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Petroleum, petrochemical and natural gas industries — Production assurance and reliability management

Industries du pétrole, de la pétrochimie et du gaz naturel — Assurance de la production et management de la fiabilité

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. 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 document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 20815 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*.

This corrected version of ISO 20815:2008 incorporates the following corrections:

— 3.1.13 “$(t + \Delta t)$” modified to “$[t, (t + \Delta t)]$”;

— 3.1.46, Equation (1) symbols and definitions modified;

— Clause G.2, Equation (G.2) symbols and definitions modified.

Introduction

The petroleum and natural gas industries involve large capital investment costs as well as operational expenditures. The profitability of these industries is dependent upon the reliability, availability and maintainability of the systems and components that are used. Therefore, for optimal production availability in the oil and gas business, a standardized, integrated reliability approach is required.

The concept of production assurance, introduced in this International Standard, enables a common understanding with respect to use of reliability technology in the various life-cycle phases and covers the activities implemented to achieve and maintain a performance level that is at its optimum in terms of the overall economy and, at the same time, consistent with applicable regulatory and framework conditions.

Annexes A through I are for information only.

Petroleum, petrochemical and natural gas industries — Production assurance and reliability management

1 Scope

This International Standard introduces the concept of production assurance within the systems and operations associated with exploration drilling, exploitation, processing and transport of petroleum, petrochemical and natural gas resources. This International Standard covers upstream (including subsea), midstream and downstream facilities and activities. It focuses on production assurance of oil and gas production, processing and associated activities and covers the analysis of reliability and maintenance of the components.

It provides processes and activities, requirements and guidelines for systematic management, effective planning, execution and use of production assurance and reliability technology. This is to achieve cost-effective solutions over the life cycle of an asset-development project structured around the following main elements:

— production-assurance management for optimum economy of the facility through all of its life-cycle phases, while also considering constraints arising from health, safety, environment, quality and human factors;

— planning, execution and implementation of reliability technology;

— application of reliability and maintenance data;

— reliability-based design and operation improvement.

For standards on equipment reliability and maintenance performance in general, see the IEC 60300-3 series.

This International Standard designates 12 processes, of which seven are defined as core production-assurance processes and addressed in this International Standard. The remaining five processes are denoted as interacting processes and are outside the scope of this International Standard. The interaction of the core production-assurance processes with these interacting processes, however, is within the scope of this International Standard as the information flow to and from these latter processes is required to ensure that production-assurance requirements can be fulfilled.

This International Standard recommends that the listed processes and activities be initiated only if they can be considered to add value.

The only requirements mandated by this International Standard are the establishment and execution of the production-assurance programme (PAP).

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14224:2006, *Petroleum, petrochemical and natural gas industries — Collection and exchange of reliability and maintenance data for equipment*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purpose of this document, the following terms and definitions apply.

3.1.1
availability
ability of an item to be in a state to perform a required function under given conditions at a given instant of time, or in average over a given time interval, assuming that the required external resources are provided

See Figure G.1 for further information.

3.1.2
common cause failure
failures of different items resulting from the same direct cause, occurring within a relatively short time, where these failures are not consequences of each other

3.1.3
corrective maintenance
maintenance that is carried out after a fault recognition and intended to put an item into a state in which it can perform a required function

See IEC 60050-191:1990, Figure 191-10 [2], for more specific information.

3.1.4
deliverability
ratio of deliveries to planned deliveries over a specified period of time, when the effect of compensating elements, such as substitution from other producers and downstream buffer storage, is included

See Figure G.1 for further information.

3.1.5
design life
planned usage time for the total system

NOTE Design life should not be confused with **MTTF** (3.1.25), which is comprised of several items that may be allowed to fail within the design life of the system as long as repair or replacement is feasible.

3.1.6
down state
internal disabled state of an item characterized either by a fault or by a possible inability to perform a required function during preventive maintenance [2]

NOTE This state is related to availability performance.

3.1.7
downtime
time interval during which an item is in a non-working state [2]

NOTE The downtime includes all the delays between the item failure and the restoration of its service. Downtime can be either planned or unplanned.

3.1.8
downstream
business process, most commonly in the petroleum industry, associated with post-production activities

EXAMPLES Refining, transportation and marketing of petroleum products.

3.1.9
failure
termination of the ability of an item to perform a required function

NOTE 1 After failure, the item has a fault.

NOTE 2 "Failure" is an event, as distinguished from "fault", which is a state.

3.1.10
failure cause
root cause
circumstances during design, manufacture or use that have led to a failure [2]

NOTE Generic failure cause codes applicable for equipment failures are defined in ISO 14224:2006, B.2.3.

3.1.11
failure data
data characterizing the occurrence of a failure event

3.1.12
failure mode
effect by which a failure is observed on the failed item

NOTE Failure-mode codes are defined for some equipment classes in ISO 14224:2006, B.2.6.

3.1.13
failure rate
limit, if this exists, of the ratio of the conditional probability that the instant of time, T, of a failure of an item falls within a given time interval, $(t + \Delta t)$ and the length of this interval, Δt, when Δt tends to zero, given that the item is in an up state at the beginning of the time interval

See ISO 14224:2006, Clause C.3 for further explanation of the failure rate.

NOTE 1 In this definition, t may also denote the time to failure or the time to first failure.

NOTE 2 A practical interpretation of failure rate is the number of failures relative to the corresponding operational time. In some cases, time can be replaced by units of use. In most cases, the reciprocal of **MTTF** (3.1.25) can be used as the predictor for the failure rate, i.e. the average number of failures per unit of time in the long run if the units are replaced by an identical unit at failure.

NOTE 3 The failure rate can be based on operational time or calendar time.

3.1.14
fault
state of an item characterized by inability to perform a required function, excluding the inability during preventive maintenance or other planned actions, or due to lack of external resources [2]

NOTE A fault is often a result of a failure of the item itself but the state can exist without a failure.

3.1.15
fault tolerance
attribute of an item that makes it able to perform a required function in the presence of certain given sub-item faults [2]

3.1.16
item
any part, component, device, subsystem, functional unit, equipment or system that can be individually considered [2]

3.1.17
logistic delay
accumulated time during which maintenance cannot be carried out due to the necessity to acquire maintenance resources, excluding any administrative delay [29]

NOTE Logistic delays can be due to, for example, travelling to unattended installations; pending arrival of spare parts, specialist, test equipment and information; or delays due to unsuitable environmental conditions (e.g. waiting on weather).

3.1.18
lost revenue
LOSTREV
total cost of lost or deferred production due to downtime

3.1.19
maintainable item
item that constitutes a part, or an assembly of parts, that is normally the lowest level in the equipment hierarchy during maintenance

See ISO 14224:2006, Annex A, for examples of maintainable items for a variety of equipment.

3.1.20
maintenance
combination of all technical and administrative actions, including supervisory actions, intended to retain an item in, or restore it to, a state in which it can perform a required function [2]

3.1.21
maintenance data
data characterizing the maintenance action planned or done

3.1.22
maintainability
⟨general⟩ ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources [2]

See Figure G.1 for further information.

3.1.23
maintenance support performance
ability of a maintenance organization, under given conditions, to provide upon demand, the resources required to maintain an item, under a given maintenance policy [2]

NOTE The given conditions are related to the item itself and to the conditions under which the item is used and maintained.

3.1.24
mean time between failures
MTBF
expectation of the time between failures [2]

NOTE The MTBF of an item can be longer or shorter than the design life of the system.

3.1.25
mean time to failure
MTTF
expectation of the time to failure [2]

NOTE The MTTF of an item can be longer or shorter than the design life of the system.

3.1.26
mean time to repair
MTTR
expectation of the time to restoration [2]

3.1.27
midstream
business category involving the processing, storage and transportation sectors of the petroleum industry

EXAMPLES Transportation pipelines, terminals, gas processing and treatment, LNG, LPG and GTL.

3.1.28
modification
combination of all technical and administrative actions intended to change an item [2]

3.1.29
observation period
time period during which production performance and reliability data are recorded

3.1.30
operating state
state when an item is performing a required function [2]

3.1.31
operating time
time interval during which an item is in an operating state [2]

3.1.32
performance objectives
indicative level for the desired performance

NOTE Objectives are expressed in qualitative or quantitative terms. Objectives are not absolute requirements and may be modified based on cost or technical constraints.

3.1.33
performance requirements
required minimum level for the performance of a system

NOTE Requirements are normally quantitative but may also be qualitative.

3.1.34
petrochemicals
business category producing the chemicals derived from petroleum and used as feedstock for the manufacture of a variety of plastics and other related products

EXAMPLES Methanol, polypropylene.

3.1.35
preventive maintenance
maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item [2]

3.1.36
production-performance analysis
systematic evaluations and calculations carried out to assess the production performance of a system

NOTE The term should be used primarily for analysis of total systems, but may also be used for analysis of production unavailability of a partial system.

3.1.37
production assurance
activities implemented to achieve and maintain a performance that is at its optimum in terms of the overall economy and at the same time consistent with applicable framework conditions

3.1.38
production availability
ratio of production to planned production, or any other reference level, over a specified period of time

NOTE This measure is used in connection with analysis of delimited systems without compensating elements such as substitution from other producers and downstream buffer storage. Battery limits need to be defined in each case.

See Figure G.1 for further information.

3.1.39
production performance
capacity of a system to meet demand for deliveries or performance

NOTE 1 Production availability, deliverability or other appropriate measures can be used to express production performance.

NOTE 2 The use of production-performance terms should specify whether it represents a predicted or historic production performance.

3.1.40
redundancy
existence of more than one means for performing a required function [2]

3.1.41
reliability
ability of an item to perform a required function under given conditions for a given time interval [2]

NOTE 1 The term “reliability” is also used as a measure of reliability performance and may also be expressed as a probability.

NOTE 2 See Figure G.1 for further information.

3.1.42
reliability data
data for reliability, maintainability and maintenance support performance

NOTE Reliability and maintainability (RM) data is the term applied by ISO 14224:2006.

3.1.43
required function
function, or combination of functions, of an item that is considered necessary to provide a given service [2]

3.1.44
risk
combination of the probability of an event and the consequences of the event [20]

3.1.45
risk register
tool to log, follow up and close out relevant risks

NOTE Each entry in the risk register should typically include

— description of the risk,

— description of the action(s),

- responsible party,
- due date,
- action status.

3.1.46
survival probability
$R(t)$
likelihood of the continued functioning of an item, as given by Equation (1):

$$R(t) = f_{\text{Pr}}(T > t) \quad (1)$$

where

f_{Pr} is a probability function;

T is the time to failure of an item;

t is a time equal to or greater than 0.

3.1.47
up state
state of an item characterized by the fact it can perform a required function, assuming that the external resources, if required, are provided [2]

NOTE This relates to availability performance.

3.1.48
upstream
business category of the petroleum industry involving exploration and production

EXAMPLES Offshore oil/gas production facility, drilling rig, intervention vessel.

3.1.49
uptime
time interval during which an item is in the up state [2]

3.1.50
variability
variations in performance measures for different time periods under defined framework conditions

NOTE The variations can be a result of the downtime pattern for equipment and systems or operating factors, such as wind, waves and access to certain repair resources.

3.2 Abbreviations

BOP	blowout preventer
CAPEX	capital expenditures
ESD	emergency shut down
FMEA	failure modes and effects analysis
FMECA	failure modes, effects and criticality analysis
FNA	flow-network analysis
FTA	fault-tree analysis

GTL	gas to liquid
HAZID	hazard identification
HAZOP	hazard and operability study
HSE	health, safety, environment
LCC	life-cycle cost
LNG	liquefied natural gases
LOSTREV	lost revenue
LPG	liquefied petroleum gases
MPA	Markov process analysis
MTBF	mean time between failure
MTTF	mean time to failure
MTTR	mean time to repair
OPEX	operational expenditure
PAP	production-assurance programme
PNA	petri net analysis
POR	performance and operability review
RBD	reliability block diagram
RBI	risk-based inspection
RCM	reliability-centred maintenance
ROV	remote operated vehicle
SIMOPS	simultaneous operations
SRA	structural-reliability analysis
QA	quality assurance

4 Production assurance and decision support

4.1 Framework conditions

The objective associated with systematic production assurance is to contribute to the alignment of design and operational decisions with corporate business objectives.

In order to fulfil this objective, technical and operational measures as indicated in Figure 1 may be used during design or operation to change the production performance. Figure 1 shows 21 factors that to a greater or lesser degree can have an effect on production performance. Some of these factors are purely technical and it is necessary that they be adhered to in design; others are related purely to operation. Most of the factors have both technical and operational aspects, e.g. a bypass cannot be used in the operational phase unless provisions have been made for it in the design phase. In addition, there are dependencies between many of the listed factors.

This imposes two important recommendations for production assurance to be efficient.

— Production assurance should be carried out throughout all project design and operational phases.

— Production assurance should have a broad coverage of project activities.

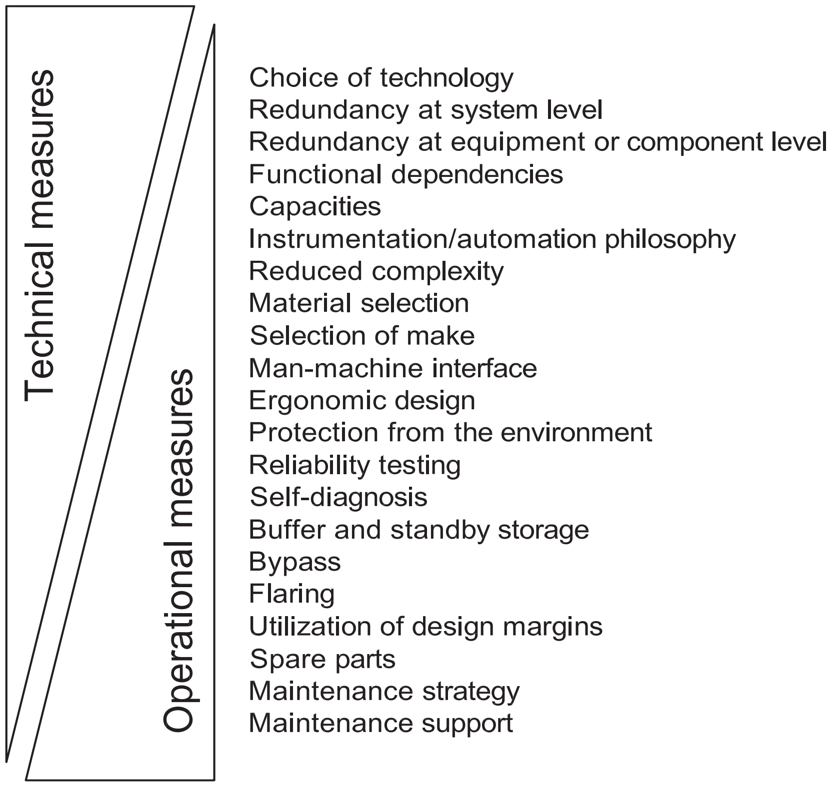


Figure 1 — Design and operational measures that affect production performance

4.2 Optimization process

The main principle for optimization of design or selection between alternative design solutions is economic optimization within given constraints and framework conditions. The achievement of high performance is of limited importance unless the associated costs are considered. This International Standard can, therefore, be considered together with ISO 15663 (all parts).

Examples of constraints and framework conditions that affect the optimization process are

— statutory health, safety and environmental regulations;

— requirements for safety equipment resulting from the risk analysis and the overall safety acceptance criteria;

— requirements to design or operation given by statutory and other regulatory bodies' regulations;

— project constraints, such as budget, implementation time, national and international agreements;

— conditions in the sales contracts;

— technical constraints.

