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Petroleum and natural gas industries — Offshore production installations — Guidelines on tools and techniques for hazard identification and risk assessment

Industries du pétrole et du gaz naturel — Installations des plates-formes en mer — Lignes directrices relatives aux outils et techniques pour l'identification et l'évaluation des risques

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 17776 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum and natural gas industries*, Subcommittee SC 6, *Processing equipment and systems*.

Annexes A, B, C and D of this International Standard are for information only.

Introduction

Oil and gas exploration and production activities have many hazards and hazardous events associated with them.

Different tools and techniques can be used to identify and assess hazards and risks, and it is important that the approach selected is appropriate to the particular circumstances.

This International Standard identifies some of the tools and techniques that may be used for this purpose in the offshore exploration and production industry and gives guidance on how they may be applied to particular activities. This International Standard incorporates advice and guidance given in other documents used in the industry, some of which are cited in the Bibliography.

This International Standard does not provide a detailed description of the practical application of the various tools and techniques, as this will need to be specifically developed to deal with particular circumstances. In many cases expert advice from competent practitioners will be required to effectively apply the tools and techniques described in this International Standard.

Petroleum and natural gas industries — Offshore production installations — Guidelines on tools and techniques for hazard identification and risk assessment

1 Scope

This International Standard describes some of the principal tools and techniques that are commonly used for the identification and assessment of hazards associated with offshore oil and gas exploration and production activities, including seismic and topographical surveys, drilling and well operations, field development, operations, decommissioning and disposal together with the necessary logistical support of each of these activities. It provides guidance on how these tools and techniques can be used to assist in development of strategies both to prevent hazardous events and to control and mitigate any events that may arise.

This International Standard is applicable to:

— fixed offshore structures;

— floating production, storage and off-take systems;

for the petroleum and natural gas industries.

This International Standard is not applicable to design and construction aspects of mobile offshore units that fall under the jurisdiction of the International Maritime Organization.

This International Standard is not intended to be used as part of certification criteria, and no defect in the management of risks should be inferred if any of the tools and techniques covered by this International Standard are not applied to an installation.

2 Terms, definitions and abbreviated terms

For the purpose of this International Standard, the following terms, definitions and abbreviated terms apply.

2.1 Terms and definitions

2.1.1
barrier
measure which reduces the probability of realizing a hazard's potential for harm and which reduces its consequence

NOTE Barriers may be physical (materials, protective devices, shields, segregation, etc.) or non-physical (procedures, inspection, training, drills, etc.).

2.1.2
control
⟨of hazards⟩ limiting the extent and/or duration of a hazardous event to prevent escalation

2.1.3
environment
surroundings in which an organization operates, including air, water, land, natural resources, flora, fauna, humans and their interrelation

2.1.4
environmental impact
any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization's activities, products or services

2.1.5
escalation
spread of the impact of a hazardous event to equipment or other areas, thereby causing an increase in the consequences of the event

2.1.6
event tree
event tree analysis
ETA
tree-like diagram used to determine alternative potential scenarios arising from a particular hazardous event

NOTE It can be used quantitatively to determine the probability or frequency of different consequences arising from the hazardous event.

2.1.7
fault tree
fault tree analysis
FTA
tree-like diagram based upon the application of "and/or" logic used to identify alternative sequences of hardware faults and human errors that result in system failures or hazardous events

NOTE When quantified, fault trees allow system-failure probability or frequency to be calculated.

2.1.8
functional requirements
minimum criteria which should be satisfied to meet the stated health, safety and environmental objectives

NOTE See 5.4.2 for further information.

2.1.9
hazard
potential source of harm

NOTE In the context of this International Standard, the potential harm may relate to human injury, damage to the environment, damage to property, or a combination of these.

2.1.10
hazards register
document providing a brief, but complete, overview of the identified hazards and the measures necessary to manage them

NOTE The hazards register also provides references to more detailed information relevant to a particular hazard.

2.1.11
hazardous event
incident which occurs when a hazard is realized

EXAMPLES Release of gas, fire, loss of buoyancy.

2.1.12
incident
accident
event or chain of events which cause, or could have caused, injury, illness and/or damage (loss) to assets, the environment or third parties

2.1.13
mitigation
limitation of the undesirable effects of a particular event

2.1.14
procedure
series of steps to be carried out in a logical order for a defined operation or in a given situation

2.1.15
risk
combination of the probability of an event and the consequences of the event

2.1.16
risk analysis
use of available information to identify hazards and to estimate risk

2.1.17
risk assessment
overall process of risk analysis and risk evaluation

2.1.18
risk evaluation
judgement, on the basis of risk analysis, of whether a risk is tolerable

2.1.19
screening criterion
target or standard used to judge the tolerability of an identified hazard or effect

NOTE See 5.3.2 for further information.

2.1.20
tolerable risk
risk which is accepted in a given context based on the current values of society

2.1.21
top event
particular hazardous event considered in the development of fault and event trees

2.2 Abbreviated terms

CBA cost-benefit analysis

CFD computational fluid dynamics

EERA escape, evacuation and rescue analysis

ESD emergency shutdown

ETA event tree analysis

FMEA failure modes and effects analysis

FTA fault tree analysis

HAZAN	hazard analysis
HAZID	hazard identification
HAZOP	hazard and operability study
HEMP	hazard effect and management process
HRA	health risk assessment
HSE	health, safety and environment
JHA	job hazard analysis
LNG	liquefied natural gas
LPG	liquefied petroleum gas
P&ID	process and instrument diagram
PHA	preliminary hazard analysis
PEM	physical effects modelling
QRA	quantitative risk assessment
SAR	search and rescue
SIL	safety integrity level

3 Hazards and risk assessment concepts

Effective management systems are required to address the health and safety aspects of the activities undertaken by all companies associated with the offshore recovery of hydrocarbons[1)]. These management systems should be applied to all stages in the life cycle of an installation and to all related activities. Such a management system, which has been developed for environmental issues, is described in ISO 14001 [3] and the principles contained in this International Standard can also be applied to issues relating to health and safety.

One key element of effective management systems is a systematic approach to the identification of hazards and the assessment of the associated risk in order to provide information to aid decision-making on the need to introduce risk-reduction measures.

Risk-reduction measures should include those to prevent incidents (i.e. reduce the probability of occurrence), to control incidents (i.e. limit the extent and duration of a hazardous event) and to mitigate the effects (i.e. reduce the consequences). Preventive measures, such as using inherently safer designs and ensuring asset integrity, should be emphasized wherever practicable. Measures to recover from incidents should be provided based on risk assessment and should be developed taking into account possible failures of the control and mitigation measures. Based on the results of the evaluation, detailed health, safety and environmental objectives and functional requirements should be set at appropriate levels.

1) For example, operators should have an effective management system. Contractors should have either their own management system or conduct their activities consistently with the operator's management system.

ISO 13702 [2] introduced the concept of strategies, but stated that such strategies do not have to be separately documented as the relevant information may be included with other HSE information for an installation or may be contained in recognized codes and standards that are relevant to the operating location. Indeed there can be significant overlap between strategies and other HSE information, so that combining this information into one source is likely to assist the understanding by the people on the installation of how the various measures are integrated.

The results of the hazard identification and risk assessment activities and the decisions taken with respect to the need for, and role of, any measures required for risk reduction should be recorded in strategies.

Hazards identification and risk assessment involves a series of steps as described below.

a) **Step 1: Identification of the hazard,** based upon consideration of factors such as the physical and chemical properties of the fluids being handled, the arrangement of equipment, operating and maintenance procedures and processing conditions. External hazards such as ship collision, extreme environmental conditions, helicopter crash, etc. also need to be considered at this stage.

b) **Step 2: Assessment of the risk** arising from the hazards and consideration of its tolerability to personnel, the facility and the environment. This normally involves the identification of initiating events, identification of possible accident sequences, estimation of the probability of occurrence of accident sequences and assessment of the consequences. The acceptability of the estimated risk must then be judged based upon criteria appropriate to the particular situation.

c) **Step 3: Elimination or reduction of the risk** where this is deemed to be necessary. This involves identifying opportunities to reduce the probability and/or consequence of an accident.

These three generic steps are inherent in all the methods which are described in this International Standard.

In selecting the appropriate hazard identification and risk assessment tools and techniques, the nature and scale of the installation, the stage in the life cycle and experience of similar installations should all be considered. The level of effort devoted to hazard identification and risk assessment should be based on the anticipated level of risk, the novelty of the undertaking and any limitations in knowledge.

Where the more complex, structured review techniques are used, the uncertainties in the assumptions used must be appreciated and considered when assessing necessary risk-reduction measures. It is important that uncertainties in the assumptions are well documented and communicated to the personnel who are using the results of the hazards and risk assessment to assist in decision-making.

For new installations or activities it is important to identify hazards as early as possible, in order that sufficient time can be given to the study and evaluation of the hazard before determining the most appropriate solution to manage it. It is always easier to make modifications early in the design stage of a project, when changes can be made with minimal effect on cost and schedule.

Hazards and risk assessment can also be applied to existing facilities, but in some cases changes that would be justified during design may not be practicable for an existing facility. As an example, improvements in layout concepts may not be practicable for existing facilities. The work necessary in undertaking modifications to an existing facility in itself introduces an additional risk of an accident which needs to be considered.

Figure 1 shows approaches with differing levels of complexity that may be used for hazards and risk assessment.

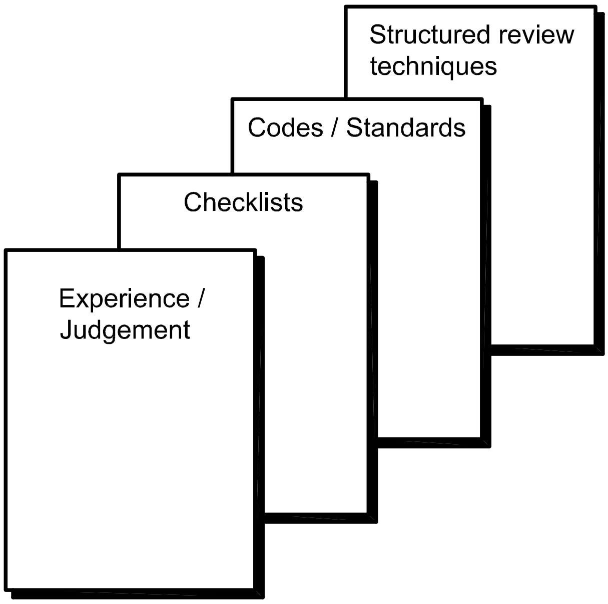

Figure 1 — Approaches to hazards and risk assessment

In many circumstances, the knowledge and expertise of experienced staff using a structured approach may be sufficient to manage risk.

Checklists are quick and easy to use, and can help determine whether design standards and practices are met and whether previously recognized hazards are properly addressed.

Where the experience gained by industry has been incorporated into codes and standards, a high level of safety can be achieved by checking for compliance with these standard practices in design, construction, operation and maintenance.

Structured review techniques can be used to identify and evaluate previously unforeseen hazards and unintended events that are not adequately addressed by the previous methods.

Further details are given in annex A.

4 Methods for hazard identification and risk assessment

4.1 Selection of methods

The level and extent of hazard identification and risk assessment activities vary depending on the scale of the installation and the stage in the installation life cycle when the identification and assessment process is undertaken. For example:

— complex installations, e.g. large production platforms incorporating complex facilities, drilling modules and large accommodation modules, are likely to require detailed studies to address hazardous events such as fires, explosions, ship collisions, structural damage, etc.;

— for simpler installations, e.g. wellhead platforms with limited process facilities, it may be possible to rely on application of recognized codes and standards as a suitable base which reflects industry experience for this type of facility;

— for installations which are a repeat of earlier designs, evaluations undertaken for the original design may be deemed sufficient to determine the measures needed to manage hazardous events;

— for installations in the early design phases, evaluations will necessarily be less detailed than those undertaken during later design phases, and will focus on design issues rather than management and procedural aspects. Any design criteria developed during these early stages need to be verified once the installation is operational.

Hazard identification and risk assessment activities may need to be reviewed and updated if significant new issues are identified or if there is significant change to the installation.

4.2 Role of experience/judgement

An often adequate approach is one in which the knowledge and expertise of staff, having appropriate experience, is used for hazard identification and assessment. This is particularly useful where the activity under consideration is similar to activities undertaken previously at the same or different locations. Practical staff experience gained in the field and feedback from hazardous events and near misses that have occurred is essential in this respect.

This approach on its own, however, is unlikely to be sufficient when dealing with novel or innovative systems and facilities, or where local conditions render previous experience invalid. For example, operating experience gained in benign tropical waters should not generally be used as the basis for evaluations of arctic installations.

4.3 Checklists

These are a useful way of ensuring that known hazards and threats have all been identified and assessed, although the use of checklists shall not be allowed to limit the scope of any review. Checklists are normally drawn up from standards and operational experience, and therefore focus on areas where the potential for mistakes is high or where problems have occurred in the past. Checklists are easy to apply and can be used at any stage in the project life cycle.

The checklist should be prepared by experienced personnel familiar with the design and operation of the facilities and with the company and industry standards and procedures. Checklists may be applied by less experienced personnel, although the effectiveness of the checklist technique is limited by the experience of the authors and the diligence of the users. However, they do not provide a creative format for the identification and evaluation of new hazards where experience is lacking.

Checklists should be reviewed and updated regularly to incorporate new experience by the company and industry, including the results from any accident or incident investigations.

Hazard registers from previous similar developments, which contain a record of hazards identified for that installation, are useful as a basis for checklists.

A checklist may be as detailed or as general as necessary, depending upon the specific application. It should be conscientiously applied, in order to evaluate whether standard procedures are being followed and to identify aspects that requires further attention. A checklist is generally the quickest and easiest method of hazards and risk assessment, and is very effective in the control of risk arising from standard, well understood hazards.

4.4 Codes and standards

Codes and standards reflect collective knowledge and experience, accumulated on the basis of company, national or international operations. These documents incorporate the lessons learned from previous designs, from hazards and risk assessment and from accident and incident investigations. They thus contain an inherent hazards and risk assessment, since the hazards have already been identified and the standard methods for their control and mitigation defined.

Information on hazards that may be contained in codes and standards is usually applicable to a particular type of operation. For example, the designer of a pressure vessel relief system can use a standard to find detailed guidance on the relief cases that should be considered. In some cases, compliance with prescriptive standards alone will reduce risks to a tolerable level. Similarly, the acceptability of emissions or discharges to the environment, or release of agents harmful to health, can be assessed by reference to environmental quality standards and occupational health exposure limits.

The use of checklists based upon the requirements laid out in codes and standards is a frequently used technique which is very effective in identifying compliance with industry standard practice and highlighting aspects which require further investigation.

4.5 Selection of structured review techniques

Where it is considered necessary to use hazards and risk assessment based upon structured review techniques, as described in annex B, the following guidelines may be used to select the appropriate method.

Identification of the main hazards is important in the early stages of a design, in order to allow design decisions to be made which reduce risk. HAZID and PHA may be useful to achieve this objective. If suitable information is available, preliminary QRA may be used at this stage and can make a contribution towards optimizing the platform layout. Sensitivity analyses, allowing the identification of parameters which have a significant effect on risk, often form a part of such assessments.

At later stages in a design, evaluation techniques, such as FMEA, FTA (2.1.7) and ETA (2.1.6), QRA and HAZOP may be found useful. Annex B presents information to input data for these techniques.

Evaluation of hazards and risks associated with construction tasks and operations, including inspection, testing and maintenance are effectively undertaken using techniques such as JHA and HAZOP, whilst FTA can sometimes be useful in identifying sequences or events which could give rise to a hazardous situation.

QRA should only be used when the input data are adequate to ensure that valid and robust results will be obtained. In most practical applications, there will be uncertainties in both the key parameters used and the QRA model itself. The effect of these uncertainties should be evaluated to confirm that they would not change the conclusion. Limitations in input data are likely to be less significant when QRA is being used to evaluate options, such as during concept selection.

QRA should only be undertaken by personnel with adequate skills and competencies. It is most important that the QRA model effectively reflects reality and thus those familiar with the facilities and their operation need to be involved in the evaluation. This is particularly true in relation to the preparation of input data and assumptions and the review of results from the evaluation.

All evaluation techniques provide results which are themselves subject to a range of uncertainty and consequently, the results should be compared with the judgement of experienced personnel.

Where there is felt to be potentially significant uncertainty in a key element of the evaluation, the use of alternative techniques should be investigated to validate results.

