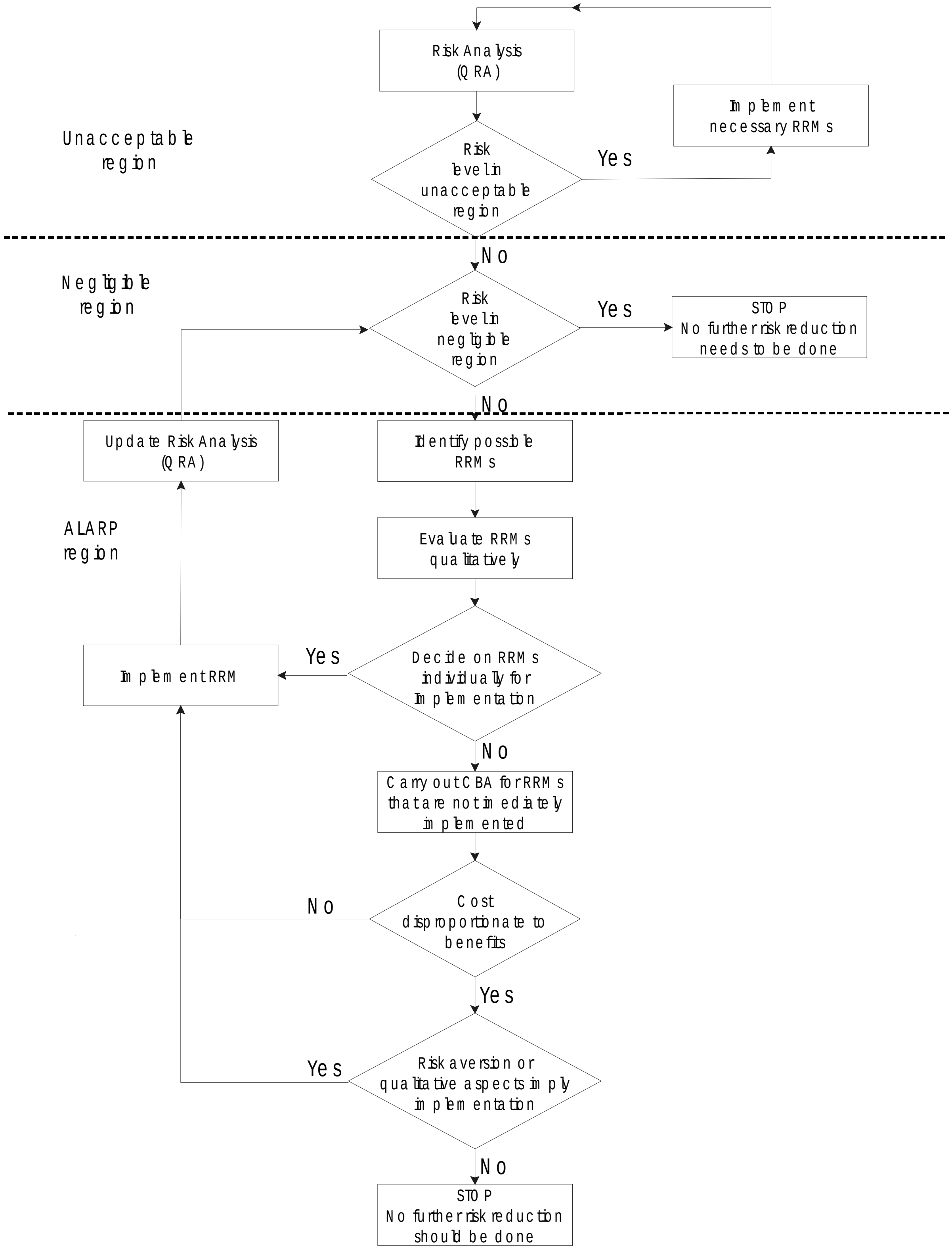


Figure E.1 – ALARP demonstration for risk to personnel

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

Carry out CBA for RRMs that are rejected
For those RRMs 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 RRMs 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 E.6.

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.2.3 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 E.2.1. This implies that the consideration is limited to an economical optimisation. The evaluation process is presented in Figure E.2. This diagram is with one exception identical with Figure E.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 LCC?
For those RRMs that have a positive net present value according to (E.1), 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 E.6.

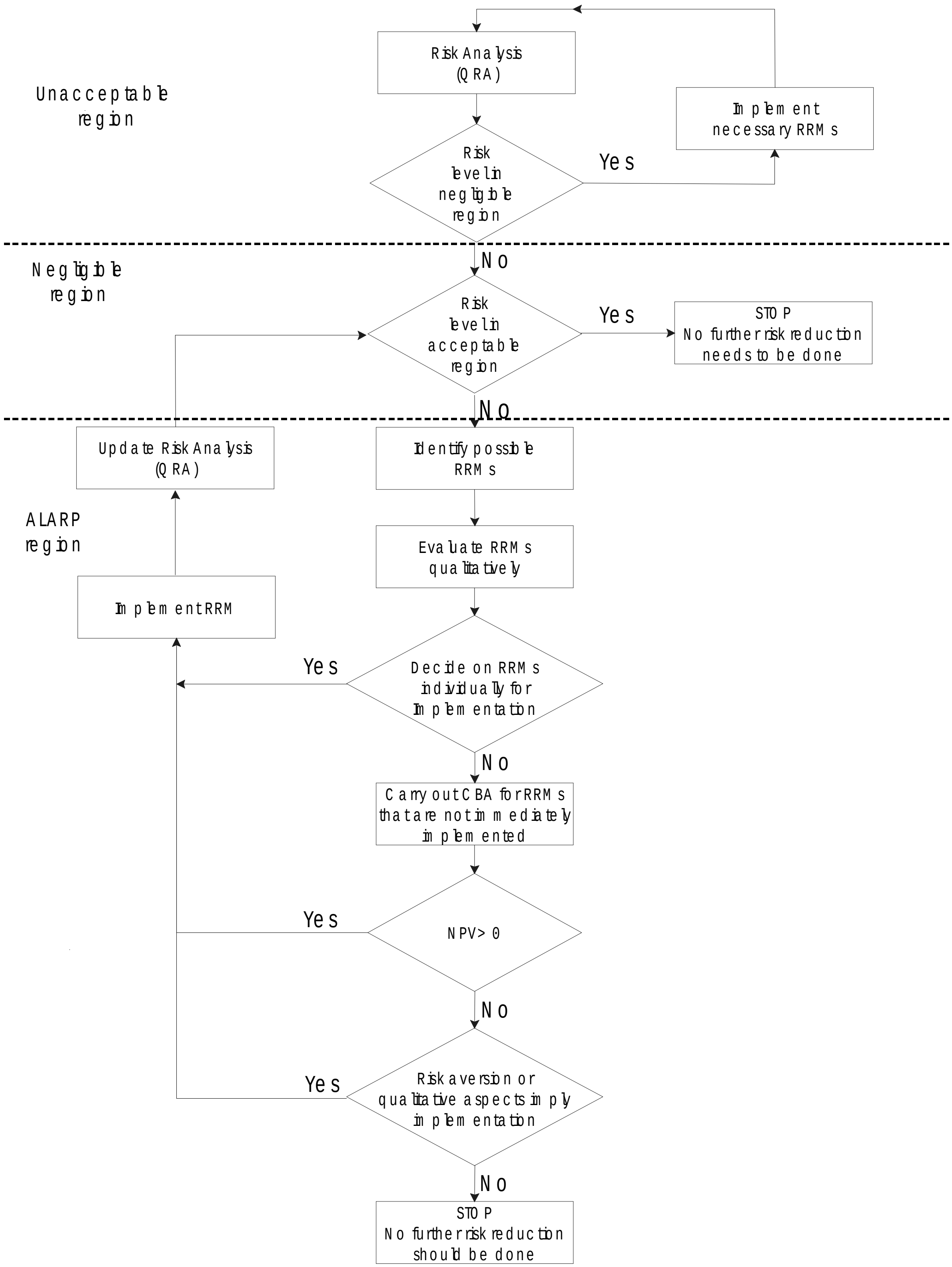


Figure E.2 – ALARP demonstration for risk to assets

E.2.4 Optimisation of emergency preparedness

The use of CBA in the ALARP consideration for emergency preparedness is categorised as Type III as outlined in E.2.1. The evaluations are carried out in the same manner as for risk to personnel, and basically follow the same approach as in Figure E.1. ALARP limits do not apply however, and the simplified approach is shown in Figure E.3.

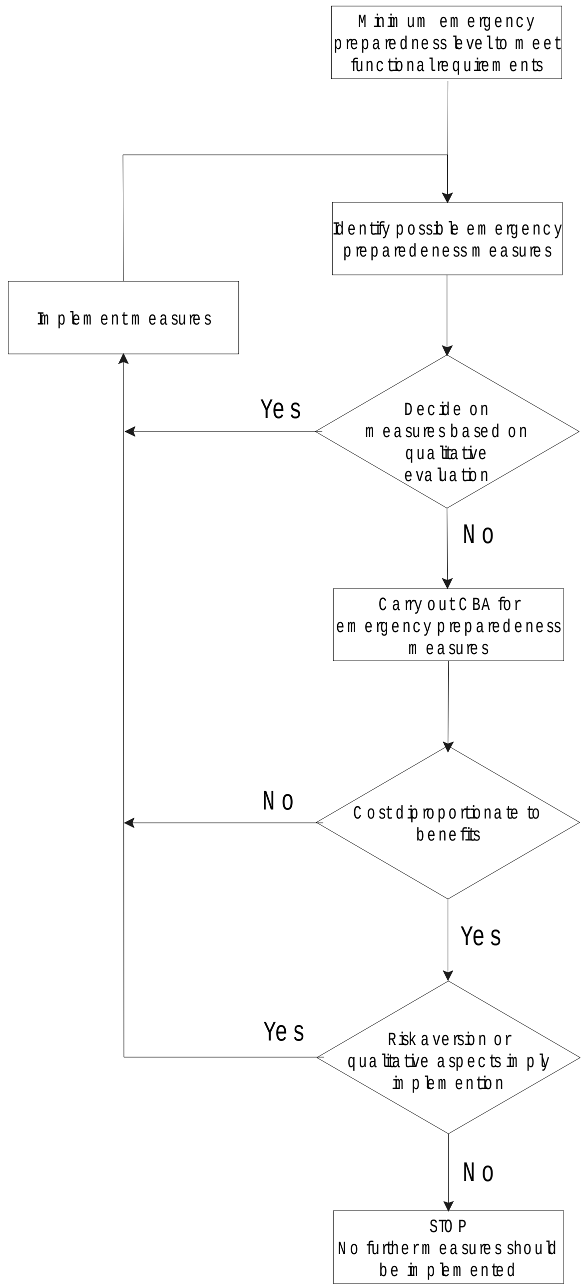


Figure E.3 - Cost benefit analysis for emergency preparedness measures

E.3 Approach to quantitative comparison of benefit and cost

E.3.1 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:

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

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 (E.1), and calculate the cost per statistically averted life. Alternatively, risk to personnel is retained in (E.1), and the valuation $V_j(C)$ is chosen to reflect the willingness to pay to avert a statistical fatality.

