Collection and Exchange of Reliability and Maintenance Data for Equipment

ANSI/API STANDARD 689
FIRST EDITION, JULY 2007

ISO 14224:2006 (Identical), Petroleum, Petrochemical and Natural Gas Industries—Collection and Exchange of Reliability and Maintenance Data for Equipment

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Contents

Page

Foreword

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

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ISO 14224 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*.

This second edition cancels and replaces the first edition (ISO 14224:1999), which has been technically modified and extended. Annex B, which contains failure and maintenance notations, has been made normative. Further, additional informative Annexes A, C, D, E and F give recommendations on the use of reliability and maintenance data for various applications.

Introduction

This International Standard has been prepared based on ISO 14224:1999, experience gained through its use, and know-how and best practices shared through the international development process.

In the petroleum, natural gas and petrochemical industries, great attention is being paid to safety, reliability and maintainability of equipment. The industry annual cost of equipment unreliability is very large, although many plant owners have improved the reliability of their operating facilities by such attention. A stronger emphasis has recently been put on cost-effective design and maintenance for new plants and existing installations among more industrial parties. In this respect, data on failures, failure mechanisms and maintenance related to these industrial facilities and its operations have become of increased importance. It is necessary that this information be used by, and communicated between, the various parties and its disciplines, within the same company or between companies. Various analysis methodologies are used to estimate the risk of hazards to people and environment, or to analyse plant or system performance. For such analyses to be effective and decisive, equipment reliability and maintenance (RM) data are vital.

These analyses require a clear understanding of the equipment technical characteristics, its operating and environmental conditions, its potential failures and its maintenance activities. It can be necessary to have data covering several years of operation before sufficient data have been accumulated to give confident analysis results and relevant decision support. It is necessary, therefore, to view data collection as a long-term activity, planned and executed with appropriate goals in mind. At the same time, clarity as to the causes of failures is key to prioritizing and implementing corrective actions that result in sustainable improvements in reliability, leading to improved profitability and safety.

Data collection is an investment. Data standardization, when combined with enhanced data-management systems that allow electronic collection and transfer of data, can result in improved quality of data for reliability and maintenance. A cost-effective way to optimize data requirements is through industry co-operation. To make it possible to collect, exchange and analyse data based on common viewpoints, a standard is required. Standardization of data-collection practices facilitates the exchange of information between relevant parties e.g. plants, owners, manufacturers and contractors throughout the world.

Petroleum, petrochemical and natural gas industries — Collection and exchange of reliability and maintenance data for equipment

1 Scope

This International Standard provides a comprehensive basis for the collection of reliability and maintenance (RM) data in a standard format for equipment in all facilities and operations within the petroleum, natural gas and petrochemical industries during the operational life cycle of equipment. It describes data-collection principles and associated terms and definitions that constitute a “reliability language” that can be useful for communicating operational experience. The failure modes defined in the normative part of this International Standard can be used as a “reliability thesaurus” for various quantitative as well as qualitative applications. This International Standard also describes data quality control and assurance practices to provide guidance for the user.

Standardization of data-collection practices facilitates the exchange of information between parties, e.g. plants, owners, manufacturers and contractors. This International Standard establishes requirements that any in-house or commercially available RM data system is required to meet when designed for RM data exchange. Examples, guidelines and principles for the exchange and merging of such RM data are addressed.

Annex A contains a summary of equipment that this International Standard covers.

- This International Standard recommends a minimum amount of data that is required to be collected and it focuses on two main issues:
  - data requirements for the type of data to be collected for use in various analysis methodologies;
  - standardized data format to facilitate the exchange of reliability and maintenance data between plants, owners, manufacturers and contractors.
- The following main categories of data are to be collected:
  - equipment data, e.g. equipment taxonomy, equipment attributes;
  - failure data, e.g. failure cause, failure consequence;
  - maintenance data, e.g. maintenance action, resources used, maintenance consequence, down time.

NOTE Clause 9 gives further details on data content and data format.