Usually the identification of hazards and the evaluation of risks are undertaken to reflect the situation at a particular point in time (e.g. construction activities, start-up of production, abandonment). Conditions on offshore installations are however dynamic, with changes in operating parameters such as pressure, temperature and produced fluids often being reflected in changed operating procedures and facilities. It is important therefore that the range of conditions for which the hazard identification and risk assessment are valid are clearly stated, and that the criteria triggering the need for re-evaluation are defined.

5 Risk management

5.1 General

5.1.1 Overview of risk management process

The process of identification of hazards and the assessment and control of risk is shown diagrammatically in Figure 2, which also illustrates the three steps described in clause 3.

After the relevant hazards have been identified, the risks arising from them are evaluated either qualitatively or, if appropriate, quantitatively. Risk-reducing measures should be introduced if the risks exceed any screening criteria, or if there are other reasonable measures that can be justified. Once the measures required to achieve a tolerable level of risk have been identified, the functional requirements of these measures should be defined.

The remainder of clause 5 provides more guidance on some of the important features of the risk management process.

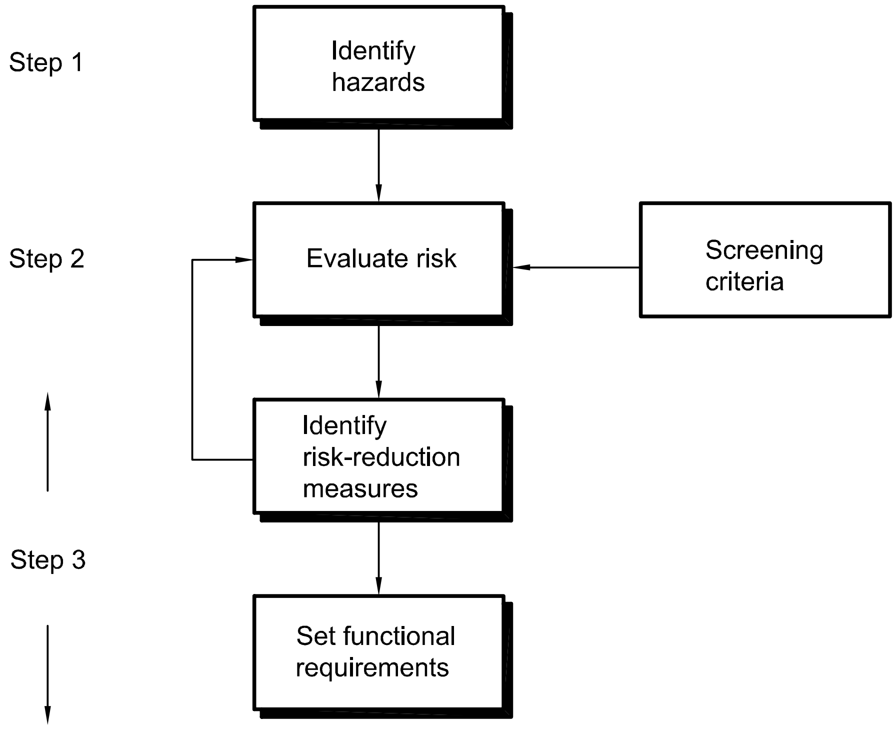

Figure 2 — The process of risk management

5.1.2 Organization and personnel

Hazards and risk assessment is normally performed by a team, but for some facilities or operations it may be undertaken by an individual. The effectiveness of a hazards and risk assessment depends on the skills, knowledge and efforts of the personnel undertaking the work.

The number of people involved and their range of experience should be determined by the size and complexity of the facility or operation being analysed. The identification of hazards and the subsequent evaluation of risk should be undertaken by personnel, or groups of personnel, who are both skilled in the techniques involved and knowledgeable about the design, operation and maintenance of the facilities under consideration.

The involvement, from an early stage, of work force representatives with “hands-on” experience has been shown to be particularly beneficial.

The effectiveness of any hazards and risk assessment is dependent upon careful planning and execution of the various tasks. Hazards and risk assessment should be started as early as possible, subject to the availability of the necessary information, in order that it may be a positive influence rather than a restrictive constraint on progress, requiring rework and additional cost.

5.1.3 Documentation

The key information and the decisions made in the identification and assessment of hazardous events should be documented in an ordered and comprehensive manner, for the benefit of both those that operate the installation and those who may be involved in subsequent changes.

The documentation should not only record the various decisions made during the assessment process, but should also detail the basis for the decisions.

The base data and assumptions used during the evaluations should be clearly stated and references provided where appropriate.

NOTE The use of tables or forms for recording information in a structured manner is often useful when using many of the evaluation techniques.

5.2 Identification

Before the risks associated with a particular activity can be assessed, it is first necessary to systematically identify the hazards which may affect, or arise from, the particular operation under consideration. The likely effect of each hazard being realized is also assessed, to determine whether the hazard is significant or not and whether it should be taken forward for further investigation.

Various systematic approaches are outlined in clause 4. A hazard checklist to assist in the identification of hazards is provided in annex D.

5.3 Assessment

5.3.1 Hazards and risk assessment

Once the hazards have been identified, the risks they present to personnel, environment and the facilities are evaluated.

For a new development project, the hazards and risk assessment normally involves some iteration, beginning with the evaluation of overall concepts and methods and then becoming more precise and focused as the necessary detail becomes available in the field development lifecycle. For simple installations, the same techniques may be used although the validity of the data used in the analysis will be better at a later stage in the project. For more complex installations, simple analytical methods may be used at an early stage, to be followed by more sophisticated methods when more data are available.

For an existing installation a similar step-by-step approach may be adopted, starting with a relatively wide-ranging consideration of the general issues and then converging on areas of specific concern, using more detailed evaluation techniques if necessary.

In evaluating risk, due consideration is given to both the likelihood (or frequency) of occurrence and the severity of consequences arising from the initiating hazardous event.

Based upon the hazards and risk assessment, recommendations should be made to management for risk reduction, where needed in order to achieve a tolerable level of risk. Recommendations may be based upon the judgement of the analyst or may use criteria adopted by the company to guide decision-making on risk reduction.

5.3.2 Screening criteria

Screening criteria are the targets or standards used to judge the tolerability of an identified hazard or effect. They are used to judge the significance of the hazards and effects and together with the results from the risk assessment provide the basis for risk management decision-making. Screening criteria may include adoption of parameters contained in codes and standards.

Screening criteria are normally framed in terms of parameter levels which define the tolerable threshold, based upon the current state of science and technology and the general views of society. Criteria developed by a company to define maximum tolerable risk levels are also screening criteria.

Appropriate screening criteria should be selected when hazards have been identified and should subsequently be used for comparison with the results of the hazards and risk assessment. Failure to achieve a screening criterion identifies an unacceptable condition unless it can be shown that the particular screening criterion is inappropriate in the particular situation. Parameters outside the tolerable range defined in the screening criteria should only be accepted after the consideration and agreement of senior management.

5.4 Risk reduction

5.4.1 Evaluation of risk-reducing measures

In many cases, the measures to control and mitigate hazards and risks are simple and obvious and involve modifications to conform to standard practice. In other cases, alternative measures to reduce risk need to be considered to achieve the best solution. It is important to consider a wide range of possible solutions to the defined hazards, and not to assume that modification of physical facilities is the most appropriate method to control and mitigate risk, e.g. by reducing the frequency and duration of exposure of personnel to risk.

The general hierarchy of risk-reducing measures is

a) prevention,

b) detection,

c) control,

d) mitigation,

e) emergency response.

Particular attention should always first be given to risk-reducing measures which have the effect of eliminating or reducing the probability of hazardous events occurring. The use of inherently safer design principles to manage risks is preferred. In inherently safer design, the following concepts are used to reduce risk:

— **reduction**, e.g. reducing the hazardous inventories or the frequency or duration of exposure;

— **substitution**, e.g. substituting hazardous materials with less hazardous ones (but recognizing that there could be some trade-offs here between plant safety and the wider product and lifecycle issues);

— **attenuation**, e.g. using the hazardous materials or processes in a way that limits their hazard potential, such as segregating the process plant into smaller sections using ESD valves, processing at lower temperature or pressure;

— **simplification**, e.g. making the plant and process simpler to design, build and operate, hence less prone to equipment, control and human failure.

Protective measures should be considered after the assessment of possible preventive measures, and should be aimed at mitigating the effects of a hazardous event once it has occurred. Measures to restrict escalation of a hazardous event, together with measures to protect personnel and measures to normalize the situation, may all be considered. Fire and gas detection systems, fire-water systems, active and passive fire protection, temporary refuge, evacuation systems, oil clean-up and recovery equipment and procedures, protective clothing, etc. are all examples of protective measures.

Factors that will influence the selection of measures to reduce the risk include

— the technical feasibility of the risk-reducing measure,

— the contribution of the risk-reducing measure,

— the costs and risks associated with implementing the measure,

— the degree of uncertainty associated with the risk, or the risk-reduction technique, including human factors.

A progressive approach to risk reduction should be adopted, giving attention first to those measures which have greatest effect in risk reduction for least effort. Successive evaluations of risk-reducing measures are undertaken until a point is reached where all the screening criteria have been satisfied (or dispensation has been given by senior management) and no further risk-reducing measures are reasonable.

Risk-reducing measures should be assessed to determine whether they are technically viable and have significant effect. In many situations such assessments can be left to the judgement of the person undertaking the risk management decision-making, who will decide what is satisfactory based upon experience and normal good practice.

In other situations, the effort required to implement a risk-reducing measure in terms of cost, time, difficulty, necessary resources, etc. needs to be considered against the benefit likely to be achieved.

An approach widely used is to evaluate the effort and cost involved in a number of different risk-reducing measures and to estimate the risk-reducing effect of each. By evaluating the cost or effort necessary to arrive at a common level of risk reduction it is often possible to identify those measures which are clearly more effective in risk reduction. In addition, sensitivity analyses should be included as part of a cost-benefit analysis in order to highlight the effect of uncertainties.

The uncertainties associated with cost-benefit analysis are such that the results of such analysis should only be used in conjunction with good engineering judgement when deciding whether or not to implement a risk-reducing measure.

Evaluation of risk-reducing measures should always be based on sound engineering principles and common sense. The following aspects should also be observed: local conditions and circumstances, the state of scientific and technical knowledge relating to the particular situation, and the estimated costs and benefits.

5.4.2 Strategies and functional requirements

The results of the hazards and risk assessment and the decisions taken in respect to the need for, and role of, any risk-reducing measures should be recorded so that they are available to those who operate the installation and for those involved in any subsequent change to the installation. In ISO 13702 [2], the term used to refer to this record is “strategy”. The level of detail in a strategy needs to be consistent with the stage of the project. In the initial stages it is of necessity relatively brief, setting out general principles and overall requirements, but as the project proceeds it will become more specific.

For a particular installation a number of such strategies may be required. The level of detail in a strategy depends upon the scale of the installation and the stage in the installation life cycle at which the risk management process is undertaken. The strategies should describe the role, and any functional requirements, of each of the systems required to manage possible hazardous events on the installation. ISO 13702 [2] provides guidance on appropriate levels of detail in the strategies.

A focused approach should be used to the specification of functional requirements, with greater attention given to the definition and monitoring of critical equipment, systems and procedures than to less critical elements. Functional requirements should be verifiable, realistic and achievable, and should be reviewed at specified intervals to ensure their continuing relevance and suitability.

An important principle to be adopted in the setting of functional requirements is that their number and level of detail should be commensurate with the magnitude of the risk to be managed. Thus caution should be exercised to avoid setting functional requirements at a level of detail that makes little contribution to the management of the risks on an installation.

In identifying the systems for which functional requirements are developed, the following factors should be considered:

— the systems selected should make a significant contribution in controlling risk;

— the parameters selected should be directly relevant to the achievement of the system goals;

— the parameters selected should be capable of verification.

Functional requirements for risk-reducing measures should include

— those parameters which are are clearly identifiable and important to fulfil a role in risk reduction;

— procedural or operational criteria, where essential in the control of risk;

— directly verifiable criteria which do not require extensive computational effort;

— recording of data to confirm compliance with functional requirements.

This should, wherever possible, be part of the normal operational and recording tasks associated with the particular activity. This reduces the possibility of duplication of effort and increases the probability that the task will be undertaken in a conscientious and efficient manner.

6 Guidelines for use in specific activities

The methods used in the identification of hazards and the evaluation of risk as described in clause 4 may be applied to any exploration and production activity. Although the general approach is the same for all activities, the techniques and detailed approach used will vary depending upon the particular activity under consideration.

Although different types of evaluation may be carried out for different exploration and production activities, it is important to recognize that they are all part of an overall activity. For individual installations, the totality of the hazard and risk evaluation activities is frequently expressed in the form of a life cycle model.

The tables in annex C provide examples of how the risk management process may be applied to the various stages in the life cycle of an offshore installation.

Annex A
(informative)

Hazard identification and risk assessment concepts

A.1 Hazards, incidents and barriers

A **hazard** is something with the **potential** to cause harm. This may include ill health or injury, damage to property, products, production losses or increased liabilities.

The concept that a hazard has the **potential** for something undesirable to happen rather than the **actual event** itself is important in understanding the approach to be adopted toward hazard identification and risk assessment. The explanation of hazard given above is also important in that it is more precise than the common usage meaning of danger, chance or risk.

The terms **acute** and **chronic** are often used to differentiate between hazards with the potential to cause harm as a result of relatively short-term events such as oil spills, fires and explosions (acute hazards), and hazards which arise from long-term events such as continuous discharges and occupational exposure (chronic hazards).

Typical examples of acute hazards are hydrocarbons under pressure, an object at height, electricity, a ship in close proximity to an installation, etc.

The concept that chronic hazards (sometimes referred to as routine hazards) are planned and accepted events is central to environmental and occupational health assessment. Chronic hazards relating to emissions and discharges include long-term flaring of gas, the discharge of produced water to the sea or the presence of physical and chemical agents harmful to health. These chronic hazards can lead to health or environmental effects which occur gradually over a long period of time following repeated and prolonged exposure to relatively low levels or concentrations of a hazardous agent.

The key characteristic of chronic or routine hazards is that they should be controlled within defined limits. For example, control of noise generation will be based on noise limits which will be set for a given location.

In the context of chronic or routine hazards, the undesired event can relate to the breaching of defined limits, such as noise levels in and around locations, or exceeding occupational exposure limits for chemical or physical agents hazardous to health.

A **hazardous event** occurs when the hazard’s potential to cause harm is realized. This might be the release of hydrocarbons under pressure, the dropping of an object, the electrocution of a person or the collision of a ship with the installation. For chronic hazards, this might include the exceedance of limits set to prevent chronic effects on health.

The term **incident** has a broader meaning, being used to describe both hazardous events and other unplanned events, or chain of events, which **could have** caused injury, illness and/or damage to the assets, revenue or environment (so called “near misses”).

In order to prevent a hazard being released, counter-measures or **barriers** are required. Barriers may be either physical, such as shields, isolation, separation, protective devices, etc. or non-physical, such as procedures, alarm systems, training, drills, etc.

In the case of a corrosion threat, appropriate barriers would be for example the use of corrosion-resistant coating, the use of a corrosion allowance in design and the implementation of an inspection programme. Health barriers would include such things as fume exhaust system procedures and personal protective equipment.

The sequence of events that leads up to a hazardous event and the consequences arising from such an event are often represented in diagrammatic form, as illustrated in Figure A.1. The left-hand side of the diagram is a “fault tree” which represents the interrelation of threats and events that would realize the hazard’s potential for harm. The right-hand side of the diagram is an “event tree” which represents the various outcomes from the hazardous event. Emergency response measures to recover from incidents should be provided based on the evaluation of these outcomes and should be developed taking into account possible failures of the control and mitigation measures or barriers.

The concept expressed in Figure A.1, that a combination of causes and events can give rise to a hazardous situation having a number of different results, is fundamental to the process of hazard identification and risk assessment. All hazardous events can be represented in the same format, although some hazardous events may only have one cause and one consequence.

The interrelation of hazards, incidents, threats and barriers as applied to a particular situation is shown in Figure A.2.

Annex D contains a listing of hazards related to different exploration and production (E&P) activities.

A.2 Consequences, control and mitigation

Should the barriers provided fail to prevent a hazardous event occurring, then counter-measures are required to limit or **mitigate** the **consequences** of the hazardous event and to bring it under control, thereby allowing the situation to be returned to normal.

In the case of an acute hazard, such as the loss of containment of pressurized gas, the consequences of such a hazardous event might be explosion and fire escalating to adjacent equipment. Various measures may be available to mitigate the effect of this hazardous event, such as a gas-detection system to give early warning of a leak and reduce the probability of ignition, a fire-detection system to identify the location of a fire and a fire-fighting system to extinguish or limit the spread of the fire. Measures may also be installed to limit the explosion overpressure and hence the physical damage, to assist personnel to escape from the immediate vicinity of the fire, to muster in a place of relative safety and, if necessary, to abandon the installation.