The optimization process can be seen as a series of steps as follows (see Figure 2 for an illustration).

a) Assess the project requirements and generate designs that are capable of meeting the project requirements.

b) Identify all statutory, regulatory and other framework requirements that apply to the project.

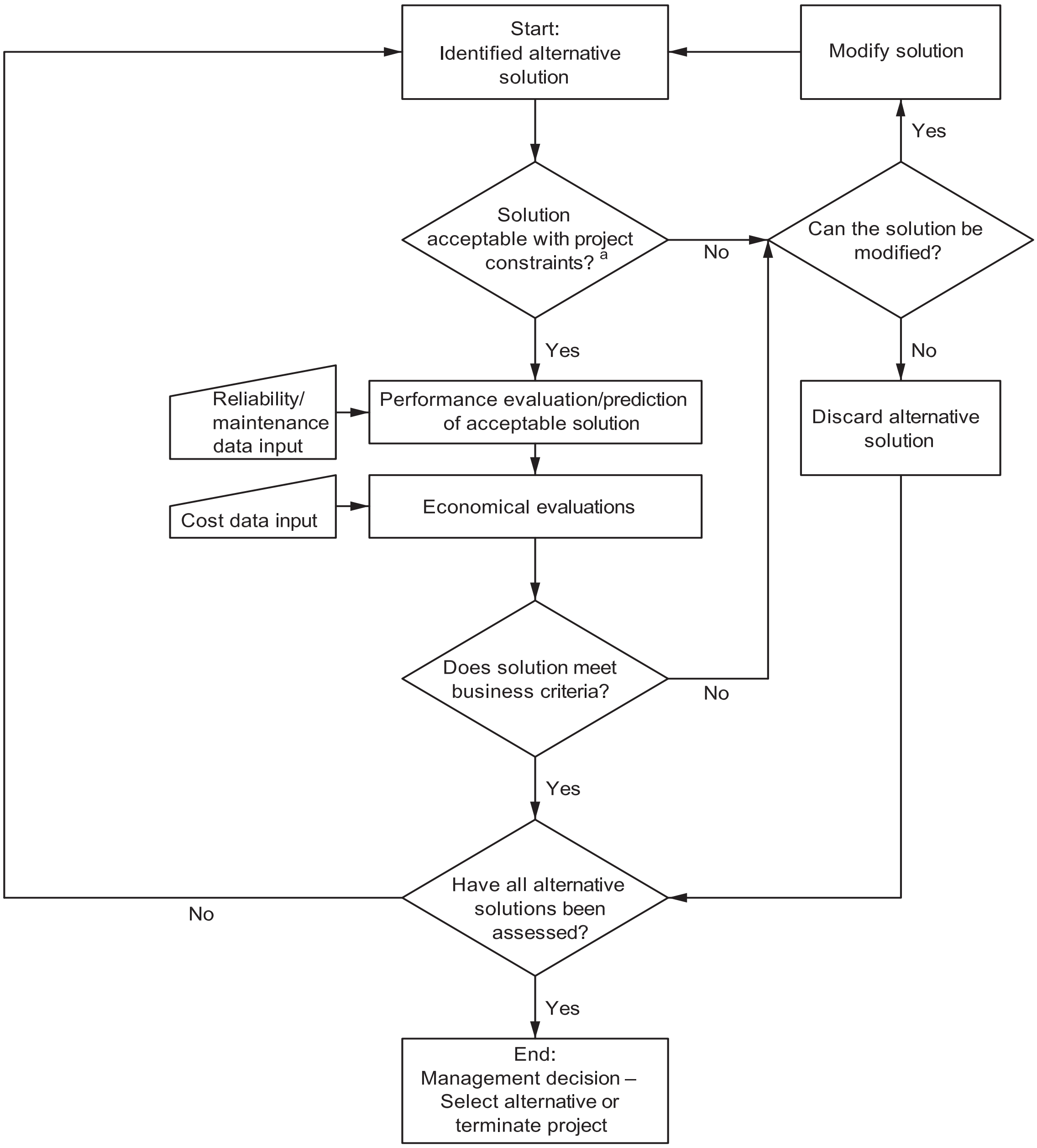
c) Predict the appropriate production-assurance parameters.

d) Identify the preferred design solution based on an economical evaluation/analysis, such as net present value analysis or another optimization criterion.

e) Apply the optimization process as illustrated in Figure 2. Be aware that the execution of the optimization process requires that the production assurance and reliability function be addressed by qualified team members.

f) If required, the process can be iterative, where the selected alternative is further refined and alternative solutions identified. The iterative process is typical for “gated” or threshold project-execution phases.

g) Sensitivity analyses may be performed to take account of uncertainty in important input parameters.



[a] Typical project constraints include HSE requirements; technical feasibility; compliance with acts, rules and regulations; economical constraints; schedule constraints.

Figure 2 — Optimization process

4.3 Production-assurance programme

4.3.1 Objectives

A production-assurance programme (PAP) shall serve as a management tool in the process of complying with this International Standard. It may be either a document established for the various life-cycle phases of a new asset-development project or a document established for assets already in operation. As production assurance is a continuous activity throughout all life-cycle phases, it shall be updated as and when required. It may contain the following:

— systematic planning of production-assurance work within the scope of the programme;

— definition of optimization criteria;

- definition of performance objectives and requirements, if any;
- description of the production-assurance activities necessary to fulfil the objectives, how they are carried out, by whom and when;
- statements and considerations on interfaces of production assurance and reliability with other activities;
- methods for verification and validation;
- a level of detail that facilitates easy updating and overall coordination.

Annex A of this International Standard suggests a model for the production-assurance programme (PAP) contents.

The PAP is the only mandatory deliverable from this International Standard.

The life-cycle phases indicated in Table 2 apply for a typical asset-development project. If the phases in a specific project differ from those below, the activities should be defined and applied as appropriate.

Major modifications may be considered as a project with phases similar to those of an asset-development project. The requirements to production-assurance activities as given for the relevant life-cycle phases apply.

4.3.2 Project risk categorization

It is necessary to define the level of effort to invest in a production-assurance program to meet the business objectives for each life-cycle phase. In practice, the production-assurance effort required is closely related to the level of technical risk in a project. It is, therefore, recommended that one of the first tasks to be performed is an initial categorization of the technical risks in a project. This enables project managers to make a general assessment of the level of investment in reliability resources that may have to be made in a project.

The project risk categorization typically varies depending on a number of factors such as financial situation, risk attitude, etc. Hence, specific risk categorization schemes may be established. However, to provide some guidance on the process, a simple risk categorization scheme is outlined below.

Projects can be divided into three risk classes:

- high risk;
- medium risk;
- low risk.

The features that describe the three risk classes are further outlined in Table 1. Typically, there is a gradual transition from one risk class to another. Hence, a certain degree of subjective assessment is required. However, the justification for the selected risk class for a project should be included in the production-assurance programme issued during the feasibility or concept phase.

The project risk categorization (high, medium and low) is further applied in Table 2 (see 4.3.3) to indicate what processes should be performed for the different project categories.

Table 1 — Project risk categorization

Technology	Operating envelope	Technical system scale and complexity	Organizational scale and complexity	Risk class [a]	Description
Mature technology	Typical operating conditions	Small scale, low complexity, minimal change of system configuration	Small and consistent organization, low complexity	Low	Low-budget, low-risk project using field-proven equipment in the same configuration and with the same team under operating condition similar to previous projects.
Mature technology	Typical operating conditions	Moderate scale and complexity	Small to medium organization, moderate complexity	Low or medium	Low- to moderate-risk project using field-proven equipment in an operating envelope similar to previous projects but with some system and organizational complexity.
Novel or non-mature technology for a new or extended operating environment	New, extended or aggressive operating environment	Large scale, high complexity	Large organization, high complexity	Medium or high [b]	Moderate- to high-risk project using either novel or non-mature equipment or with new or extended operating conditions. Project involves large, complex systems and management organizations.

[a] The term “low or medium” indicates that projects comprising the indicated features can be classified as either low-risk or medium-risk projects, likewise for the term “medium or high”.

[b] The novel or non-mature technology should have a potential significant impact on the project outcome to be classified as high-risk.

4.3.3 Programme activities

Production-assurance activities should be carried out in all phases of the life cycle of facilities to provide input to decisions regarding feasibility, concept, design, manufacturing, construction, installation, operation, maintenance and modification. Processes and activities shall be initiated only if they are considered to contribute to added value of the project.

The production-assurance activities specified in the PAP shall be defined in view of the actual needs, available personnel resources, budget framework, interfaces, milestones and access to data and general information. This is necessary to reach a sound balance between the cost and benefit of the activity.

Production assurance should consider organizational and human factors as well as technical aspects.

Important tasks of production assurance are to monitor the overall performance level, manage reliability and the continuous identification of the need for production-assurance activities. A further objective of production assurance is to contribute technical, operational or organizational recommendations.

The processes and activities specified in the PAP shall focus on the main technical risk items initially identified through a top-down screening process (see 4.3.2). A risk-classification activity can assist in identifying performance-critical systems that should be subject to more detailed analysis and follow-up.

The emphasis of the production-assurance activities changes for the various life-cycle phases. Early activities should focus on optimization of the overall configuration, while attention to critical detail increases in the later phases.

In the feasibility and concept phases, the field layout configuration should be identified. This also includes defining the degree of redundancy (fault tolerance), overcapacity and flexibility, on a system level. This requires establishing the CAPEX, OPEX, LOSTREV, expected cost or benefit of risks and revenue for each alternative.

These financial values are, in turn, fed back into the operators’ profitability tools, for evaluation of profitability and selection of the alternative that best fits with the attitude towards risk. Optimal production availability for field layouts requires that overemphasis on CAPEX is avoided, and it is recommended that this be achieved through long-term partnering between suppliers and operators, as well as between suppliers and their sub-suppliers. Such long-term relationships ensure mutual confidence and maturing of the technology. Early direct involvement of the above parties with focus on the overall revenue in a life-cycle perspective is advised. This means, for example, implementing the resulting recommendations as specifications in the invitations to tender.

An overview of the production-assurance processes is given in Table 2 and Clause 5, while descriptions of the recommended activities for the processes are given in Annex B and Annex C.

The production-assurance processes defined in this International Standard are divided into two main classes: core processes and interacting processes. The main reason for this split is to indicate for which processes a potential production-assurance discipline is normally responsible and for which processes other disciplines (e.g. project management, QA, etc.) are normally responsible. However, all processes can be equally important to ensure success.

Table 2 provides recommendations (indicated by an “X”) on which processes should be performed as a function of the project risk categorization (see 4.3.2). The table also provides recommendations (indicated by an “X”) as to when the processes should be applied (in what life-cycle phase).

Production-assurance requirements (process 1) can be used to illustrate the interpretation of the table. This process, which is further described in Annex B, should be implemented for medium- and high-risk projects, and performed in the feasibility, concept design, engineering and procurement life-cycle phases.

Table 2 — Overview of production-assurance processes versus risk levels and life-cycle phases

Production-assurance processes for asset development				Life-cycle phase						
				Pre-contract award		Post-contract award				
Low-risk projects	Medium-risk projects	High-risk projects	Process name and number [c]	Feasibility	Conceptual design [a]	Engineering [b]	Procurement	Fabrication/Assembly/Testing	Installation and commissioning	Operation
—	X	X	1. Production-assurance requirements	X	X	X	X	—	—	—
X	X	X	2. Production-assurance planning	X	X	X	X	X	X	x
—	X	X	3. Design and manufacture for production assurance	—	X	X	—	X	X	X
X	X	X	4. Production assurance	X	X	X	X	X	X	X
—	X	X	5. Risk and reliability analysis	X	X	X	—	—	—	—
X	X	X	6. Verification and validation	X	X	X	—	—	—	—
X	X	X	7. Project risk management	X	X	X	X	X	X	X
—	—	X	8. Qualification and testing		X	X	X	X		
X	X	X	9. Performance data tracking and analysis	—	—	—	—	—	X	X
—	—	X	10. Supply-chain management	—	—	—	X	—	—	—
X	X	X	11. Management of change	—	X	X	X	X	X	X
X	X	X	12. Organizational learning	X	X	X	X	X	X	X

[a] Including front-end engineering and design (FEED).

[b] Including pre-engineering and detailed engineering.

[c] The following production-assurance processes are within the main scope of work for this International Standard: 1, 2, 3, 4, 5, 6 and 9.

NOTE It should be noted that a process can be applicable for a certain risk class or life-cycle phase although no “X” is indicated in this table. Likewise, if it can be argued that a certain process does not add value to a project, it may be omitted.

4.4 Alternative standards

There are a number of national standards and International Standards and guidelines that support and direct the implementation of production assurance and reliability activities in projects.

Table 3 shows how the production-assurance and reliability processes described within this International Standard link to some of these standards. Work processes carried out in accordance with these standards can be considered to also satisfy the requirements for relevant processes in this International Standard.

The alternative standards listed in Table 3 are not normative for this International Standard.

The list of standards in Table 3 is non-exhaustive. Other standards may also cover specific requirements in this International Standard. If alternative standards are referred to for compliance to specific requirements, it is the responsibility of the user to demonstrate such compliance.

Table 3 — Alternative standards

Standard	1. Production-assurance requirements	2. Production-assurance planning	3. Design and manufacture for production assurance	4. Production assurance	5. Risk and reliability analysis	6. Verification and validation	7. Project risk management	8. Qualification and testing	9. Performance data tracking and analysis	10. Supply chain management	11. Management of change	12. Organizational learning
IEC 60300-1 [3]	X	X	—	—	—	—	—	—	—	—	—	—
IEC 60300-2 [4]	—	X	—	X	—	X	—	—	—	—	—	—
IEC 60300-3-2 [5]	—	—	—	—	—	—	—	—	X	—	—	—
IEC 60300-3-4 [7]	X	—	—	—	—	X	—	—	—	—	—	—
IEC 60300-3-9 [30]	—	—	—	—	X	—	X	—	—	—	—	—
IEC 60300-3-14 [9]	—	—	—	—	X	—	—	—	—	—	—	—
DNV-RP-A203 [22]	—	—	—	—	—	—	—	X	—	—	—	—
API RP 17N [32]	X	X	X	X	X	X	X	X	X	X	X	X

5 Production-assurance processes and activities

The production-assurance processes defined in this International Standard are divided into two main classes, i.e. core processes and interacting processes. The main reason for this split is to indicate for which processes a potential production-assurance discipline is normally responsible and for which processes other disciplines (e.g. project management, QA, etc.) are normally responsible.

Annex B provides recommendations for the core production-assurance processes and activities that may be carried out as part of a production-assurance program in the various life-cycle phases of a typical asset-development project.

Projects other than asset developments, e.g. drilling units, transportation networks, major modifications, etc., have phases that more or less coincide with those described in the following. The activities carried out can, however, differ from those described.

Hence, the production-assurance program may be adapted for each part involved to ensure that it fulfils the business needs.

In addition to the core production-assurance processes and activities described in Annex B, a number of interacting processes is described in Annex C. These processes are normally outside the responsibility of the production-assurance discipline, but information flow to and from these processes is required to ensure that production-performance and reliability requirements can be fulfilled.

Figure 3 illustrates which processes are defined as core production-assurance processes and which are considered interacting processes. Details regarding objectives, input, output and activities for each of the processes are further described in Annexes B and C.