- The main areas where such data are used are the following:
  - reliability, e.g. failure events and failure mechanisms;
  - availability/efficiency, e.g. equipment availability, system availability, plant production availability;
  - maintenance, e.g. corrective and preventive maintenance, maintenance supportability;
  - safety and environment, e.g. equipment failures with adverse consequences for safety and/or environment.

- This International Standard does not apply to the following:

  — data on (direct) cost issues;

  — data from laboratory testing and manufacturing (e.g. accelerated lifetime testing);

  — complete equipment data sheets (only data seen relevant for assessing the reliability performance are included);

  — additional on-service data that an operator, on an individual basis, can consider useful for operation and maintenance;

  — methods for analysing and applying RM data (however, principles for how to calculate some basic reliability and maintenance parameters are included in the annexes).

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.

IEC 60034-1:2004*, Rotating electrical machines — Part 1: Rating and performance*

IEC 60076-1:2000, *Power transformers — Part 1: General*

IEC 60076-2:1993, *Power transformers — Part 2: Temperature rise*

EC 60076-3, *Power transformers — Part 3: Insulation levels, dialectric tests and external clearances in air*

IEC 60529:2001, *Degrees of protection provided by enclosures (IP Code)*

IEC 62114, *Electrical insulation systems — Thermal classification*

3 Terms and definitions

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

NOTE Some derived RM parameters, which can be calculated from collected RM data covered by this International Standard, are contained in Annex C. References to Annex C are given as deemed appropriate.

3.1
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 over a given time interval, assuming that the required external resources are provided

NOTE For a more detailed description and interpretation of availability, see Annex C.

3.2
active maintenance time
that part of the maintenance time during which a maintenance action is performed on an item, either automatically or manually, excluding logistic delays

NOTE 1 A maintenance action can be carried out while the item is performing a required function.

NOTE 2 For a more detailed description and interpretation of maintenance times, see Figure 4 and Annex C.

3.3
boundary
interface between an item and its surroundings

3.4
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 another

NOTE Components that fail due to a shared cause normally fail in the same functional mode. The term common mode is, therefore, sometimes used. It is, however, not considered to be a precise term for communicating the characteristics that describe a common-cause failure.

3.5
corrective maintenance
maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function

NOTE For more specific information, see IEC 60050-191:1990, Figure 191-10.

3.6
critical failure
failure of an equipment unit that causes an immediate cessation of the ability to perform a required function

NOTE Includes failures requiring immediate action towards cessation of performing the function, even though actual operation can continue for a short period of time. A critical failure results in an unscheduled repair.

3.7
degraded failure
failure that does not cease the fundamental function(s), but compromises one or several functions

NOTE The failure can be gradual, partial or both. The function can be compromised by any combination of reduced, increased or erratic outputs. An immediate repair can normally be delayed but, in time, such failures can develop into a critical failure if corrective actions are not taken.

3.8
demand
activation of the function (includes functional, operational and test activation)

NOTE For a more detailed description, see C.2.2.

3.9
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

NOTE This state is related to availability performance (see 3.1).

3.10
down time
time interval during which an item is in a down state

NOTE The down time includes all the delays between the item failure and the restoration of its service. Down time can be either planned or unplanned (see Table 4).

3.11
equipment class
class of similar type of equipment units (e.g. all pumps)

NOTE Annex A describes a variety of equipment classes.

3.12
equipment data
technical, operational and environmental parameters characterizing the design and use of an equipment unit

3.13
equipment unit
specific equipment unit within an equipment class as defined by its boundary (e.g. one pump)

3.14
error
discrepancy between a computed, observed or measured value or condition and the true, specified or theoretically correct value or condition

NOTE 1 An error can be caused by a faulty item, e.g. a computing error made by faulty computer equipment.

NOTE 2 The French term “erreur” can also designate a mistake.

3.15
failure
termination of the ability of an item to perform a required function

NOTE 1 After the failure, the item has a fault.

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

NOTE 3 This concept as defined does not apply to items consisting of software only.

NOTE 4 See also Table B.1 and Clauses F.2 and F.3.

3.16
failure cause
root cause
circumstances associated with design, manufacture, installation, use and maintenance that have led to a failure

NOTE See also B.2.3.