(E.1) 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 E.3.4. Quantification of costs (RC_n and IC_0 in (E.1)) is discussed in E.4, whereas quantification of benefits (f_{nij}, C_{nij}) is discussed E.5. The potential problems of valuation - $V_j(C)$ - of personnel risk, risk to environment and risk to assets are discussed in E.6.

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 E.3.2 through E.3.4 is to recommend how to treat these aspects, such that there should be a consistent use without significant variations in the approach chosen.

E.3.2 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 3.1.17 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 (E.1) is determined.

E.3.3 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 seldom 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 subclauses 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 should occur.

E.3.4 Depreciation of future losses

Costs due to material damage or production delay are usually depreciated using for instance the 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 should be depreciated in the same way, which actually is according to a strict interpretation of (E.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 HES 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.4 Quantification of costs

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

- Running costs (operating, maintenance, etc.).
- Investment costs.

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

Both running costs and investment costs should be taken as incremental costs for the RRM in question or if applicable, combination of several RRMs. These costs are deterministic and should 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 should be taken as the cost before tax, and without consideration of the partners' shares.

E.5 Quantification of benefit

E.5.1 General quantitative expression for benefit

The general expression for quantification of benefits is as follows:

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

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.5.2 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.5.3 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.5.4 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:

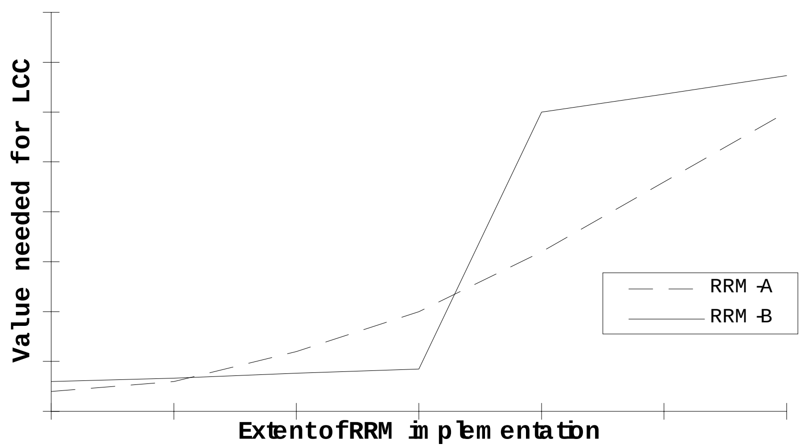
- Production delay costs.
- Costs related to damage to equipment and structures.
- Cost of temporary solutions.

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.6 Valuation aspects

E.6.1 What constitutes "gross disproportion"?



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 RRMs. The vertical axis shows the values considered for instance as cost of averting a statistical fatality in order to achieve LCC>0 according to (E.1). Two RRMs are considered, both capable of being implemented to a higher or lesser extent, on a continuous scale.

Figure E.4 – Illustration of "gross disproportion"

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.6.2 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 MNOK to 7 MNOK), 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 MNOK ,5 MNOK per statistically saved life, in the CBA.

It could be argued that a typical value in Norway was 10 MNOK to 20 MNOK, 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 E.4. It is not uncommon that the level that 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.6.3 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 tons to 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.6.4 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 E.5.4. 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 blowout. 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
(informative)
Scenario based system design (SBSD)

F.1 Introduction

SBSD is a systematic, analytical approach to be used when deviations from the standards and regulations are necessary, on the basis of risk assessment. Such deviations may often be required for installations, which are special in one way or the other. The NPD have generally expressed reluctance towards extensive use of SBSD, to an extent that would impair the safety level, which is inherent in the regulations. The industry should therefore, in spite of the basic wish to have maximum flexibility, attempt to implement SBSD in a conscious and controlled manner. The basic approach in this informative annex is to state relevant and required limitations for the use of SBSD, whilst giving as much flexibility as is defensible.

The purpose of SBSD is to use risk assessment to establish requirements to essential safety systems and functions when deviations from the requirements in regulations and standards are necessary due to special circumstances.

The standards or regulations may not be particularly suited in order to find optimised and economically feasible solutions in a variety of different circumstances, with respect to safety, technical and financial aspects.

SBSD is not an alternative to risk assessment, SBSD is an approach which utilises risk assessment techniques in order to determine what should be requirements to safety systems and functions. It will be required to document that RAC are met through the use of risk assessment.

The suggested approach to SBSD is new and has not been tested out. It has been included in order to offer it for testing. Experience with the approach will be reflected in the next revision of this NORSOK standard.

F.2 Opportunities for use of scenario based design (SBSD)

F.2.1 Types of installations

SBSD may be used for the following types of installations:

- Normally Unmanned Installations.
- Manned installations, in special cases or conditions, such as use new technology.
- Change of operational mode (demanning, ‘upmanning’, etc) for manned or unmanned installations.

The most typical use of SBSD is for normally unmanned installations, however it may also be used for manned installations in special circumstances. One such may be change of operational mode.

SBSD is not likely to be used extensively for an integrated, manned installation in operation, but might see some use at the early project stages of such installations, in the case of special circumstances.

Use of SILs according to IEC 61508 for design of electric, electronic and programmable part of safety systems, is by nature application of SBSD. This is on the other hand according to regulations and standards, and falls therefore outside the definition of SBSD in this annex.

F.2.2 Life cycle phases

SBSD is often most attractive to apply at an early project stage. However, at that stage a total risk picture has not always been established. Hence, the application of RAC in SBSD may need to reflect a necessary conservatism related to the overall RAC in order to ensure compliance with overall RAC at a later stage.

SBSD may also be used in later phases, but there will be more restrictions on what can be achieved in terms of simplifications.

Guidelines with respect to usage in different phases:

- The main usage will be in the feasibility and concept definition stages.
- Another application may be in the operations phase, when planning and designing modifications.
- When used in operations phase for an installation originally designed according to regulations, there will have to be special circumstances, such as change of operational mode, to justify changing the basic philosophy.

F.3 Requirements for use of scenario based system design (SBSD)

F.3.1 Types of risk analysis

Application of SBSD will always require a QRA.

The following are guidelines with respect to use of different types of analyses:

- Any type of QRA may be used for SBSD, as long as the study addresses performance of the applicable barrier functions according to the principles outlined below. In general, the requirements to the QRA will be at least as strong as indicated in annex B, in particular for the documentation of methodology, analysis model and use of data.
- The analysis should be suitable for explicit analysis of barriers.
- Dependencies between systems with respect to effect on risk must be addressed.
- Performance in relation to RAC will need to be demonstrated.
- The selection of scenarios should be based on RAC and decision criteria as outlined below.

Typical examples of studies may be:

- Detailed collision risk analysis, in order to determine required impact resistance.
- Detailed process risk analysis in order to determine whether passive fire protection on supports for process equipment is required.
- Detailed process risk analysis in order to determine whether a certain active fire protection system such as firewater, is required.

Two reports have addressed these aspects, and may be consulted as background documents:

- Methods for establishment of design criteria, report from an ad hoc OLF working group, Report No ST-96-031-01.
- Risk analysis as decision support for design of normally unmanned installations, Aker report 58357.

F.3.2 Barrier principle to be adopted

F.3.2.1 General

A necessary requirement for application of SBSD is that performance of barriers is focused upon. These may be considered on three levels:

- Overall level: Fulfil total barrier requirements and intentions
- Functional level: Fulfil individual barrier function's performance requirements
- System level: Fulfil individual system's performance requirements

This principle is mainly applicable to fire and explosion hazards, where barriers are implemented for prevention and protection purposes.

Use of SBSD should ensure that barriers with satisfactory performance characteristics are specified for one of these three levels.

F.3.2.2 Overall level

The barrier function on the overall level is aimed at prevention of escalation due to accidental effects. This level addresses:

- Escalation due to fire.
- Escalation due to explosion.

If requirements to the barriers are formulated on this level, it should be done in order to ensure that escalation is prevented, with respect to functionality, reliability, availability and vulnerability. In addition, the time aspect of the escalation must be evaluated.

One example may be a limit (such as 10^{-4} per installation per year) on events, which will cause escalation by fire from one fire area into a neighbour fire area.

F.3.2.3 Functional level

The following are barrier functions that are important to maintain even in a context where simplified solutions are sought according to SBSD:

- Overpressure protection.
- Leak detection.
- Fire detection.
- HC potential limitation.
- Fire protection.
- Blast protection.

If requirements to the barriers are formulated on this level, it should be done in order to ensure that these barrier functions are maintained, with respect to functionality, reliability, availability and vulnerability. Again, the time aspect should be addressed.

A requirement at the functional level could typically be a maximum frequency of undetected leaks from the process plant, which could be satisfied through use of inherently safe process systems (with low leak probability) as an alternative to extensive gas detection systems.

F.3.2.4 System level

The following systems are often used to some extent in order to meet the barrier functional requirements:

Barrier function	Often used systems
• Overpressure protection.	• Process instrumentation. • HIPPS • Material thickness/design margin.
• Leak detection.	• Automatic gas detection. • Manual gas detection.
• Fire detection.	• Automatic fire detection. • Manual fire detection.
• HC potential limitation.	• ESD system. • ESVs • Blowdown system/flare.
• Fire protection.	• Active fire protection. • Passive fire protection. • Manual fire protection.
• Blast protection.	• Active deluge protection. • Relief areas. • Passive blast protection/structural integrity.