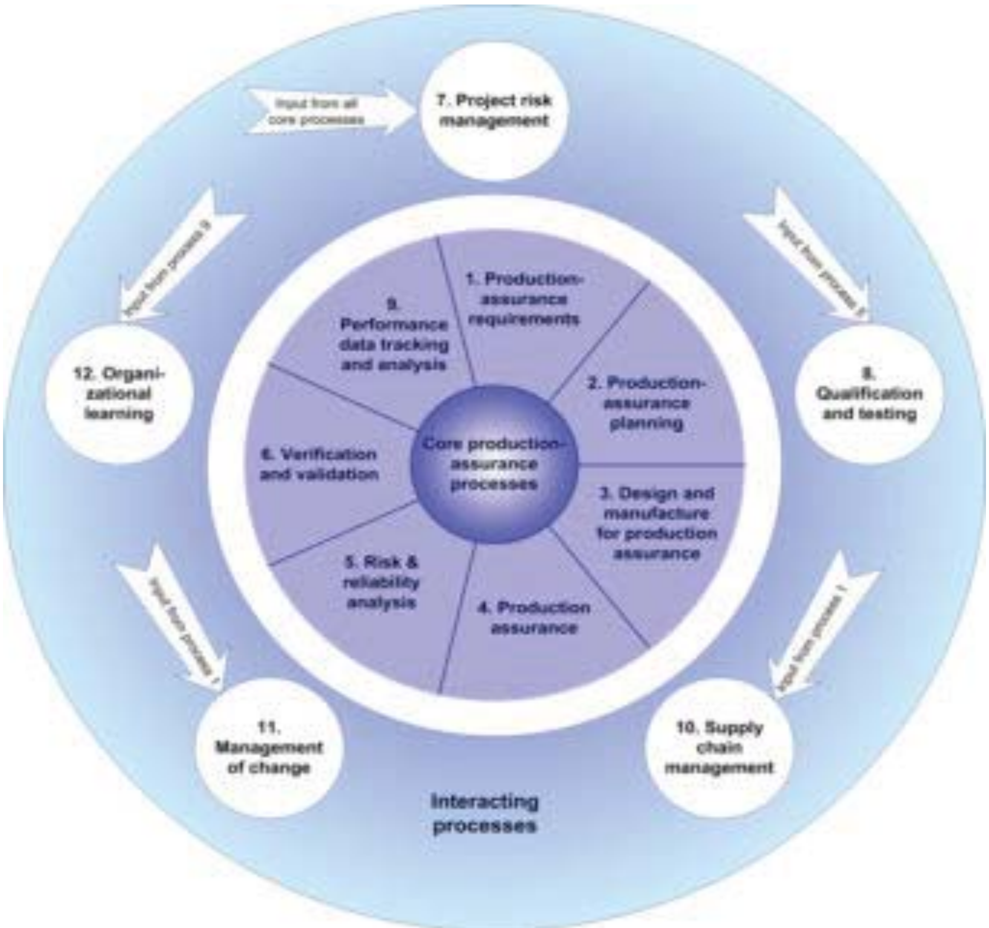


Figure 3 — Core and interacting production-assurance processes

Annex A
(informative)

Contents of production-assurance programme (PAP)

A.1 General

This International Standard introduces the concept of production assurance (see Scope) and provides processes and activities that culminate in a production-assurance programme (PAP) document (see 4.3.1). This annex suggests a model for that document. A PAP (see 4.3) should cover the topics covered in A.2 through A.8.

A.2 Title

Production-assurance programme (PAP) for ..... [insert the description of the project].

A.3 Terms of reference

A general description of the PAP similar to the following may be given:

a) purpose and scope;

b) system boundaries and life-cycle status;

c) revision control showing major changes since last update;

d) distribution list which, depending on the content, shows which parties receive all or parts of the PAP.

A.4 Production-assurance philosophy and performance objectives

A description of the philosophy and performance objectives similar to the following may be given:

a) description of overall optimization criteria (see 4.2);

b) definition of performance objectives and requirements (see Annex F) with references to performance targets, objectives and requirements in contract documents and any separate documents that may further specify the targets, objectives and requirements, e.g. loss categories and battery limits to define what is included and what is excluded in the targets;

c) definition of performance measures.

A.5 Project risk categorization

A description of the project risk categorization (see 4.3.2) should be included in the PAP to justify the selection of production-assurance programme activities.

A.6 Organization and responsibilities

A description of the production-assurance organization with corresponding authorities and responsibilities should be clearly stated in the PAP. Descriptions similar to the following may be given:

a) description of the organization and responsibilities, focusing on production performance, internal and external communication, responsibilities given to managers and key personnel, functions, disciplines, sub-projects, contractors and suppliers;

b) description of the action management system, defining how the production-assurance activities recommendations and actions are communicated, evaluated and implemented;

c) description of the verification and validation functions specifying planned third-party verification activities related to production assurance/reliability (if any).

A.7 Activity schedule

A description of the activity schedules similar to the following may be given:

— overview of the production-assurance activities during life-cycle phases, which may contain a table similar to Table 2 to indicate past and future production-assurance activities;

— list of the plans or references to other documents containing the plans for production assurance/reliability activities showing the main project milestones and interfacing activities;

— clear statements of the relationship between the various production-assurance activities, e.g. input/output relationship, timing, etc.

A.8 References

References are made to key project documentation and relevant corporate or company standards.

Annex B
(informative)

Core production-assurance processes and activities

B.1 Production-assurance requirements — Process 1

This process is administrative by nature and supports the economical optimization process (see 4.2) aiming at formulating production-assurance requirements. The main activity for this process is related to communication among relevant parties. Production-assurance process 1 is described in Table B.1.

Unnecessary limitations in the form of unfounded performance requirements should be avoided to prevent otherwise favourable alternatives from being rejected during the optimization process.

Optimal production availability in the oil and gas business requires a standardized, integrated reliability approach, as this clause provides for asset development.

This is an economic optimization problem, with defined framework conditions and constraints. This optimization problem involves both production-assurance and interfacing processes.

The constraints from other disciplines as outlined in Figure 2 should be considered together with relevant performance measures (see Annex G) in the optimization process.

In the feasibility and concept phases, the asset configuration should be identified. This also includes the degree of redundancy (fault tolerance), overcapacity and flexibility, on a system level. This requires establishing the CAPEX, OPEX, LOSTREV, expected cost or benefit of risks and revenue for each alternative. These financial values are, in turn, fed back into the operators' profitability tools, for evaluation of economical viability and selection of the alternative that best fits with the attitude towards risk. Optimal production availability for field layouts requires that overemphasis on CAPEX be avoided, and it is recommended that this be achieved through long-term partnering between suppliers and operators, as well as between suppliers and their sub-suppliers. Such long-term relationships ensure mutual confidence and maturing of the technology together. Early, direct intervention of the above parties with focus on the overall revenue in a life-cycle perspective is advised. This means, for example, implementing the resulting recommendations as specifications in tender documents.

Table B.1 — Production-assurance requirements — Process 1

Process elements	Life-cycle phase(s)			
	Feasibility	**Conceptual design**	**Engineering**	**Procurement**
Objective	Provide tentative production-assurance requirements for various asset-development options	Provide production-assurance requirements for the selected asset-development option(s)	Allocate the production-assurance requirements from the concept phase to the subsystems, as required	Ensure that the relevant manufacturers at each level of the supply chain understand what reliability is required, and with which reliability standards to comply
Input	Alternative asset-development plans	The selected asset-development plan, with the estimated production availability formulated as a system requirement in the invitation to tender Alternative field-layout configurations Production-availability analysis	Output from the concept phase	Output from the engineering phase
Production-assurance activities	Identify additional constraints Initiate estimation of the production availability for the asset-development options specified as input on a system level Planning, reporting and follow-up for the requirements	Initiate estimation of the production availability for the asset-development options These estimates are aggregated from each main supplier's scope of supply, as defined by the asset development Planning, reporting and follow-up for the requirements	Define and allocate the production-assurance requirements to the subsystems, as required This definition is based on the production-availability analysis Planning, reporting and follow-up for the requirements	Ensure that the reliability requirements are included in the tender documents, through interfacing with the procurement organization Planning, reporting and follow-up for the requirements
Output	Production-availability estimates for the asset-development options specified as input Estimated production availability for each option, formulated as a system requirement for the option to be selected Other relevant qualitative or quantitative production-assurance requirements	Production-availability estimates for the asset-development options specified as input, allocated according to each main supplier's scope of supply Other relevant qualitative or quantitative production-assurance requirements	Subsystem production-availability requirements for the selected option, as required This includes the applied subsystem reliability data Other relevant qualitative or quantitative production-assurance requirements	Subsystem reliability requirements, including with which reliability standards to comply Other relevant qualitative or quantitative production-assurance requirements

Specification of performance objectives and requirements are further described in Annex F.

B.2 Production-assurance planning — Process 2

This process is relevant for all life-cycle phases and relates to planning and management of the production-assurance process. The main production-assurance management tool shall be the production-assurance programme (PAP).

An overall PAP for an asset may be considered to coordinate or replace separate project PAPs on lower levels.

Further requirements for the PAP are described in 4.3 and in Annex A. Production-assurance process 2 is described in Table B.2.

Table B.2 — Production-assurance planning — Process 2

Process elements	Life-cycle phase(s) All
Objective	To establish and maintain a production-assurance programme (PAP) (see 4.3) to ensure that the production-assurance requirements are fulfilled
Input	Project plans. Required to schedule the production-assurance activities before decisions are made and after the required information is established Project risk categorization Output from process 1 production-assurance requirements (see Clause B.1)
Production-assurance activities	A production-assurance programme (PAP) shall be established and updated for asset-development projects. The required contents of the PAP are the production-assurance performance objectives, organization and responsibilities and activity schedules (see Annex A). The core of the production-assurance program defines the activities required to comply with the constraints (see Figure 3) and the production-assurance requirements (see Clause B.1). I.e., this activity requires scheduling of the tabulated production-assurance activities for the relevant risk level and project phase. The production-assurance activities should be performed in a timely manner in order to support decisions before they are made. The extent of the production-assurance programme (i.e. amount of planned activity) should be based on the project risk categorization as described in 4.3.2. This means that an asset-development project defined as high or medium risk normally is comprised of more production-assurance activities than a low-risk project.
Output	Initial production-assurance programme (PAP) Updated PAP for later life-cycle phases, including the following: — status and reference to documentation for the scheduled PAP activities; — documentation of the fulfilment of the production-assurance requirements (alternatively, references to evidence); — reference to the risk register (see Clause C.2); all mitigating actions arising from the production-assurance program should be transferred to the risk register for follow-up and close-out. NOTE A close-out report for production-assurance activities upon completion of a project can be useful.

B.3 Design and manufacture for production assurance — Process 3

Systematic identification of potential opportunities for reliability improvement and risk reduction should be performed during all life-cycle phases, except the feasibility and procurement phase where this process is considered less relevant. Identification of improvement potentials should be based on observed in-service performance data and analyses. Production-assurance process 3 is described in Table B.3.

Table B.3 — Design and manufacture for production assurance — Process 3

Process elements	Life-cycle phase(s) All (except feasibility and procurement)
Objectives	Identify the need for improved system reliability performance or reduced risk in a project to ensure that performance requirements are not compromised Based on tracking and analysis of performance data, identify and communicate potentials for improved equipment or system reliability or risk reduction to the system or equipment manufacturers
Inputs	Output from process 1: Production-assurance requirements Output from process 9: Performance data Output from process 5: Reliability-analysis results Output from process 5: Production-availability results Output from process 5: Risk-identification results
Production-assurance activities	The specific production-assurance and reliability-management activities related to this process are performed within other processes. Hence, the only additional activity that should be performed for this process is related to the communication of the potential reliability-improvement or risk-reduction requirements or proposals to the right recipient.
Output	Reliability-improvement or risk-reduction proposals

B.4 Production assurance — Process 4

This process is relevant for all life-cycle phases and relates to the management, follow-up and documentation of the production-assurance process and demonstration that the production-performance requirements are adhered to. Production-assurance process 4 is described in Table B.4.

Table B.4 — Production assurance — Process 4

Process elements	Life-cycle phase(s) All
Objective	Reporting and follow-up of the production-assurance activities to manage and demonstrate the production-assurance process
Input	Production-assurance requirements (see Clause B.1) Production-assurance planning (see Clause B.2) Output from the production-assurance activities (see below)
Production-assurance activities	Reliability assurance (management and demonstration) is comprised of reporting and follow-up of the production-assurance activities and should be performed for all the project phases.
	Follow-up of the production-assurance process: A follow-up system for production assurance should be applied to ensure progress of the PAP activities and the resulting actions that are transferred to a risk register. A risk register or a similar document should be used as a production-assurance demonstration document.
Output	Production-assurance demonstration document, which contains evidence that the production-assurance requirements are fulfilled

B.5 Risk and reliability analysis — Process 5

This process covers the actual performance of the production-performance analyses, i.e. risk and reliability analyses. Production-assurance process 5 is described in Table B.5.

It is necessary that optimal technical safety and reliability be designed into new projects and integrated into the design process through all the design phases. In traditional design processes, technical safety and reliability aspects are generally not considered until some verification of equipment or components is required. This is usually too late in the system design process to obtain an optimal design. Hence, early design for reliability is necessary to support the project development.

The objective is to define a process that can be used to integrate reliability considerations into the design process, thus representing a pro-active approach.

The feasibility- and concept-phase reliability activities should focus on the optimization of the overall configuration and identification of the critical subsystems, while attention to the details of critical subsystems increases in the engineering phase.

Table B.5 — Risk and reliability analysis — Process 5

Process elements	Life-cycle phase(s)		
	Feasibility	**Conceptual design**	**Engineering**
Objectives	To provide partial decision support for selecting an asset-development plan, e.g. — topside or subsea solution; — capacity, pressure rating and pumping requirements for a pipeline system; — process plant development solution	To provide partial decision support for selecting an asset configuration, e.g. — number and type of wells and manifolds; — number of pumps in a pumping station; — number of compressors in a process plant	To provide partial detailed design decision support
Inputs	Alternative asset-development plans Output from process 2 production-assurance planning (see Clause B.2)	Selected asset-development plan, with the estimated production availability formulated as a system requirement in the invitation to tender Alternative field-layout configurations Output from process 4: Production assurance (see Clause B.4)	Selected field layout configuration Alternative design solutions, as they arise in the design process Output from process 4: Production assurance (see Clause B.4).
Production-assurance activities	The purpose of production-availability analysis in this phase is to contribute to optimizing the asset-development plan. The production availability for alternative asset-development plans should be established. The parameters below are guidance to establish — fault tolerance, i.e. redundancy; — proven versus novel solutions; — flexibility, e.g. possibility for alternative routings, reconfigurations and future expansions; — maintainability, e.g. minimizing the amount of downtime required for maintenance.	The purpose of production-availability analysis in this phase is to contribute to optimizing the field-layout configuration. The production availability for 2 or 3 alternative layout-configuration options should be established. Identify such options by varying the parameters below: — fault tolerance, i.e. redundancy; — proven versus novel solutions; — simplicity, e.g. minimizing the number of required connections, which are potential sources of failures; — overcapacity, e.g. partial or complete fulfilment of the design intent of the system in a degraded mode of operation; — flexibility, e.g. the possibility for alternative routings, reconfigurations and future expansions; — maintainability, e.g. minimizing the amount of downtime required for maintenance.	The purpose of production-availability analysis in this phase is mainly to verify compliance with requirements, since most of the decisions influencing the requirements have already been made. However, recommendations for spare parts should be established.