All measures taken following a hazardous event, ranging from the first steps in mitigation and control through achievement of a safe condition to reinstatement of the operation, are frequently termed **emergency response** or **emergency preparedness** measures.

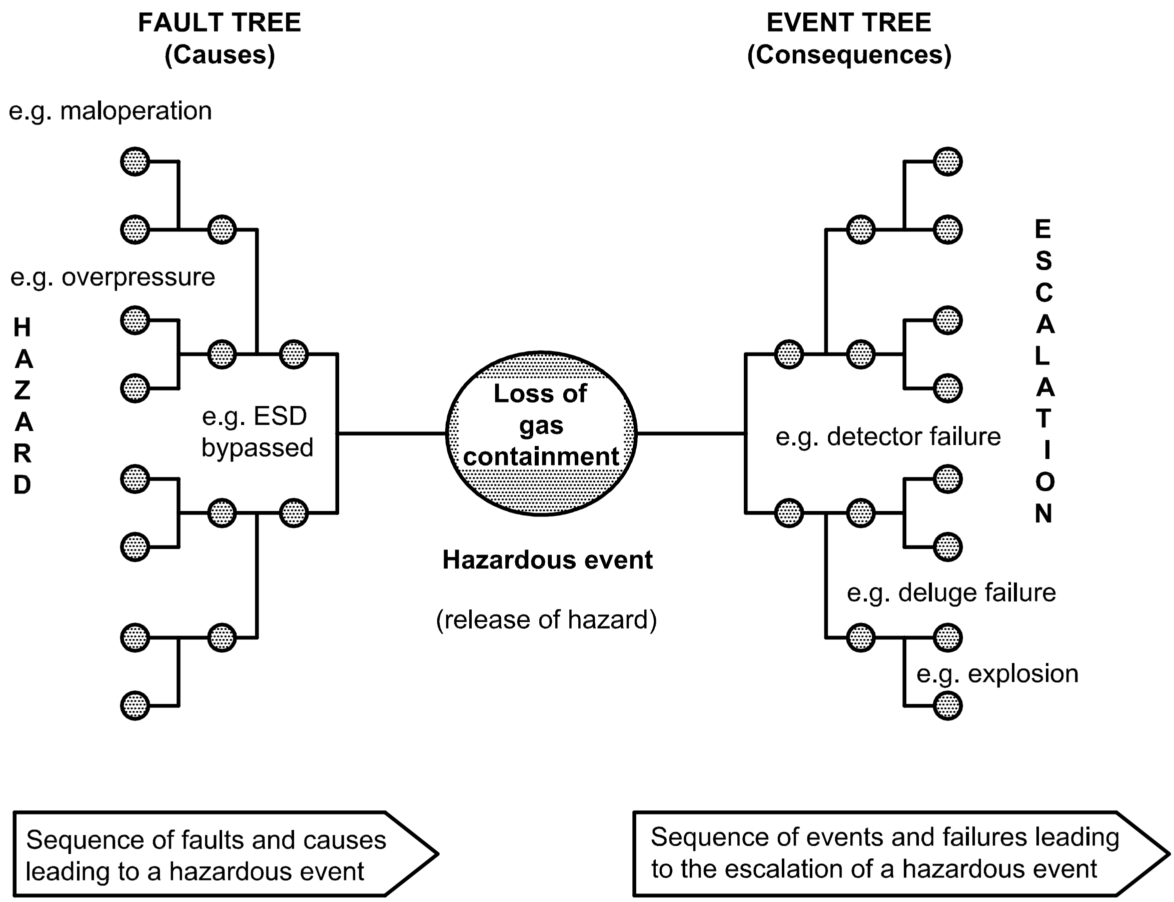

Figure A.1 — Diagrammatic representation of a hazardous event

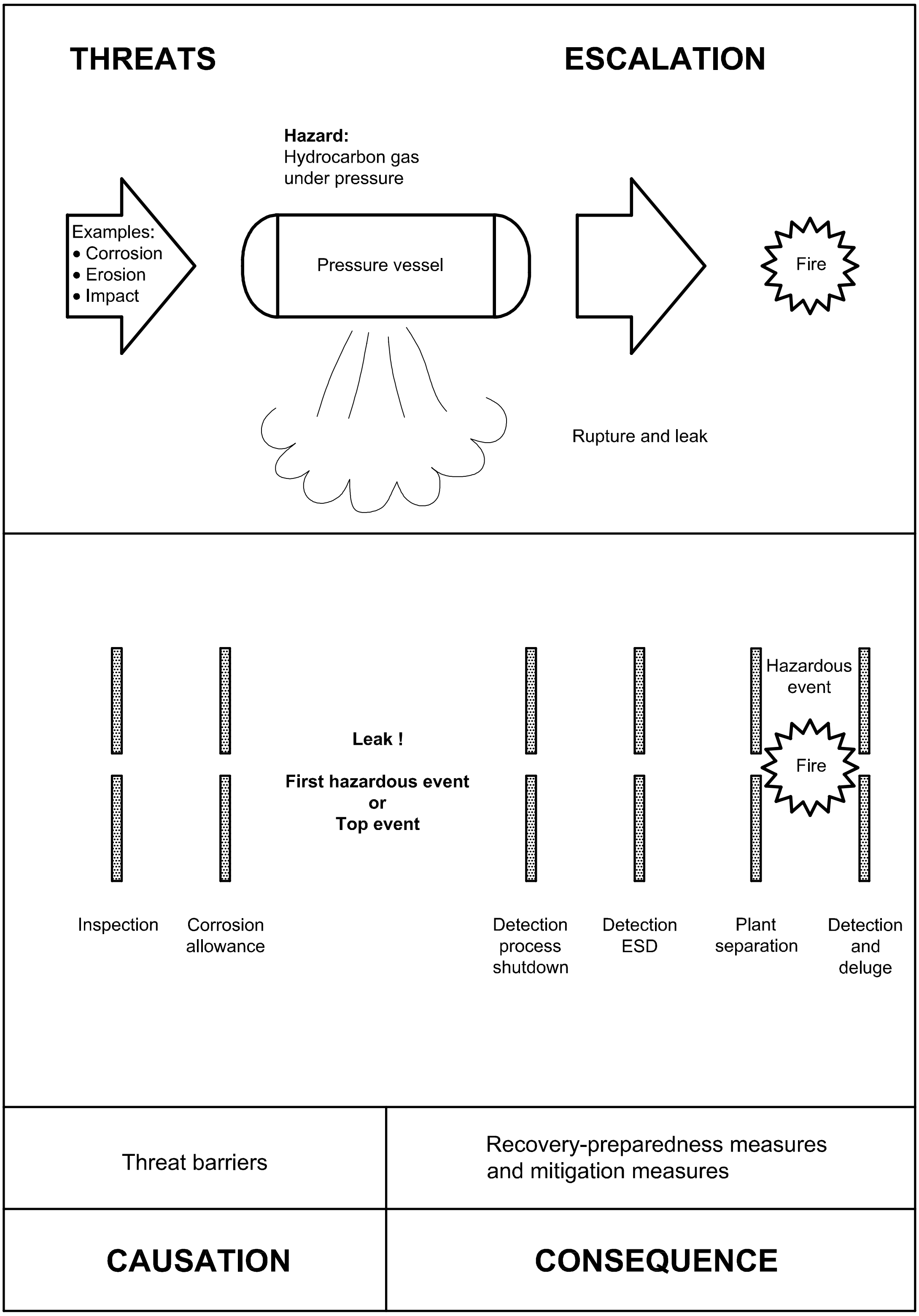

Figure A.2 — Terminology — Acute release

A.3 Risk

Risk is a term in general usage to express the combination of the likelihood a specified hazardous event will occur and the severity of the consequences of that event. Using this definition, the level of risk may be judged by estimating the likelihood of the hazardous event occurring and the severity of the consequences that might be expected to follow from it.

When identifying hazards and assessing their effect, the term risk is frequently used in slightly different ways depending upon the approach adopted. When using the more experience-based qualitative approaches, it is normal to express risk as the direct product of the probability of occurrence and the severity. Thus the risk associated with a particular activity is judged by estimating both the probability and the consequence often in relative terms such as “low”, “medium” or “high”, and combining the two using some previously agreed rules. This approach to the expression of risk is perfectly adequate for many types of evaluation, allowing a structured approach to be adopted in situations where more precise numerical methods would be inappropriate.

In some situations however, it is necessary to define risk in somewhat more precise terms and in these situations the usual approach is to express risk as "the probability that a specified hazardous event will occur in a specified time period or as a result of a specified situation." This approach uses the definition of the probability of a number of different consequences to give the overall risk picture. Using this approach, three parameters are needed to define risk:

— the undesired consequence of the event in question;

— the probability of its occurrence;

— the time frame or event frame to which the probability of occurrence refers.

The terms “likelihood”, "probability” and “frequency” are often used in relation to risk, and it is important that they are clearly understood and used in a consistent way.

Likelihood and **chance** are expressions which indicate, in general terms, the possibility of something happening.

Probability is the ratio of the number of chances that a particular event may occur to the total number of chances. It is expressed as a number in the range 0 to 1, zero being the certainty that the event will not occur, and 1 the certainty that the event will occur. It is also normal to express probability in percentage terms.

Frequency is a rate which expresses how often a particular event occurs within a stated time period. It is defined as the reciprocal of the average time between events, and thus is often expressed in terms such as 1 per 1 000 years. The difference between frequency and probability is clearly demonstrated by noting that for an event which is likely to occur every three months, the frequency of occurrence is 4 per year whereas the probability of the event occurring in any one year should always be less than 1.

In order to make decisions on the results of a risk assessment, screening criteria need to be established.

The screening criteria

— should be appropriate to the hazards identified;

— should reflect best practice as contained in national or international standards, but should be aimed at fitness for purpose and not be unduly prescriptive;

— should be easy to communicate and neutral in respect to the favoured concept or proposed solution;

— should be set at an appropriate level to reflect company strategic and organizational objectives;

— should take local conditions into consideration in order to reflect differing approaches to risk management; factors which may have an effect on the criteria are geographical location, environmental conditions, political and/or economic constraints and societal attitudes;

— should be acceptable to both the company, the regulators and society in general, and should reflect broadly held views of tolerability. It may be acceptable for some groups of workers to experience a level of risk higher than that acceptable to the general public. These higher risks are because the personnel are fully briefed on the risks, and appropriate controls are in place.

In addition, care should be exercised when screening out low probability/high consequence events.

For qualitative assessments, it is possible to use a risk matrix to compare options and the value of risk-reducing measures. An example of a risk matrix is shown in Table A.1.

Table A.1 — Example of risk matrix and consequences that may be considered

Consequence					**Increasing probability**			
Severity rating	**People**	**Assets**	**Environ-ment**	**Reputation**	**A**	**B**	**C**	**D**
					Has occurred in E&P industry	Has occurred in operating company	Occurred several times a year in operating company	Occurred several times a year in location
0	Zero injury	Zero damage	Zero effect	Zero impact				
1	Slight injury	Slight damage	Slight effect	Slight impact	**Manage for continued improvement**			
2	Minor injury	Minor damage	Minor effect	Limited impact				
3	Major injury	Local damage	Local effect	Considerable impact				
4	Single fatality	Major damage	Major effect	Major national impact	**Incorporate risk-reducing measures**		**Fail to meet screening criteria**	
5	Multiple fatalities	Extensive damage	Massive effect	Major international impact				

Table A.1 gives an indication of risk tolerability in general terms, but matrices specific to the activity under consideration should be prepared and used.

Annex B
(informative)

Structured review techniques

B.1 General

This annex describes some of the more normally used structured review techniques and procedures. Some of these techniques have been specifically developed for environmental and occupational health management, often using similar principles as for safety management. With interpretation, these techniques are also capable of addressing emissions, discharges, waste generation and occupational exposure to hazardous substances, etc. Many of the techniques described also contain screening and acceptance criteria for controls.

B.2 Hazard identification (HAZID)

HAZID is a technique for the identification of all significant hazards associated with the particular activity under consideration.

The process normally adopted is to firstly identify all the possible undesirable consequences that could occur and then to identify hazards which, when realized, would cause that consequence. It is usual to include in the hazard list all reasonably foreseeable hazards, without deciding whether each hazard poses a significant risk to the activity in question. Once the gross list of hazards has been established, each hazard is then reviewed to see whether it is significant and should be evaluated further.

A structured approach to the identification of undesirable consequences is normally adopted starting with the broad categorizations such as human impacts, environmental impacts and economic impacts.

Each of these categories can then be further subdivided by the type of resulting damage, for example, toxic exposure, thermal exposure, overpressure, mechanical force, radiation, electrical shock, etc. The more precisely the consequences of interest are defined, the easier it will be later to identify hazards. Checklists, hazard registers from similar activities and previous HAZIDs are frequently used in order to assist in the task of consequence identification and hazard identification.

Once the consequences of interest have been defined, the analyst can identify those system, process and plant hazards which, when realized, give rise to the consequence. Common methods for hazard identification include analysing process material properties and process conditions, reviewing organization and industry experience, developing interaction matrices, and applying hazard evaluation techniques such as fault trees or coarse failure modes and effects analysis. It is important at this stage to think as widely as possible in order to ensure that no foreseeable hazards are overlooked

An alternative approach may also be used involving consideration of a list or register of all possible hazards as shown in annex D. Each hazard listed is assessed to determine whether it is relevant to the situations and activities being considered. At this stage no decisions are taken as to the importance or significance of the hazard, which is assessed later. All hazards identified as relevant are added to a gross list of hazards.

Once the gross list of hazards applicable to the particular situation has been prepared (either by the use of a hazard hierarchy or by consideration of consequences), each hazard is assessed to determine whether it is significant or not. Typical reasons for classification of a hazard as not significant are as follows:

— very low frequency of occurrence, for example impact by asteroid;

— insignificant effect on risk levels, for example release of gas from a pipeline a considerable distance from an installation;

— the effect of realization of a hazard may be included in another more severe hazard.

It is important to record both the gross list of hazards and the reasons for classifying some as not significant. This allows easy reassessment of the hazards list in the event of changing process or operational conditions. All the risk dimensions (personnel, environment and assets) need to be carefully considered before hazards are classified as non-significant.

It is also normal practice to prepare a formal hazards register, detailing each hazard together with appropriate data such as potential cause, potential consequence, system, equipment and geographical location (as appropriate) and some form of identification reference. Where possible, hazards are often grouped to assist in reducing further computational effort.

B.3 Preliminary hazard analysis (PHA)

PHA is an analytical technique used to identify hazards which, without adequate precautions, will give rise to a hazardous event. Typical hazardous event sources considered include oil and gas under high pressure, other fluids at high temperature, objects at height (lifted items), objects at velocity (helicopters, ships), explosives, radioactive materials, noise, inflammable materials, toxic materials, etc.

PHA is often used to evaluate hazards early in a project, being undertaken at the conceptual and front-end engineering stages. It does not require detailed design to be completed, but allows the identification of possible hazards at an early stage and thus assists in selection of the most advantageous arrangement of facilities and equipment.

The general process adopted involves the following steps:

a) definition of the subsystems and operational modes;

b) identification of the hazards associated with the particular subsystem or operation;

c) definition of the particular hazardous event resulting from realization of the hazard;

d) estimation of the probability of the event occurring and the possible consequence of each of the hazardous situations, and then using a particular set of rules to categorize the probabilities and consequences;

e) identify and evaluate actions to be taken to reduce the probability of the hazardous event occurring or to limit the consequence;

f) evaluate the interaction effect of different hazardous events and also consider the effects of common-mode and common-cause failures.

PHA is undertaken in a structured manner, usually using some form of table. Each hazardous event that has been identified for the particular subsystem or operation is studied in turn and recorded in one line of the table, arriving at a “risk rating” either for that particular hazardous event or the subsystem or operation.

PHA is often followed by more detailed FMEA and HAZOPs at a later stage of the design process.

B.4 Job hazard analysis (JHA)

JHA is a qualitative method of assessing risks associated with a particular job in order to decide upon the precautions and contingency provisions that should be taken to reduce the risks. Although the exact format of the evaluation may differ from company to company, the general approach involves breaking the job or activity down into a number of logical steps to be taken to accomplish the task. For each step, a number of questions are asked in order to identify hazards, consequences and risks associated with that particular step and the precautions and contingency measures that can be taken.

For each step in the job, typically the following approach would be adopted.

— **Identification of hazards:** What exactly is going to be done? What materials will be dealt with? What tools and equipment will be used? When will the job be done (daytime, nighttime, time of year, etc.)? Where will the job be done (at height, in confined space, etc.)? How might the task affect people, activities or equipment close by?