3.17
failure data
data characterizing the occurrence of a failure event

3.18
failure impact
impact of a failure on an equipment's function(s) or on the plant

NOTE On the equipment level, failure impact can be classified in three classes (critical, degraded, incipient); see 3.6, 3.7 and 3.26). Classification of failure impact on taxonomy levels 3 to 5 (see Figure 3) is shown in Table 3.

3.19
failure mechanism
physical, chemical or other process that leads to a failure

NOTE See also B.2.2.

3.20
failure mode
effect by which a failure is observed on the failed item

NOTE See also B.2.6.

3.21
failure on demand
failure occurring immediately when the item is solicited to start (e.g. stand-by emergency equipment)

NOTE See also Clause C.6.

3.22
fault
state of an item characterized by inability to perform a required function, excluding such inability during preventive maintenance or other planned actions, or due to lack of external resources

3.23
generic reliability data
reliability data covering families of similar equipment

3.24
hidden failure
failure that is not immediately evident to operations and maintenance personnel

NOTE Equipment that fails to perform an “on demand” function falls into this category. It is necessary that such failures be detected to be revealed.

3.25
idle time
part of the up time that an item is not operating

3.26
incipient failure
imperfection in the state or condition of an item so that a degraded or critical failure might (or might not) eventually be the expected result if corrective actions are not taken

3.27
indenture level
level of subdivision of an item from the point of view of maintenance action

3.28
item
any part, component, device, subsystem, functional unit, equipment or system that can be individually considered

NOTE In this International Standard, the common term “item” is used on all taxonomy levels 6 to 9 in Figure 3. See also 3.30, which defines a specific item level.

3.29
logistic delay
that accumulated time during which maintenance cannot be carried out due to the necessity to acquire maintenance resources, excluding any administrative delay

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

3.30
maintainable item
item that constitutes a part or an assembly of parts that is normally the lowest level in the equipment hierarchy during maintenance

3.31
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

3.32
maintenance data
data characterizing the maintenance action planned or done

3.33
maintenance impact
impact of the maintenance on the plant or equipment's function(s)

NOTE On the equipment level, two severity classes are defined: critical and non-critical. On plant level, three classes are defined: total, partial or zero impact.

3.34
maintenance record
part of maintenance documentation that contains all failures, faults and maintenance information relating to an item

NOTE This record can also include maintenance costs, item availability or up time and any other data where relevant.

3.35
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

NOTE For a more detailed definition and interpretation of maintainability, see Annex C.

3.36
maintenance man-hours
accumulated duration of the individual maintenance times used by all maintenance personnel for a given type of maintenance action or over a given time interval

NOTE 1 Maintenance man-hours are expressed in units of hours.

NOTE 2 As several people can work at the same time, man-hours are not directly related to other parameters like MTTR or MDT (see definitions in Annex C.5).

3.37
modification
combination of all technical and administrative actions intended to change an item

NOTE Modification is not normally a part of maintenance, but is frequently performed by maintenance personnel.

3.38
non-critical failure
failure of an equipment unit that does not cause an immediate cessation of the ability to perform its required function

NOTE Non-critical failures can be categorized as "degraded" (3.7) or "incipient" (3.26).

3.39
operating state
state when an item is performing a required function

3.40
operating time
time interval during which an item is in operating state

NOTE Operating time includes actual operation of the equipment or the equipment being available for performing its required function on demand. See also Table 4.

3.41
opportunity maintenance
maintenance of an item that is deferred or advanced in time when an unplanned opportunity becomes available

3.42
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

3.43
redundancy
existence of more than one means for performing a required function of an item

NOTE For more detailed definitions and interpretations, see C.1.2.

3.44
reliability
ability of an item to perform a required function under given conditions for a given time interval

NOTE 1 The term "reliability" is also used as a measure of reliability performance and can also be defined as a probability.

NOTE 2 For more detailed definitions and interpretations, see Annex C.