Table B.5 (*continued*)

Process elements	Life-cycle phase(s) Feasibility	Conceptual design	Engineering
	The purpose of the equipment-reliability analysis is to screen the delivery project to identify the critical parts, which are then studied in more detail to identify possible improvements. A reliability-analysis technique may be selected (see Annex I).	The purpose of the equipment-reliability analysis is to screen the delivery project to identify the critical parts, which are then studied in more detail to identify possible improvements. A reliability-analysis technique may be selected (see Annex I).	The purpose of the equipment-reliability analysis is to screen the delivery project to identify the critical parts, which are then studied in more detail to identify possible improvements. A reliability-analysis technique may be selected (see Annex I).
Output	Production-availability estimates for the options specified as input Identified risks (for transfer to the risk register; see Clause C.2)	Production-availability estimates for the options specified as input Identified risks (for transfer to the risk register; see Clause C.2)	Production-availability estimates for the options specified as input Identified risks (for transfer to the risk register; see Clause C.2)

B.6 Verification and validation — Process 6

The main objective of this process is to ensure that the implemented solution is in compliance with the requirements in the production-assurance programme. The production-assurance verification and validation process has an important interface with the design review and other technical verification activities in the sense that the production-assurance aspects should be addressed in the review. However, the design review process itself is normally the responsibility of engineering departments. Production-assurance process 6 is described in Table B.6.

Table B.6 — Verification and validation — Process 6

Process elements	Life-cycle phase(s) Feasibility, conceptual design and engineering [a]
Objective	To ensure that the implemented production performance is in compliance with the requirements in the PAP
Input	Output from process 4: Production assurance Output from process 7: Project risk management
Production-assurance activities	The production-assurance verification process is comprised of document control and design review. The essence of the document control is to check that the assumptions, selected methods, input data, results and recommendations are reasonable. The production-assurance validation process is comprised of a final check of the predicted/implemented production performance versus the requirements in the PAP. The essence of the validation is to check that all the activities scheduled in the PAP are completed and that all entries in the risk register are closed out. Compliance with ISO 9000 series is regarded as an alternative fulfilment of the verification and validation process.
Output	PAP updates including reference to the closed out activities and actions in the risk register.

[a] Installation, commissioning and operation are covered in process 9 (see Clause B.7).

B.7 Performance data tracking and analysis — Process 9

This process covers the complementary parts of process 6 (Verification and validation) in the sense that it represents the “verification” and “validation” of the production performance during installation, commissioning and operation. Production-assurance process 9 is described in Table B.7.

Table B.7 — Performance data tracing and analysis: Process 9

Process elements	Life-cycle phase(s)	
	Installation and commissioning	**Operation**
Objective	Prepare for collection and analysis of performance data	Collect and analyse operational performance data to identify possible improvement potentials and to improve the data basis for future production-assurance and reliability-management activities.
Input	System descriptions from the engineering phase	Inventory models Performance records (e.g. from maintenance management systems)
Production-assurance activities	Prior to the operation phase, equipment inventory models should be established to enable the start of performance tracking (data collection) and analysis. Reference is made to ISO 14224 for performance data tracking and analysis recommendations. Furthermore, collection of performance data relating to the installation process itself should be considered to identify potentials for future installation performance improvements.	During operation, performance data should be collected continuously or at predetermined intervals. Analysis of the collected data should be undertaken regularly to identify reliability improvement and risk reduction potentials.
Output	Inventory models Installation performance data	Operational performance data Input to design and manufacture for production assurance (see Clause B.3)

Collection and analysis of performance data is further described in Annex E. Furthermore, Annex G provides examples of performance measures that can be tracked and analysed.

NOTE Data qualification is part of process 5, risk and reliability analysis.

Annex C
(informative)

Interacting production-assurance processes and activities

C.1 Introduction

The interacting processes described in this annex are not included in the responsibility of the production-assurance discipline. However, these interacting processes are required in order to achieve the required production performance.

C.2 Project risk management — Process 7

All mitigating actions arising from the production-assurance program should be linked to or transferred to the risk register for follow up and close out, in order to have only one register for all kinds of risks. This transferral is the responsibility of the production-assurance discipline.

The risk register and the PAP are the information carriers and the decision tools with regard to risk.

Interacting process 7 is described in Table C.1.

Table C.1 — Project risk management — Process 7

Process elements	Life-cycle phase(s) All
Objective	The objective of project risk management is to ensure that all risk elements capable of jeopardizing the successful execution and completion of a project are identified and controlled/mitigated in a timely manner.
Input	Transferred action items from all the production-assurance processes
Production-assurance activities	Follow-up and close-out of all actions transferred from the production-assurance processes
Output	Risk register

C.3 Qualification and testing — Process 8

The objective of this testing versus production assurance is to ensure that acceptable robustness against dominating failure modes for critical technology items is demonstrated through the qualification test program.

Interacting process 8 is described in Table C.2.

Table C.2 — Qualification and testing — Process 8

Process elements	Life-cycle phase(s) Conceptual design	Engineering	Procurement and fabrication/assembly/testing
Objective	Identify the technology items requiring qualification testing	Ensure that acceptable robustness against dominating failure modes for critical technology items is demonstrated through the qualification test program.	Ensure that acceptable robustness against dominating failure modes for critical technology items is demonstrated through the qualification test program.
Input	Scope of supply Design basis	Output from equipment reliability analysis Output from production-availability analysis The reliability processes should identify the relevant failure modes[a] for the technology items tested and communicate this to the engineering organization that is responsible for establishing the test program through the risk register.	Output from equipment reliability analysis. Output from production-availability analysis. The reliability processes should identify the relevant failure modes[a] for the technology items to be tested and communicate this to the engineering organization through the risk register, which is responsible for establishing the test program.
Production-assurance activities	Identifying the technology items requiring qualification testing by novelty scoring (see I.21).	Establish qualification procedures Perform testing Establish qualification test reports	Establish qualification procedures Perform testing Establish qualification test reports
Output	List of technology items requiring qualification testing	The engineering organization should communicate the test results regarding the relevant failure modes to the production-assurance discipline.	The engineering organization should communicate the test results regarding the relevant failure modes to the production-assurance discipline.

[a] The evaluation of relevant failure modes should also consider operational experience of similar components in addition to the lab/qualification test results in order to catch possible failure events that are more closely associated with some particular operational conditions and/or procedures and, normally, not revealed by lab tests.

Reliability testing is further described in Clause I.9.

C.4 Supply chain management — Process 10

The main purpose of this interacting process is to ensure that manufacturers at each level of the supply chain are aware of and understand the specified production-assurance requirements and take appropriate actions to increase the probability that the specified requirements can be achieved.

Interacting process 10 is described in Table C.3.

Table C.3 — Supply chain management — Process 10

Process elements	Life-cycle phase(s) Procurement
Objective	Ensure that manufacturers at each level of the supply chain understand the production-assurance requirements and take appropriate actions to increase the probability that the specified requirements can be achieved.
Input	Output from process 1: Production-assurance requirements Output from process 5: Risk and reliability analysis
Production-assurance activities	Ensure that production-assurance requirements (e.g. reliability requirements) flow down into the supply chain.
Output	Distributed production-assurance requirements for the supply chain

C.5 Management of change — Process 11

The engineering discipline is responsible for technical changes.

The objective of the management of change process versus the production-assurance is to ensure that no changes compromise the production-assurance requirements. The consequence of this is that a risk assessment versus the production assurance is required.

The impact of changes should be qualitatively assessed as part of project risk management to determine the level of effort required to analyse the impact. The outcome of this assessment can typically be

— no activities, for changes with minor-risk impact versus the production assurance;

— design review, for changes with medium-risk impact versus the production assurance;

— equipment-reliability and/or production-availability analysis, for changes with a high-risk impact versus the production assurance.

The assessment of the impact on the production assurance from the changes should normally be an integrated part of the design review. Hence, the design review form should include a production-assurance checkpoint (e.g. the impact on production availability from the change).

However, if the risk of compromising the production assurance is deemed high, the equipment-reliability and/or production-availability analysis should be updated/initiated.

Interacting process 11 is described in Table C.4.

Table C.4 — Management of change — Process 11

Process elements	Life-cycle phase(s) All (except feasibility)
Objective	To ensure that no changes compromise the production-assurance requirements
Input	Output from process 1: Production-assurance requirements Output from process 3: Design and manufacture for production assurance Description of the change
Production-assurance activities	Assess production-assurance impacts from changes, e.g. during design reviews
Output	Input to or update of the risk register (see Clause C.2) Performance impact assessments resulting from changes Initiation of the equipment-reliability and/or production-availability analysis

C.6 Organizational learning — Process 12

The purpose of the interacting process "organization learning" in a production-assurance perspective should be to communicate positive and negative experiences related to reliability and production performance from previous asset-development projects to reduce the likelihood that product and process failures of the past are repeated. The process is considered relevant for all life-cycle phases.

Interacting process 12 is described in Table C.5.

Table C.5 — Organizational learning — Process 12

Process elements	Life-cycle phase(s) All
Objective	To ensure that product and process failures of the past is not repeated
Input	Lessons learnt during previous projects Performance data
Production-assurance activities	The responsibility of the production-assurance and reliability-management function in projects is to participate in reviews of lessons learnt and other relevant experience transfer. Furthermore, relevant lessons learnt in one project should be transferred into future projects.
Output	Lessons learnt (positive and negative) Risk register

Annex D
(informative)

Production-performance analyses

D.1 General

Production-performance analyses should be planned, executed, used and updated in a controlled and organized manner.

Production-performance analyses should provide a basis for decisions concerning the choice of solutions and measures to achieve an optimum economy within the given constraints. This implies that the analysis should be performed at a point in time when sufficient details are available to provide sustainable results. However, results should be presented in time for input to the decision process.

Production-performance analyses should be consistent and assumptions and reliability data traceable.

Suitable analysis tools, calculation models, data and computer codes that are acceptable to the involved parties should be chosen. Be aware that analysis tools and calculation models are under constant development.

Recommendations given in this annex apply to the production-performance analyses of complete installations, but can also apply to reliability and availability analyses of components/systems with obvious modifications.

D.2 Planning

D.2.1 Objectives

The objectives of the analyses should be clearly stated prior to any analysis. Preferably, objectives can be stated in a production-assurance activity plan as a part of the PAP structure. Objectives can be to:

— verify production-assurance objectives or requirements;

— identify operational conditions or equipment units critical to production assurance;

— predict production availability, deliverability, availability, reliability, etc.;

— identify technical and operational measures for performance improvement;

— compare alternatives with respect to different production-assurance aspects;

— enable selection of facilities, systems, equipment, configuration and capacities based on economic optimization assessments;

— provide input to other activities, such as risk analyses or maintenance and spare-parts planning.

D.2.2 Production-performance analysis information

The system for analysis should be defined, with necessary boundaries relative to its surroundings. An analysis of a complete production chain can cover reservoir delivery, wells, process and utilities, product storage, re-injection, export and tanker off-take.

Operating modes for inclusion in the analysis should be defined. Examples of relevant operating modes are start-up, normal operation, operation with partial load and run-down. Depending on the objective of the analysis, it can also be relevant to consider testing, maintenance and emergency situations. The operating phase or period of time for analysis should also be defined.

The performance measures predicted should be defined. In production-availability and deliverability predictions, a reference level that provides the desired basis for decision-making should be selected. It should also be decided whether to include the production-performance effect from revision shutdowns, as well as those catastrophic events normally identified and assessed with respect to safety in risk analyses.

The analysis methodology for use should be decided on the basis of study objectives and the predicted performance measures.

D.3 Procedure

D.3.1 Preparation

A review of available technical documentation should be performed as the initial activity, as well as establishing liaison with relevant disciplines. Site visits may be performed and are recommended in some cases.

Review all input documentation, establish liaison with relevant disciplines and visit sites, if necessary.

D.3.2 Study basis

The documentation of study basis has two main parts: system description and reliability data.

The system description should describe, or refer to documentation of, all technical and operational aspects that are considered to influence the results of the production-performance analysis and that are required to identify the system subject to the analysis, e.g. design basis, piping and instrumentation diagrams, process flow diagrams, operation and maintenance strategies, reliability data, maintainability data, equipment criticality information, cause and effect matrices, production profiles, equipment capacities, etc.

Reliability data should be documented. A reference to the data source should be included. Reference can be made to engineering or expert judgement, but an historically based data estimation should be used if one can be determined.

The basis for quantification of reliability input data should be readily available statistics and system/component reliability data, results from studies of similar systems or expert/engineering judgement. Production and operability review (POR) sessions can be used to predict plant-specific downtimes. In the analysis, the approach taken for reliability data selection and qualification should be specified and agreed upon by the involved parties.

D.3.3 Model development

Develop a model that includes the following activities:

- functional breakdown of the system;
- evaluation of the consequences of failure, maintenance, etc., for the various subparts;
- evaluation of events for inclusion in the model, including common-cause failures;
- evaluation of the effect of compensating measures, if relevant;
- model development and documentation.

D.3.4 Analysis and assessment

D.3.4.1 Performance measures

Evaluate the performance of the analysed object. Various performance measures may be used. Production availability and deliverability (whenever relevant) are the most frequently used measures. Depending on the objectives of the production-performance analysis, the project phase and the framework conditions for the project, the following additional performance measures may be used:

- proportion of time or number of times production (delivery) is equal to or above demand (demand availability);
- proportion of time or number of times production (delivery) is above zero (on-stream availability);
- proportion of time or number of times the production (delivery) is below demand;
- proportion of time or number of times the production (delivery) is below a specified level for a certain period of time;
- number of days with a certain production loss;
- resource consumption for repairs;
- availability of systems/subsystems.

As a predictor for the performance measure, the expected (mean) value should be used. The uncertainty related to this prediction should be discussed and, if possible, quantified (see D.3.7).

Annex G provides a guide on the elements for inclusion in the performance measure for predictions and for historical performance reporting.

D.3.4.2 Sensitivity analyses

Sensitivity analyses should be considered to take account of uncertainty in important input parameters such as alternative assumptions, variations in failure and repair data or alternative system configurations.

D.3.4.3 Importance measures

In addition to the performance measure, a list of critical elements (e.g. equipment, systems, operational conditions and compensatory means) should be established. This list assists in identifying systems/equipment that should be considered for production-assurance and reliability improvement.

For conventional reliability analysis, methods such as FTA, relevant reliability importance measures as found in literature can be used.

When production availability or deliverability is predicted, importance measures can be defined by the contribution to production unavailability from each item/event. In order to take account of the effects of compensating measures, it can be necessary to establish the criticality list based on successive sensitivity analyses where the contribution from each event is set to zero.

D.3.5 Reporting and recommendations

The various steps in the production-performance analysis, as described above, and all assumptions should be reported.

The appropriate performance measures should be reported for all alternatives and sensitivities.

Recommendations identified in the analysis should be reported. A production-assurance management system should be used to follow up and decide upon recommendations. Recommendations may concern design issues or further production-performance analyses/assessments. In the latter case, the interaction with the PAP is evident. Furthermore, recommendations may be categorized as relating to technical, procedural, organizational or personnel issues. Recommendations may also be categorized by whether they affect the frequency or the consequence of failures/events.

D.3.6 Catastrophic events

Some serious, infrequent events will cause long-term shutdown of production. These events are classified as catastrophic, and should be distinguished from the more frequent events which are considered in analyses of production availability and deliverability. The expected value contribution from a catastrophic event is normally a rather small quantity, which is an unrepresentative contribution to the production loss. If the catastrophic event occurs, the actual loss would be large and this could mean a dramatic reduction in the production availability or deliverability.

The consequences for production as a result of accidents in production and transportation systems are normally considered in the risk analysis. The results from the risk analysis may be included in the production-performance analysis report in order to show all production-loss contributors.