— **Assessment of the consequences of the identified hazard:** This is usually done using a scale of High, Medium or Low. In this context the following questions are useful. What is the effect of the hazard? Is it a short-term or long-term effect? Does it affect the equipment or people? How much damage can it cause? How many people can be hurt? Is the effect immediate or is there a time delay allowing escape?

— **Assessment of the probability of occurrence of the hazard:** This is again usually done using a scale of High, Medium or Low. In this context the following questions are useful. Is it likely that the hazard will arise every time the job is done or will it be less frequent (once in 10 times, or 100 times or once in a lifetime)? If the unsafe situation arises is it certain the worst will happen? Do the characteristics of the job, the people doing it or the equipment being used have any effect on the probability?

— **Determination of the risk associated with the action:** Again carried out using a scale of High, Medium or Low, calculated using the product of the probability of occurrence and the consequences. The following logic is usually applied; High × High = High, High × Medium or Medium × High = High, High × Low or Low × High = Medium, Medium × Medium = Medium, Medium × Low or Low × Medium = Medium, Low × Low = Low.

— **Determination of precautions** that can be taken to guard against the risks identified. Precautions may be identified by the following types of question. Would rescheduling the work reduce the risk? Can concurrent activities be phased apart? Are there physical actions possible to reduce the probability of occurrence?

— **Assessment of the residual** risk after feasible precautions have been taken. This involves identifying contingency measures that would reduce the consequence in the event of a hazardous situation. The normal form of such questions is “What if ....?”

In order to ensure uniformity of approach and a systematic evaluation, it is normal to use a standard form to undertake JHA. This allows the precautions and contingency measures to be clearly identified and can then act as a checklist to ensure implementation.

JHA is best undertaken by a small team of personnel who are fully conversant with the equipment, systems and procedures to be used during the job, and can approach the analysis using logical thought and common sense.

B.5 Fault tree analysis (FTA)

FTA is an evaluation technique that may be used to determine the various causes of a predicted hazardous event. The technique was developed to identify causes of equipment failure and was used primarily as a tool in reliability and availability assessment. The fault tree is a graphical model displaying the various combinations of equipment failures and human errors that can result in the occurrence of the hazardous event, usually referred to as the top event. The strength of the fault tree technique is its ability to include both hardware failures and human errors, and thereby allow a realistic representation of the steps leading up to the occurrence of a hazardous event. This allows an holistic approach to the identification of preventive and mitigative measures, and will result in attention being focused on the basic causes of the hazardous event, whether due to hardware or software.

FTA is particularly well suited to the analysis of complex and highly redundant systems. For systems where single failures can result in hazardous events, single-failure-oriented techniques such as FMEA and HAZOP analysis are more appropriate. For this reason fault tree analysis is often used in situations where another hazard evaluation technique, such as HAZOP analysis, has pin-pointed the possible occurrence of a hazardous event which requires further investigation.

The output of a fault tree analysis is a failure-logic diagram based upon Boolean logic gates (i.e. AND, OR) that describes how different combinations of events lead to the hazardous situation. A large number of fault trees may be necessary to adequately consider all the identified top events for a large process plant, and the analyst needs to exercise judgement when selecting the top events to be considered.

By reviewing the fault trees, it is possible to identify the different combination of failures or malfunctions which give rise to the hazardous event. The different failure combinations may be qualitatively ranked depending upon the type and number of failures necessary to cause the top event. Inspection of these lists of failure combinations can reveal system design or operational weaknesses for which possible safety improvements can be considered by the introduction of additional barriers.

In order to undertake fault tree analysis, it is necessary to have a detailed understanding of how the plant or system functions, detailed process drawings and procedures, and knowledge of component failure modes and their effects. Experienced and well-qualified staff should always be used to ensure an efficient and high-quality evaluation.

Time and cost requirements for a fault tree analysis depend on the complexity of the systems involved and the necessary level or resolution. Modelling a single top event involving a simple process with an experienced team could require a day or less. Complex systems and large problems with many potential accident events may require considerably longer.

B.6 Event tree analysis (ETA)

An event tree is a graphical way of showing the possible outcomes of a hazardous event, such as a failure of equipment or human error. An ETA involves determining the responses of systems and operators to the hazardous event in order to determine all possible alternative outcomes. The result of the ETA is a series of scenarios arising from different sets of failures or errors. These scenarios describe the possible accident outcomes in terms of the sequence of events (successes or failures of safety functions) that follow the initial hazardous event. An ETA is well suited for analysing complex processes that have in place several layers of safety systems or emergency procedures to respond to specific initiating events.

Event trees are used to identify the various escalation paths that can occur in a complex process. After these escalation paths are identified, the specific combinations of failures that can lead to defined outcomes can then be determined. This allows identification of additional barriers to reduce the likelihood of such escalation.

The results of an ETA are the event tree models and the safety system successes or failures that lead to each defined outcome. Accident sequences depicted in an event tree represent logical AND combinations of events; thus, these sequences can be put into the form of a fault tree model for further qualitative analysis. Analysts may use these results to identify design and procedural weaknesses, and normally provide recommendations for reducing the likelihood and/or consequences of the analysed potential accidents.

Using ETA requires knowledge of potential initiating events (that is, equipment failures or system upsets that can potentially cause an accident), and knowledge of safety system functions or emergency procedures that potentially mitigate the effects of each initiating event.

An ETA can be performed by a single analyst, as long as the analyst has a detailed knowledge of the system, but a team of two or four people is often preferred. The team approach promotes brainstorming, which results in a more complete event tree. The team should include at least one member with knowledge of ETA, and the remaining members should have knowledge of the processes and experience working with the systems included in the analysis.

B.7 Hazard and operability analysis (HAZOP)

In HAZOP analysis, an interdisciplinary team uses a systematic approach to identify hazards and operability problems occurring as a result of deviations from the intended range of process conditions. An experienced team leader systematically guides the team through the plant design, using a fixed set of “guide words” which are applied to specific “process parameters” at discrete locations or “study nodes” in the process system. The “study node” may be either a discrete point in the process system or it may be a particular run of piping.

For example the guide word “High” combined with the process parameter “level” results in questions concerning possible “high-level” deviations from the design intent. Sometimes, a leader will use checklists or process experience to help the team develop the necessary list of deviations that the team will consider in the HAZOP meetings. The team analyses the **effects** of any deviations at the point in question and determines possible causes for the deviation (e.g. operator error, blockage in outflow, etc.), the **consequences** of the deviations (e.g. spillage of liquid, pollution, etc.) and the **safeguards** in place to prevent the deviation (e.g. level control, piped overflow, etc.). If the causes and consequences are significant and the safeguards are inadequate, the details are recorded so that follow-up action can be taken. In some cases, the team can identify a deviation with a realistic cause but with indeterminable consequences, and in this event, follow-up studies to determine the possible consequences may be recommended.

The results from a HAZOP analysis are the team's findings, which include the hazards and operating problems identified, recommendations for changes in design, procedures, etc. to improve the system, and recommendations to conduct studies in areas where no conclusion was possible due to a lack of information. It is normal practice to record the results of the team discussions concerning the causes of deviations, their effects, and safeguards in place for each node or section of the process in a column-format table.

The objective of the HAZOP study is to identify possible problems areas and to make recommendations as to how the particular problems may be resolved. It is therefore critically important that clear procedures and responsibilities are established to ensure that the recommendations of the HAZOP analysis are reviewed and action taken by the appropriate personnel.

Access to detailed information concerning the design and operation of a process is necessary before a HAZOP analysis can be carried out, and thus it is most often used at the detailed design stage after the preparation of the P&IDs or during modification and operation of existing facilities. A HAZOP analysis also requires considerable knowledge of the process, instrumentation and operation either planned or actual, this information is usually provided by team members who are experts in these areas. Trained and experienced leaders are an essential part of an efficient, high-quality HAZOP analysis.

Typically a HAZOP team consists of five to seven people with different backgrounds and experience in such aspects as engineering, operations, maintenance, health, safety and environment and so forth. It is normal for the team member who leads the analysis to be assisted by another, often referred to as the secretary, who records the results of the team's deliberations as the work proceeds. For a simple process or in a limited-scope review, a team can have as few as three or four people if they have the necessary skills and breadth of experience.

B.8 Health risk assessment (HRA)

HRA involves the identification and assessment of occupational health hazards. The method usually adopted involves breaking down the particular activity under consideration into a series of specific tasks, and then evaluating the health risk associated with each task. A wide approach should be adopted with consideration given to all aspects which could have an adverse effect on health. These include

— chemical effects such as exposure to toxic gases, contact with corrosive chemicals or irritants, lack of oxygen, exposure to airborne particles especially asbestos, etc.,

— biological hazards such as microorganisms,

— physical effects such as temperature, noise, vibration and motion, radiation, pressure, etc.,

— ergonomic effects such as tripping, strains due to lifting, posture, repetitive actions, etc.,

— psychological effects such as stress, effects of height, claustrophobia, isolation, etc.

Consideration should be given to both acute and chronic hazards.

Tolerable exposure limits for chemical and radiographic hazards, in particular, are defined in various national and International Standards, reference to which may be included in the screening criteria.

After identifying the hazards arising from each task, the severity of the possible hazardous situation is assessed and used in health risk management decision-making.

Contingency measures to limit the effects of a hazardous event should also be investigated and detailed in the health risk assessment. This may include the provision of special rescue arrangements, emergency medical facilities including specific antidotes, screening campaigns and similar provisions.

A tabular approach is frequently used in health risk assessment, allowing the identified hazards to be clearly set out together with the necessary precautions and contingency measures. The use of a well-organized approach is also beneficial in identifying combinations of hazards which should also be considered.

Safety data sheets are effective tools in identifying health hazards and appropriate precautionary measures to be used when using or handling hazardous substances or undertaking routine operations with inherent risk. Safety data sheets are usually based upon the best available information relating to the particular hazard, and need to be kept up to date as knowledge increases.

Safety data sheets may be produced by national or international bodies or by a company, and form a “checklist” of aspects relating to the particular material, process or task. Although the exact form of the safety data sheet varies, the following generic data are normally included:

— specification of the material, process or task covered by that particular data sheet;

— definition of the range of materials or situations for which the data sheet is valid;

— hazards associated with the material, process or task;

— precautionary measures to be taken;

— contingency measures that should be considered to guard against the possible realization of the hazards;

— abnormal situations which give rise to particular hazards, for example, particular combinations of chemicals, concurrent tasks, effect of weather, etc.

Further guidance in the use of HRA in respect to hazardous chemicals is found in annex D.

B.9 Failure modes and effects analysis (FMEA)

FMEA is a tabulation of facility equipment items, their potential failure modes and the effects of these failures on the equipment or facilities. The failure mode is simply a description of what caused the equipment to fail. The effect is the incident, consequence or system response to the failure.

The FMEA identifies single-failure modes that can occur, or contribute to the cause of an accident. The FMEA is not useful for identifying combinations of failures that can lead to accidents. The FMEA may be used in conjunction with other hazard identification techniques such as HAZOP for special investigations, e.g. for special or complex instrumentation systems.

The purpose of an FMEA is to identify equipment failure modes and the effect of each on the process system. In the design phase, FMEA can be used to identify the need for additional protective systems or redundancy. During facilities modifications, FMEA can be used to identify the effects of field modifications to existing equipment. The FMEA is also useful during operation to identify single failures that could result in significant accidents. Because FMEAs are subjective, the technique requires at least two analysts who are familiar with the process and the equipment. Different analysts may evaluate different sections of the facility.

A “failure modes, effects and criticality analysis” (FMECA) is the same as an FMEA except that the relative ranking (criticality) of each failure mode is included in the analysis.

B.10 Physical-effects modelling (PEM)

PEM is a technique in which mathematical modelling, usually computer-based, is used to predict physical behaviour under accident conditions. PME is used extensively in QRA to allow quantitative estimation of risk. It is also used extensively in many other evaluation techniques in which mathematical modelling is used to allow estimation of the consequences of a hazardous event, the frequency of which may be unknown or only roughly estimated.

The following physical-effects models are typical of the models frequently used in risk evaluations:

— models of the substructure, deck and modules used to assess the effect of different accidental loads such as ship impact, explosion, extreme environmental conditions, dropped objects, etc.;

— hydrocarbon-release models used to determine the leak rates from holes of different sizes; these models are also used with process flash calculations to determine the mass of the different phases resulting from a leak;

— dispersion models used to determine the spread of gas resulting from a leak;

— explosion-overpressure calculations used to evaluate the pressures occurring as a result of ignition of a gas leak. A range of methods exist, the simplest of which allows estimates of the maximum explosion overpressure to be made, based upon the total volume of the area which may be filled; explosion pressures at different points may be obtained as a function of time, and the effect of blast on remote structures and facilities can be determined; results from an explosion-overpressure model may be used in a dynamic structural program to assess the effect of an explosion on the structure;

— fire modelling, in different forms, used to determine heat flux levels resulting from a fire at different locations on an installation. As with explosion modelling, a range of models is used, from simple formulations based upon test correlations to complex numerical methods based on CFD principles.

It is important that all models used should be fully validated and the range of conditions for which they are appropriate should be understood. Successful application requires that they be used by personnel with adequate training and experience.

The accuracy of the results from a model depends upon both the sophistication of the model with its uncertainties in input and the physical effect itself.

All models have an in-built inaccuracy which should be recognized when using the results for decision-making. It is usually not advisable to base design calculations solely on model results, as most systems need to be capable of withstanding a range of possible anticipated loadings, not all of which will have been modelled. For example, a blast wall should not be designed purely to withstand the overpressure calculated in the explosion model if it is reasonably practical and cost-effective for the wall to withstand greater loadings.

B.11 Escape, evacuation and rescue analysis (EERA)

EERA is a technique to evaluate the performance of the emergency response facilities and procedures. It is most effectively undertaken in conjunction with PEM or QRA, and consists of a structured review of the performance of the escape, evacuation and rescue facilities and procedures in representative scenarios. For EERA to be effective, there should be clear connection between the scenarios used as representative and conditions that might occur following a hazardous event.

Facilities addressed in an EERA usually include escape routes (including bridge links to other installations if appropriate), mustering facilities in temporary refuge, evacuation facilities including helicopter and helideck operation, lifeboats, liferafts, escape chutes and rescue arrangements such as stand-by boats, SAR helicopters, and non-specific marine craft in the locality. A smoke-ingress analysis is frequently included as part of an EERA in order to ensure that the temporary refuge can remain free of smoke for an adequate period.

It is usual to use a checklist detailing the requisite performance characteristics of the various systems and to consider how the systems will behave in an emergency situation. The adequacy, availability and survivability of the systems are considered in each of the representative scenarios, taking due account of system redundancy.

EERA that are undertaken on a qualitative basis allow shortcomings of the emergency response arrangements to be identified and improvements in the systems to be considered and tested. Where frequency-based quantitative data are available, changes in the risk levels may be estimated resulting from changes in the emergency response arrangements. In this instance cost-benefit analysis may be used to examine the viability of the proposed improvement, but in these situations care should be exercised to ensure that engineering judgement and good practice are given due weight in the decision-making process.

B.12 Quantitative risk assessment (QRA)

QRA is the generic term used for techniques which allow the risk associated with a particular activity to be estimated in absolute quantitative terms rather than in relative terms such as “high” or “low”. It may be used to determine all risk dimensions, including risk to personnel, risk to the environment, risk to the installation and/or the assets and financial interests of the company. In general the process involves the following steps.

— **Identification of hazards,** which is usually undertaken using some form of HAZID as described in B.2.

— **Determination of a set of representative hazardous events,** which includes events arising from the realization of all the hazards identified as being significant in the HAZID. In order to allow the analysis to proceed without disproportionate work, it is normal to group similar hazardous events.

— **Estimation of the frequency** of occurrence of the representative hazardous events. This is normally done by reference to appropriate historical data. Both generic industry- and company-based information may be used from appropriate databases, but particular care needs to be taken to ensure its validity. In some situations however, historical data may not be available or be unreliable, and in this instance a predictive analysis approach based upon physical properties may be used. In some situations quantified fault-tree analysis may be used to determine the frequency of particular hazardous events.

— **Evaluation of the direct effects of the hazardous event**, which normally involves an event-tree approach in which all the possible outcomes of the hazardous event are considered and the likelihood of each type of end event determined. This step in the process involves the use of mathematical models to predict both physical phenomena such as dispersion of gas or released fluids, overpressures due to explosions, size and duration of fires, etc., and the performance of equipment and systems such as availability of a gas-detection system, efficiency of oil spill clean-up equipment, ability of structure or equipment to resist accidental loads. The end result of this phase of the assessment is a series of “end events”, together with their estimated frequency of occurrence which is usually expressed in terms of frequency per year.