3.45
required function
function or combination of functions of an item that is considered necessary to provide a given service

3.46
subunit
assembly of items that provides a specific function that is required for the equipment unit within the main boundary to achieve its intended performance

3.47
surveillance period
interval of time (calendar time) between the start date and end date of RM data collection

NOTE For more detailed definitions and interpretations, see Annex C.

3.48
tag number
number that identifies the physical location of equipment

NOTE For more detailed definitions and interpretations, see Annex C.

3.49
taxonomy
systematic classification of items into generic groups based on factors possibly common to several of the items

3.50
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

NOTE This relates to availability performance.

3.51
up time
time interval during which an item is in an up state

4 Abbreviated terms

NOTE Specific abbreviations used for equipment types (e.g. BOP) and units (e.g. kW) are not included in the list below, but covered within each chapter where they are used.

CAPEX	capital expenditure
CDF	cumulative distribution function
CM	condition monitoring
CMMIS	computerized maintenance-management information system
DHSV	downhole safety value
ESD	emergency shutdown
FTA	fault-tree analysis
FMECA	failure mode, effect and criticality analysis
HIPPS	high-integrity process-protection system
KPI	key performance indicators
LCC	life cycle cost
LEL	lower explosion limit
MEG	monoethylene glycol
MI	maintainable item
MTBF	mean time between failures
MTTF	mean time to failure
MTTR	mean time to repair
MTTM	mean time to maintain
MUT	mean up time
MDT	mean down time
NDT	nondestructive testing
OPEX	operational expenditure
PM	preventive maintenance
P&ID	process and instrument diagram
PSD	process shutdown
PSV	process safety valve
QRA	quantitative risk assessment
RA	reliability and availability
RAM(S)	reliability, availability, maintainability (and safety)
RBI	risk-based inspection
RCM	reliability-centred maintenance
RM	reliability and maintenance
SIL	safety integrity level
SSIV	subsea isolation valve
TEG	triethylene glycol
TTF	time to failure
TTR	time to repair
WO	work order

5 Application

5.1 Equipment coverage

This International Standard is applicable to equipment types used in the petroleum, natural gas and petrochemical industry, including but not limited to equipment categories such as process equipment and piping, safety equipment, subsea equipment, pipeline systems, loading/unloading equipment, downhole well equipment and drilling equipment. The equipment may be permanently installed at the facilities or used in conjunction with installation, maintenance or modification phases.

Annex A contains examples of how this International Standard should be used for specific equipment types. The users are expected to define taxonomies for additional equipment classes as needed based on the principles given by this International Standard.

Some principles for RM data collection at equipment level can be applied for monitoring and analysing performance at plant and system levels constituted by various equipment types. However, facility- and plant-performance monitoring also requires other types of data not covered by this International Standard.

5.2 Time periods

This International Standard is applicable to data collected during the operational life cycle of equipment, including installation, start-up, operation, maintenance and modification. Laboratory testing, manufacturing and fabrication phases are excluded from the scope of this International Standard. It is, however, emphasized that analysis of relevant historic RM data shall be used in the dimensioning of such testing prior to operation. Technology qualification and development require, and benefit from, past reliability knowledge to reveal potential improvement areas (see 8.3).

5.3 Users of this International Standard

This International Standard is intended for users such as the following.

a) Installation/plant/facility: Operating facility, e.g. maintenance and engineering personnel logging equipment failures or recording maintenance events into facility information management systems.

b) Owner/operator/company: Reliability staff or others creating (generic) equipment reliability databases for equipment located in company facilities; reliability engineers requiring data or maintenance engineers preparing maintenance plans. This International Standard provides a format for analysing any RM data element as appropriate associated with an analysis (as described in Annex D); e.g. root-cause analysis, analysis of historic performance, prediction of future performance, use in a design process, etc.

c) Industry: Groups or companies exchanging equipment RM data or joint industry reliability database project co-operation. Improved communication of equipment reliability performance requires the principles in this International Standard to be adhered to (as a “reliability language”).

d) Manufacturers/designers: Use of RM data to improve equipment designs and learn from past experience.

e) Authorities/regulatory bodies: A format for communicating any RM data on an individual-event basis or as otherwise required from the operating company. This International Standard is, for example, vital for authorities addressing safety equipment reliability.

f) Consultant/contractor: A format and quality standard for data collection projects and analyses of safety, reliability or maintenance aspects commonly performed by contractors/consultants for the asset owners (e.g. oil companies).