Additional guidance is given in Annex H.

D.3.7 Handling of uncertainty

The uncertainty related to the value of the predicted performance measure should be discussed and, if possible, quantified. The quantification may have the form of an uncertainty distribution for the expected value of the performance measure or a measure of the spread of this distribution (e.g. standard deviation, prediction interval).

The main factors causing variability (and hence uncertainty in the predictions) in the performance measure should be identified and discussed. Also, factors contributing to the uncertainty as a result of the way the system performance is modelled should be covered.

Importance and sensitivity analyses may be carried out to describe the sensitivity of the input data used and the assumptions made.

Annex E
(informative)

Reliability and production-performance data

E.1 Collection of reliability data

E.1.1 General

Systematic collection and treatment of operational experience is considered an investment and a means for improvement of production and safety critical equipment and operations. The purpose of establishing and maintaining databases is to provide feedback to assist with the following:

— product design;

— current product improvement;

— establishing and calibrating the maintenance and the spare-parts programmes;

— condition-based maintenance;

— identifying contributing factors to production unavailability;

— improving confidence in predictions used for decision support.

E.1.2 Equipment boundary and hierarchy definition

A clear boundary description is imperative and a strict hierarchy system should be applied.

Boundaries and equipment hierarchy should be defined according to ISO 14224:2006, Annex A. Major data categories are defined as follows:

— installation data: description of installation from which reliability data are collected;

— inventory data: technical description of equipment, plus operating and environmental conditions;

— failure data: failure-event information, such as failure mode, severity, failure cause, etc.;

— maintenance data: corrective-maintenance information associated with failure events, and planned or executed preventive maintenance event information.

E.1.3 Data analysis

To predict the time to failure (or repair) of an item, a probability model should be determined. The type of model depends on the purpose of the analysis. An exponential lifetime distribution can be appropriate. The model, if it is expected to delineate a trend, should allow the use of a time-dependent failure rate.

The establishment of a failure (or repair) time model should be based on the collected reliability data, using standard statistical methods.

E.2 Qualification and application of reliability data

The establishment of correct and relevant reliability data (i.e. failure and associated repair/downtime data) requires a data-qualification process that involves conscious attention to the original source of data, interpretation of any available statistics and estimation method for analysis usage. Suitable reliability-data management and coordination are needed to ensure reliability-data collection for selected equipment and consistent use of reliability data in the various analyses.

Selection of data should be based on the following principles.

— Data should originate from the same type of equipment and, if possible, originate from identical equipment models.

— Data should originate from equipment using similar technology.

— Data should originate from periods of stable operation, although early-life or start-up problems should be given due consideration.

— Data should, if possible, originate from equipment that has been exposed to comparable operating and maintenance conditions.

— The basis for the data used should be sufficiently extensive.

— The amount of inventories and failure events used to estimate or predict reliability parameters should be sufficiently large to avoid bias resulting from “outliers”.

— The repair and downtime data should reflect site specific conditions.

— The equipment boundary for the originating data source and analysis element should match as far as possible (study assumptions should otherwise be given).

— Population data (e.g. operating time, observation period) should be indicated to reflect the statistical significance (uncertainty related to estimates and predictions) and the “technology window”.

— Data sources should be quoted.

Data from event databases (compliant with ISO 14224) provide a relevant basis for meeting the recommendations above. In case of scarce data, it is necessary to use engineering judgement and a sensitivity analysis of input data should be done.

E.3 Production-performance data

Production-performance data at facility/installation level should be reported in such a way that enables systematic production assurance to be carried out. The type of installation and operation determines the format and structure of performance reporting. Annex G outlines the types of events that it is important to cover for a production facility. It is necessary to establish the relationship between facility-performance data and critical-equipment reliability data. Assessment of actual performance should be carried out by the installation operator on a periodic basis in order to identify specific trends and issues requiring follow-up. The main contributors to performance loss and areas for improvement can be identified. In this context, reliability techniques can be used for decision-support and calibration of performance predictions. Comparisons with earlier performance predictions should be done, thereby gaining experience and provide feedback for future and/or other similar performance predictions.

Annex F
(informative)

Performance objectives and requirements

F.1 General

The specification of production-assurance objectives and requirements can be considered for system design, engineering and purchase of equipment, as well as for operations in defined life-cycle periods.

In this respect, IEC 60300-3-4 should also be considered.

F.2 Specifying production assurance

The purpose of specifying production assurance is to ensure correct handling of safety and production-assurance aspects and to minimize economic risk. The cost of design, production and verification of the system with a specified level of reliability or production assurance should be considered prior to stating such production-assurance requirements.

Quantitative or qualitative objectives/requirements may be specified. Requirements should be realistic and should be compatible with the technological state of the art. It should be stated whether the specification is an objective or a requirement.

a) The goals and requirements within a production-assurance specification should include, but not be limited to the following:

- limitations and boundaries;
- application of the system;
- definition of a fault;
- definition of the period of time for which the production-assurance requirements applies (e.g. from first oil and to the end of design life);
- operating conditions and strategies;
- environmental conditions;
- maintenance conditions and strategies;
- methods intended for application to verify compliance with the production-assurance requirements;
- when numerical production-assurance requirements are specified, the corresponding confidence levels should be specified;
- definition of non-conformance to the requirement;
- how non-conformance should be handled.

b) Quantitative requirements may be expressed on the basis of performance measures such as the following:

- production availability;
- system availability;
- survival probability at time t of an item;
- time to failure;
- time to repair;
- spare parts mobilization times.

— Qualitative requirements may be expressed in terms of any of the following:

- design criteria for the product;
- system configuration;
- inherent safety (acceptable consequence of a failure);
- production-assurance activities to be performed.

F.3 Verification of requirement fulfilment

The method of verification of requirement fulfilment should be stated. Verification can be by

- field or laboratory testing,
- documented relevant field experience,
- analysis,
- field performance evaluation after delivery.

Data for calculations should be based on recognized sources of data, such as the results obtained from operational experience on similar equipment in the field or from laboratory tests. The reliability data should be agreed between the supplier and the customer.

Annex G
(informative)

Performance measures for production availability

G.1 General

Performance measures for production availability are used in analyses for prediction or planning, as well as for the reporting of historical performance in the operational phase. The performance measures include the effect of downtime caused by a number of different events. It is imperative to specify in detail the different type of events and whether they should be included or excluded when calculating the performance measure. This annex provides a guide to this subject in order to achieve a common format for performance predictions and reporting among field operators.

Various detailed production-reporting systems exist, but the one selected should enable comparable/exchangeable field reporting as indicated below.

For a typical hydrocarbon production facility, the following measures can be of interest for predictions as well as for historical reporting:

— production (un)availability of oil for storage or for export, measured at the exit of the process facility;

— (un)availability (time-based) or production (un)availability (volume-based) of water injection. One may, in addition, estimate the production (un)availability of the production system, taking into account the production unavailability of water injection;

— (un)availability (time-based) or production (un)availability (volume-based) of gas injection. One may, in addition, estimate the production (un)availability of the production system, taking into account the production unavailability of gas injection;

— (un)availability (time-based) or production (un)availability (volume-based) of utility systems. One may, in addition, estimate the production (un)availability of the production system, taking into account the production unavailability of the utility systems;

— production (un)availability of gas for export, measured at the exit of the process facility;

— production (un)availability of gas for export according to contractual requirements (e.g. variable contractual nomination) and evaluation of penalties due to failure to fulfil contractual requirements;

— deliverability of gas export, measured at the delivery point and including the effect of compensating measures;

— production (un)availability of the subsea installation in isolation without considering downstream elements;

— (un)availability of the process facilities in isolation;

— (un)availability of gathering or exporting hydrocarbon/petrochemical network (volume-based);

— mean volume of flared gas according to various flaring policies;

— top ten contributors to losses with relative values.

Depending on the objective of the study, the above results may be established on a year-by-year basis based on the production profile or for only a specific production period, e.g. the production-plateau period, first year, maximum-water-production period, etc.

The uncertainty related to the value of the predicted performance measures should be discussed and, if possible, quantified. For details, see D.3.7.

An illustration of the relationship between some production-assurance terms is shown in Figure G.1.

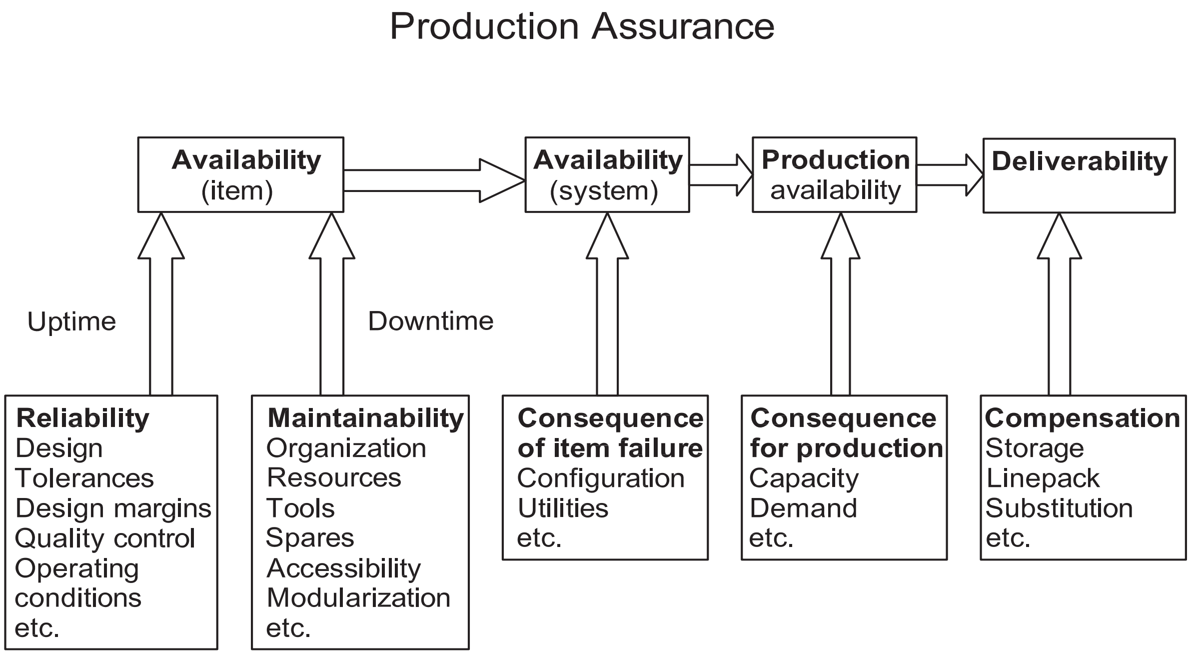


Figure G.1 — Illustration of the relationship between some production-assurance terms

G.2 Production availability

Production availability (and deliverability), P_A, is a performance measure based on volume as defined in Equation (G.1).

$$P_A = \frac{V_P}{V_R} \tag{G.1}$$

where

V_P is the produced volume;

V_R is a reference production volume.

Various types of performance reference measures may be chosen to enable the prediction of reporting of production availability. Ideally, the same reference level as used in production-availability-analyses phases should be used also when reporting historical production availability during the operational phase. Some alternative reference measures are given in items a) to e).

When presenting results of production-availability analyses, it is recommended that the mean value be presented together with the probabilistic-distribution values to indicate the potential up- and downside range.

a) Contracted volume

If there is a sales contract, the contracted volume is the preferred reference level. The contracted volume may be specified with seasonal variations (swing). In that case, the swing profile should be used as the reference level. The contracted volume may also be specified as an average over a period of time, where the buyer nominates the daily supplies at some time in advance. When reporting historical production availability or deliverability, the reference-level volume should be the actual nominated volumes (it is should be stated whether these nominations are, e.g., daily, weekly, monthly or yearly based). In a prediction, a distribution of volumes reflecting the foreseen variations in the nominated volumes should be used, but the ability of the facilities to deliver the maximum quantity should also be assessed.

b) Design capacity

The design capacity of the facility may be used as a reference level. This can be an appropriate reference level when only a part of the production chain, e.g. a process facility, is subject to analysis. The design capacity is easily available at an early phase in a project. A limitation is that production can be restricted by factors outside the system boundaries (e.g. well potentials), which can lead to misleading conclusions. It is, therefore, important to understand how oil or gas export depends on time-variable capacity limitations in the process design functions, such as oil treatment, gas processing, water treatment, gas injection, water injection, etc.

c) Well-production potential

The well-production potential may be a reference level if it is less than the design capacity. This is the case especially during the production-decline period; but it can also be the case in the production ramp-up period. It should be kept in mind that reservoir simulations are associated with uncertainty and should be handled accordingly in the analysis. The well-production potential may be adjusted during the operating phase.

d) Planned production volume assuming no downtime (planned or unplanned)

Assuming that there is no downtime results in the maximum production volume under the constraints of design capacities and well-production potentials. This is the preferred reference level in production-availability predictions, as well as in historical reporting. The uncertainty of reservoir simulations should be kept in mind. The length of the plateau period and the production rates in the decline period are uncertain.

Regarding integrating reservoir risk and production performance, it is important to ensure that production profiles be risked only once when they are used as the reference level for a production-availability estimation.

e) Planned production volume

The planned production volume when expected downtime is considered can be used as a reference level when reporting historical production availability in the operational phase. A less-than-average downtime occurring in a period results in a the performance measure that is greater than 100 %. The disadvantage of using this reference level is that the costs of downtime are concealed.

In addition to the volume-based performance measures, time-based measures can be used to calculate A_{O}, the average operational availability expressed as a ratio, as given in Equation (G.2).

$$A_{\mathrm{O}} = \frac{t_{\mathrm{MUT}}}{t_{\mathrm{MUT}} + t_{\mathrm{MDT}}} \quad \text{(G.2)}$$

where

t_{MUT} is the mean uptime, estimated by using the actual uptime observed in the field;

t_{MDT} is the mean downtime, estimated by using the actual up- and downtimes observed in the field.

The advantage of using availability as a performance measure is that uptime and downtime is easy to establish compared to the reference level of the volume-based measures. On the other hand, the disadvantage is that this measure is not well suited to handle partial shutdowns. In some cases, the measure can be modified by defining uptime and time in operation as well-years.

G.3 Other parameters

The production-availability parameter described in Clause G.2 is a single figure representing the average performance of a defined system. However, it is only one of several parameters that can be used. In downstream industries in particular, a wide range of performance measures is utilized.

These other parameters may include or exclude specific sources of loss of production or provide information about how the losses are expected to occur. In some cases, this can be of equal or greater importance than the overall production-availability figure, for example the interruption frequency can be a key element of a gas-supply system.

Whatever measures are used for an analysis, it is necessary to state explicitly the basis on which they are calculated.

Tables G.1 to G.5 provide guidance on the events that should be included in production-availability predictions and the reporting of historical production-availability for a production system (i.e. volume-based performance measures). Time-based availability predictions or statistics can apply to the same event categorization. Event categorization for other specific operations (e.g. pipe laying) and its associated system/equipment typically have another format, which it is necessary to specify as required. Battery limits for the facilities, as well as any third-party processing, tie-ins, subsea installations, etc., should be clearly defined.