— **Evaluation of the consequences of the identified end events**, which involves assessing the consequences of the end events in terms of what effect they have on the various risk dimensions. This step may again use some mathematical modelling, but normally a large part of this phase involves the comparison of the direct effects calculated in the previous step against the current knowledge of how these affect the risk dimensions. Thus the toxicity level of a particular release may be compared against known lethal exposure limits to determine whether personnel will be killed. Pollution levels at a particular location arising from a particular release event may be compared against known ecological data to determine the environmental consequence of that particular end event. The explosion overpressures may be used to determine the damage to the facilities and structure as a means of determining the financial effects arising from loss of production and the necessary repairs. In order to allow risk to be expressed in absolute terms, it is normal to group the consequences into categories and then to express risk as the frequency of occurrence of events having a consequence in that particular category. The outcome of this phase of the assessment is thus a series of consequences or consequence categories arising from a particular hazardous event, together with their estimated frequency of occurrence.

— **Risk summation**. The overall frequency of each of the consequence or consequence categories is determined by summing up the relevant frequencies for all the possible end events. The total risk for each of the risk dimensions being considered is then defined by the various consequence frequencies, often being represented in the form of a risk matrix. These risk levels may then be compared with the predetermined screening criteria to determine the tolerability of the risk levels. It is important that the limitations inherent in some screening criteria, such as Fatal Accident Rate (FAR), Average Individual Risk (AIR) and safety-function impairment, are appreciated when reviewing the risk results.

Assumptions should reflect actual practice, including inspection and maintenance frequencies and techniques, frequency of drills and operating procedures, etc.

QRA should only be used as a tool to assist in decision-making and not as a mechanistic means of deciding a course of action. The results of QRA should be used with caution, particularly when they are being compared with arbitrary screening criteria.

In deciding when it is appropriate to use QRA, the following factors should be considered.

— The results of the analysis are only as good as the assumptions and data used as input. Thus, however sophisticated the analytical models used, the results will be open to question if the input information is not both reasonably accurate and valid. It is important to appreciate that validity and accuracy are different. As an example, it is obvious that statistical data relating to leakage from one type of flange may not be valid as a way of predicting leakage from a process plant having a different type of flange, even though the data may have been very accurately collected. Conversely although the statistical data may be valid for the particular application, it may be inaccurate because some leaks may not have been detected and recorded or the total population of flanges among which the failures occurred may have been incorrectly estimated or counted. It is therefore very important that the accuracy and validity of the input data be appropriate to the use being made of the QRA results. If the QRA results are to be used for the comparison of alternative approaches, the accuracy of the input data may be less than when absolute risk levels are being sought.

— Many of the analytical tools now in existence use sophisticated computer models, such as computational fluid dynamics, to predict effects such as the dispersion of gas or the effects of fires and explosions. Although the results now achievable are considerably better than those possible previously, it is important to realize that they are not completely accurate and are subject to considerable variation and uncertainty, arising from factors such as wind gusts and eddies. Additionally, a considerable degree of estimation is necessary in some steps in the QRA process, particularly when predicting the possible consequences of a hazardous event, and this should be appreciated when selecting the evaluation process to adopt.

— Experience shows that human factors are a very major cause of hazardous events and at present these are not handled well in most QRAs. For example it is difficult, with any precision, to predict the frequency of leaks on the basis of the amount or type of work being undertaken on an installation at a particular time. Thus it is usually inappropriate to use QRA as the sole means of deciding which of a number of alternative operational or construction approaches to use.

— It is always tempting to use the results of QRA when compared with absolute risk criteria as a means to justify not carrying out risk-reducing measures, with data being manipulated solely to meet the criteria

QRA can be used to assess risk to personnel, assets and environment as well as risk to the public. At present, QRA or environmental QRA is confined to “incidental” or “acute” hazardous events. In exploration and production operations, the facilities are in many cases sufficiently remote that considerations of this type of risk to the public do not dominate. In downstream activities, risk to the public is often the main concern.

The application of QRA is not necessarily limited to large, complex and expensive studies. It is a technique which can be used quickly and cheaply to help structure a solution to problems for which the solution is not intuitively obvious. Without the quantification of risk there may, in some situations, be a danger of allocating scarce resources for little benefit. Because risk is a product of probability and consequence, inappropriate investment on risk-reducing measures may occur if the probability of occurrence of high-consequence events is not adequately estimated.

B.13 Cost-benefit analysis (CBA)

CBA is a technique used to assist in the decision-making process by allowing the direct comparison of the benefits arising from a particular action with the costs. It may be used in conjunction with a relative or qualitative evaluation of risk or when risks have been estimated in quantitative terms.

The analysis starts with the definition of a particular course of action which is predicted to give rise to some benefit. This may be a changed operational procedure, improved equipment performance, higher training or experience levels for operators, lower manning levels on an installation, changed inspection or maintenance frequencies, etc.

The benefit accruing from taking the particular action is determined using the appropriate tools, and expressed in terms of reduced risks and/or reduced costs. The benefit arising from the reduced risk is then expressed in monetary terms, using the best available information appropriate to the local situation. This step is often difficult due to the highly subjective and sensitive nature of the matters that need to be decided and the changing public perception of risk.

It is important that both positive and negative effects of a particular action be considered, and that the approach adopted in assigning monetary values to the various risk dimensions be as consistent as possible.

The benefit of the action expressed in monetary terms is then compared with the cost of undertaking the particular action. Due to the fact that the benefits received and the costs involved normally occur at different times, discounted cash flow techniques are frequently used to allow comparison of net present value.

B.14 Risk matrix

In some situations, it may be beneficial to evaluate risks using qualitative techniques. This is particularly likely to be the case for operational issues for which it may be difficult or unnecessary to undertake a more rigorous QRA. For each application a risk matrix like the example given in Table A.1 should be prepared to adequately bound the range of consequences and frequencies that are relevant to the particular application.

B.15 Safety integrity level (SIL) assessment

Where instrument-based systems are used as the sole or secondary level of protection it is important to ensure that the equipment provided is appropriate to the application.

IEC 61508 [6] sets down the methods by which the safety functions and SIL can be determined for a specific application. The safety functions are those actions required to return the process to a safe state. The SIL is a measure of how good the system needs to be in terms of system reliability or average probability of failure on demand.

IEC 61508 includes a number of different methods of determining safety integrity levels. The method selected depends on the country of application. The standard does not apply to those systems used to protect against economic loss, but the same principles can be applied.

Four levels of integrity are recognized in IEC 61508-1 [6]. The safety integrity level required for a specific application depends on parameters such as the consequences of failure on demand and likely demand rate. Other parameters may also be relevant, such as occupancy in the hazard area and possibility of avoiding the incident.

Associated with each integrity level are specified performance targets related to the failure of the system to function. The performance figures specified relate to the overall performance of the system and include the sensor, logic solver and final actuation device. IEC 61508 includes requirements for hardware and software for each of the integrity levels. Methods which allow determination as to whether specific architectures meet the specified levels of performance are included in the standard.

IEC 61508 recognizes that to achieve a specified safety integrity level requires low probabilities of failures due to human error and equipment degradation. The standard therefore includes requirements for each stage in the development of a system, from system specification through to operation and maintenance. Requirements are also included relating to operating and maintenance procedures and frequency of testing.

B.16 Acute environmental impact assessment

An acute environmental impact assessment is an evaluation of the possible effects on the environment of acute accidental discharges or releases. The assessment usually starts with the definition of credible release scenarios and the estimation of their frequency or probability. In the context of offshore production facilities, the most important aspect is normally the accidental discharge of crude oil, arising from either a well blow-out or releases from the process system and subsea pipelines. Releases of other pollutants such as diesel oil, kerosene, glycols or particularly toxic chemicals may also be considered if significant quantities are used during offshore activities.

Having determined possible release scenarios, which are usually characterized by release rate and duration, or sometimes just by a total release amount, the effect on the environment is assessed. Different approaches of varying complexity may be used to express the consequences of acute pollution. These approaches are briefly described below.

Exposure-based analysis: This is a more detailed approach, based upon the duration and rate of the release as well as an assessment of the drift of the oil or chemicals using a drift simulation model. The consequences of the accidental release are gauged by considering the effect on specific areas of the ocean, typically using a grid of quadrants 15 km by 15 km.

Damage-based analysis: This is the most detailed approach, in which the consequences of acute pollution are assessed based on a consideration of the duration and rate of release, the oil or chemical drift and the potential effect on the natural environment. The consequences are normally related to the most vulnerable populations, with particular attention given to shoreline and beach habitats.

One of the parameters frequently used as a measure of the effects of acute pollution on the marine environment is the recovery time. This is the time necessary for the environment to revert to the conditions existing prior to the acute pollution. This parameter may, in principle, be used irrespective of the analysis level chosen, but only in damage-based analysis is the recovery time estimated quantitatively. More qualitative and indirect assessments are used in source-based and exposure-based analyses. The estimation of recovery time is rather uncertain, and therefore time bands are often used (e.g. less than 1 year, 1 to 10 years, more than 10 years, etc). Other measures of the effect on the environment may be used in particular circumstances.

The results of an acute environmental impact assessment are normally expressed in the form of a two-dimensional matrix, with the frequency or probability of occurrence on one axis and the environmental consequences on the other. Such a matrix may be used for comparing alternative arrangements or activities, comparison with company or national standards, and as a means of identifying unacceptable conditions. In order to minimize, as far as is reasonable, the effect of acute discharges and releases, environmental emergency response measures should be planned and implemented as described in ISO 15544 [5].

Annex C
(informative)

Hazards identification and risk assessment considerations for offshore E&P activities

Tables C.1 to C.10 in this annex contain examples of hazards and risk assessment for offshore installations and associated facilities for different exploration and production (E&P) activities. The following aspects are included.

- Seismic and topographical surveys — Table C.1
- Drilling and well completions — Table C.2
- Field development — Tables C.3 to C.7
- Operations — Table C.8
- Decommissioning and disposal — Table C.9
- Logistics — Table C.10

The tables are intended to illustrate the application of the hazard identification and risk evaluation process to a large integrated manned installation in hostile environments. The tables should be reviewed and only those steps which have value, in relation to the actual situation in question, should be used. In many cases considerable simplification will be possible.

The entity responsible for carrying out the relevant hazard identification and risk evaluation activities should be determined by discussion between the various companies involved in the particular activity.

Table C.1 — Examples of hazard identification and risk assessment considerations during seismic and topographical survey activities

Activity: Seismic and topographical exploration	**Description:** This activity includes all aspects relating to seismic, geotechnical and topographical surveys including planning, award of contract, mobilization, implementation and processing of data.	
Hazard identification and risk assessment step	**Examples of aspects to be considered and activities undertaken**	**Comments**
Identify hazards	• Hazardous materials and gases under pressure • Marine operations including hazards associated with on-deck and over-the-side working • Environmental effects • Lifting and mechanical handling • Helicopter operations	The hazards associated with seismic and topographical surveys arise particularly from the handling of hazardous materials, including explosives and compressed air, and the many mechanical handling tasks necessary on deck in the marine environment. Loss or damage to the seismic streamer with spillage of kerosene is an environmental hazard.
Hazards and risk assessment	• Experience and regulations • JHA • Checklists and safety data sheets • Environmental risk assessment • HRA	Due to the routine nature of many of the tasks, particular emphasis should be placed upon experience when undertaking HSE evaluations. Checklists are an important tool in ensuring that all matters are considered. JHAs are useful for non-routine operations and environmental evaluations necessary, particularly in sensitive ecological areas.
Screening criteria	• Class requirements and operational regulations • Discharge limits • Exposure limits for chemicals	International regulations provide general requirements whilst local conditions determine other criteria.
Risk-reducing measures	• Improved mechanical handling procedures • Improved handling procedures for hazardous materials • Greater control of waste and discharges • Revised scheduling of operations to avoid damage to fisheries • Revised schedule to avoid possible severe weather conditions (e.g. tropical storms, cyclones, etc.)	Procedures and standing instructions relating to routine operations should be reviewed at preset intervals to see whether further improvement is desirable or possible. Revised scheduling of the survey may reduce the potential for harm to immature fish stocks or reduce the risk of severe weather conditions affecting seismic or topographical surveys.
Functional requirements	• Limiting marine environmental operational conditions • Oil-spill contingency measures • Man-overboard contingency measures	Functional requirements relating to the normal safety systems should be established on a general basis, and particular criteria established for different operating environments (e.g. Gulf of Mexico, North Atlantic, etc.).

Table C.2 — Examples of hazard identification and risk assessment considerations during drilling, well-completion and well-servicing activities

Activity: Drilling and well completions	**Description:** This activity includes all tasks involved in the planning, design, procurement, construction, installation and commissioning of offshore wells used for the exploitation of oil and gas resources.	
Hazard identification and risk assessment step	**Examples of aspects to be considered and activities undertaken**	**Comments**
Identify hazards	• Well design and well control • Mud system • Marine environment (installation integrity and effects of operations) • Drilling programme • Hazardous materials (chemicals, explosives, radioactive, toxics from the reservoir, etc.) • Well testing • Shallow gas • Wireline and coiled tubing work • Blow-out • Seabed condition/stability • Vessel collision • Helicopter crash	The identification of hazards needs to be undertaken by both the concession holder and the rig owner/drilling contractor in close cooperation. Experience of similar operations, together with local knowledge from wells in the same geographical area, should be used to identify hazards. Particular attention should be given to identifying hazards arising when normal techniques are extended outside their previous range of conditions (e.g. high-pressure/high-temperature wells, very deep water, extreme environmental conditions, high H_2S content, etc.). Additional hazards may arise in less standard operations such as tender-assisted platform drilling and rig skid-over operations with a jack-up or cantilever drilling.
Hazards and risk assessment	• HAZIDs to identify suitability of codes and standards experience to safely manage drilling activities • Where appropriate, apply structured review techniques such as HAZOP • Use of HRA and JHA to address operational safety • Environmental risk assessment • Occupational health assessments to include both standard and non-routine operations	The validity of current techniques used to assess normal operations should be reviewed in the light of particular circumstances. Drilling and/or completion HAZOP analysis allow the possible hazards arising from non-routine tasks to be assessed and measures identified to reduce risk. HRA and JHA are useful for evaluating operational safety matters and nearly always identify measures that might be taken to reduce risk. Environmental risk assessments are aimed at predicting the possible effect of both intentional (drill cuttings, waste water, etc.) and unintentional discharges such as blowouts. Many materials used in connection with well operations are particularly hazardous and require particular care in handling (hydrochloric and hydrofluoric acids for well stimulation, barium brines for drilling fluids, cement dust, completion fluids, etc.).
Screening criteria	• Discharge limitations • Barrier design • Class requirements/Regulation requirements for installation • Noise thresholds • Corporate risk criteria	National and international regulations provide most of the screening criteria, together with corporate criteria of both the concession holder and the rig owner/drilling contractor. Local conditions may give rise to particular criteria such as discharge limitations and barrier design.

Table C.2 (*continued*)

Activity: Drilling and well completions	**Description:** This activity includes all tasks involved in the planning, design, procurement, construction, installation and commissioning of offshore wells used for the exploitation of oil and gas resources.	
Hazard identification and risk assessment step	**Examples of aspects to be considered and activities undertaken**	**Comments**
Risk-reducing measures	• Improved drilling and/or casing programme • Improved mechanical handling and drilling systems • Use of less hazardous materials • Fewer concurrent activities • Improved well control equipment or systems • Improved completion system for reducing risk during completion and working steps, such as nippling up and down of X-mas tree • Better qualified and trained personnel, with specific training given before non-standard or particularly hazardous operations • Improved oil-spill contingency plans and/or better oil recovery equipment • Rescheduling of drilling/completion activities to avoid the possibility of severe weather conditions occurring during particularly sensitive operations	The identification and implementation of risk-reducing measures should be undertaken jointly by the concession holder and the rig owner/drilling contractor. Replanning the schedule to reduce the number of concurrent operations is often a very effective risk-reducing measure which may be achieved without significant cost implication.
Functional requirements	• Performance of general safety systems such as detection and fire-fighting systems • Integrity and performance of well-control systems including choke and kill system • Performance and operational limits for well test equipment and systems • Particular limits on discharge in ecologically sensitive areas • Mooring and station-keeping requirements, and weather limits for particular operations • Limits on concurrent activities • Oil-spill contingency measures	Functional requirements relating to the well integrity safety systems are particularly important and need to be reviewed at regular intervals. Levels of operational readiness are of equal importance if the safety equipment and systems are to be utilized in an effective manner. Training, exercises and drills are important in ensuring operational readiness.