If requirements to the barriers are formulated on this level, it should be done in order to ensure that selection of systems is such that each barrier function is maintained to the extent and for the time required.

F.4 Acceptance and decision criteria

F.4.1 Risk acceptance criteria (RAC)

The overall RAC should always be applied when SBSD is being used.

The following requirements apply to the establishment and use of RAC and decision criteria for SBSD:

- FAR criteria (or IR, or corresponding criteria) need to be defined for small groups or local areas (or; at the detail level relevant for the SBSD analysis):
  - Areas may need to be quite restricted, when large fire areas exist.
  - An installation with one fire area, will need to be split into local areas.

- Impairment frequency of main safety functions (or corresponding) may be used alternatively, with the following restrictions:
  - An installation with one fire area, will need to be split into local areas.
  - At least one main safety function to be defined for the installation, irrespective of how small it is.
  - A decision criterion based on comparison needs to be considered in addition to one of the preceding options. Such decision criteria should be dedicated to the safety barrier in question.

Breakdown of overall RAC to decision criteria to be used in SBSD does involve a number of problems related to interpretation and overall optimisation. It does not appear to be fruitful to try such breakdown in general.

In spite of this, a decision criterion associated with prevention of escalation is the most suited for SBSD and decisions regarding barriers.

The quantification and presentation of risk results should reflect the requirements for risk expressions and presentation according to the acceptance criteria. As an illustration, if the RAC specify that risk shall be illustrated for defined groups of people, then the risk analysis for SBSD shall obviously also address risk for the same groups.

F.4.2 Decision criteria

F.4.2.1 General

The use of a comparison criterion for barrier functions should involve the following steps:

- Quantify the success probability of the barrier's main function with the non-standard/unconventional design, resulting from SBSD. Success probability should consider the following parameters (subject to exposure to the relevant accidental loads):
  - Reliability
  - Availability
  - Survivability
- Compare with success probability for standard/conventional barrier design.
- Non-standard/unconventional solution should not have significantly lower probability of fulfilling the main function.

A simple illustration of how this could be applied could consider a limit of 10^{-4} per installation per year for events, which will cause escalation by fire from one fire area into a neighbour fire area. This may be satisfied through use of conventional fire barriers, or through use of inherent safe process systems that would reduce the likelihood of loss of containment to such a low level, that fire barriers would not be required in order to meet the 10^{-4} limit.

Application of the ALARP principle is very suitable for SBSD. Hence, all recommendations for use of the ALARP approach (see annex E) will apply, with respect to documentation, etc.

Application of SBSD will normally imply effects on both risk to personnel and risk to assets. However, these risk parameters should be reported separately.

F.4.2.2 System level

Application of the decision criteria on the lowest level implies that each system's functional requirements are maintained.

If performance requirements are satisfied on a system level, then an equivalent solution has been found.

F.4.2.3 Functional level

Application of the decision criteria on the functional level implies that the combined function of several systems shall satisfy the performance requirements for that function. Satisfaction of the functional level implies more room for optimisation, such that the requirements for one system may be relaxed if there are compensatory factors present.

If performance requirements are satisfied on a functional level, then an equivalent barrier solution has been found, applying other systems than those that are stipulated in the regulations and standards.

F.4.2.4 Overall level

Application of the decision criteria on the overall level implies that the combined function of several barriers, each involving up to several systems, shall satisfy the performance requirements for escalation of an accident. This approach is similar to that adopted by some operators, that have defined 'escalation' as a main safety function for which impairment is considered.

Satisfaction on the overall level implies the most extensive opportunity for optimisation, such that the requirements for one system may be relaxed if there are compensatory factors present. These compensatory factors could also involve operational and organisational measures (manual intervention, operational restrictions, weather envelope, etc), however applied with care and due consideration of limitations for use.

It is important to ensure that the analysis used to assess satisfaction on an overall level addresses all aspects of a particular protective function.

If performance requirements are satisfied on a functional level, then an equivalent level of protection against escalation has been found, but not necessarily with the same barriers and systems.

F.5 Prerequisites and limitations for use of scenario based system design (SBSD)

F.5.1 Limitations

The following limitation has been defined in order to prescribe a conscious and controlled application of SBSD:

- SBSD shall only be applied for consideration of whether to simplify one system at the time. Other systems may need to be considered as compensatory actions. Manual and/or organisational actions may also be used as compensatory actions, but in this case a significant improvement in the integrity of the barrier should be required, as it is often difficult to verify or measure the quantitative effect of operational and organisational compensating measures.
- The choice of compensating measures should give the highest priority to inherent safety actions, and then follow the prioritisation given in A.3.5.

The following systems should not be considered for complete omission during SBSD:

- Gas detection.
- Fire detection.
- HC potential limitation/isolation.
- Evacuation.

This implies for example that a basic automatic gas detection system should be provided, irrespective of how low the gas leak probability could be made. Similarly, an automatic fire detection system should be provided, even though it could be demonstrated that fires were extremely unlikely.

F.5.2 SBSD in relation to contract incentives

The use of the ALARP principle is important when SBSD is used. It has been demonstrated that ALARP is difficult to implement effectively when an EPCI Lump Sum contract is used.

For SBSD to work effectively, additional contract mechanisms should be used.

F.5.3 Use of data

If there are no, poor quality or irrelevant data available, it will be required that the advantages of the non-conventional alternative should be significantly better that the conventional solution. This should normally be interpreted as a minimum of one order of magnitude difference of relevant parameters.

In addition, the source of data and its relevance must always be stated and evaluated.

Annex G
(informative)
Procedure for probabilistic explosion simulation

G.1 Introduction and basic requirements

G.1.1 General

In the following a procedure (see Figure G.1) for the complete calculation of explosion risk from leak to unacceptable structural response is described.

The procedure described here is meant to be used for detailed analyses of platforms in operations or in the project phases where the necessary information on all design elements influencing the risk picture is available. In early project phases, the procedure must be simplified according to the design information available. The amount of equipment must be estimated based on equivalent areas in previous studies. Sensitivity analyses shall be used to establish whether minor changes in amount of equipment, pressure relief areas and ventilation will change the gas explosion loads significantly.

In cases where low loads are expected or where the structure has high strength so that larger conservatism can be accepted in the estimations of gas explosion loads, this procedure may of course be simplified providing that the conservatism is under control. Simplifications and deviations from the procedure shall be agreed upon by the operator in advance and be stated in the report.

The procedure will follow the course of event chronologically, but includes some iteration. Nevertheless, to get a correct balance in use of resources and an adequate focus on the relevant approach, it is essential that one considers the approach as a whole backwards through the course of events when planning the work. This means that undesirable consequences must be evaluated, unacceptable responses must be defined, the necessary resolution and accuracy of the loads must be determined and the rest of the methodology must be established accordingly.

The procedure aims at estimating the most probable explosion load and not a worst case, but in such a way that when simplifications are made according to an assumed idealistic model, the total risk picture, load or response, should not be too low, but rather be on the conservative side. This does not imply that every element of the procedure must be conservative, but that one has a reasonable control that the end product, i.e. load and response, is conservative.

The purpose of the procedure is to standardise the analyses so that the risk of explosions can be compared between different areas, installations and concepts, even if the analyses are performed in different circumstances and by different personnel. At the same time the procedure shall not stop the development towards better methods.

G.1.2 General simplifications in modelling

Presently the problems related to inhomogeneous clouds are solved through establishment of equivalent stoichiometric clouds at time of ignition. This may, however, result in a too short duration of the load.

The explosion simulations are performed with these clouds. In practice it is expected that the explosion simulations can be performed for a set of standard clouds before a probability distribution of cloud sizes is established.

A large number of scenarios for gas cloud formation must be evaluated based on the leak segment, leak points, directions and the time of ignition. These may be represented by a set of 'standard' scenarios, i.e. clouds and locations. Symmetry considerations, reasoning and simplifications based on understanding of the physics may be used to reduce the number of scenarios for consideration, and select those to be simulated by a CFD tool. The size distribution for equivalent clouds is established on this basis. Information about the most probable cloud locations may also be used if available.

A set of 'standardised' cloud locations and ignition points are chosen. The purpose of the dispersion analysis is to relate the frequencies of the different leak scenarios through the ignition probability to the frequencies for the different standard ignited stoichiometric clouds. In special cases it might be desirable to use non-stoichiometric, but still homogeneous, clouds.

The frequencies for the different ignited stoichiometric clouds are combined with the explosion simulations in order to estimate the explosion risk including design loads when necessary.

Where simplified relations between input parameters and the results from the CFD calculations are used both for gas dispersion and explosion, the applicability of these relations shall be documented.

It shall be possible to combine the methodology with analysis of fire in the risk analysis in a consistent way.

The procedure has quite extensive requirements to the factors that shall be considered and the number of parameter variations. It is not necessary to follow this rigorously if it can be documented that simplifications do not influence the results significantly.

In order to facilitate the evaluation and the comparison between different studies, presentation of results from the different intermediate steps in a simple and perspicuous way is emphasised. This shall include:

- Leak frequencies both for the different leak categories, process segments, and total.
- Typical leak durations or profiles.
- Ignition probability densities for both intermittent and continuous sources and how these are influenced by the action of platform systems like gas detection and shutdown.
- Calculated ignition probabilities for the different leak and ignition categories.
- Ventilation conditions, average and as function of wind conditions.
- Average or distribution of time from start of leak to both gas detection and ignition for different leak categories.
- Frequencies for unignited gas cloud sizes.
- Frequencies for ignited gas cloud sizes and total ignition frequency.
- Sketches showing sizes and location of gas clouds, leakage and ignition points used in the explosion simulations.
- Explosion pressures as function of gas cloud sizes.

G.2 The sequence of events

G.2.1 Leakage

G.2.1.1 Frequency of classes/distribution

The starting point is a distribution of hole sizes. Based upon the pressure in the system, initial leak rates shall be calculated and classified according to a distribution with narrow categories. The categories shall match possibly wider categories used in the fire risk analyses. The following narrow categories should be used (all values in kg/s):

0,1-0,5; 0,5-1; 1-2; 2-4; 4-8; 8-16; 16-32; 32-64; >64.

A continuous distribution of leak sizes may be used, then the frequencies for the defined categories shall be stated.