While others, such as developers of computer-maintenance-management software, can find this International Standard to be useful, the primary users are expected to be owners and/or operators who should find the data to be collected readily available within operating facilities.

5.4 Limitations

Through analysis of data, RM parameters can be determined for use in design, operation and maintenance. This International Standard does not provide detailed descriptions of methods for analysing data. However, it does give recommendations for defining and calculating some of the vital RM parameters (Annex C) and reviews the purposes and benefits of some analytical methodologies for which data can be used. Such analytical methodologies and application areas can be found in other International Standards, and relevant International Standards have been exploited for the purpose of identifying and co-ordinating the RM data requirements (see Annex D).

Although cost data are important in establishing priorities for improvement opportunities and are frequently included in the analysis of reliability performance, cost data (parameters) are not specifically included in this International Standard. Most facilities track the costs of maintenance (man-hours), equipment replacements, capital improvements, business interruption and environmental events. These data may be maintained in the computerized maintenance management information system (CMMIS). When costs are required for setting the analysis of reliability in an economic perspective or performing calculation of life cycle costing, the user should obtain that information from the appropriate sources within the operating facility or company.

Due to the variety of uses for RM data, requirements for data in a data-collection programme should be adapted to the expected application(s). Credible analysis results are directly related to the quality of the data collected. While this International Standard does not specify detailed quality measures, data quality control and assurance practices are outlined to provide guidance for the user.

The technical information gathered to describe the equipment and its location within a plant, facility or system is, in this International Standard, not meant to be exhaustive and complete like the overall plant technical information system, but rather used to identify and explain variables for the purposes of the analytical functions. Use of common technical terms is, however, recommended and linked to life cycle information-system and equipment technical standards. Even though this International Standard describes how to record maintenance activities for the purpose of equipment reliability and availability optimization, this International Standard is not meant to act as a standard to specify in detail how maintenance programmes are documented.

The technical status of equipment and degradation of equipment performance can be recorded through condition-monitoring systems, which requires details beyond the equipment data covered in this International Standard. However, this International Standard contains RM data elements that can be used in such condition-monitoring systems.

This International Standard is not meant to be a software specification of such database systems but can, in general, be complied with to facilitate and improve the industry RM data exchange.

5.5 Exchange of RM data

A major objective of this International Standard is to make it possible to exchange RM data in a common format within a company, between companies, within an industrial arena or in the public domain. Measures for ensuring the quality of data are discussed in Clause 7. Some additional aspects to be considered with respect to exchange of RM data are the following.

a) Detailed versus processed data: Data can be exchanged on various levels from the actual failure and maintenance records to data on a more aggregated level. For example, if only the number of failures of a certain category is required, it is necessary to exchange only the failure rate for these failures. This sort of information is commonly given in public data sources (e.g. reliability-data books). For exchanging data on the overall performance of a unit or a plant (benchmarking), the so-called key performance indicators (KPI) parameters may be used. Examples of such KPI parameters are given in Annex E.

b) Data sensitivity: Some data fields can be of a certain sensitive character and/or possibly be used for purposes for which they were not intended (e.g. to obtain commercial advantages, non-qualified communication of plant/equipment experience). To avoid this, two options can be utilized:

— “blank” such data;

— make such data anonymous.

The latter can be achieved by defining some anonymous codes representing the data element where only a few authorized persons know the conversion between the codes and the actual data. This is recommended if these data fields are essential for the data taxonomy.

It is important to recognize the potential commercial sensitivity of exchanging reliability and other performance data. Competition law prohibits “collective boycott” agreements or arrangements between competitors where competitors agree not to deal with certain suppliers/contractors. A benchmarking study where competitors exchange information so that suppliers/contractors can be “ranked” incurs a real risk that the parties to the benchmarking study will arrive at a common conclusion not to use particular suppliers/contractors and this should be avoided. Collective boycott arrangements are violations of competition law and can leave individuals and companies exposed to criminal actions.