Table C.3 — Examples of hazard identification and risk assessment considerations during the prospect evaluation and feasibility assessment phases of field development activities

Activity: Field development	**Description:** This activity includes all tasks involved in the planning, design, procurement, construction, installation and commissioning of offshore installations used for the exploitation of oil and gas resources. **Subactivity:** Prospect evaluation and feasibility assessment.	
Hazard identification and risk assessment step	**Examples of aspects to be considered and activities undertaken**	**Comments**
Identify hazards	• Consider broad hazards occurring throughout life cycle • Identify main hazards and effects arising from wells, produced fluids and processing, structure, export facilities, utilities and manning arrangements, environment, logistic support arrangements, etc. • Identify possible hazards associated with the construction and installation of the installation and its subsequent decommissioning and disposal	Particular attention should be given to hazards that could arise due to the use of new technology or the extension of existing technology outside its previous range.
Hazards and risk assessment	• Experience from previous or similar projects • Codes and standards, including company guidelines • PHA • Environmental risk assessment	The financial robustness of the development should be possible to evaluate based upon identified hazards and risk analysis. Major hazards and risks (e.g. presence of icebergs, particularly toxic reservoir, particularly sensitive ecology of region, etc.) should be highlighted to allow risk management decision-making. Rough environmental risk assessment concentrates on possible impact of development without consideration of frequency of occurrence.
Screening criteria	• Company maximum tolerable risk levels for personnel, environment and assets • National and international regulations for health, safety and the environment • Special local constraints due to factors such as sensitivity of ecology, seismic activity	At this stage the screening criteria are relatively broad.
Risk-reducing measures	• Inherently safer options to be selected whenever practicable • Need for and extent of offshore processing • Minimize hazardous inventory on the installation • Minimize offshore manning without jeopardizing HSE considerations or production regularity • Consider phased field development or long-term well testing to obtain better appreciation of risks • Consider new technology where clear benefits are apparent • Give adequate consideration to minimizing offshore inspection and maintenance tasks and evaluate alternative maintenance philosophies	
Functional requirements	• High-level criteria regarding overall performance of installation (e.g. production availability target, limitations on pressures and temperatures, service life, target manning levels or frequency of visits for not normally manned installations, limiting environmental criteria such as waves, wind, etc.) • High-level functional requirements for health, safety and environment protection systems to be established (e.g. maximum impairment frequency for temporary refuge)	

Table C.4 — Examples of hazard identification and risk assessment considerations during the evolution and definition of field development concept

Activity: Field development	**Description:** This activity includes all tasks involved in the planning, design, procurement, construction, installation and commissioning of offshore installations used for the exploitation of oil and gas resources. **Subactivity:** Evolution and definition of field development concept.	
Hazard identification and risk assessment step	**Examples of aspects to be considered and activities undertaken**	**Comments**
Identify hazards	• Refine the hazard identification undertaken at feasibility stage • Use checklists and feedback from previous field developments to produce a comprehensive hazards register	An iterative approach to hazard identification is necessary as the development concept emerges.
Hazards and risk assessment	• Experience from previous or similar projects • Codes and standards • Checklists • HAZID • PHA • FMEA • PEM • Preliminary EERA • QRA • Environmental risk assessment • Preliminary HAZOP	PHA based upon HAZID results allows consideration of HSE effects during layout studies. The life cycle approach should be used in identifying hazards. PEM is of particular importance in assisting in the layout of major equipment (e.g. location and orientation of major vessels, compressors, air intakes, flare, etc.). Failure modes and effects analysis is of assistance in determining system arrangements. QRA may also be used to identify high-risk areas and allow measures to be implemented to reduce the risk. Preliminary HAZOPs used to evaluate hazards arising from alternative operating philosophies. The environmental consequences of different development concepts may be estimated using environmental risk assessment.
Screening criteria	• Primary codes and standards selected • Identify all appropriate company codes and standards • Firm up on environmental limitations and requirements • Emission and discharge limitations	Screening criteria may be modified during this phase as the concept changes. The applicable codes, standards and regulations will also evolve and form part of the data input to the detailed engineering phase.
Risk-reducing measures	• Reduced offshore processing • Type and complexity of the processing facilities • Selection based on ranking of a wide range of options with transparent safety criteria • Health and safety objectives clearly stated and included in the concept selection procedure • Adopt inherently safer processes and less hazardous materials • Layout of facilities, including escape and evacuation routes • Arrangements for temporary refuge • Simplify operational methods and philosophies • Reduce hazardous inventories • Reduce manning levels • Reduce emissions and discharges	
Functional requirements	• Define low-level functional requirements for critical systems and operations • Criteria to cover both performance of equipment and operation of systems • Strategies for addressing the problems of fire, explosion and smoke to be developed together with the associated functional requirements • Strategies for addressing escape, evacuation and rescue together with the associated functional requirements	Functional requirements proposed during this phase will be tested and upgraded as necessary during detailed engineering and also later during operations.

Table C.5 — Examples of hazard identification and risk assessment considerations during the detailed engineering phase of field development activities

Activity: Development	**Description:** This activity includes all tasks involved in the planning, design, procurement, construction, installation and commissioning of offshore installations used for the exploitation of oil and gas resources. **Subactivity:** Detailed engineering.	
Hazard identification and risk assessment step	**Examples of aspects to be considered and activities undertaken**	**Comments**
Identify hazards	• Update hazards register produced during conceptual design phase • Re-evaluate hazards associated with construction, transportation, installation and hook-up in the light of latest design arrangements	
Hazards and risk assessment	• Experience of previous or similar projects • International, national and company codes and standards • Fault-tree and event-tree analyses • FMEA • HAZOP analysis • PEM • QRA • HRA • Environmental risk analysis	Fault-tree and event-tree models can be effectively used in detail design to check system operation. PEM is helpful in optimizing the layout of equipment such as gas and fire detectors, location of escape routes. HAZOP analysis should be used extensively to identify hazardous situations that may arise either in normal operation or due to mal-operation. QRA allows quantitative evaluation of different design options and can assist in identifying and improving high-risk areas. The overall risk levels on the installation may also be determined, as well as the frequency of impairment of critical safety functions such as temporary refuge, escapeways and evacuation facilities. Results from the QRA may also be used to determine release frequencies, which may then be used in conjunction with the environmental risk assessment to determine the environmental risks. Health risk assessments are an essential tool to ensure adequate provisions are taken to protect personnel from the effects of noise, vibration, hazardous chemicals, radioactive sources, poor ergonomic conditions, etc.
Screening criteria	• Review screening criteria prepared during conceptual design and update as appropriate	Care should be taken to ensure that national or international regulations that form the basis for screening criteria have not been revised since the conceptual design phase.
Risk-reducing measures	• Optimize performance of critical systems by improvements to layout and detail design (e.g. optimize location of fire and gas detectors, deluge nozzles, drip trays and bunding, etc.) • Accessibility, ergonomics of the working environment • Operating procedures and maintenance routines • Recognition of possible problems during construction, commissioning or decommissioning and implementation of risk-reducing measures • Procedures for incorporating past lessons learnt • Effective operations input into the design (operations personnel part of the team) • Encouragement to raise proactive safety improvement ideas • Less hazardous materials or consumables needed for inspection and testing	QRA may be used together with experience and engineering judgement to evaluate alternative risk-reducing measures.

Table C.5 (*continued*)

Activity: Development	**Description:** This activity includes all tasks involved in the planning, design, procurement, construction, installation and commissioning of offshore installations used for the exploitation of oil and gas resources. **Subactivity:** Detailed engineering.	
Hazard identification and risk assessment step	**Examples of aspects to be considered and activities undertaken**	**Comments**
Functional requirements	• Update functional requirements as necessary to achieve tolerable risk levels • Prepare functional requirements for specific plant and equipment to allow procurement, testing and inspection • Finalize functional requirements for operational matters such as inspection frequencies, maintenance requirements, emergency response, etc.	The functional requirements are updated as the critical systems are optimized and information becomes available from vendors. Consideration is also given at this stage to ensuring that the functional requirements can be adequately monitored and verified.

Table C.6 — Examples of hazard identification and risk assessment considerations during the procurement, construction and installation phases of field development activities

Activity: Field development	**Description:** This activity includes all tasks involved in the planning, design, procurement, construction, installation and commissioning of offshore installations used for the exploitation of oil and gas resources. **Subactivity:** Procurement, construction and installation.	
Hazard identification and risk assessment step	**Examples of aspects to be considered and activities undertaken**	**Comments**
Identify hazards	• Hazards due to the transportation and storage of hazardous materials • Fabrication-site hazards • Inspection and testing hazards • Load-out, marine transport, lifting and installation hazards • Hook-up hazards • Hazards arising from high manning levels and many different trades and contractors	During this phase many different entities are involved; the concession holder should ensure that all hazards are identified and clear limits of responsibility established.
Hazards and risk assessment	• Experience of previous and similar work • Codes and standards • Checklists and safety data sheets • HAZID and JHA • HAZOPs for non-standard construction and installation operations • Health risk assessment	Where many different entities are working together, clear responsibilities for evaluations need to be established. The overall responsibility is the concession owner's, but this may be delegated in specific instances (e.g. fabricator to be responsible for all evaluation work of subcontractors). Extensive use of Permit-to-Work system incorporating use of checklists and JHA.
Screening criteria	• Criteria from national workplace health and safety regulations • Limits of exposure to hazardous materials or toxic gases • Company risk criteria • Company and international codes and standards for offshore marine operations • Insurance requirements for construction and marine operations	The screening criteria that are applicable during operations are rarely modified during this phase. There is however a need to establish screening criteria to cover procurement, construction, installation and hook-up tasks. Various entities are responsible for establishing screening criteria and undertaking the subsequent evaluations, but the concession holder should coordinate and review these activities.
Risk-reducing measures	• Identify safer construction sequences • Provide adequate working environment and all necessary lifting and positioning aids • Use large-scale prefabrication • Employ extensive onshore pre-commissioning • Schedule offshore marine operations when severe environmental conditions are less likely to occur • Use less hazardous materials in construction process	
Functional requirements	• Criteria for inspection and testing • Requirements for lifting, moving and positioning objects • Local environmental requirements for different construction activities such as welding, blasting, painting, insulation, electrical termination, etc. • Requirements for movement of modules and decks in the construction yard and load-out onto barges • Requirements for temporary systems during construction, testing and pre-commissioning • Hot-work limits and concurrent working limitations • Minimization of offshore work, particularly hazardous operations such as hot work	

Table C.7 — Examples of hazard identification and risk assessment considerations during the commissioning and handover phases of field development activities

Activity: Field development	**Description:** This activity includes all tasks involved in the planning, design, procurement, construction, installation and commissioning of offshore installations used for the exploitation of oil and gas resources. **Subactivity:** Commissioning and handover.	
Hazard identification and risk assessment step	**Examples of aspects to be considered and activities undertaken**	**Comments**
Identify hazards	• Hazards arising from high manning levels and many different trades and contractors • Hazards due to part operation of installation facilities for commissioning • Hazards due to remedial works routines • Hazards arising from incorrect or deficient documentation	
Hazards and risk assessment	• Experience of previous and similar work • Codes, standards and procedures • Checklists and safety data sheets • HAZID and JHA • HAZOPs for non-standard commissioning tasks • HRA	The Permit-to-Work system is used extensively during this phase, together with the associated use of checklists and hazard evaluations such as JHA and sometimes HAZOP type assessments. Particular attention required to assessment of coordination procedures and liaison between different entities. Review of information distribution.
Screening criteria	• Generally screening criteria are in line with operational criteria • Temporary situations (e.g. abnormal discharges, flaring, short-term accommodation short-term chemical exposure limits)	
Risk-reducing measures	• Employ extensive onshore pre-commissioning • Integrate commissioning team of concession holder and contractor staff • Ensure familiarity of staff with equipment by early project involvement and training (e.g. use of onshore simulator or training in equipment vendor's works) • Use lock-out systems • Ensure availability and adequacy of all necessary documentation • Schedule commissioning as much as possible to reduce risk due to concurrent activities	
Functional requirements	• Criteria for temporary HSE critical facilities • Emergency response arrangements • Discharges and emissions during commissioning activities • Temporary environmental protection requirements • Manning restrictions prior to commissioning of essential systems	

Table C.8 — Examples of hazard identification and risk assessment considerations during operations

Activity: Operations	**Description:** This activity includes all tasks involved in the management, operation and maintenance of offshore installations involved in the extraction of oil and gas together with the pipelines connected to them.	
Hazard identification and risk assessment step	**Examples of aspects to be considered and activities undertaken**	**Comments**
Identify hazards	• Blow-outs from wells and wellhead equipment • Fires and explosions from process equipment • Releases from or faults in utility systems • Dropped and falling objects • Extreme environmental conditions (waves, currents, wind, earthquake) • Ship or helicopter collisions • Effects from nearby facilities such as pipelines or subsea wells • Special operations such as diving, heavy lifting, construction • Effects due to humans, including concurrent activities • Occupational health hazards (exposure to emissions, hazardous chemicals, radioactive sources, etc.) • Environmental hazards (oil spills, toxic chemical spills, toxic emissions, etc.)	Hazardous situations or near misses that have arisen on other installations in the same general area are useful in identification of likely hazards during the operations. The interaction of activities taking place concurrently may give rise to hazards not previously considered significant (e.g. inspection activities in normally unmanned areas may be more hazardous if painting or coating is being carried out in a nearby location). Hazards arising from the proximity of third-party facilities should not be overlooked (e.g. non-operated pipelines and risers, nearby loading facilities or subsea production wells). Hazards arising due to human error are particularly important during operations, and particular care is needed to adequately identify hazards arising from incorrect operation or faulty maintenance.
Hazards and risk assessment	• Competence and experience of operating personnel is used for continuous evaluation of operating HSE risks • Company and national regulations based upon previous experience govern the normal operation of the facilities • Checklists, Permit-to-Work procedures and JHA used for routine activities • HAZOP analysis used to evaluate non-routine operations • For major modifications to the installation, QRA incorporating fault-tree and event-tree analyses may be used • Environmental risk analysis and health risk assessments may need modification to reflect operational changes such as higher water cuts, changed process fluids, changed manning levels, different chemicals, paints, etc.	The training competence and experience of the operating and maintenance staff is most important during operations. Emphasis should be given to information feedback from hazardous events or near misses to assist in evaluating operating situations for future activities. Particular attention should be given to the evaluation of shift and tour hand-over procedures and how they interface with operating procedures such as the Permit-to-Work system. Inspection and testing often involves procedures which give rise to hazards in locations where they are not normally expected (e.g. radioactive sources, hazardous chemicals, pressure test equipment). The effects of these abnormal situations in the normal operating regime need careful consideration. The cumulative effects of changes over time, including deterioration of the facilities, need to be evaluated to ensure that safety measures are still appropriate.
Screening criteria	• Company risk levels for personnel, environment and assets • Safety equipment regulatory requirements • Maximum tolerable exposure limits for chemical, radiological and physical hazards to personnel • Maximum tolerable pollution levels	Many of the operations screening criteria arise from national or international regulations. Company-based regulations are also a major source of screening criteria.

Table C.8 (*continued*)

Activity: Operations	**Description:** This activity includes all tasks involved in the management, operation and maintenance of offshore installations involved in the extraction of oil and gas together with the pipelines connected to them.	
Hazard identification and risk assessment step	**Examples of aspects to be considered and activities undertaken**	**Comments**
Risk-reducing measures	• Reduce hazardous substances by modifying the process system • Use chemicals less hazardous to health or less polluting to the environment • Reduce manning levels • Improve performance of safety systems by modifying equipment or by changing inspection and/or maintenance procedures • Improve the working environment by reducing noise and vibration, providing improved access to not normally manned areas, providing improved equipment for material handling (e.g. conveyors, goods lifts, additional laydown areas, etc.)	Measures to reduce or eliminate the probability of the hazardous event occurring should be given preference. In particular, measures to reduce stocks of hazardous materials and ignition sources should be given close attention. Prefabrication techniques can significantly reduce hot work.
Functional requirements	• Performance of safety systems, including gas and fire detection, shutdown system, fire protection, alarms and PA, escape and evacuation systems • Inspection and maintenance procedures and frequencies to ensure the required reliability and availability of the critical systems • Limitations on concurrent activities and hazardous operations such as grinding, welding, stress-relieving, etc. • Limitations on hydrocarbon and non-hydrocarbon hazardous inventories • Operating parameter limitations, including pressures, temperatures and flowrates • Manning levels and manning limitations on normally unmanned installations, including number of visits • Emergency response provisions, including times for mustering, mobilization of fire-fighting and rescue teams, mobilization of man-overboard boat, evacuation and rescue procedures, mobilization of medevac facilities and mobilization of oil-spill clean-up facilities	Functional requirements need to be reviewed at regular intervals to ensure that they are being achieved and that the criterion itself is still appropriate. Procedures and arrangements to cover the control of deviations and non-conformities, the recording and dissemination of data, and of evaluating the possible effects of deviations need to be established and maintained. Effective control and distribution of consumables and spare parts and tools assist in achieving the necessary functional requirements and limit the possibility of hazardous situations arising due to the use of incorrect specification replacement parts. It should be recognized that, after all risk-reducing measures have been taken, certain residual hazards will remain and adequate provision in the form of contingency plans and emergency response facilities is needed.