The value for the lower limit (0,1 kg/s) must be evaluated in each case according to the smallest cloud that can contribute to the explosion risk.

G.2.1.2 Duration, transient source strength

Representative transient leak profiles shall be considered. One can deviate from this in cases where such transients will not influence the relevant size of clouds or the probability of ignition significantly. If so, this has to be documented.

Choice of transient source strength must be evaluated with regard to:

a) Characteristic time for reduction of leak rate compared to characteristic time for ignition. Segments that are emptied quickly must thus be treated with transient source strength.
b) The amount of gas that leaks should not substantially exceed the amount of gas isolated within the segment.

c) Leak rates that are reduced quickly, but initially produces rich clouds (a significant fraction of gas above UEL).

The use of time dependent leak rate requires that the ignition model can handle time dependent cloud size.

G.2.1.3 Selection of representative process segment or explicit calculations for all process segments

This is determined by how accurate calculations that are needed. Basically all segments should be calculated explicitly. Coarse models can be used provided they are calibrated against CFD runs of selected representative segments. It should be considered whether the representative segments should be chosen as the one with the highest pressure or longest duration of the leak or otherwise.

This shall also be performed with segments of significant difference in the reactivity in the medium. Less emphasis is placed on differences in operating temperature, etc. (that may influence the buoyancy of the leak), as we at this time do not want to establish equivalent stoichiometric clouds that only cover the area partly vertically, see G.2.1.4.

Exceptions are open geometries where the buoyancy will have considerable influence.

G.2.1.4 Shape of equivalent stoichiometric cloud

Normally the gas cloud will be considerably larger than the equivalent stoichiometric cloud, and the combustible part of the cloud has an irregular shape. This can nevertheless be modelled by a cubic cloud, extending from floor to ceiling. When the size of the cloud indicates a height (or width) larger than the area, the cloud is placed from floor to ceiling and wall to wall and the length is adjusted to give the correct volume. This normally means that we do not consider a stratified (inhomogenous ‘pancake-like’ cloud) in an enclosed area, even if CFD runs should indicate that stratification do occur. This is expected to give some degree of conservatism, which should be commented upon where CFD indicates stratification. In CFD simulations one has to consider the limits of the software. This applies both to how to locate the ignition relation to the periphery of the cloud and the smallest dimension of the cloud. In case FLACS is used, the smallest dimension of any cloud shall be resolved with at least 13 cells.

G.2.1.5 Location and direction of leak

In order to obtain a representative distribution least three leak points in one module shall be used, all of them with six jet directions and possibly diffuse leak. There shall be at least one scenario with leak orientation against prevailing ventilation direction.

Symmetry considerations and evaluations based on the understanding of physics, geometry, wind and ventilation directions may be used in order to limit the number of scenarios that need explicit simulation. Simplifications made must be documented.

Both mass, impulse and energy should be conserved in the jet leak from a high pressure system. If this is deviated from, the accuracy of the simplification must be commented, or preferably documented. Releases that quickly lose its impulse can be modelled by directing the jet towards a suitable wall or larger equipment.

G.2.1.6 Medium

The fraction of the mass that flashes or evaporates from a liquid release shall be modelled as a corresponding gas release. This can be modelled as a diffuse release. It is important to have the correct composition, especially to achieve the correct reactivity.

The fraction of an oil release that forms oil mist shall be modelled as a corresponding mass of gas. The combustion properties of the corresponding gas shall be discussed and documented.

G.3 Cloud formation

G.3.1 Wind direction and strength

Principally at least eight wind-directions shall be considered with a frequency and speed distribution determined from the wind rose of the area. Often these can be grouped into a few (2-4) different ventilation regimes. CFD ventilation simulations may be used to establish these. It is acceptable to assume that the ventilation rate for a wind direction is proportional to the wind speed, but it is important also to consider that the proportionality constant is different for the different wind directions. This shall be taken into account when the contributions from the different wind directions to the ventilation regimes are established.

The above proportionality considerations are not valid for low wind speeds as the buoyancy from hot equipment will influence the ventilation. It shall be documented how this is handled.

The number of wind and ventilation speeds which shall be included should, for consistency reasons, not be much lower than the number of release rates.

One should try to establish a simple relationship between the gas concentration and the ratio between leak rate and ventilation rate. The validity range for the relationship shall be indicated. The relationship may subsequently be used for extrapolation to other leak rates and ventilation velocities.

Where a time dependent ignition probability model is used, the frequency distribution of cloud sizes shall be calculated for the cloud sizes at the time of ignition. Thus one has to use a model for calculation of transient cloud size from the leaks. See also G.4.

G.3.2 Calculation of equivalent stoichimetric cloud

The size of the equivalent stoichiometric cloud at the time of ignition shall be calculated as the amount of gas in the explosive region, weighted by the concentration dependency of the flame speed. We appreciate that this does not consider the possible initial turbulence in the cloud (especially for jet leaks). This will be reconsidered when more experimental data on gas explosions in clouds generated by jet leaks and corresponding tests of the calculation models are available.

Until further notice, the clouds shall not be selected in order to represent possible stratification of the gas. This is omitted until both the explosion simulation and the dispersion models are further tested against stratification.

G.3.3 Dispersion, selection of models

CFD models shall be used for dispersion calculations. In order to include the large number of parameter variations that the procedure implies, it may be necessary to use correlations based on these dispersion calculations. The validity of these correlations must be documented by independent calculations. It is expected that at least 10-15 CFD dispersion calculations will be necessary per module.

G.4 Ignition

G.4.1 Location of gas cloud and point of ignition

Basically, ignition source should be placed homogeneously in the cloud. When distributing the ignition locations on the layout, one should ensure that the different cloud locations will give ignition locations with different pressure for each cloud (preferably both high and low). One should always have at least one edge ignition due to the consequence of continuous ignition sources, and the ignition probability should amongst other factors be evaluated based on the type of ignition source. When detailed analysis is performed or when a sufficiently detailed layout is available, the distribution of ignition sources on the layout may take into account the concentration of ignition sources in different areas. If there is no special concentration of ignition sources in the room either room fixed or cloud fixed locations may be selected.

The location of the ignition sources and the time until ignition have to be considered in relation to the dispersion analysis.

G.4.2 Exposure of ignition source to the cloud

With regard to the JIP ignition model (3), the exposure part is already covered as the dispersion is calculated explicitly. This also applies to the time dependency in the exposure part. Hence the exposure part of the JIP ignition probability is not used.

For each new time-step in the dispersion analysis, the following parameters shall be calculated as they affect the probability of ignition:

- Total volume exposed to flammable gas (within concentration between LEL and UEL) which can be ignited by discontinuous ignition sources.
- New volume exposed to flammable gas which can be ignited by continuous ignition sources.
- Equivalent stoichiometric clod size at time if ignition (typical ErrFAC*fuel in FLACS or similar)

G.4.3 Conditional probability of ignition, given the exposure

NOTE This is also important for the effect of the deluge.

Continuous ignition sources
This is expected to give ignition immediately upon contact with the cloud. The probability of ignition will be proportional with the volume being exposed to flammable gas, provided a constant ignition probability density (see G.4.2).

Intermittent sources
Here also in the conditional probability is time dependent:
P(t) = P exposure [V(t)] * P intermittent (t)

Spontaneous ignition of the leak
A late spontaneous ignition should be treated as intermittent. Immediate spontaneous ignition occurs so quickly that the scenario should result in a fire.

Modelling of the transient cloud size
A simplification of the cloud development using continuous relations is acceptable. If the stationary cloud is rich, it will, on its way up, have passed an area with a maximum stoichiometric cloud. The time to reach this maximum stoichiometric equivalent cloud as well as the time from the maximum to the stationary solution shall be reasonably well modelled.

NOTE The last time is zero if the stationary solution is lean or stoichiometric.

The growth rate
The maximum point for the leak rate, which will give a rich cloud in a stationary cloud, may conservatively be used as the amount of gas that may give in stationary cloud with the worst ventilation rate. If this contributes a lot, one should estimate the real equivalent size of the cloud.

Gas detection and actions thereof that might influence the probability of ignition and the formation of a cloud (isolation of ignition sources, shut-down and blow-down), should be taken into account such that the time dependencies are included in the model.

G.5 Explosion

G.5.1 Definition of load

In order to determine the structural response and safety margin of safety critical structural elements of an installation, a time dependent gas explosion overpressure and drag force shall be applied. Design values of load for structural design shall be established based on the relation between pressure and impulse (P-I) of a predicted load, overpressure/drag and the frequency of exceedance of the load as given by RAC.

Thus the dimensioning load will not be a single pressure value, but the collection of pressure and impulse (time) combinations with a given frequency for exceeding both pressure and impulse. This results from the union of the pressure impulse surface and the acceptance criterion for frequency. A relation between maximum pressure and duration may be used if the simulations show this to be a good simplification, but then the relation has to be documented.

The P-I-surface shall be established for the average pressure over the predefined area.

In cases when there is a considerable variation in the overpressure over the exposed area, additional P-I relation for the local area with the highest local overpressure shall be established. This P-I-surface shall then be applied to all the other local areas in the total area, unless this will be unrealistic (for instance if extremely high pressure in the corners are applied to the whole area).

A drag load must be assessed for larger piping and equipment. If no drag-impulse relation is established, drag shall be calculated from the distribution of flow velocities in the CFD calculations for some selected dimensioning scenarios.

G.5.2 Selection of simulating models

One should select an advanced CFD-type of model such as FLACS.

G.5.3 Selection of standard for modelling

The standard for modelling shall be selected according to requirements from the software supplier. This should be sufficient to the extent that effects observed in the Blast & Fire Project may be modelled.

Experience shows that it is vital to use a sufficiently detailed representation of the module geometry in the explosion simulations. Studies shall be performed on selected scenarios to show the sensitivity of the load to variations in the lower cut off limit for equipment size being included. Where detailed module geometries are not available, the input geometry shall be based on comparison with detailed geometries in similar modules or type of equipment.

The equipment densities used in the simulations shall be documented and compared to densities in similar types of modules.

G.5.4 Extrapolation/interpolation between different ignition points

There are few limits in making many CFD analyses with variation only of ignition point but with otherwise constant scenario parameters. Thus it is not necessary to interpolation/extrapolation between a small number of calculations for different ignition locations.