It is necessary, therefore, that any exchange comply with the national and international laws governing anti-competitive practices. Hence, it is recommended that prior to embarking upon such an exercise, clarification of the local guidelines is sought to avoid possible infringement.

c) Data security: Systematized operational-equipment performance (i.e. quality RM data that have a cost to obtain) is an asset generally of great value, and data not open to the public domain shall be treated with appropriate security measures to avoid misuse and not affect the reputation of associated parties. This relates to storage of data (e.g. safe location), transmission of data (e.g. Internet), access to data for authorized users (e.g. password), etc.

d) Value of data: In some cases, it is useful to define a “value measure” for an amount of reliability data. This can be the case in joint industry projects where several contributors are supposed to contribute with an equal “value” of data. Two approaches may be used:

— calculating the actual cost of collecting the data;

— value the data by combining the population with aggregated surveillance time.

6 Benefits of RM data collection and exchange

Although many plant owners have improved the reliability of their operating facilities, lost production and poor equipment reliability still represent a high annual industrial cost. Even though most failure events are not catastrophic, increased clarity as to the causes of failure events is a key to prioritizing and implementing corrective maintenance actions. This results in sustainable improvements in reliability, leading to improved profitability and safety.

Benefits of reliability data analysis are wide-ranging, including the opportunity to optimize the timing of equipment overhauls and inspections, the content of maintenance procedures, as well as the life cycle costing of sparing and upgrade programmes in operating facilities world-wide. Other benefits resulting from the collection and analysis of RM data include improvements in decision-making, reductions in catastrophic failures, reduced environmental impacts, more effective benchmarking and trending of performance, and increased process unit availability.

Improvement of equipment reliability is dependent on experiences from real-life usage. The collection, analysis and feedback of data to equipment designers and manufacturers are, therefore, paramount. Also, when purchasing new equipment, RM data are key parameters to take into account.

In order to merge data from several equipment units, plants or across an industry arena, it is required that parties agree on what data are useful to collect and exchange and that those data are contained in a compatible format.

Recently, several nations with oil and gas industries have issued regulations requiring the companies to have a system for the collection, analysis and implementation of corrective and preventive actions, including improvement of systems and equipment. Some of these regulations refer to International Standards, including this International Standard.

Collecting RM data is costly and therefore it is necessary that this effort be balanced against the intended use and benefits. Commonly one would select equipment for RM data collection where the consequences of failures do have impact on safety, production, environment or high repair/replacement cost as indicated below.

A typical feedback loop for potential uses of data is shown in Figure 1.

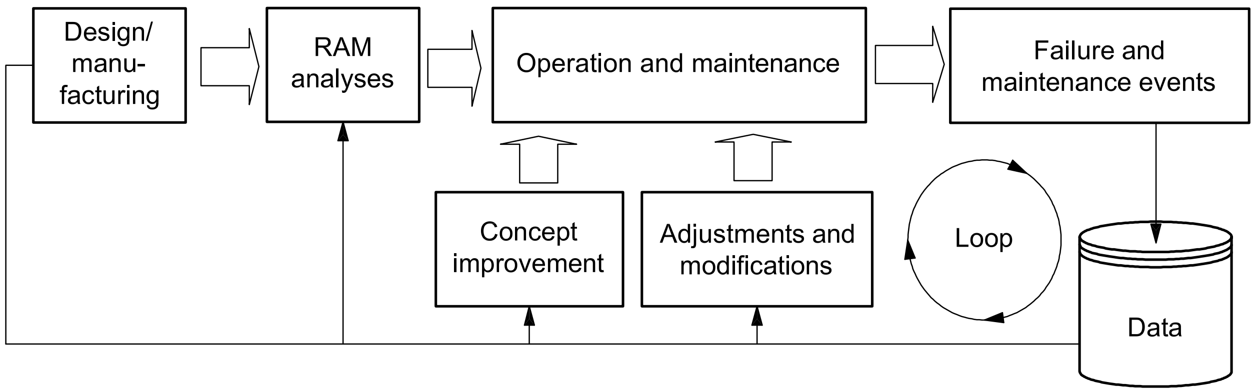


Figure 1 — Typical feedback of analysis from collected reliability and maintenance data