Table G.1 — Production facility — Production loss categories

Type of event			Comments
A	**Wells (downhole and subsea/surface)**		"Wells" covering everything from (and including) the tubing hanger downwards to (and including) the reservoir
	A1	Reservoir uncertainties	Production losses due to reservoir uncertainties (e.g. reservoir production less than anticipated) NOTE Can also be positive if reservoir produces more than anticipated; hence, it can be necessary to alter the reference level for the performance measurement.
	A2	Planned reservoir interventions	Production losses arising from planned activities to the reservoir, for example, logging, fracturing, re-perforating, etc. The production-availability impact depends on test design and procedures. The production downtime and loss caused by the activity shall be included. A possible positive effect on the production rate should also be considered, since this can influence the reference level for the performance measure. The reference level may, afterwards, be raised, but the investment to achieve this appears as a loss.
	A3	Unplanned reservoir interventions	Production losses arising from unplanned intervention in the reservoir. As above, the production downtime and loss caused by the activity shall be included, and it can require that the performance reference level be altered.
	A4	Well production testing	Production losses occurring whilst well production testing to check well production potential. Such type of reservoir testing has various production-loss impacts, depending on the configuration, available test equipment (flowmeter, test separator, test lines) and operational test procedure used.
	A5	Downhole well equipment failure	Production losses occurring until the initiation of well intervention

Table G.1 (*continued*)

Type of event			Comments
	A6	Unplanned subsea well intervention	Production losses arising from the repair of subsea equipment failures (also called workover), including losses related to heavy lifts. Reliability-based contingency preparedness is anticipated.
	A7	Planned downhole well interventions	Production losses arising from periodic equipment testing and well inspection/surveys. Also includes planned re-completions, zonal isolations, sidetracks, SIMOPS activities, etc.
	A8	Flow assurance (unplanned)	Production losses related to flow-assurance problems (e.g. hydrates, scaling, wax, asphaltenes, etc.), exclusively from and not accounted on those items listed above
	A9	Post-modification impact	Reduction or shutdown in production caused by a modification project (after run-in), for example side-tracking, re-completion, etc.
B	**Subsea installations**		Covers subsea X-mas tree, flowlines or pipelines, umbilicals, manifolds, subsea valves and risers. Future subsea processing is also considered. Hence, all equipment subsea from tubing hanger to riser/ umbilical topside/onshore termination
	B1	Subsea equipment failure	Production losses occurring until subsea intervention starts This category normally also covers B4 as an event is usually logged against equipment.
	B2	Unplanned subsea intervention	Production losses arising from repair of failed subsea equipment and may include downhole/other intervention required to undertake subsea repair. Reliability-based contingency preparedness is anticipated.
	B3	Planned subsea interventions	Production losses arising from planned activities that include preventive maintenance, planned flow-assurance activities, testing, inspection, etc., on equipment.
	B4	Flow assurance (unplanned)	The production downtime and loss related to flow-assurance problems (e.g. hydrates, scaling, wax, asphaltenes, etc.).
	B5	Post modification impact	Reduction or shutdown in production caused a modification project (after run-in), for example new template/manifold tie-ins
C	**Production facilities**		Topside and onshore developments covering production facilities (e.g. dry X-mas tree, flowlines or pipelines, umbilicals, manifolds, valves, etc.)
	C1	Production facilities equipment failure	Production losses occurring until maintenance starts
	C2	Unplanned production facilities maintenance	Production losses arising from repair of failure, which may include other maintenance required to undertake repair; reliability based contingency preparedness is anticipated
	C3	Planned production facility maintenance	Production losses arising from planned activities that include preventative maintenance (pigging), testing, inspection, etc., on equipment
	C4	Flow assurance (unplanned)	The production downtime and loss related to flow-assurance problems
	C5	Post modification impact	Reduction in or shutdown of production caused by a modification project (after run-in), for example pipeline tie-ins
D	**Process and utilities**		Covers process and utility functions located topsides or onshore
	D1	Equipment failure and repair	Production losses related to failure and corrective maintenance; the corrective maintenance itself may be split, if needed. This covers failure of utility/ ancillary/auxiliary systems such as power, chemicals, etc.
	D2	Preventive maintenance (planned)	Reduction in production caused by the execution of preventive maintenance (e.g., due to safety-barrier procedures); includes equipment testing of topsides safety equipment that affects production

Table G.1 (*continued*)

Type of event			Comments
	D3	Process/operational problems	Process upsets due to separation problems, low set points for sensors, testing/diagnosing process facilities. It also includes operator errors that cause production losses and may also include losses due to burn-in of modification projects and flow-assurance issues.
	D4	Post-modification impact	Reduction in or shutdown of production caused by a modification project (after run-in), for example well compression, tie-ins from other facilities, etc.
E	**Export facilities**		Covers main export activities of tanker offtake or pipelines
	E1	Offloading	These are shutdowns caused by (e.g. full-storage) offloading equipment failures, including repair activities or a tanker not being present due to weather impact or technical reasons.
	E2	Downstream restrictions	These are planned and/or unplanned shutdowns caused by downstream process/pipeline/receiving facilities outside the boundary limits (third-party issues). It may also cover third-party processing within a field infrastructure. Turnarounds for downstream facilities are also covered in this loss category.
	E3	Flow assurance	Flow-assurance problems for processed products in pipeline, both planned (e.g. pigging) or unplanned (e.g. hydrate plug removal). Production losses related to flow-assurance problems, exclusive of and not accounted for by the items listed above.
F	**Turnaround and modification**		—
	F1	Turnaround	Full shutdown due to integrity management or regulatory requirements It is important to capture losses due to the planned period of the turnaround and also losses from any unplanned extension to the turnaround.
	F2	Modification	Full shutdown due to modification (e.g. tie-in or major module instalment/modification). Losses arising after run-in (post-modification) are recorded in A9, B5, C5 or D4. It is important to capture losses due to the planned period of the modification and also losses from any unplanned extension to the modification.
G	**Other**		—
	G1	Bad weather	Production impact due to weather
	G2	Accidents or contingency requirements	Safety-related events or shutdown required due to safety contingency (e.g. ship-collision risk) Downtime caused by events of a catastrophic nature should be reported separately in predictions.
	G3	Labour conflicts	—
	G4	Environmental policies	Reduced production to accommodate environmental-discharge limits (flaring, produced-water disposal, etc.)
	G5	Security	Terrorism, riots, etc.
	G6	Authority restrictions	Restrictions by country regulatory bodies, national quotas, OPEC, etc.
	G7	Product quality deviations	Out of product specification (below and above specification)
H	**Pre-production**		—
	H1	Project schedule delays	Losses due to slippage of actual first-oil date from planned first-oil date due to project delays Wells and facility schedule losses should be reported in H2 and H3.

Table G.1 (*continued*)

Type of event			Comments
	H2	Wells schedule delays	Production losses due to slippage of drilling programme, resulting in the actual reservoir potential being less than the planned reservoir potential due to wells starting late. This can be compensated if the wells have a higher-than-expected flow rate. Only applicable in ramp-up and plateau phases and can require altering the performance reference level
	H3	Facilities schedule delays	Production losses associated with equipment not being operational on the planned start dates or taking longer to commission and ramp up to maximum capacity Only applicable in ramp-up phase

Table G.2 — Upstream drilling rig — Loss categories

Type of event			Comments
A	**Rig drilling**		Reporting of drilling-rig time loss; covers platform rigs, mobile drilling units, etc., and covers, for example, drilling, regular BOP and safety-equipment-related activities, logging/coring, orienting the well, running and cementing casings/liners activities and others; exploration and production drilling
	A1	Moving from one well to the next	Activities carried out to move the rig from one location to another, such as removing and re-installing anchor lines of floating rigs in offshore scenarios
	A2	Rig downtime due to rig equipment failure	Activities developed to repair equipment that is essential to proceed with normal operations, including possible safeguards on the well for repairing and others, e.g. setting a temporary plug in the well, pulling/running/repairing/re-installing the BOP, other repair-related activities, including to accessories such as logging tools
	A3	Rig downtime due to well problems	Combating a possible kick, fishing activities, re-setting or correcting the wellhead installation, reaming, re-drilling, working on a mechanically unstable well, adjusting drilling-fluid parameters, correcting cement job, others
	A4	Waiting on operations	Waiting for something to proceed with intervention operations, e.g. waiting on weather, spare parts, materials or others

Table G.3 — Upstream installation and intervention — Loss categories

Type of event			Comments
A	**Intervention and workover**		Covers all major intervention equipment, including platform rigs, mobile drilling units, coiled tubing systems, ROVs; includes checking or setting safety barriers in the well before intervention, regular BOP and safety-equipment-related activities, running/installing X-mas tree, gravel packer and tubing activities and others Installation (e.g. completion, pipe-laying, subsea equipment) and intervention (e.g. workover, manifold retrieval)
	A1	Moving from one location to the next one	Activities carried out to move the installation or intervention resources from one location to the next one
	A2	Installation and intervention equipment failure	Activities developed to repair equipment that is essential to proceed with normal operations, including possible safeguards on the well for repairing and others, e.g. setting a temporary plug in the well pulling/running/repairing/re-installing the BOP; other repair-related activities; including to accessories such as logging tools
	A3	Waiting on operations	Waiting for something to proceed with intervention operations, e.g. waiting on weather, spare parts, materials or others

Table G.4 — Midstream events — Loss categories

Type of event			Comments
A	**Pipeline**		Covers only line pipe, flanges, block valves, etc.
	A1	Planned interventions	Losses associated with planned activities that include preventive maintenance, testing, inspection, inspection pigging, surveys, etc.
	A2	Unplanned activities and equipment failures	Production-assurance impact arising from repair of pipeline failure, including third-party damage; also includes logistic delays Plus geotechnical problems: pipeline movement, river crossing wash outs, etc.
	A3	Flow assurance	Flow assurance (hydrates, etc.), flow-assurance pigging plus failure of drag-reducing agents
	A4	Post modifications impact	Losses associated with modification work, i.e. tie-ins
	A5	Downstream process shutdowns and restrictions	These are shutdowns caused by downstream process/receiving facilities outside the boundary limit of the terminal (third-party issues).
B	**Pump/Compressor station**		All equipment and activities within boundary limit of the pump/ compressor station, including process and utilities (power, chemicals, instrument air, etc.)
	B1	Planned interventions	Losses associated with planned activities that include preventive maintenance, safety testing, inspection, etc.
	B2	Unplanned activities and equipment failures	Losses associated with unplanned activities, e.g. failure of prime movers and utilities (instrumentation, power, etc.)
	B3	Process/operational problems	Process upsets, including logistic delays (e.g. on unmanned facilities); real trips including operator errors
	B4	Post modifications impact	Losses associated with modification work, i.e. adding new pumps/ compressors to increase capacity
C	**Terminal**		Oil/condensate terminal (all production losses described in B1 to B4 preceding and the events listed in C1 to C3 following)
	C1	Offloading	These are shutdowns caused by (e.g. full-storage) offloading equipment failures or the tanker not being present, loading stopped due to bad weather, etc.
	C2	Downstream process shutdowns and restrictions	These are shutdowns caused by downstream process/receiving facilities outside the boundary limit of the terminal (third-party issues).
	C3	Product quality deviation	Product out of specification (below or above specification)
D	**LNG plants, gas plants, etc.**		Including all production losses described in B1 to B4 preceding and the events listed in D1 and D2 following)
	D1	Product quality deviation	Product out of specification (below or above specification)
	D2	Downstream process shutdowns and restrictions	These are shutdowns caused by downstream process/receiving facilities outside the boundary limit of plant (third party issues).
E	**Other**		—
	E1	Revision shutdowns	Can be considered as excluded both in predictions and for historical reporting (e.g. when revision shutdowns are defined in sales contracts)
	E2	Accidental events	Safety-related events Downtime caused by events of catastrophic nature should be reported separately in predictions

Table G.5 — Downstream events — Loss categories

Type of event			Comments
A	**Process unit unavailability**		Process plants typically consist of a number of process units (includes production losses described in Table G.1 and the following specific listed events).
	A1	Product quality deviation	Losses arising from product out of specification requiring that it be reprocessed, disposed, given away
	A2	Domino losses	Losses caused by shutdown/slowdown of other process units
	A3	Turnarounds	Losses associated with planned turnarounds (major overhauls of process units planned well in advance)
	A4	Turnaround overruns	Production losses due to unplanned overrun of turnaround activities.
	A5	Commercial	Losses caused by production constraints due to commercial aspects of the business

Annex H
(informative)

Catastrophic events

H.1 General

Some serious, infrequent events can cause long-term shutdown of production. These events are classified as catastrophic and should be distinguished from the more frequent events that are considered in the analyses of production availability and deliverability. The catastrophic events should be treated separately in production-performance analyses.

Typical catastrophic events include the following:

- earthquakes;
- fires and explosions;
- blowouts;
- sabotage;
- structural collapse;
- major problems with casing or wellheads;
- riser or export pipeline ruptures;
- falling loads with large damage potential;
- other events or combinations of events with large damage potential.

Important factors in the analysis of catastrophic events are considered in more detail in the remainder of this annex.

The purpose of the availability analyses is to predict the actual production availability, A, for the installation for the time period considered. This quantity is uncertain (unknown) when the analysis is carried out and it is necessary to predict it. The uncertainty related to the value of A can be expressed by a probability distribution $H(a)$, with mean or expected value, $\bar{A}$, being the predictor of A. A Monte-Carlo study of the production availability is generally performed by generating a sequence of independent, identically distributed quantities, for example A_1, A_2, A_n, from the probability distribution, $H(a)$. The distribution can be estimated from the sample A_1, A_2, A_n.

In theory and as far as the uncertainty distribution $H(a)$ is concerned, there is no problem in including catastrophic events in this analysis. If a catastrophic event results in a production loss, z, and its associated probability equals p, this can be reflected in the distribution, H. But using the “full distribution” makes it difficult to predict A using the expected value. In this case, the spread around the mean would be very large and the probability density could have a bimodal form very different from the typical Gaussian distribution. The problem is that the expected value of the contribution from the catastrophic event is normally a rather small quantity, namely $p \cdot z$, which is an unrepresentative contribution to the production loss. If the catastrophic event occurs, the actual loss would be z and this could mean a dramatic reduction in the production availability, A.

If the time period considered is long, then the probability that a catastrophic event will occur could be quite large and consequently the contribution $p \cdot z$ significant. Hence, in such cases, the inclusion of catastrophic events is more meaningful.

H.2 Criterion for inclusion in analyses

The consequences for production as a result of catastrophic events in production and transportation systems should always be considered, either by production-availability analysis or total-risk analysis. In general, catastrophic events should be included in risk and financial analyses but not in production-availability analysis. Criteria for exclusion from production-availability analyses can include the following.

— The probability of the event occurring during lifetime of the system is less than 25 %.

— The downtime as a result of one occurrence of the event during the lifetime results in a reduction of the production availability or deliverability by more than 1 %.

It should, however, be considered to refer to the predicted production-availability loss value estimated, if this is a part of the total risk analysis. This enables a consistency check of the framework conditions and reference level, making it comparable to predictions in the production-availability analysis.

In analyses limited to subsystems, one should consider from case to case whether the catastrophic events should be included.

Annex I
(informative)

Outline of techniques

I.1 General

Production-performance analyses, such as reliability and availability analyses, are systematic evaluations and calculations that are carried out to assess the performance of a system. The system can, for example, be a production or transportation system, a compression train, a pump, a process shutdown system or a valve. These analyses are part of a production-assurance programme (PAP).

It is useful to apply the following as a guide.

— Production-performance analysis considers the production from facilities with several production levels, e.g. offshore or onshore production systems, installation(s) or operation(s).

— Availability analysis considers the uptimes of two states (running/not running) of items (components, equipment, units and systems).

— Reliability analysis considers the first failure of two states of items (components, equipment, units and systems).