G.5.5 External pressure

Propagation of explosions from modules into gas blown out of the module produces an external pressure field that may create considerable pressure on the external surfaces of other areas on the platform. In case FLACS is used, far-field pressure may be calculated with FLACS Blastblock (the scenario must be re-calculated).

It is recommended that worst-case scenarios and some scenarios around the dimensioning scenarios are calculated.

G.6 Calculations of response

G.6.1 Relation of response analysis to RAC

If the acceptance criteria for explosions relate to the frequency of the explosion load, the purpose of the response analysis is to show compliance of the response with the limit state requirements.

If the acceptance criteria for explosions relate to the frequency of the load response, the purpose of the response analysis is to show that the frequency of exceedance of the limit state requirements are within the acceptance criteria.

G.6.2 Limit state

Structural response shall be classified according to ALS, as defined in G.6.1.

The following strength and functionality requirements shall be amongst those considered:

- Global structural collapse.
- Rupture or unacceptable deflection of an explosion barrier including unacceptable damage of the passive fire protection of the barrier.

- Damage to equipment and piping resulting in unacceptable escalation of events (applies also for pipe and cable penetrations through barriers. This includes damage due to deflection/damage of supporting structure.
- Unacceptable damage to safety critical equipment which need to function after the explosion.

Structural response shall be calculated for the explosion loads as given in 5.1.

G.6.3 Selection of principles for analysis

Response analysis of structures subjected to gas explosion loads involves prediction of complicated deformation processes with material and geometrical non-linearities. For obtaining accurate descriptions of explosion responses, understanding of details of deformation and collapse mechanisms and material behaviour is extremely important.

Prediction of responses shall be carried out using appropriate analytical models. SDOF and finite element analysis modelling technique with dynamic and non-linear capabilities (NLFEM) may be utilised. Dynamic and deformation characteristics of the structure shall be adequately accounted for in the selected analytical procedure.

Two approaches for the description of explosion load that can be used in the structural analysis are:

1. The explosion load can be described as a triangular, time dependent overpressure/drag given by the dimensioning incidents from the pressure-impulse surface as outlined in clause 5. This is based on a dimensioning load and is thus particularly useful in early design situations.

2. Direct linearisation of the overpressure – time curve resulting from each CFD simulation. (Modern NLFEM programs also have the capability to use complete overpressure-time descriptions and thus no load linearisation is required). Procedures for load linearisation can be found in "Design of Offshore Facilities to Resist Gas Explosion Hazard Engineering Handbook".

Subsequently, response analysis of each CFD simulation can be carried out. Each response is evaluated as acceptable or unacceptable based on the limit state criteria in G.6.2. Finally the total frequency for unacceptable response is obtained as the sum of the frequencies for the single scenarios with unacceptable response. Thus, the load for each scenario is transferred directly to a response. As the method goes directly from the CFD simulation to the response of a structure, no dimensioning load will be produced. Hence this method is only suitable for calculation of the frequency of unacceptable response of a given structure.

The uncertainty of the response is mainly governed by the uncertainty in the load and the accuracy of the structural analysis models. Thus it is not necessary to take into account the uncertainty of material quality, fluctuations in materials dimensions, etc.

As the problems related to inhomogeneous clouds are solved through establishment of equivalent stoichiometric clouds, the calculated loads may have a too short duration. The effect of increasing the load duration should be discussed in the response analysis.

G.7 Calculation of pressure mitigating effects

G.7.1 Effect of deluge

Deluge reduces high overpressure in congested areas, but has no such effect on scenarios with low pressure. As it is necessary to establish deluge before ignition, deluge will only be effective with late ignition (typically 20 s or later).

The ignition probability will normally not increase when using deluge. As of today, FLACS seems to give a good prediction of tests with deluge. Thus it is acceptable to use FLACS for scenarios with deluge.

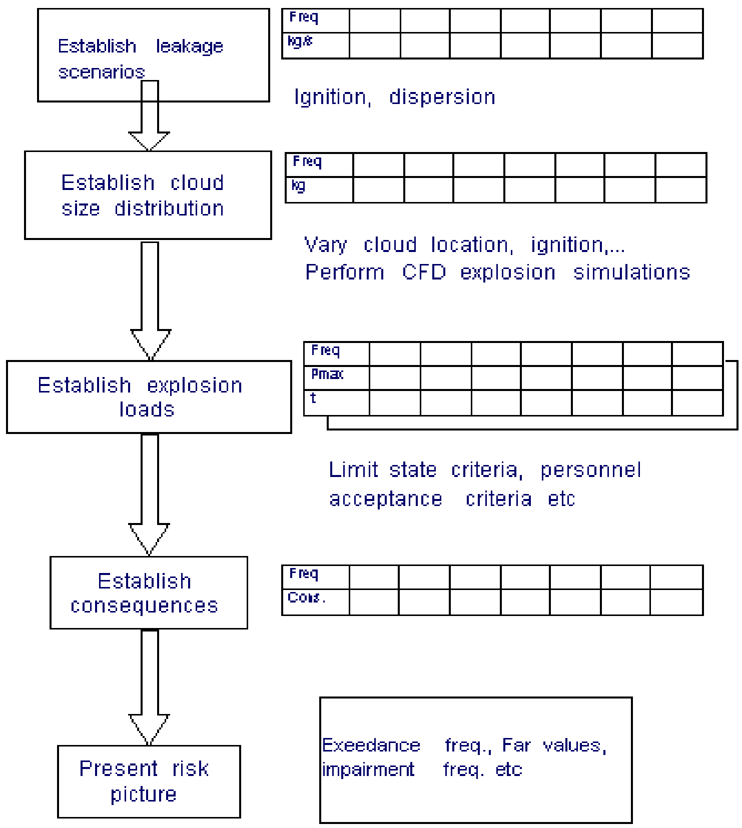


Figure G.1 – Schematics of procedure for calculation of explosion risk

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HUMAN RESISTANCE

AGAINST

THERMAL EFFECTS, EXPLOSION EFFECTS, TOXIC EFFECTS AND OBSCURATION OF VISION

DNV Technica **Scandpower A/S**

20 March 2001

Report no.	**Rev. no.** 0	**Date:** 20 March 2001
Report title: HUMAN RESISTANCE AGAINST THERMAL EFFECTS, EXPLOSION EFFECTS, TOXIC EFFECTS, AND OBSCURATION OF VISION		
Client: STATOIL		
Client specification:		

Report summary:

A human impact load study was carried by DNV Technica and Scandpower on behalf of Statoil in september 1993. The main objective of the study was to carry out a state of the art study on human impact loads and provide a consistent set of human impact load criteria for use in the fatality assessment in offshore and onshore risk analyses. Human impact load criteria for the following loads was established:

- High air temperature
- Thermal incident fluxes
- Explosion loads
- Toxic gases
- Obscuration of vision

It should be noted that the different effects should be seen in light of each other in order to identify the most critical one. However, often fatal situations are a result of a combination of the above mentioned parameters, together with panic among personnel.

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1. INTRODUCTION

A study of environmental impact on humans was carried by DNV Technica and Scandpower on behalf of Statoil in september 1993. The main objective of the study was to carry out a state of the art study on environmental impacts on humans and provide a consistent set of criteria for use in fatality assessments in offshore and onshore risk analyses. Impact criteria for the following loads were established:

- High air temperature
- Thermal incident fluxes
- Explosion loads
- Toxic gases
- Obscuration of vision

It should be noted that the different effects should be seen in light of each other in order to identify the most critical one. However, fatal situations are often a result of a combination of the above mentioned parameters, together with panic among personnel.

Probit functions, table values and charts which can be used to calculate the fatality rate for given loads and exposure times are presented in the following. It is important to use the results from the probit functions, table values and charts as guidance in the fatality assessment, rather than absolute values.

In the fatality assessment load and exposure time are important parameters. Consequence calculations should form the basis for the assessment describing loads as a function of distance and exposure time taken into account shielding effects. Possibilities for personnel to escape from the accident venue, effect of protective measures as clothes and smoke masks are important aspects to address in the fatality assessment. In general offshore personnel will have less possibilities to escape from a large accident compared to onshore personnel. However, in general onshore personnel are lightly clothed compared to offshore personnel, making them more vulnerable to e.g radiation in the immediate vicinity of the accident.

2. DEFINITIONS

LD_{xx}:

The time related dose (heat radiation over time) which would be lethal to xx percent of the population.

Thermal dose:

The thermal dose is defined by the following equation:

$$\text{Thermal dose} = I^n * t \quad \text{(Eq. 2.1)}$$

where I is the incident flux (kW/m^2), t is the exposure time (seconds) and n is a constant equal to 4/3.

LC_{xx}:

The time related dose (Concentration over time) which would be lethal to xx percent of the population.

Toxic dose:

$$\text{Toxic dose} = C^n * t \quad \text{(Eq. 2.2)}$$

where C is the concentration in ppm, t is the exposure time in minutes and n is a constant.

Probit:

The range of susceptibility in a population to a harmful consequence can be expressed mathematically using a criterion in the form of an equation which expresses the percentage of a defined population which will suffer a defined level of harm (normally death) when it is exposed to a specified dangerous load. This is a "Probit" equation which has the form:

$$Pr = a + b\mathrm{Ln}(I^n * t)$$

where Pr is the probit (or the probability measure), a,b and n are constants. I is the radiation intensity given in kW/m^2 and t is the exposure time in seconds. The probit, Pr, can be related to percent fatalities using published tables. Table 2.1, Ref. [1], gives the relationship between the probit Pr and percent fatalities.

TABLE 2.1: Relationship between the Probit Pr and Percent Fatlities

3. THERMAL EFFECTS

3.1 General

The main effects of high air temperature or incident heat fluxes is of physiological and pathological art. The impact criteria contained in this section relate to impact from short and long duration of high air temperature which may cause heat stress resulting in fatal outcome and of thermal radiation which may cause first, second, third degree burns or fatal outcome.

Inside living quarters, control rooms or other compartments where personnel should be safe in a fire situation, the air temperature may become too high leading to physiological effects on humans such as difficulties with breath resulting in incapacitation, high pulse or core temperature leading to collapse. In most cases the air temperature inside the enclosures will not be sufficiently high for that pathological effects such as skin burns to be dominant. However, during escape or at the evacuation stations personnel may be directly exposed to the fire and thermal radiation may be more critical than the air temperature and pathological effects will be dominant.