Table C.9 — Examples of hazard identification and risk assessment considerations during decommissioning and disposal

Activity: Decommissioning and disposal	**Description:** This activity includes all operations necessary for the decommissioning, removal and disposal of redundant offshore oil and gas installations and their associated pipeline.	
Hazard identification and risk assessment step	**Examples of aspects to be considered and activities undertaken**	**Comments**
Identify hazards	• Decommissioning condition survey, including remote inspection and diving • Accumulated products such as wax, scale, diesel sludge, oily water, etc. • Purging, cutting, lifting and removal of equipment • Marine operations • On-shore demolition and disposal	The approach to decommissioning and disposal should be similar to that adopted during development, in that a phased approach should be used. Initial broader-based assessments should be followed by more detailed evaluations as the most appropriate concepts become apparent. The initial hazard identification therefore needs to be updated as more information is available regarding the condition of the installation.
Hazards and risk assessment	• HAZID techniques to identify hazards and allow risk-reducing measures to be adopted • Checklists and safety data sheets to be used to ensure specific standard tasks are undertaken safely • Preliminary hazard analysis and job hazard analysis to be used to evaluate less standard tasks • HAZOPs to be used to evaluate more major decommissioning and demolition tasks • Health risk assessments to be used to ensure that health hazards are adequately controlled • CBA	The techniques should aim to assess the risk to the health and safety of the personnel directly involved in the decommissioning and disposal operations and to the environment.
Screening criteria	• National and international environmental regulations • Company environmental standards • Maximum tolerable exposure limits for chemical, radiological and physical hazards to personnel • Company risk criteria	Due to the extremely sensitive nature of this activity, the screening criteria adopted often need to reflect the views of the local society as well as national and international regulations. Wide discussion and debate may be required in some geographical areas prior to formalization of the screening criteria.
Risk-reducing measures	• Provide alternative methods of decommissioning and disposal (e.g. for large-scale or small-piece removal) • Agree trade-off between risk to the environment and personnel undertaking the decommissioning and disposal process • Undertake careful consideration in some geographical areas due to little previous experience • Prefer remotely operated vehicles for particularly hazardous operations	The evaluation of risk-reducing measures during decommissioning and disposal is particularly difficult in some geographical locations due to environmental considerations. Particular attention needs to be given to establishing the monetary values of environmental and societal benefits when using CBA to assist in decision-making. The effect of decisions on the prestige and standing of the concession holder also needs careful consideration.
Functional requirements	• Performance of environmental protection systems • Safety systems in operation during decommissioning (e.g. temporary power supplies, fire protection, temporary ventilation and purging systems, temporary access ways, ladders and platforms) • Criteria for marine operations including lifting, towing, diving, ROV operations, station keeping, etc. • Systems for the removal of hazardous residues and their safe transport and disposal • On-shore demolition and disposal procedures and practices	The functional requirements adopted need to be sufficiently comprehensive to include all matters which are critical in ensuring that risks associated with decommissioning and disposal are tolerable. The performance of temporary systems is particularly important.

Table C.10 — Examples of hazard identification and risk assessment considerations during logistical activities

Activity: Logistics	**Description:** This activity includes all logistical operations necessary to support the exploration and production activities previously considered. It includes the transport of personnel and goods by sea and air, including the export of the produced fluid by tanker or barge, all forms of offshore marine support such as diving, towing, anchor-handling, safety vessels, etc. together with the necessary onshore logistical support including storage, dispatch and disposal of materials.	
Hazard identification and risk assessment step	**Examples of aspects to be considered and activities undertaken**	**Comments**
Identify hazards	• Helicopter and ship transportation of personnel and equipment • Marine operation of barges, tankers, supply boats, standby vessels, diving support vessels, flotels, etc. • Storage, transportation and transfer of materials including hazardous substances such as radioactive sources, chemicals, explosives, etc. • Severe or extreme environmental conditions • Disposal of toxic and hazardous waste • Health risk hazards associated with the storage, transportation and transfer of food and potable water	Close cooperation is necessary between the concession holder and the logistics service contractors to ensure that all hazards are identified and suitable measures adopted to reduce risks. In this task the concession holder should take the lead to oversee and coordinate the various evaluations. Limits of responsibility should be clearly defined and documented to ensure that all evaluations are covered.
Hazards and risk assessment	• Experience and compliance with regulation • Checklists and safety data sheets for hazard identification and handling procedures • HAZOP analysis to evaluate non-standard operational situations • Environmental risk analysis used to estimate the frequency and consequences of both acute and chronic discharges • Health risk assessment to evaluate the risks associated with the handling, storage transport and transfer of hazardous materials	Evaluations based upon checking compliance with regulations or accepted good practice are very important. Many standard logistics activities including marine operations are undertaken in accordance with company procedures and standing instructions, which need to be reviewed at regular intervals to ensure their continued validity. HAZOP-type structured review techniques are now frequently used to identify hazards and risk-reducing measures associated with non-routine diving operations.
Screening criteria	• Company risk criteria • National and International marine operation regulations • National and International air and marine transportation regulations for personnel and hazardous materials • Company logistics operating standards • National regulations regarding quality of bulk materials such as potable water, aviation fuel, diesel fuel, etc.	Many logistics operations, such as the transport of passengers or freight, are controlled by International Standards and regulations.
Risk-reducing measures	• Reduce offshore manning levels to reduce numbers of helicopter flights and passengers • Improve handling conditions for hazardous materials • Hold more frequent drills to ensure effectiveness of emergency response function of logistics • Modify marine operations standing instructions to reduce hazards (e.g. vessels en-route to an installation to set a way-mark off the installation) • Exercise closer control of concurrent logistics activities which could give rise to hazardous situations, e.g. diving operations undertaken at the same time as critical platform operations	It is important to assess all relevant matters when considering logistics risk-reducing measures in order to identify trade-offs. For example, it may be possible to visit unmanned installations at less frequent intervals if larger tanks for diesel, methanol, glycol, etc. are provided on the platform. The risk reduction due to fewer helicopter flights needs to be offset against the higher platform inventory, which may result in higher risk of pollution or damage to the facilities.

Table C.10 (*continued*)

Activity: Logistics	**Description:** This activity includes all logistical operations necessary to support the exploration and production activities previously considered. It includes the transport of personnel and goods by sea and air, including the export of the produced fluid by tanker or barge, all forms of offshore marine support such as diving, towing, anchor-handling, safety vessels, etc. together with the necessary onshore logistical support including storage, dispatch and disposal of materials.	
Hazard identification and risk assessment step	**Examples of aspects to be considered and activities undertaken**	**Comments**
Functional requirements	• Performance of critical safety systems on support vessels, e.g. hyperbaric lifeboat, diving support vessels, emergency disconnect-mooring systems, fire detection and protection systems in storage areas, etc. • Performance of emergency response facilities such as safety standby boat, helicopter search and rescue readiness and capabilities, readiness of onshore emergency teams and facilities • Performance of systems for the transport and disposal of hazardous waste • Standards of competence/training of logistics personnel such as helicopter landing officers, helicopter passengers, crane operators	Functional requirements need to be measurable and verifiable at regular intervals. This needs to be strictly observed during the setting of functional requirements for this activity.

Annex D
(informative)

Hazards checklist

Tables D.1 and D.2 provide checklists of hazards, sources and effects which may be used as appropriate for the identification of hazards and the assessment of their possible effects. Before using Tables D.1 and D.2, the tables should be reviewed to confirm that they are appropriate and complete for the intended application.The hazards in Table D.1 are grouped under the following main headings:

01 Hydrocarbons

02 Refined hydrocarbons

03 Other flammable materials

04 Explosives

05 Pressure hazards

06 Hazards associated with differences in height

07 Objects under induced stress

08 Dynamic situation hazards

09 Environmental hazards

10 Hot surfaces

11 Hot liquid

12 Cold surfaces

13 Cold fluids

14 Open flame

15 Electricity

16 Electromagnetic radiation

17 Ionizing radiation — Open source

18 Ionizing radiation — Closed source

19 Asphyxiates

20 Toxic gas

21 Toxic fluid

22 Toxic solid

23 Corrosive substances

24 Biological hazards

25 Ergonomic hazards

26 Psychological hazards

27 Security-related hazards

28 Use of natural resources

29 Medical

30 Noise

31 Entrapment

The categorization of the hazards in Tables D.1 and D.2 reflects the category considered likely to be most important for that particular hazard, but should not be taken to mean that other categories may not be more important in certain applications. Moreover, the inclusion of one hazard category does not preclude other categories also being relevant (e.g. hydrocarbon gas is shown as a major hazard which arises because it is flammable. In this case the potential to escalate to cause widespread damage is considered the most important criterion).

Table D.1 — The hazards and effects checklist

Safety hazards	Health hazards	Environmental hazards
F = Flammable MH = Major hazard Se = Security hazard WP = Work practice	B = Biological agent C = Chemical agent E = Ergonomic agent P = Physical agent LS = Life style agent Psy = Psychological agent M = Medical issue	D= Discharge hazards R = Use of natural resources Pr = Presence

Hazard number	Hazard description	Safety	Health	Environ-mental	Sources
01	**Hydrocarbons**				
01.01	Oil under pressure	MH	C	D	Flowlines, pipelines, pressure vessels and piping
01.02	Hydrocarbons in formation	MH	—	D	Oil wells especially during well drilling and entry/workover operations
01.03	LPGs (e.g. Propane)	MH	C	D	Process fractionating equipment, storage tanks
01.04	LNGs	MH	C	D	Cryogenic plants, tankers
01.05	Condensate, NGL	MH	C	D	Gas wells, gas pipelines, gas separation vessels
01.06	Hydrocarbon gas	MH	C	D	Oil/gas separators, gas processing plants, compressors, gas pipelines
01.07	Oil at low pressures	MH	C	D	Oil storage tanks
01.08	Wax	F	C	D	Filter separators, well tubulars, pipelines
01.09	Coal	F	P	R	Fuel source, mining activities
02	**Refined hydrocarbons**				
02.01	Lube and seal oil	—	C	D	Engines and rotating equipment
02.02	Hydraulic oil	—	C	D	Hydraulic pistons, hydraulic reservoirs and pumps

Table D.1 (*continued*)

Hazard number	Hazard description	Safety	Health	Environ-mental	Sources
02.03	Diesel fuel	F	C	D	Engines, storage
02.04	Petroleum spirit/gasoline	F	C	D	Storage
03	**Other flammable materials**				
03.01	Cellulosic materials	F	—	—	Packing materials, wood planks, paper rubbish
03.02	Pyrophoric materials	F	C	D	Metal scale from vessels in sour service, scale on filters in sour service, iron sponge sweetening units
04	**Explosives**				
04.01	Detonators	WP	C	—	Seismic operations, pipeline construction
04.02	Conventional explosive material	MH	C	Pr	Seismic operations, pipeline construction, platform decommissioning
04.03	Perforating gun charges	MH	—	—	Well completion activities associated with drilling rigs and workover operations
05	**Pressure hazards**				
05.01	Bottled gases under pressure	WP	—	—	Welding and metal cutting operations, laboratory gas sources
05.02	Water under pressure in pipeworks	WP	—	—	Water disposal, water floods and injection operations, strength testing of pipeworks, well fracturing and treatments
05.03	Non-hydrocarbon gas under pressure in pipeworks	MH	—	—	Purging and leak testing of facilities
05.04	Air under high pressure	WP	—	—	Seismic air guns and related piping
05.05	Hyperbaric operations (diving)	WP	P	—	Undersea operations
05.06	Decompression (diving)	WP	P	—	Undersea operations
05.07	Oil and hydrocarbon gas under pressure	WP	—	D	Flowlines, pipelines, pressure vessels and piping
06	**Hazards associated with differences in height**				
06.01	Personnel at height >2 m	MH	—	—	Work involving scaffolding, suspended access, ladders, platforms, excavations, towers, stacks, roofing, working overboard, working on monkey board
06.02	Personnel at height <2 m	WP	—	—	Slippery/uneven surfaces, climbing/descending stairs, obstructions, loose gratings
06.03	Overhead equipment	MH	—	—	Objects falling while being lifted/handled or working at a height over people, equipment or process systems, elevated work platforms, slung loads
06.04	Personnel under water	MH	—	—	Objects falling onto divers from operations overhead
07	**Objects under induced stress**				
07.01	Objects under tension	WP	—	—	Guy and support cables, anchor chains, tow and barge tie-off ropes, slings
07.02	Objects under compression	WP	—	—	Spring-loaded devices, such as relief valves and actuators, and hydraulically operated devices
08	**Dynamic situation hazards**				
08.01	On-water transport (boating)	WP	—	—	Boat transport to and from locations and camps, transporting materials, supplies and products, marine seismic operations, barges moving drilling rigs and workover rigs

Table D.1 (*continued*)

Hazard number	Hazard description	Safety	Health	Environ-mental	Sources
08.02	In-air transport (flying)	MH	—	—	Helicopter and fixed wing travel to and from locations and camps, transporting materials, supplies and products
08.03	Boat collision hazard to other vessels and offshore structures	MH	—	—	Shipping lane traffic, product transport vessels, supply and maintenance barges and boats, drifting boats
08.04	Equipment with moving or rotating parts	WP	—	—	Engines, motors, compressors, drill stems, thrusters on DP ships
08.05	Use of hazardous hand tools (grinding, sawing)	WP	—	—	Workshop, construction sites, maintenance sites, rotating equipment
08.06	Use of knives, machetes and other sharp objects	WP	—	—	Galley, seismic line clearing, grubbing operations
08.07	Transfer from boat to offshore platform	WP	—	—	Basket transfer, rope transfer
09	**Environmental hazards**				
09.01	Weather	WP	—	—	Winds, temperature extremes, rain, etc
09.02	Sea state	MH	—	—	Waves, tides or other sea states
09.03	Tectonic	MH	—	—	Earthquakes or other earth movement activity
10	**Hot surfaces**				
10.01	Process piping and equipment between 60 °C and 150 °C	WP	P	—	Oil-well piping, piping in fractionation systems, glycol regeneration
10.02	Process piping and equipment over 150 °C	MH	P	—	Hot oil piping, piping associated with stills and reboilers
10.03	Engine and turbine exhaust systems	WP	P	—	Power generation, gas compression, refrigeration compression, engine-driven equipment such as forklifts
10.04	Steam piping	WP	P	—	Sulfur plants, power boilers, waste heat recovery systems, heat tracing and jackets
11	**Hot fluids**				
11.01	Temperatures between 100 °C and 150 °C	WP	P	—	Glycol regeneration, low quality steam systems, cooling oils, galley
11.02	Temperatures greater than 150 °C	MH	P	—	Power boilers, steam generators, sulfur plants, waste heat recovery units, hot-oil heating systems, regeneration gases used with catalysts and desiccants
12	**Cold surfaces**				
12.01	Process piping between – 25 °C and – 80 °C	MH	P	—	Cold ambient climate, Joule-Thomson expansions (process and leaks), propane refrigeration systems, LPG gas plants
12.02	Process piping less than – 80 °C	MH	P	—	Cryogenic plants, LNG plants, LNG storage vessels including tankers, vapour lines off liquid nitrogen storage
13	**Cold fluids**				
13.01	Oceans, seas and lakes less than 10 °C	—	P	—	Northern and Southern oceans and lakes

Table D.1 (*continued*)