Reliability is mainly focused on safety. In the context of a PAP, it may be used to evaluate the probability that the first failure occurs after a given period of time.

Availability is mainly focused on the time during which an item is running correctly. In the context of a PAP, it can be appropriate for single components or for production trains made of component in series. It may also be used to perform “availability allocations” in order to establish the requirements for the providers of such components.

Some relevant analysis methods and techniques are described briefly in I.1 to I.22. Reference can be made to the documents cited in these subclauses or to reliability-analysis textbooks for more detailed descriptions.

I.2 Failure modes and effects analysis

A summary of failure modes and effects analysis (FMEA) and failure mode, effect and criticality analysis (FMECA) is given in Table I.1.

Table I.1 — Failure modes and effects analysis (FMEA) and failure mode, effect and criticality analysis (FMECA)

Analysis elements	Summary
Analysis description	Two bottom-up techniques for analysing and establishing systematically the effects of potential failure modes
Objective of analysis	An FMEA is a systematic technique for establishing the effects of potential failure modes within a system. The analysis can be performed at any level of assembly. This can be done with a criticality analysis, in which case it is called an FMECA. FMECA is a semi-quantitative analysis, where the failure probability and the consequence data are used to assess the criticality of each failure mode. It is a systematic methodology to increase the inherent reliability of a system or product. It is an iterative process of identifying failure modes, assessing their probabilities of occurrence and their effects on the system, isolating the causes, and determining corrective actions or preventive measures. When the analysis is done from a functional standpoint, it is usually performed at a plant or unit level, whereas if the focus is on the hardware, it usually descends down to the maintainable-item level. The amount of data required is different depending on the focus (see Tables I.2 to I.4 for details). While it is most often used in the early stages of the design process to improve the inherent reliability, the FMECA technique is equally useful in addressing system safety, availability, maintainability, or logistics support.
Reference to existing standards	MIL-STD-1629 [21] IEC 60812 (1987-05) [10]
Overall need for information	The analysis is an inductive and systematic process in which individual failures at component level are generalized into potential failure modes at system level. The structured method consists of the following steps: a) system definition (both from functional and hardware standpoints); b) identification of failure modes (it is necessary that it include the operational and environmental conditions present when failure occurs); c) determination of causes (understanding of the failure mechanism and identification of the lowest level in hierarchy affected); d) assessment of effects (in terms of system performance, reliability, maintainability and safety); e) identification of detection means (to verify that suitable detection means exist for all critical failure modes); f) classifications of severity (to assign priorities to corrective actions; typically with 3 or 4 levels); g) estimation of probability of occurrence (from failure rates based on experience or public data bases or classification into 3 or 4 levels by using engineering judgement); h) computation of the criticality index (a combination of the probability of occurrence and the severity of the failure); i) determination of corrective action (by eliminating the cause of the failure, decreasing their probability of occurrence, improving failure detection or reducing the severity of the failure).

I.3 Fault tree analysis

A summary of the fault-tree analysis (FTA) is given in Table I.2.

Table I.2 — Fault-tree analysis (FTA)

Analysis elements	Summary
Analysis description	This is a graphical, top-down method used to analyse the logical links between failure of an overall system and the failures of its components and to perform probability calculations. NOTE 1 FTA deals only with two-state components and systems. NOTE 2 It can be used to analytically calculate the unavailability of a production system, but is not suited to assess its production availability when several production levels must be taken under consideration. NOTE 3 Except when some hypotheses (e.g. no repair) are met, unreliability cannot be assessed by using FTA.
Objective of analysis	There are several objectives such as the following examples: — build a graphical representation of the combinations of the individual components failures that lead to failure of the whole system and, by doing so, obtain the Boolean equation linking the undesirable event (at the whole system level) to the failure of the individual components; — analyse qualitatively the reliability/availability (see Notes 1 to 3) of the system by identifying the combinations of basic failures leading to the undesirable event. These combinations of failures are the so-called “minimal cut sets” (coherent FT) or “prime implicants” (non-coherent FT); — analyse semi-quantitatively the reliability/availability (see Notes 1 to 3) of the system by sorting its minimal cut sets (or prime implicant) in order of decreasing probabilities; — calculate the probability of failure (see Notes 1 to 3) of the whole system; — evaluate various importance factors in order to assess the impact of the failures of the individual components; — evaluate the impact of the individual input uncertainties over the result(s).
Reference to existing standards	IEC 61025 [11]
Overall need for information	A fault tree represents a Boolean process, which is used to calculate the probability of the corresponding overall event from the individual probabilities of the basic events appearing in the formula. Therefore, the inputs used are the pure probabilities of failures, which it is necessary to evaluate from the reliability parameters of the related components: — probability of failure; — failure rates, repair rates; — test interval, test efficiency, human error, etc. FTA is also a very good support for performing common-cause failure analyses, sensitivity analyses and uncertainty analyses. The fault tree can also be used in combination with a cause-consequence diagram to analyse underlying causes of the event failure.

I.4 Reliability block diagram

A summary of a reliability block diagram (RBD) is given in Table I.3.

Table I.3 — Reliability block diagram

Analysis elements	Summary
Analysis description	Formally, this is a logic diagram representing how a system works and allowing probabilistic calculations. An RBD is made of two-state boxes (representing individual components) linked together according to the functional logic of the overall system. NOTE 1 This is more a representation than an analysis method (in contrast to FTA, which is both). Less abstracted than FTA, this is the method preferred by engineers to represent systems. NOTE 2 An RBD deals only with two-state components and systems; FTA and RBD have exactly the same calculation limitations (see Table I.2). NOTE 3 An RBD is not suited to production-assurance analysis, which require flow networks that accommodate multi-state systems.
Objective of analysis	The purpose of RBD is to build a logical model remaining as close as possible to the system architecture and representing those components that shall be operating/failed in order that the overall system be operating/failed. An RBD is generally an output of the functional analysis of the system under study. From the point of view of logic, an RBD represent a Boolean equation. It is equivalent to a fault tree and can be use for exactly the same purpose with the same computation techniques (see Table I.2). An RBD can be considered as a kind of “electrical” circuit. Looking for combinations of component failures leading to system failure is equivalent to identifying where this circuit can be “cut.” Hence, the origin of the term “cut set.”
Reference to existing standards	IEC 61078 [12]
Overall need for information	Same as for fault tree (see Table I.2).

I.5 Models for production-availability calculations

I.5.1 General

Except for the Markov process analysis (MPA), classical models are not well adapted for production-availability calculations. And even MPA is efficient only for very small systems. Therefore, it is necessary to use models able to

— handle the complex behaviour of production systems,

— obtain the various probabilistic parameters needed,

— perform calculations quickly on industrial size system.

A solution widely adopted is to perform “Monte Carlo simulations” on “behavioural models.”

I.5.2 Monte-Carlo simulation principles

Monte-Carlo simulation is a computation technique that replaces the analytical calculations by statistical calculations. It is based on the simulation of a great number of production system histories according to the following principle.

— The instants of occurrence of the events (e.g. failures, repairs, bad weather, rig mobilization) occurring over a given history are calculated by using random numbers according to relevant probability distributions.

— The relevant parameters (e.g. production losses, number of spare parts used, work load, time to first failure) are captured over the given history in order to constitute statistical samples.

— When a sufficient number of histories has been accumulated, statistical calculations are used to estimate the wanted parameters (e.g. production availability, average production losses, average work load, mean time to first failure) from the statistical samples.

Monte-Carlo simulation is very well suited to predict the production-availability of a production facility. As it is not analytical, it can be used to model a variety of situations, including complex failure and repair distributions, the effects of different repair policies, redundancy, operational aspects, etc. In addition, the process easily accommodates the combined consideration of stochastic and deterministic events.

I.5.3 Behavioural modelling

Before performing Monte-Carlo simulation, it is first necessary to build the model being simulated. It is necessary that such model have the following characteristics:

— approximate as closely as possible the actual system behaviour (e.g. react when events occur);

— encompass all elements having an impact on production (e.g. production flow through the various equipment, system response to component failure or repair, operation, maintenance, spare parts and flaring philosophies, SIMOPS, production profiles, etc.);

— code in a concise way the vast number of potential states of the production system.

The relevant mathematical framework to achieve above requirements consists of the so-called “finite-states automata,” which generalize all the classical models (RBD, FTA, MPA).

Such “finite-state automata” are widely used for applications including Markov graphs, flow diagrams, Petri nets, formal languages (proprietary or published), etc. Their performances and modelling capacities vary over a large range and it is recommended to verify carefully that the particular package selected is suitable for a given production-availability study.

I.5.4 Flow network analysis (FNA)

A summary of the flow-network analysis (FNA) is given in Table I.4.

Table I.4 — Flow network analysis

Analysis elements	Summary
Analysis description	This is a diagram looking like an RBD but representing a production system. It is composed of boxes (representing the production capacities of individual process components) linked together according to the circulation of the production flow throughout the production system. NOTE 1 This is more a representation than an analysis method. It is widely used by engineers who often confuse it with RBD. NOTE 2 It is generally necessary to mix RBD and flow networks (FN) to represent both the circulation of the flow and the impact of utility failures. NOTE 3 Most of the proprietary software packages devoted to production-availability calculations are based on Monte Carlo simulation on RBD/FN-like models. Their modelling capacities and computation performances vary over a large range and it is wise to analyse them cautiously before using them.
Objective of analysis	The purpose of flow network (FN) is to — build a flow model that remains as close as possible to the system architecture (e.g. equipment in series, redundancies) and representing the production capacity of the system as a function of the production capacities of its components; — use it as a Monte-Carlo simulation support to perform the calculations and evaluate the relevant production parameters defined in the PAP.
Reference to existing standards	None
Overall need for info	The flow diagram itself can be drawn from the process flow diagrams (PFD) and process instrumentation diagrams (PID) of the system under study and the inputs includes those presented in Table I.2 (see also Table I.6). Inputs identified in I.5.3 are also needed but cannot be graphically represented.

I.5.5 Petri net analysis

A summary of the Petri net analysis (PNA) is given in Table I.5.

Table I.5 — Petri net analysis

Analysis elements	Summary
Analysis description	This is a graphical method that uses Petri nets (represented as finite-state automata) to build a dynamic behavioural model of the system. Potential events are represented by transitions and potential states by places. Arcs and predicates (equations) are used to model the conditions to validate transitions (i.e. events able to occur). Arcs and assertion (equations) are used to model when a transition is fired (i.e. an event occurs). NOTE Petri nets look more abstract than RBD, FNA or MPA but, for a light intellectual investment, they present several advantages: — Most of the information can be displayed on the graph itself. — Steppers can be implemented to verify the behaviour of the model. — Very fast Monte-Carlo computations can be implemented.
Objective of analysis	There are several objectives: — building an efficient behavioural model for Monte Carlo simulations; — describing accurately both function and dysfunction of the dynamic systems like production facilities; — representing easily and accurately the logistics, the resources used by several users (e.g. a single repair team for several components) and the reconfiguration of the system after a component failure or repair; — simulating the behaviour step by step manually (i.e. by using a “stepper”) to verify that it reflects that of the actual production system; — using any probabilistic law (e.g. not just the classical exponential law) for component failures, repairs, etc., and mixing deterministic and random delays within the same model; — obtaining easily both classical results (e.g. similar to those obtained by FTA, RBD, MPA) and any other relevant parameter: production losses, production (un)availability, flared gas quantity, maintenance man-hours, number of repairs performed by a given repair team, number of failures, load of the repair support, etc.; — extracting the shortest and/or the most probable sequences of event (scenarios) starting from the perfect state (if any) and leading to the fully failed state (if any).
Reference to existing standards	Standards exist dealing with validation and proof, but they are not directly applicable for production-availability purposes.
Overall need for information	A Petri net is an automatum behaving dynamically like the actual system under study. Every event that can occur on the actual system (see I.5.3) can be modelled in the Petri net. Therefore, the types of information that can be accommodated limited only by the skill of the analyst and the detail needed for the study. Logistics, resources, spare parts, preventive maintenance policy, reconfigurations, flaring policy are the more common types of information generally required.

I.6 Design reviews

Formal design reviews are normally carried out for many systems during the course of a development project. Special production-assurance design reviews should be considered, or production-assurance aspects should be included in other design reviews. Maintainability aspects may, for example, be included in working environment design reviews.

Design reviews should be performed by a group of persons from relevant disciplines. The design review should be performed with the systematic application of guide words or check lists.

Design reviews can focus on any aspect influencing regularity such as

- general quality of products,
- product specification,
- design margins/safety margins affecting reliability of equipment,
- system configuration/redundancy,
- operational conditions,
- maintenance philosophy,
- maintenance procedures,
- maintainability/access/modularization,
- working environment for maintenance activities,
- required skills for maintenance personnel,
- spare parts availability,
- tools required,
- safety,
- product experience.

Reference can be made to an existing standard, IEC 61160 [13].

I.7 Hazard and operability study

The purpose of a hazard and operability (HAZOP) study is to identify hazards in process plants and to identify operational problems and provide essential input to process design. Besides being useful from a production-assurance point of view, the HAZOPs can also be used to identify alternative safe ways of operating the plant in an abnormal situation to avoid shutdown.

HAZOPs may be used on systems as well as operations. Used on operations, such as maintenance or intervention activity, findings from the HAZOP can provide input to regularity analyses.

Reference can be made to existing standards IEC 61882 [14] and ISO 17776 [20].

I.8 Performance and operability review

Performance and operability review (POR) involves a thorough review of failure and downtime scenarios in the production system under analysis. The objectives with the review include

- an evaluation of how failures in the system are identified and the implications of the consequences of the various failure modes;

- an estimate of the downtime related to the preparation for repair and start-up of production (focus on process-related conditions that can impact these issues); this should be seen in conjunction with reliability-data qualification and suggested estimates that can be assessed in a POR exercise;
- an evaluation of preliminary reliability data for a production-availability model.

The total downtime related to restoration of a failed item consists of several phases. These include

- a pre-repair phase (e.g. troubleshooting, isolation, depressurization, gas freeing, mechanical pre-work);
- an active repair time (typically called MTTR);
- a post-repair phase (e.g. mechanical post-work, start-up).

A POR group is established consisting of regularity analysts and experts in disciplines such as process operation and maintenance. During POR sessions, failure scenarios of each sub-part or stage of the model are evaluated through a systematic review. Total downtime estimates are established by achieving time estimates for all downtime phases.

Figure I.1 illustrates an example of downtime associated with a failure event.