Type of fire, the distance from the fire and the timeof exposure are very important parameters in the assessment of fatalities. On an offshore platform it is believed that personnel will be exposed to a fire for a longer time due to short distances and more time is needed to evacuate the platform than on an onshore installation. However, in general offshore personnel are more protectively clothed than onshore personnel, making them more resistant against thermal radiation.

The majorities of the data are given for lightly clothed personnel which is representative for onshore personnel. However, some data are also presented for well clothed personnel which is representative for offshore situations.

Thermal effects is described in detail in Appendix A.

3.2 Physiological Effects

Most physiological effects of thermal radiation onto man involve voluntary exposures which are relatively lengthy, i.e. at least several minutes. However, inside living quarters, control rooms or other types of compartments exposed to fire where personnel may stay for a period of time, they will be exposed to low thermal radiation levels and instead high air temperature may become the most critical parameter.

Personal trapped inside a helicopter due to a fire following a helicopter crash may be on excample of a fire where high temperature and not heat radiation becomes critical.

Table 3.1 adopted from Ref. /A.2/ indicates some Physiological Effects of elevated temperature levels on the human individual based on full-scale fire tests.

TABLE 3.1: Elevated Temperature Response on Human Individuals, Ref. /A.2/

Temperature (^oC)	Physiological Response
127	Difficult breathing
140	5-min tolerance limit
149	Mouth breathing difficult, temperature limit for escape
160	Rapid, unbearable pain with dry skin
182	Irreversible injury in 30 seconds
203	Respiratory systemes tolerance time less than four minutes with wet skin

Elevated temperatures have influence on the pulse rate, Ref. /A.3/. The pulse rate climbs steadily with time and air temperature. The pulse jumps from normal 84 to 120 beats a minute when the air temperature increases to 100 ^oC. It further increases to 150 beats/minute after 10 minutes at an air temperature of 113 ^oC.

In general the maximum air temperature that can be tolerated by the human respiratory tract is approximately 203 ^oC, Ref. /A.3/. Above air temperatures of 150 ^oC, the impact is dominated by pain from skin burns, which occur in less than 5 minutes. Between air temperatures of 70 - 150 ^oC, the impact is dominated by difficulties to breath. It is believed that below 70 ^oC the situation inside a compartment will not be fatal, but may of course lead to an uncomfortable situation for personnel. No probit function has been developed on this matter, hence special assessment must be made to calculate the fatality rate among trapped personnel inside compartments if the temperature inside rises to between 70 - 150 ^oC. The average time to incapacitation has been proposed as follows for temperatures between 70 - 150 ^oC, Ref. /A.3/:

$$t = 5.33*10^8/[(T)^{3.66}] \qquad \text{(Eq. 3.1)}$$

where

t = exposure time (minutes)
T = temperature (^oC)

This equation is also illustrated in Figure 3.1.

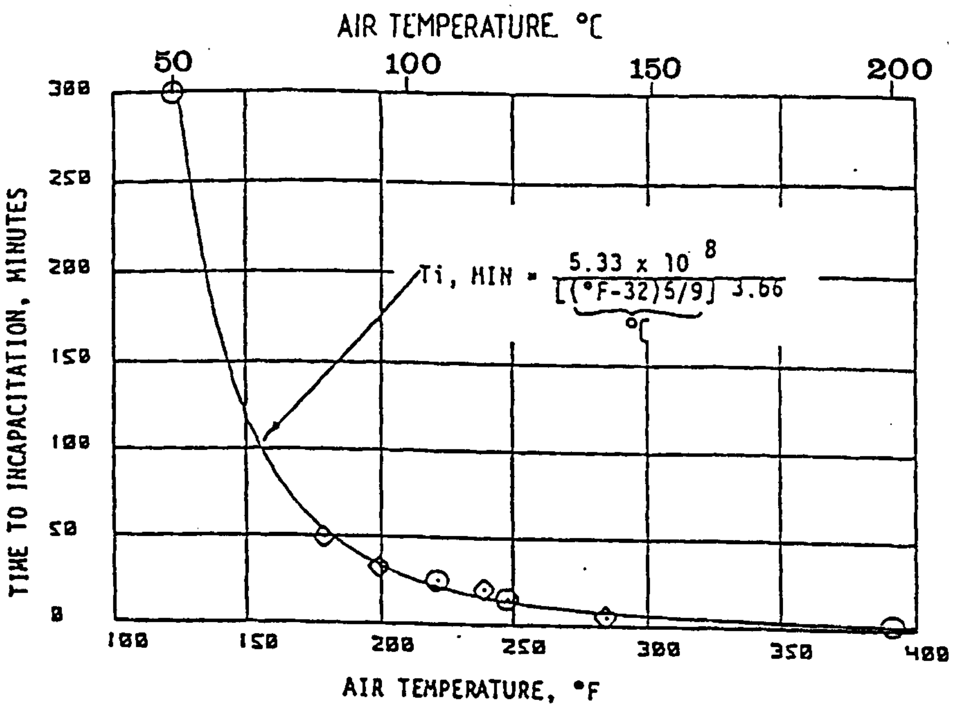

FIGURE 3.1: Air Temperature Hazard Limit Curve, Ref. /A.3/

With temperatures of 70 °C and 150 °C inside a compartment, time to incapacitation may be 94 minutes and 6 minutes respectively based on the above presented equation and curve.

3.3 Pathological Effects

Pathological effects on humans are relevant to address in the immediate vicinity of the accident, on unshielded escape ways and evacuation stations and inside enclosures if radiation becomes a dominant factor (above 150 °C). Pathological effects covered in this section are:

- Pain
- First degree burns
- Second degree burns
- Third degree burns
- Fatal burns.

Thermal doses required to reach second degree burns and third degree burns are approximately the same doses as 1% fatality and 50 % fatality respectively to averagely dressed exposers.

The severity of an injury from heat is determined by the depth of skin to which a temperature difference of 9 K has occurred. The following burn types are reached for different depths of skin:

First degree burns	< 0.12	mm
Second degree burns	< 2	mm
Third degree burns	> 2	mm

Thickness of skin varies from more than 5 mm on the back to only 0.5 mm on the eyelids, but on average is between 1-2 mm.

In the assessment of fatality rates on an offshore or onshore installation it is important to take into account the following factors:

- Information prior to fire (alarms)
- Development of accidents
- Personnel reaction time
- Emergency procedures
- Escape time,
- Shielding effects,
- Radiation levels as a function of time,
- Total exposure time,
- Other critical aspects like visibility, toxic gases, explosion loads etc.

In Table 3.2 ranges of thermal doses required to give pain and burns are given, based on the different sources presented in Appendix A. For a given radiation level or a given exposure time, time or necessary radiation level to pain, first, second or third degree can be calculated by use of the thermal doses presented in Table 3.2 and equation 2.1 in Chapter 2.

TABLE 3.2: Ranges of Thermal Doses required to give Pain, Burns and Fatal Outcome

Effect	Thermal dose ($s*[kW/m^2]^{4/3}$)	Comments/references
Pain	108 - 127	Ref. /A.4/, bare skin
	85 - 129	Ref. /Gas De France/, bare skin
Significant injury level/ First degree burns	600 - 800	Ref. /A.7/, bare skin
	250 - 350	Ref. /Gas De France/, bare skin
	210 - 700	Ref. /A.12/, bare skin
Second degree burns/ 1 % lethality level for average clothing	900 - 1300	Ref. /A.9/,bare skin
	500 - 3000	Ref. /A.12/, bare skin
Third degree burns/ 50 % lethality level for average clothing	> 2000 - 3000	Ref. /A.12/, bare skin

The fatality rate when personnel is exposed to thermal radiation over a given period of time can be calculated by use of probit functions. Several probit functions have been developed based on experiments carried out on animals and humans. The most known probit functions are the Eisenberg function, Ref. /A.8/, for naked skin and the TNO function, Ref. /A.11/, for naked skin. The Eisenberg probit function is based on experiments carried out at nuclear explosions. The TNO model is based on the Eisenberg probit function adjusted for experiments carried out at hydrocarbon fires.

Compared to the probit function from Eisenberg the TNO model for naked human skin comes up with higher fatality rate. The thermal dose required for a given lethality level is in general lower for hydrocarbon fires than for nuclear explosions, because radiation from hydrocarbon fires is long waved penetrating deeper into the skin compared to the radiation from nuclear explosions which is short waved. It is believed that the TNO model is more suitable for use in the estimation of fatality levels than the Eisenberg model in typical offshore and onshore risk analyses where personnel are directly exposed to the fire, because the TNO model is based on hydrocarbon fires. However, the calculated fatality rates should be used as guidance in the fatality assessment more than as absolute values.

The TNO model, ref. /A.11/ is as follows:

Naked human skin: $Pr = -12.8 + 2.56(tI^{4/3})$ (Eq. 3.1)

The calculated fatality rates for different thermal incident fluxes and exposure times by use of the TNO probit function presented above are shown in Table 3.3.

TABLE 3.3: Fatality Rate as a Function of Radiation Level and Exposure Time

Exposure time (seconds)	TNO probit model (Naked human skin, Eq. 3.1) Fatality rate (%)		
	10 kW/m^2	20 kW/m^2	30 kW/m^2
10	0	5	39
20	1	53	93
30	11	87	100
40	31	97	100
50	53	99	100
60	71	100	100

If the probit function is not directly used in the fatality assessment, it is recommended to use the following radiation levels for lightly clothed personnel as 100 % fatality limit in the below given exposure time intervals:

16 kW/m^2	-	Exposure time less than 0.5 minute
10 kW/m^2	-	Exposure time from 0.5 minute to 1 minute
4 kW/m^2	-	Exposure time from 1 minute to 2 minutes
2 kW/m^2	-	Exposure time from 2 minutes to 10 minutes

The critical radiation levels are based on the TNO probit function assuming that the 50 % fatality limit represents the lethal dose for an average person and that incapacitation occurs close to the lethal dose, i.e. 75 % of the LD_{50} is set as the incapacitation dose here. This corresponds to 81 % of the lethal incident radiation flux.