Hazard number	Hazard description	Safety	Health	Environ-mental	Sources
14	**Open flame**				
14.01	Heaters with fire tube	F	P	D	Glycol reboilers, amine reboilers, salt bath heaters, water bath heaters (line heaters)
14.02	Direct-fired furnaces	F	P	D	Hot oil furnace, Claus plant reaction furnace, catalyst and desiccant regeneration gas heaters, incinerators, power boilers
14.03	Flares	—	P	D	Pressure-relief and blowdown systems
15	**Electricity**				
15.01	Voltage > 50 V to 440 V in cables	MH	—	—	Power cables, temporary electrical lines on construction sites
15.02	Voltage > 50 V to 440 V in equipment	WP	—	—	Electric motors, electric switchgear, power generation, welding machines, transformer secondary
15.03	Voltage > 440 V	MH	—	—	Power lines, power generation, transformer primary, large electrical motors
15.04	Lightning discharge	WP	—	—	Major lightning-prone areas
15.05	Electrostatic energy	WP	—	—	Non-metallic storage vessels and piping, product transfer hoses, wiping rags, unearthed equipment, aluminium/steel, high-velocity gas discharges
16	**Electromagnetic radiation**				
16.01	Ultraviolet radiation	—	P	—	Arc welding, sunshine
16.02	Infrared radiation	—	P	—	Flares
16.03	Microwaves	—	P	—	Galley
16.04	Lasers	—	P	—	Instrumentation, surveying
16.05	E/M radiation: high voltage AC cables	—	P	—	Transformers, power cables
17	**Ionizing radiation — Open source**				
17.01	Alpha, beta — Open source	—	P	D	Well logging, radiography, densitometers, interface instruments
17.02	Gamma rays — Open source	—	P	D	Well logging, radiography
17.03	Neutron -— Open source	—	P	D	Well logging
17.04	Naturally occurring ionizing radiation	—	P	D	Scales in tubulars, vessels and process plant fluids (especially in C3 reflux streams)
18	**Ionizing radiation — Closed source**				
18.01	Alpha, beta — Closed source	—	P	—	Well logging, radiography, densitometers, interface instruments
18.02	Gamma rays — Closed source	—	P	—	Well logging, radiography
18.03	Neutron — Closed source	—	P	—	Well logging
19	**Asphyxiates**				
19.01	Insufficient oxygen atmospheres	—	C	—	Confined spaces, tanks
19.02	Excessive CO_2	—	C	D	Areas with CO_2 firefighting systems such as turbine enclosures
19.03	Drowning	—	C	—	Working overboard, marine seismic operations, water transport
19.04	Excessive N_2	—	C	—	N_2-purged vessels

Table D.1 (*continued*)

Hazard number	Hazard description	Safety	Health	Environ-mental	Sources
19.05	Halon	—	C	D	Areas with halon fire-fighting systems such as turbine enclosures and electrical switchgear and battery rooms
19.06	Smoke	—	C	D	Welding/burning operations, fires
20	**Toxic gas**				
20.01	H_2S (hydrogen sulfide, sour gas)	MH	C	D	Sour gas production, bacterial activity in stagnant water, confined spaces in sour operations
20.02	Exhaust fumes	—	C	D	Enclosed spaces
20.03	SO_2	—	C	D	Component of H_2S flare and incinerator flue gas
20.04	Benzene	—	C	D	Component of crude oil, concentrated in glycol vent emissions and Wemco units
20.05	Chlorine	MH	C	D	Water treatment facilities
20.06	Welding fumes	—	C	—	Construction and metal fabrication/repair, welding toxic metals (galvanized steel, cadmium-coated steel), metal cutting, grinding
20.07	Tobacco smoke	—	LS	—	Accommodation, office buildings, boats, aircraft
20.08	CFCs	—	—	D	Air conditioning, refrigeration, aerosol sprays
21	**Toxic liquid**				
21.01	Mercury	—	C	D	Electrical switches, gas filters
21.02	PCBs	—	C	D	Transformer cooling oils
21.03	Biocide (gluteraldehyde)	—	C	D	Water treatment systems
21.04	Methanol	—	C	D	Gas drying and hydrate control
21.05	Brines	—	C	D	Hydrocarbon production, well kill fluid, packer fluids
21.06	Glycols	—	C	D	Gas drying and hydrate control
21.07	Degreasers (terpenes)	—	C	D	Maintenance shops
21.08	Isocyanates	—	C	D	Two-pack paint systems
21.09	Sulfanol	—	C	D	Gas sweetening
21.10	Amines	—	C	D	Gas sweetening
21.11	Corrosion inhibitors	—	C	D	Additive to pipelines and oil/gas wells, chromates, phosphates
21.12	Scale inhibitors	—	C	D	Cooling and injection water additive
21.13	Liquid mud additives	—	C	D	Drilling fluid additive
21.14	Odorant additives (mercaptans)	—	C	D	Custody transfer facilities for gas, LPG and LNG
21.15	Alcohol-containing beverages	WP	LS	—	
21.16	Non-prescribed drugs	WP	LS	—	
21.17	Used engine oils (polycyclic aromatic hydrocarbons)	—	C	D	Used engine oils
21.18	Carbon tetrachloride	—	C	D	Plant laboratory
21.19	Grey and/or black water	—		D	Septic systems, camps, detergents
22	**Toxic solid**				
22.01	Asbestos	—	C	D	Thermal insulation and construction materials, old roofing (encountered during removal)
22.02	Man-made mineral fibre	—	C	D	Thermal insulation and construction material
22.03	Cement dust	—	C	D	Oil well and gas well cementing, civil construction
22.04	Sodium hypochlorite	—	C	D	Drilling fluid additive

Table D.1 (*continued*)

Hazard number	Hazard description	Safety	Health	Environ-mental	Sources
22.05	Powdered mud additives	—	C	D	Drilling fluid additive
22.06	Sulfur dust	—	C	D	Sulfur recovery plants
22.07	Pig trash	—	C	D	Pipeline cleaning operations
22.08	Oil-based muds	—	C	D	Oil and gas well drilling
22.09	Pseudo-oil-based muds	—	C	D	Oil and gas well drilling
22.10	Water-based muds	—	C	D	Oil and gas well drilling
22.11	Cement slurries	—	C	D	Oil and gas well drilling, plant construction
22.12	Dusts	—	C	D	Grit blasting, sand blasting, catalyst (dumping, screening, removal, drumming)
22.13	Cadmium compounds and other heavy metals	—	C	D	Welding fumes, handling coated bolts
22.14	Oil-based sludges	—	C	D	Oil storage tank cleaning
23	**Corrosive substances**				
23.01	Hydrofluoric acid	WP	C	D	Well stimulation
23.02	Hydrochloric acid	WP	C	D	Well stimulation
23.03	Sulfuric acid	WP	C	D	Wet batteries, regenerant for reverse-osmosis water makers
23.04	Caustic soda (sodium hydroxide)	—	C	D	Drilling fluid additive
24	**Biological hazards**				
24.01	Food-borne bacteria (e.g *E. coli*)	—	B	—	Contaminated food
24.02	Water-borne bacteria (e.g *Legionella*)	—	B	—	Cooling systems, domestic water systems
24.03	Parasitic insects (pin worms, bed bugs, lice, fleas)	—	B	—	Improperly cleaned food, hands, clothing, living sites (pin worms, bed bugs, lice, fleas)
24.04	Cold and flu virus	—	B	—	Other people
24.05	Human Immune deficiency Virus (HIV)	—	B	—	Contaminated blood, blood products and other body fluids
24.06	Other communicable diseases	—	B	—	Other people
25	**Ergonomic hazards**				
25.01	Manual materials handling	—	E	—	Pipe handling on drill floor, sack handling in sack store, manoeuvring equipment in awkward locations
25.02	Damaging noise	WP	P	Pr	Releases from relief valves, pressure control valves
25.03	Loud steady noise > 85 dBA	—	P	Pr	Engine rooms, compressor rooms, drilling brake, air tools
25.04	Heat stress (high ambient temperatures)	—	P	—	Near flare, on the monkey board under certain conditions, in open exposed areas in certain regions of the world during summer
25.05	Cold stress (low ambient temperatures)	—	P	—	Open areas in winter in cold climates, refrigerated storage areas
25.06	High humidity	—	P	—	Climates where sweat evaporation rates are too low to cool the human body, personal protective clothing
25.07	Vibration	—	P	Pr	Hand-tool vibration, maintenance and construction worker, boating
25.08	Workstations	—	E	—	Poorly designed office furniture and poorly laid out workstations
25.09	Lighting	—	P	Pr	Work areas requiring intense light, glare, lack of contrast, insufficient light

Table D.1 (*continued*)

Hazard number	Hazard description	Safety	Health	Environ-mental	Sources
25.10	Incompatible hand controls	—	E	—	Controls poorly positioned in workplace requiring workers to exert excessive force, lacking proper labels, hand-operated control valves, for example in driller house, heavy machinery, control rooms
25.11	Awkward location of workplaces and machinery	—	E	—	Machinery difficult to maintain regularly due to their awkward positioning, for example valves in an usually high or low position
25.12	Mismatch of work to physical abilities	—	E	—	Requiring older workers to maintain a high level of physical activity over the course of an 8/12 hour day, heavy construction work performed by slight individuals
25.13	Mismatch of work to cognitive abilities	—	E	—	Requiring individuals to monitor a process without trying to reduce their boredom by giving them a higher task load, asking a worker to supervise something he/she is not qualified to do
25.14	Long and irregular working hours/shifts	—	E	—	Offshore locations utilizing long shift cycles, overtime, night shifts, rollover shifts
25.15	Poor organization and job design	—	E	—	Ambiguity of job requirements, unclear reporting relationships, over-/under-supervision, poor operator/contractor interfaces
25.16	Work planning issues	—	E	—	Work overload, unrealistic targets, lack of clear planning, poor communications
25.17	Indoor climate (too hot/ cold/ dry/ humid, draughty)	—	E	—	Uncomfortable climate for permanently manned areas
26	**Psychological hazards**				
26.01	Living on the job/away from family	—	Psy	—	Homesickness, missing family and social events, unable to be involved in community, feeling of isolation and missing part of life. Drifting away from spouse and family, development of different interests and friends, threatened by spouse's independence, wind-down period at start of break. Inability to support spouse in domestic crisis. Difficult to turn off in leisure time
26.02	Working and living on a live plant	—	Psy	—	Awareness that mistakes can be catastrophic, vulnerable to the mistakes of others, responsible for the safety of others. Awareness of difficulty of escape in an emergency. Awareness of risks in helicopter travel, adverse weather.
26.03	Post traumatic stress	—	Psy	—	Serious incidents, injuries to self and others
26.04	Fatigue	—	Psy	—	Physically demanding or arduous work, long or excessive working hours.
26.05	Shift work	—	Psy	—	Construction, operations or drilling activities involving 24 hour working, saturation diving operations, changing rest and sleep patterns associated with activities.
26.06	Peer pressure	—	Psy	—	Pressure from others at the work location to behave in a manner which may affect well-being of the individual
27	**Security-related hazards**				
27.01	Piracy	Se	—	—	
27.02	Assault	Se	—	—	
27.03	Sabotage	Se	—	—	
27.04	Crisis (military action, civil disturbances, terrorism)	Se	—	—	
27.05	Theft, pilferage	Se	—	—	

Table D.1 (*continued*)

Hazard number	Hazard description	Safety	Health	Environ-mental	Sources
28	**Use of natural resources**				
28.01	Water	—	—	R	Cooling water
28.02	Air	—	—	R	Turbines, combustion engines (pump and compressor drivers)
29	**Medical**				
29.01	Medical unfitness	—	M	—	Medically unfit staff for the task
29.02	Motion sickness	—	M	—	Crew change on water, marine operations
30	**Noise**				
30.01	High-level noise	—	M	—	Plant areas, e.g. turbines, compressors, generators pumps blow down, etc.
30.02	Intrusive noise	—	Psy	—	Intrusive noise in sleeping areas, offices and recreational areas
31	**Entrapment**				
31.01	Fire / explosion	MH	—	—	Blockage of routes to muster location or contamination of muster area
31.02	Mechanical damage	WP	—	—	Objects blocking access / escape routes
31.03	Diving	WP	—	—	Snagging of lines / umbilicals

Tableau D.2 — Checklist of sources — Hazards — Effects

Source [a]	Routine hazards	Potential effects
Flare	CH_4	Global warming/climate change/atmospheric ozone increase
	SO_x	Acid deposition, water acidification
	NO_x	Atmospheric ozone increase/acid deposition
	N_2O	Global warming/stratosphere ozone depletion/climate change
	CO_2	Global warming/climate change
	CO	Health damage
	Noise	Nuisance/health damage
	Light	Nuisance/health effects
	H_2S	Health damage/odour nuisance
	Odorous compounds	Nuisance/odour
	Particulates	Health damage/ecological damage/soot deposition
	Radiation	Health damage/ecological
	Heat	Nuisance/ecological damage
	trace toxics – metals – PAH	Ecological/health damage
Energy-generating equipment – turbines – boilers/heaters – furnaces – transport (diesel, gasoline) – drilling, etc	CH_4	Global warming/climate change/atmospheric ozone increase
	SO_x	Acid deposition, water acidification, global cooling
	NO_x	Atmospheric ozone increase/acid deposition/fertilization
	N_2O	Global warming/stratosphere ozone depletion/climate change
	CO_2	Global warming/climate change
	CO	Health damage
	Noise	Nuisance/health damage/wildlife damage
	Light	Nuisance/health damage/wildlife damage
	Odorous compounds	Nuisance/odour
	Particulates/dust	Ecological damage/health damage/soot deposition
	Radiation	Ecological/health damage
	PAH	Ecological/health damage
	H_2S	Nuisance, health damage, ecological damage
	Heat	Health damage, ecological damage
	PCB	Health damage, ecological damage
	Trace toxics (e.g. catalysts, heavy metals, chemicals)	Health damage, ecological damage
Venting – tanker loading – production – pressure relief – glycol venting	CH_4	Global warming/climate change/atmospheric ozone increase
	VOC/C_xH_x	Atmospheric ozone increase/health damage/ecological damage
	Specific chemicals	Health damage/ecological damage
Refrigeration	CFC	Global warming/climate change/stratosphere ozone depletion
Fire extinguishers	Halons	Global warming/climate change/stratosphere ozone depletion
Fugitives – valves, pumps, etc.	CH_4	Global warming/climate change/atmospheric ozone increase
	VOC/CxHx/specific chemicals	Global warming/climate change/atmospheric ozone increase/ health damage/ ecological damage
Water, water-based mud Oil-based mud	Oil	Floating layer/unfit for drinking recreation/tainting of fish/biological damage
Aqueous effluents, site drains	Soluble organics/dissolved HC/BTEX	Tainting of fish, damage to aquatic organisms
Storm water run-off	Heavy metals	Accumulation in living organisms and sediments, adverse effects on organisms
Produced water	Salts	Biological damage

Tableau D.2 (*continued*)

Source [a]	**Routine hazards**	**Potential effects**
Cooling water	Barite (mud), drilling fluids, drilling cuttings	Smothering/damage to sea bed and biota
Tank-bottom water	Nutrients	Eutrophication
	Odour	Nuisance
	Chemicals/corrosion inhibitors/biocides/ fungicides	Damage to aquatic organisms
	Fresh-water discharge	Decreased salinity
	Suspended solids	Decreased transparency, damage to coral reefs, damage to and bottom organisms, recreation, habitat
	PAH	Damage to aquatic organisms
	Grease	Damage to bottom sediments
	Salts/brine	Increased salinity, damage to aquatic organisms
	Acids/caustics	Damage to aquatic organisms
	Temperature change	Change in oxygen concentration, damage to aquatic organisms, increased growth/blooms
	Detergents	Eutrophication/toxicity
Black water and/or grey water (sewage and wash water)	Pathogens	Health damage
	Anoxia (deoxygenation)	Biological damage
	Nutrients	Eutrophication
	Specific chemicals	Damage to aquatic organisms
	Odorous compounds	Nuisance odour/smell
Sacrificial anodes	Heavy metals	Damage to aquatic organisms
Detonators	Noise/pressure waves	Damage to aquatic organisms/repellent
Chemicals	Paints	Biological toxic or chronic damage/global warming
	Solvents	Health/biological toxic or chronic damage/global warming
	Cleaners	Biological toxic or chronic damage
Eroded materials	Soil sediments	Smothering, biological damage
Solid/liquid wastes, medical waste, spent catalyst	Hazardous wastes toxic substances	Water contamination
Household, food/kitchen and office waste	Organic and specific wastes pathogens	Water contamination damage to health
Human resources	Presence of workforce with different socio/cultural backgrounds during construction and operation; community intrusion	Socio/cultural effects; employment increase/decrease; demands on local resources/surfaces

Tableau D.2 (*continued*)

Source [a]	Routine hazards	Potential effects
Need for energy	Energy take – heaters/boilers – power generation – steam generation – cooling	Loss of energy resources
	Water take – cooling – process – drinking water – waste waters – recharge/pressure maintenance	Damage to wetlands
		Draw-down of ground-water level/damage to water-well users
		Impact on downstream users
Need for consumables	Use of nonrenewable raw materials	Depletion of raw materials
[a] Any indented (–) are covered by all aspects in the adjacent columns.		

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