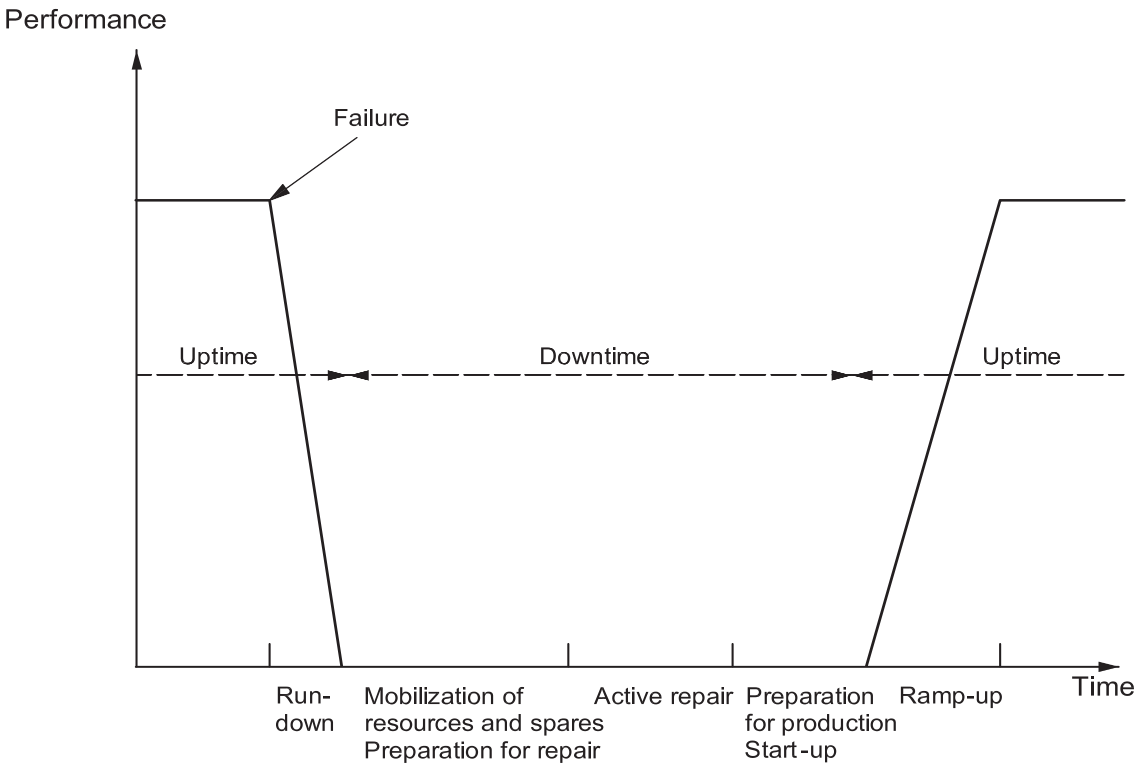


Figure I.1 — Illustration of downtime associated with a failure event

I.9 Reliability testing

Several types of reliability testing can be performed in order to predict reliability of components.

As mentioned in BS 5760-2 [1], tests may include the following:

- reliability-growth testing;

- development-reliability demonstration testing;
- environmental-stress screening, including burn-in, during production;
- production-reliability assurance testing;
- in-service reliability demonstration.

It should be noted that reliability testing is not applicable for most components, sub-systems and systems in the petroleum, petrochemical and natural gas industries. Accelerated lifetime testing involves overstressing in terms of environmental and operational conditions, which provokes different or alternative failure modes and degradation mechanisms compared to normal operating conditions. It has proved extremely challenging to reproduce normal lifetime degradation from accelerated lifetime testing.

The production-availability model may be used to perform sensitivity studies in order to detect for which of the components a better knowledge of their reliability parameters is necessary, or what reliability it is necessary to demonstrate for given components to reach the scheduled targets.

I.10 Human factors

Interfaces between the products, systems, equipment (including its operations and maintenance documentation) and its operation and maintenance personnel should be analysed to identify the potential for, and the effects of, human errors in terms of product fault modes. Particular attention should be given to the following:

- analysis of the product to ensure that the human interface, and related human tasks, are identified;
- evaluation of potential human mistakes at the interface during operation and maintenance, their causes and consequences;
- initiation of product and/or procedure modifications to reduce the possibility of mistakes and their consequences.

Reference to relevant literature:

- EEMUA Publication 191 [23];
- EEMUA Publication 201 [24];
- API Publication 770 [26].

I.11 Software reliability

Software systems are likely to contain faults due to human error in design and development, and these faults can give rise to failures during operation. The improved reliability of hardware components, and of electronic components in particular, can reduce the contribution of hardware unreliability to system failure. Hence, systematic failures due to software faults can frequently become the predominant cause of failure in programmable systems.

In analysing a system containing software components, the block diagram technique, FMECA (see Clause I.2) or the fault-tree analysis (see Clause I.3) can both be applied to take account of the effects of a software failure on the system behaviour. This is useful for identifying software components that are critical to the function of the system. For these methods to be applied quantitatively, it is necessary to measure the reliability of the software components.

Note that faults in software systems have unique characteristics in the manner in which the faults occur, as follows.

— The faults are latent within the software from the start and are hidden.

— All identical software have the same faults.

— Once a fault is detected and successfully repaired, it does not occur again.

— Extensive testing can eliminate many software faults.

— Software should be developed, designed, tested and used with the same kind of hardware (i.e. change of hardware can activate latent faults within the software).

For further description of software reliability, reference can be made to IEC 61508-3 [15] and IEC 60300-3-6 [27].

I.12 Dependent failures

The classical equations used to calculate system reliability from component reliability assume that the failures are independent. Some dependent/common-cause failures can occur that lead to system performance degradation or failure through simultaneous deficiency in several system components due to internal or external causes. External causes can include human or environmental problems while internal causes are generally associated with hardware.

Production-performance (e.g. production availability) predictions should include an evaluation of dependent/common-cause failures.

I.13 Life data analysis

Life data analysis is used to fit the life data (failure data) to a particular distribution. It is then possible to use the known characteristics of the distribution to gain a more complete understanding of the failure behaviour of the item. Many distributions are available and one can be more suitable to model a particular data set than another.

NOTE 1 The choice of the most appropriate distribution usually requires prior knowledge of the operative failure regime.

NOTE 2 Further description of life data analysis can be found in ISO 14224:2006, Annex C.

NOTE 3 Only Monte-Carlo simulation is able to handle all probabilistic distributions.

I.14 Reliability-centred maintenance analysis

In a reliability-centred maintenance (RCM) analysis that has proposed to establish the (preventive) maintenance programme in a systematic way, the following steps are normally covered:

— functionality analysis, which defines the main functions of the system/equipment;

— criticality analysis, which defines the failure modes of the equipment and their frequency (for which FMECA can be used);

— identification of the causes of failure and the mechanisms for critical fault modes;

— definition of the type of maintenance based on the criticality of the failure, the failure probability, the maintenance cost, etc.

The RCM process should be updated throughout the life cycle in conjunction with revisions of the maintenance programme, also using relevant field experience data as well as verifying the criticality assessment.

Valid production-performance analysis information used in early project phases should be fed into the RCM process, when appropriate, to enable consistency and interaction between the two studies. Coordination of reliability data utilized in the two studies should be ensured. Similarly, the “living” RCM study information should be consulted when production-assurance and reliability analyses are updated during operational stages.

I.15 Risk-based inspection analysis

Risk-based inspection analysis (RBI) is a methodology which aims at establishing an inspection programme based on the aspects of probability and consequence of a failure. The methodology combines production-assurance and risk-analysis work and is typically applied to static process equipment (e.g. piping, pressure vessels and valve bodies). The failure mode of concern is normally loss of containment.

Interactions between RBI, RCM, production assurance, availability and risk analyses are important to ensure consistency in relevant failure rates and associated downtime patterns for equipment covered in these analyses. Experience using RBI undertaken in the operating phases may also be utilized in connection with production-performance analysis of design alternatives in the planning stages as well as in early maintenance planning.

For further description of RBI, reference can be made to API RP 581 [25].

I.16 Test interval optimization

In order to comply with acceptance criteria and/or more specific requirements, for example safety systems, testing at certain intervals is necessary. Based on a system analysis, the test interval for both components and the system in general may be optimized with respect to the specified acceptance criteria/requirement and cost of testing. The component condition after testing (i.e. good-as-new or bad-as-old) should be clearly stated. Frequent testing normally leads to a high safety availability when the test coverage is adequate (by test coverage is meant the relevance of the tests (i.e. the likelihood of revealing a hidden functional failure during a test). Testing can, however, be expensive and can also in specific cases deteriorate the system (e.g. pressure testing of valves) and even introduce additional failures to the system. The test interval should be optimized based on an iterative process where the overall system-acceptance criteria and costs are among the optimization criteria.

I.17 Spare parts optimization

A summary of spare-parts optimization is given in Table I.6.

Table I.6 — Spare parts optimization

Analysis elements	Summary
Analysis description	Spare-parts optimization is based on operational research and selected reliability methods and may either be analytical or use simulations. The optimization process aims at balancing the cost of holding spare parts against the probability and cost of a spare-part shortage.
Objective of analysis	Optimize spare parts storage in terms of — initial quantity of spare parts, — reorder point, — replenishment quantity, — stock allocation (nominal).
Reference to existing standards	IEC 60300-3-12 [8] IEC 60300-3-14 [9]
Overall need for information	The following data are required: — demand rates, unit prices and criticality for defined spare parts; — work breakdown structure (configuration); — turn-around times, repair fractions, lead times; — supply links, transportation times, storage and re-supply costs.

Spare-parts optimization may be done by using optimization algorithms (e.g. genetic algorithms, ant colony) on the production-availability model.

I.18 Methods of structural reliability analysis

The methods of structural reliability analysis (SRA) represent a tool for calculating system probabilities where “system failure” is formulated by means of the so-called limit-state function and a set of random variables called the basic variables. The basic variables represent causal mechanisms related to load and strength that can give rise to the “system failure” event. The limit function is based on physical models. Methods of SRA are used to calculate the probability and to study the sensitivity of the failure probability to variations of the parameters in the calculation. Simulation is often used, but this is a very time-consuming technique in cases of small probabilities.

Methods of SRA are tools for calculating probability. Thus, the models used in this type of analysis are related to other reliability models, like lifetime models for mechanic and electronic equipment, reliability models for software, availability models for supply systems and models for calculating the reliability of human actions. All models of this kind can be used to calculate single probabilities that are input into different methods used in risk and production-performance analyses, such as for the basic events in fault tree and RBD analyses. A special feature of methods of SRA is, however, that the influence from several random variables and failure modes can be taken into account in a single analysis. Thus, using methods of SRA, the splitting of events into detailed sub-events is often not necessary to the same extent as in, for example, FTA.

I.19 Life-cycle-cost analysis

Production-assurance predictions are an important input parameter into life-cycle-cost analysis (LCC) evaluations. LCC evaluations are normally performed to select between two or more alternatives. The evaluations may include parts or whole facilities. The format of the input should be suitable to calculate the LOSTREV as part of the production-performance analysis, whilst CAPEX and OPEX are normally covered in the overall LCC analysis. One should recognize that OPEX includes the corrective maintenance cost (workload, spares, logistics and other resource consumption) that can be estimated from the production-performance analysis outlined in this International Standard.

Each alternative should be presented with the appropriate production-performance measures as a percentage of planned production. If production performance varies with time, performance measures should be presented as a function of time (one figure for each year of the field life). The related reference level profile should also be presented so that the production loss, and hence the LOSTREV, can easily be calculated. It is important to clarify the assumptions, in each case, whether, and if so when, the production loss can be recovered.

Unless the LCC evaluations aim at predicting the total LCC, the production-performance input can be limited to the differences between the alternatives. The production-performance input should include relevant figures for oil production, gas export and other as required.

Reference can be made to the existing International Standard: ISO 15663 (all parts) [17], [18], [19].

I.20 Risk and emergency preparedness analysis

Risk and emergency preparedness analyses link many aspects of reliability and production assurance with safety and environmental issues. Specifically, the interfaces to a risk and emergency preparedness analysis are as follows.

— Input to the risk and emergency preparedness analysis in terms of reliability of safety systems (fire water system, fire and gas detection system, ESD system); such individual system analyses can be a part of the overall production-performance analysis.

— Risk and emergency preparedness analysis can impose reliability requirements on certain equipment, typically safety systems.

— Risk and emergency preparedness analysis can impose requirements to equipment configuration that affect production assurance.

— Production can be made unavailability due to catastrophic events (see D.3.6 and Annex H).

EXAMPLE Manning levels, logistics and equipment test strategies.

— Coordination of study assumptions and data in risk and emergency preparedness analyses and production-performance analyses is recommended.

I.21 Novelty scoring analysis

Equipment for qualification can be classified according to: the newness of the technology and the amount of experience from previous application of a similar technology in the actual operational and environmental context. DNV RP-A203 [22] describes the classification illustrated in Table I.7, where the technology is subdivided into four categories:

a) no new technical uncertainties;

b) new technical uncertainties;

c) new technical challenges;

d) demanding new technical challenges.

Table I.7 — Classification of the new technology

Application area	Technology		
	Proven	Limited field history	New or unproven
Known	1	2	3
New	2	3	4

This classification applies to the system level as well as to each separate part and function. The classification is used to highlight which parts and functions have to be carefully scrutinized in the development process. Technology in category 1 is proven technology where proven methods for qualification, testing, calculations, and analysis can be used to document compliance with requirements. Technology defined as categories 2 to 4 is considered as new technology.

I.22 Markov process analysis

A summary of the Markov process analysis (MPA) is given in Table I.8.

Table I.8 — Markov process analysis

Analysis elements	Summary
Analysis description	MPA is a graphical model representing the behaviour of a system that jumps from state to state all along its life and allowing probabilistic calculations (reliability, availability, production availability). NOTE 1 Beyond probabilities, MPA allows the computation of the mean cumulated times spent in each state. This allows closure of the gap between reliability/availability calculations and production-availability calculations. NOTE 2 The main problem with MPA is the exponential increase in the number of possible states, which restricts this method to small systems. NOTE 3 Classical MPA is a process without “memory,” i.e., the future doesn't depend on the past. When this is not the case, it is necessary to use “semi-Markov” processes and analytical calculations become very difficult.
Objective of analysis	There are several objectives: — build a diagram (Markov graph) representing visually the behaviour of the whole system under study and defining an underlying set of differential equations allowing probabilistic calculations; — compute the (un)reliability and the pointwise (un)availability of the system under study; — compute the steady-state (un)availability of the whole system under study; — compute the mean (un)availability or production (un)availability of the system under study over a given period of time; — identify the shortest and/or the most probable sequences of event (scenarios) starting from the perfect state and leading to the fully failed state; — compute the expected requirement for spare parts and repair resources during the system’s lifetime.
Reference to existing standards	IEC 61165 [28]
Overall need for information	A Markov diagram represents a set of linear differential equations allowing the calculation of the probability that the system is in a given state at a given time. The inputs are data defining the transition rates and the relationships among the various states, such as: — failure rates, repair rates of individual components; — common-cause failures rates; — logistic delays (transformed into equivalent transition rates); — probabilities of failure upon demand (e.g. fail to start). Operation and maintenance philosophies are also included as inputs having an impact on the structure of graph itself, or on the transition rates (e.g. simultaneous repair of several components for a single transition).

Bibliography

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[5] IEC 60300-3-2, *Dependability management — Part 3-2: Application guide — Collection of dependability data from the field*

[6] IEC 60300-3-3, *Dependability management — Part 3-3: Application guide — Life cycle costing*

[7] IEC 60300-3-4, *Dependability management — Part 3-4: Application guide — Guide to the specification of dependability requirements*

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[17] ISO 15663-1, *Petroleum and natural gas industries — Life cycle costing — Part 1: Methodology*

[18] ISO 15663-2, *Petroleum and natural gas industries — Life-cycle costing — Part 2: Guidance on application of methodology and calculation methods*

[19] ISO 15663-3, *Petroleum and natural gas industries — Life-cycle costing — Part 3: Implementation guidelines*

[20] ISO 17776, *Petroleum and natural gas industries — Offshore production installations — Guidelines on tools and techniques for hazard identification and risk assessment*

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[30] IEC 60300-3-9: *Dependability management — Part 3-9: Application guide — Risk analysis of technological systems*

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[32] API RP 17N, *Recommended practice — Subsea production system — Reliability and technical risk management*; Sixth draft, 18/01/2007[2)]

1) Available from Engineering Equipment & Materials Users' Association, 10-12 Lovat Lane, LONDON, EC3R 8DN

2) Note: This document is pending publication. Tentative schedule for publication is first quarter 2008.