For clothed personnel the Neisser curve, Ref. /A.12/ is recommended to use assuming that the 50 % fatality limit represents the lethal dose for an average person and that incapacitation occurs close to the lethal dose, i.e. 75 % of the LD_{50} is set as the incapacitation dose. This corresponds to 81 % of the lethal incident radiation flux. It is recommended to use the following radiation levels for clothed personnel as 100 % fatality limit in the below given exposure time intervals:

25 kW/m^2	-	Exposure time less than 0.5 minute
13 kW/m^2	-	Exposure time from 0.5 to 1 minute
8 kW/m^2	-	Exposure time from 1 minute to 2 minutes
4 kW/m^2	-	Exposure time from 2 minutes to 10 minutes

The approach assumes a constant heat load over the exposure period. In reality, most fires will initially expand and then decay with time, and thus the radiation received at any given point will also be a function of time. A full integration of the dose received may be performed if greater detail is required.

4. EFFECTS OF EXPLOSIONS

4.1 General

People can survive fairly strong blast waves and in accidental explosions there are very few cases in which the blast effect has killed people directly. Typical injuries following an explosion are caused by

- burn
- hitting fragments
- buildings or other structures falling down or being disintegrated
- persons falling or "flying" and subsequently hitting a solid object (Whole body displacement).

Appendix B presents a detailed presentation of the different effects from an explosion and can be used in a detailed consequence study. Most of the background of the material presented in Appendix B are based on tests performed by explosives and not HC explosions. This must be taken into account when the formulas and figures from Appendix B are used.

Important parameters for determining the effects and the risk from an explosion are

- maximum overpressure
- time to reach the maximum overpressure
- indoor or outdoor exposure of people
- possibility at flying fragments
- designed pressure sustainability of building.

In a risk analysis the most important effects are

- flying fragments hitting personal
- to hole body displacement resulting in impact damage
- damage due to impact coused by collapsed structures

4.2 Overpressure

Figure 4.1 shows lethality as function of overpressure and duration of the blast wave. If the long axis of body is parallel to blast winds and the subject is facing any direction the acceptable overpressure will increase. If the thorax is near a reflecting surface that is perpendicular to the blast winds the acceptable overpressure will decrease.

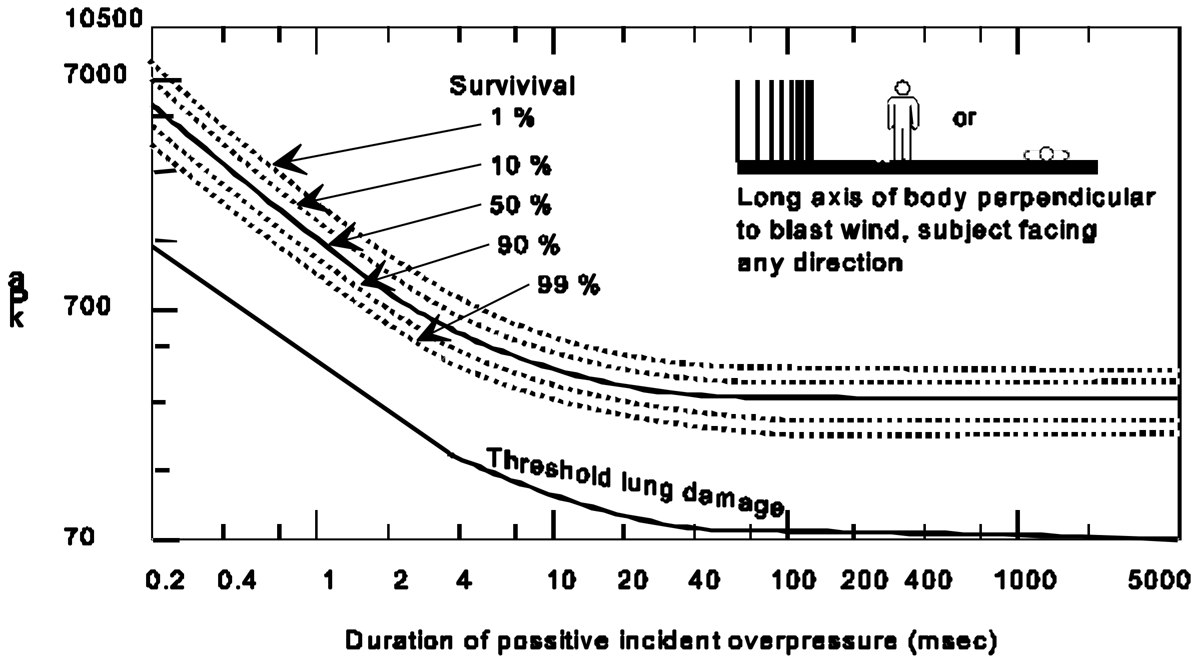

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FIGURE 4.1: Survival Curves for Man

For comparison a blast wave in the order of 25 kPa to 50 kPa is the threshold for eardrum perforation. For more information about lethality see Appendix B.

4.3 Fragments

Flying fragments from en explosion are more dangerous than the bare overpressure. Fragments may be debris from demolished buildings caused by the explosion or loose equipment in the building.

Fragments from glass breakage is a very common type of serious and extreme dangerous type of fragments, possibility for glass fragments must be determined during an analysis of explosion effects. The pressure needed for breakage of conventional glass is:

- 1 % level glass breakage ?p_{peak} = 1.7 kPa
- 90 % level glass breakage ?p_{peak} = 6.2 kPa

Table 4.1 shows the expected effects of flying missiles from an explosion.

TABLE 4.1: Injuries from Missiles

Injury	Peak overpressure (kPa / bar)	Impact velocity (m/s)	Impulse (N s/m²)
Skin laceration threshold	7 - 15 / 0.07 - 0.15	15	512
Serious wound threshold	15 - 20 / 0.15 - 0.2	30	1024
Serious wounds near 50 % probability	25 - 35 / 0.25 - 0.35	55	1877
Serious wounds near 100 % probability	50 - 55 / 0.5 - 0.55	90	3071

4.4 Hole Body Displacement

Explosion effects also involve whole-body displacements and subsequent impact. During the whole-body displacement, blast overpressure and impulses interact with the body in such a manner that it is essentially picked up and translated.

The head is the most vulnerable part of the body for injuries from whole-body displacement. The whole-body displacement (accelerations) is a function of the size, shape and mass of the person and the blast forces.

50 % of the people being picked up and translated with a speed more than 0.6 m/s will suffer minor injuries. One percent of those with a speed of about 4 m/s will suffer injuries like ruptured organs and bone fractures. If thrown against a solid wall about 40 % will suffer major injuries.

Table 4.2 shows the expected effects from hole body displacement.

TABLE 4.2: Criteria for Tertial Damage involving Total Body Impact

Total body impact tolerance	Related impact velocity (m/s)
Most "Safe"	3.05
Lethality Threshold	6.40
Lethality 50 %	16.46
Lethality Near 100 %	42.06

5. TOXIC EFFECTS

5.1 General

Effect of toxic gases can be divided into two categories:

- Local irritant which may cause incapacitation mainly by effects on the eyes and the upper respiratory tract which may impair escape capability and sometimes cause delayed death due to lung damage

- Systematically acting agents which cause damage to the body via the blood and distribution in the body, so called narcotic gases.

The main toxic gases of fire effluents are carbon monoxide, (CO), carbon dioxide, (CO_2), hydrogen sulphide, (H_2S), nitrogen oxides, (NO_x), ammonia, (NH_3), sulphur dioxide, (SO_2) and hydrogen fluoride, (HF). CO and CO_2 are classified as narcotic gases, while the other are classified as irritants. The individual effects of CO, CO_2 and O_2 depletion are discussed in detail, before the combined effect of all is derived. The effect of irritants are also discussed in this section.

Although CO is not the most toxic of the above mentioned gases, it is present in relatively high concentrations in smoke, and so its effects are usually dominant.

There is a lot of uncertainties in the calculation of amount of smoke produced in a fire situation and amount of toxic gases in the smoke. This depends on type of burning fuel and ventilation conditions.

The proportion of toxic gases in smoke depends on the chemical structure of the burning materials and the degree of ventilation to the fire. The differences between different hydrocarbons are quite small, and ventilation has the main effect. Fires in which the ventilation is restricted occurs only for fires in modules or compartments. These fires will either be fuel controlled or ventilation controlled. In general, reduced ventilation greatly increases the ratio of CO, while the O_2 and the CO_2 remain more or less unaffected.

Typical gas concentrations close to the fire are given in Table 5.1 collated by Bonn, Ref. /C.2/, based on Ref. /C.3/, /C.4/ and /C.5/.

TABLE 5.1: Initial Gas Concentrations in Smoke, Ref. /C.2/

Gas	Concentration in smoke (%)			
	Well ventilated fire		Under ventilated fire	
	Gas fire	Liquid fire	Gas fire	Liquid fire
CO	0.04	0.08	3	3.1
CO_2	10.9	11.8	8.2	9.2
O_2	0	0	0	0

On an onshore installation the possibilities to escape from the accident are greater than on an offshore installation. Based on this offshore personnel will be exposed to toxic gases over a longer time period leading to in general lower acceptable concentrations than on an onshore installation.

The consequences of inhalation of toxic chemicals can only be derived from animal experiments. The uncertainties in translating animal data to data relevant for humans are large and therefore "safety factors" are included in the modelling. In general animals have a higher adsorption rate and humans have a higher respiratory rate in accident situations.

Toxic effects are discussed in detail in Appendix C.

5.2 Effects of CO

Extensive investigations examining human fire fatalities have shown carbon monoxide to be the primary toxicant in many deaths due to smoke inhalation, Ref. /C.6/ and /C.7/. The toxicity of carbon monoxide is due to the formation of blood carboxyhemoglobin, which results in a reduced ability of the blood to transport oxygen to critical body organs referred to as anaemic anoxia. There exist further evidence that relatively low levels of carboxyhemoglobin saturation may have adverse effects on reaction time which is important to escape from a fire. The toxicity of carbon monoxide may be modified by heat stresses. Experiments on test animals under heat stress showed that blood carboxyhemoglobin concentrations at the time of death were much lower than in animals not stressed by heat.