Industry and business value elements of utilizing this International Standard are summarised below:

a) economic aspects:

— cost-effective design to optimize CAPEX,

— cost-effective operation to optimize OPEX,

— improved profitability (reduced revenue loss),

— LCC/whole-life management,

— reduced cost of insurance;

b) general aspects:

— “being able to operate” (operatorship license),

— life extension of capital equipment,

— improved product quality,

— better (data-based) equipment purchase,

— better resource planning;

c) safety and environmental aspects:

— improved personnel safety,

— reduced catastrophic failures,

— reduced environmental impact,

— improvement of safety procedures and regulations (e.g. extend test interval based on RM performance),

— compliance with authority requirements;

d) analytical:

— higher-quality data,

— larger population of data,

— improved decision-making,

— reduced uncertainty in decision-making,

— qualified benchmarking,

— facilitation of industrial co-operation,

— creation of a common “reliability” language (understanding, various disciplines),

— verification of analysis techniques,

— better predictability,

— basis for a risk-based inspection and reliability-availability-maintainability studies.

7 Quality of data

7.1 Obtaining quality data

7.1.1 Definition of data quality

Confidence in the collected RM data, and hence any analysis, is strongly dependent on the quality of the data collected. High-quality data are characterized by the following:

a) completeness of data in relation to specification;

b) compliance with definitions of reliability parameters, data types and formats;

c) accurate input, transfer, handling and storage of data (manually or electronic);

d) sufficient population and adequate surveillance period to give statistical confidence;

e) relevance to the data user’s need.

7.1.2 Planning measures

The following measures shall be emphasized before the data-collection process starts.

a) Define the objective for collecting the data in order to collect data relevant for the intended use. Examples of analyses where such data may be used are quantitative risk analysis (QRA); reliability, availability and maintainability analysis (RAM); reliability-centred maintenance (RCM); life cycle cost (LCC); safety integrity level (SIL) analysis. (See also Annex D.)

b) Investigate the source(s) of the data to ensure that relevant data of sufficient quality are available. Sources cover inventory/technical equipment information, RM event data and associated plant impacts.

c) Define the taxonomical information to be included in the database for each equipment unit (see Clause 8).

d) Identify the installation date, population and operating period(s) for the equipment from which data can be collected.

e) Define the boundaries for each equipment class, indicating what RM data are to be collected (see Clause 8).

f) Apply a uniform definition of failure and a method of classifying failures (see Clause 9).

g) Apply a uniform definition of failure maintenance and a method of classifying maintenance failures (see Clause 9).

h) Define the checks used in data quality verification (see 7.1.3 and 7.1.9). At a minimum, the following shall be verified.

   1) The origin of the data is documented and traceable.

   2) The data originate from similar equipment type, technology and operating conditions.

   3) The equipment is relevant for the purpose (e.g. not outdated models).

   4) The data comply with definitions and interpretation rules (e.g. definition of failure).

   5) Recorded failures are within the defined equipment boundary and surveillance period.

   6) The information is consistent (e.g. consistence between failure modes and failure impact).

   7) Data are registered in the correct format.

   8) Sufficient data are collected to give acceptable statistical confidence, e.g. not biased by outliers. (See recommendations for calculating confidence limits in C.3.2.)

   9) Operating and maintenance personnel are consulted to validate the data.

i) Define a priority level for the completeness of data by a suitable method. One method of weighting the importance of the different data to be collected is by using three classes of importance in accordance with the following classification:

   — HIGH: compulsory data (coverage $\approx$ 100 %);

   — MEDIUM: highly desirable data (coverage $>$ 75 %);

   — LOW: desirable data (coverage $>$ 50 %).

j) Define the level of detail of RM data reported and collected and link it closely to the production and safety importance of the equipment. Base prioritization on safety, regularity and/or other severity measures.

k) Prepare a plan for the data-collection process (see 7.2), e.g. schedules, milestones, data-collection sequence for installations and equipment units, surveillance periods to be covered (see 8.3.1), etc.