The following physiological effects on human individuals from carbon monoxide is given below based on Ref. /C.9/:

1500	ppm	Headache after 15 minutes, collapse after 30 minutes, death after 1 hour
2000	ppm	Headache after 10 minutes, collapse after 20 minutes, death after 45 minutes
3000	ppm	Maximum "safe" exposure for 5 minutes, danger of collapse in 10 minutes
6000	ppm	Headache and dizziness in 1 to 2 minutes, danger of

death in 10 to 15 minutes

12800 ppm Immediate effect, unconscious after 2 to 3 breaths, danger of death in 1 to 3 minutes

The above presented effects of CO indicates that with several thousand ppm of CO in the atmosphere will cause very critical situations on an offshore installation or an on-shore installation.

Several probit functions have been developed based on experiments data from animals. They are presented in Appendix C. However, the following probit function is recommended to use in the fatality assessment, Ref. /C.12/:

$$Pr = -37.98 + 3.7\ln(C*t) \qquad \text{(Eq. 5.1)}$$

In Table 5.2 the lethality levels for different CO concentrations and exposure times by use of the probit equation are presented. In this table also the necessary CO concentrations and exposure time for a 50 % lethality level are presented.

TABLE 5.2: Lethality Level for Different CO Concentrations and Exposure Times by Use of the Recommended Probit Function

Probit Function	Fatality rate (%)			Concentration/exposure time for 50 % lethality	
	2000 ppm 10 minutes exposure	6000 ppm 10 minutes exposure	10000 ppm 10 minutes exposure		
Eq. 5.1	0	1.5	35	2000 ppm	54 min
				4000 ppm	27 min
				6000 ppm	18 min
				8000 ppm	13 min
				10 000 ppm	11 min

Based on a 50 % lethality level it can be concluded that the probit function is more or less consistent with the previous presented threshold limits.

5.3 Effects of CO_2

While carbon dioxide is not particular toxic at levels normally observed in fires, moderate concentrations do stimulate the rate of breathing. This condition may contribute to the overall hazard of a fire gas environment by causing accelerated uptake of toxicants and irritants. The rate and depth of breathing are increased 50 % by 20 000 ppm carbon dioxide and doubled by 30 000 ppm carbon dioxide in air. At 50 000 ppm, breathing becomes laboured and difficult for some individuals, although this concentration of carbon dioxide has been inhaled for up to one hour without serious aftereffects.

Table 5.3 illustrates carbon dioxide responses, Ref. /C.15/.

TABLE 5.3: Carbon Dioxide Responses, Ref. /C.15/

Concentration of carbon dioxide (ppm)	Responses
100 000	Approaches threshold of unconsciousness in 30 minutes
120 000	Threshold of unconsciousness reached in 5 minutes
150 000	Exposure limit 1 minutes
200 000	Unconsciousness occurs in less than 1 minute

These values are also referred to in Ref. /C.10/.

No probit functions have been found in the literature describing the lethality level of different CO_2 concentrations and exposure time. Based on this the following 100 % fatal limits of CO_2 are recommended to use for different exposure times:

150 000 ppm of CO_2 Exposure time < 5 minutes
120 000 ppm of CO_2 Exposure time 5 - 30 minutes
100 000 ppm of CO_2 Exposure time > 30 minutes

5.4 Effects of Oxygen Depletion

Oxygen constitutes 21 % by volume of clean air. Decreases in oxygen concentration down to about 15 % are counteracted by the body increasing the flow of blood to the brain, and only minor effects on motor coordination are apparent.

Oxygen concentrations below 15 % by volume produce oxygen starvation effects such as increased breathing, faulty judgement and rapid onset of fatigue.

Oxygen concentrations below 10 % cause rapid loss of judgement and comprehension followed by loss of consciousness, leading to death within a few minutes. This is taken to be the limiting oxygen concentration for escape lasting a few seconds. If escape is not possible within few seconds, incapacitation and death is assumed to occur.

Oxygen concentrations of 10 % and 15 % require a clean air content in the mixing gas of 47 % and 71 % respectively. These would be achieved when the gas is diluted to 52 % and 29 % respectively of its concentration. A gas concentration of 52 % would cause death unless escape is possible in a few seconds.

Table 5.4 indicates the responses of human individuals to different reduced levels of oxygen in air, Ref. /C.15/.

TABLE 5.4: Human Responses due to reduced Levels of Oxygen in Air, Ref. /C.15/

Concentration of oxygen in air (%)	Responses
11	Headache, dizziness, early fatigue, tolerance time 30 minutes
9	Shortness of breath, quickened pulse, slight cyanosis, nausea, tolerance time 5 minutes
7	Above symptoms becomes serious, stupor sets in, unconsciousness occurs tolerance time 3 minutes
6	Heart contractions stop 6 to 8 minutes after respiration stops
3-2	Death occurs within 45 seconds

No probit functions are found in the literature describing the lethality level for personnel when exposed to different concentrations of oxygen in the air and exposure time. Based on this the following fatal limits of O_2 depletion are recommended to use for different exposure times:

10 % of O_2 Exposure time < 5 minutes
15 % of O_2 Exposure time > 5 minutes

5.5 Overall Smoke Effects

The combined effects of CO, CO_2 and oxygen depletion are the main causes of fatalities in smoke. The criteria for them are compared in Table 5.5. For the under ventilated fires, CO has the main effect, which depends strongly on exposure time. For well-ventilated fires, CO production is much reduced and oxygen depletion appear to have main effect.

TABLE 5.5: Smoke Concentration to prevent Escape in Few Minutes

Gas	Smoke concentration (%) to prevent escape in few minutes			
	Well ventilated fire		Under ventilated fire	
	Gas fire	Liquid fire	Gas fire	Liquid fire
CO	-	-	33	32
CO_2	92	85	-	-
O_2	56	56	56	56
Comb. effects	52	48	19	18

Based on this the following concentrations of smoke may cause very critical situations (nearly 100 % fatality rate) among exposed personnel after few seconds:

52 % of smoke in well ventilated gas fuelled fires
48 % of smoke in well ventilated liquid fuelled fires
19 % in under ventilated gas fuelled fires
18 % in under ventilated liquid fuelled fires

The combined effects of CO, CO_2 and oxygen depletion are a difficult task and the above presented values should be used as guidance only to identify the problem.

5.6 Effects of Other Gases

Table 5.6 illustrates the effects likely to be experienced by humans exposed to various concentrations of H_2S.

TABLE 5.6: Effects on People exposed to H_2S

Concentration (ppm)	Effect
20 - 30	Conjunctivitis
50	Objection to light after 4 hours exposure. Lacrimation
150 - 200	Objection to light, irritation of mucous membranes, headache
200 - 400	Slight symptoms of poisoning after several hours
250 - 600	Pulmonary edema and bronchial pneumonia after prolonged exposure
500 - 1000	Painful eye irritation, vomiting.
1000	Immediate acute poisoning
1000 - 2000	Lethal after 30 to 60 minutes
> 2000	Acute lethal poisoning

Several probit functions have been developed based on experiments data from animals. They are presented in Appendix C. However, the following probit function, Ref. /C.21/, is recommended to use in the fatality assessment:

$$Pr = -31.42 + 3.008\ln(C^{1.43} * t) \quad \text{(Eq. 5.2)}$$

The probit function is to some degree more conservative than the values presented in Table 5.6.

The toxicological effects of NO_x, NH_3, SO_2 and HF are given in Table 5.7.

TABLE 5.7: Toxicological Effects of NO_x, NH_3, SO_2 and HF, Ref. /C.16/

Toxicant	Toxicological Effects
NO_x	Strong pulmonary irritant capable of causing immediate death as well as delayed injury
NH_3	Pungent, unbearable odour; irritant to eyes and nose
SO_2	A strong irritant, intolerable well below lethal concentrations
HF	Respiratory irritants

In Table 5.8 predicted lethal concentrations for humans and published values are given.

TABLE 5.8: Predicted Lethal Concentrations for Humans and published Values, Ref. /C.17/

Toxicant	Human LC_{50} (ppm) predicted from metabolic rate		Human lethal concentrations (ppm) Ref. /16/
	5-min	30-min	
NH_3	55 000		2 000
SO_2	17 000	8 000	600 - 800 (few min)
HF	44 000	4 600	
NO_x	410	180	250 (few min)

Several probit functions have been developed for NH_3, SO_2, and HF. Below probit function for each of these gases are presented to use in the fatality assessment:

NH_3, Ref. /C.18/:
$Pr = -9.82 + 0.71\ln(C^2*t)$, LC_{50} = 15 240 ppm,
5 minutes exposure (Eq. 5.3)

SO_2, ref/C.19/:
$Pr = -15.67 + 2.1\ln(C*t)$, LC_{50} = 3 765 ppm,
5 minutes exposure (Eq. 5.4)

HF, ref/C.20/:
$Pr = -48.33 + 4.853\ln(C*t)$, LC_{50} = 11 845 ppm,
5 minutes exposure (Eq. 5.5)

No probit model is found in the literature for NO_x.

The presented LC_{50} values for NH_3, SO_2, and HF in Table 5.7 is not so conservative as the LC_{50} values received at by use of the probit functions.

6. OBSCURATION OF VISION

The absence of vision may delay or prevent escape from fires and cause people to be exposed to the fire gases for an unacceptable long period of time. While the exposure to high concentrations of toxic and hot gases usually will be significant only in the vicinity of the fire, the effect of reduced visibility may also be significant far away from the fire source. For example, in multi-compartment buildings, the smoke blocking effect may be significant in rooms far away from the room of fire origin.

Moreover, the smoke blocking effect is reported to be the first condition becoming critical of the three hazardous conditions of fires i.e. heat stresses, obscuration of vision, toxic effects.

The hazard of smoke is characterized by three factors. The first threat is reduced visibility due to soot. The second is that hot smoke can cause pain and injuries, and the third is that a concentration of toxic and irritating components can lead to incapacitation or death. The relative order of these factors can be found by comparison of threshold values with actual exposure in a fire scenario.

A visibility of 4-5 m is about the threshold of diminished performance, and this is the smoke level that one should have in mind when designing smoke ventilation systems. A visibility of less than one arm length will be of no help at all when escaping from a fire environment.

Important factors to consider in a risk analysis with regard to obscuration of vision (and time to escape) are

- exposure to smoke
- arrangement of escapeways (layout, sign, illumination, railing, etc.)
- training of personnel
- familiarization with the installation.

Obscuration of vision is described in detail in Appendix D.