l) Plan how the data will be assembled and reported and devise a method for transferring the data from the data source to the reliability data bank using any suitable method (see 7.2).

m) Train, motivate and organize the data-collection personnel, e.g. interpretation of sources, equipment know-how, software tools, involvement of operating personnel and equipment experts, understanding/experience in analysis application of RM data, etc. Ensure that they have an in-depth understanding of the equipment, its operating conditions, this International Standard and the requirements given for data quality.

n) Make a plan for quality assurance of the data-collection process and its deliverables. This shall, as a minimum, include procedures for quality control of the data and recording and correcting deviations. This verification of data quality shall be documented and may vary depending on whether the data collection is for a single plant or involves several company or industry facilities. When merging individual databases, it is imperative that each data record have a unique identification.

o) It is recommended to carry out a cost-benefit analysis of the data collection by running a pilot exercise before the main data-collection phase is started and to revise the plan if necessary.

p) Review the planning measures after a period of using the system (see 7.2.3).

7.1.3 Verification of quality

During and after the data-collection exercise, analyse the data to verify consistency, reasonable distributions, proper codes and correct interpretations in accordance with the planning measures (see 7.1.2). This verification-of-quality process shall be documented and may vary depending on whether the data collection is for a single plant or involves several company or industry facilities. When merging individual databases, it is imperative that each data record have a unique identification.

Assess the quality of data being collected as early as feasible in the data-collection process in accordance with the planning measures (see 7.1.2). A suitable procedure is an assessment by the data collector, who shall be provided with guidelines for what quality measures he/she should focus on in accordance with the planning measures. The main objective of this early assessment is to look for any problems that can require the planning measures to be immediately revised to avoid unacceptable data being collected.

Personnel other than those having collected the data shall verify the quality of each individual data record and the overall reliability pattern reflected by the sum of individual events in accordance with the planning measures (see 7.1.2).

7.1.4 Limitations and problems

Some of the problems and limitations to be aware of when obtaining quality data are summarized in Table 1.

Table 1 — Problems and limitations and storage

Issue	Challenges
Source	The data source can lack required data and the source information can be spread over several different systems (computers, files, books, drawings). It is recommended to carefully evaluate this aspect in the planning measures (see 7.1.2) in order to assess data quality, collection method and cost.
Interpretation	Commonly, data are compiled from the source into a standardized format (database). In this process, the source data can be interpreted differently by various individuals. Proper definitions, training and quality checks can reduce this problem (see 7.1.2).
Data format	In order to limit database size and make it easier to analyse the data, coded information is preferable to a free-text format; however, take care to ensure that the codes selected are appropriate for the information required and be aware that, although codes reduce the size of the database, some information is not collected. Free text should, however, be included in addition to codes to describe unexpected or unclear situations.
Data collection method	Most data needed for this category of data collection are today stored in computerized systems (e.g. CMMIS). By using state-of-the-art conversion algorithms and software, it is possible to transfer data among different computer databases in as (semi-)automated way, thereby saving cost.
Competence and motivation	Data collection in the "normal" manual way can become a repetitive and tedious exercise. Therefore, take care to employ people with sufficient know-how to do the jobs, avoid using personnel with low competence/experience, as data quality can suffer, and find measures to stimulate the RM data-collection staff, e.g. by training, doing plant visits and involving them in data analyses and application of results. Other examples are feedback on data-collection results, involvement in QA processes, relevant information fields in facility CMMIS to stimulate reporting quality, etc.

7.2 Data collection process

7.2.1 Data sources

The facility CMMIS constitutes the main source of RM data. The quality of the data that can be retrieved from this source is dependent on the way RM data are reported in the first place. Reporting of RM data according to this International Standard shall be allowed for in the facility CMMIS, thereby providing a more consistent and sound basis for transferring RM data to equipment RM databases. Other source information can be spread across several different systems (computers, files, books, drawings), for example, feedback on data collection results, involvement in QA processes, adequate or improper use of information fields in facility CMMIS to stimulate reporting quality, etc.

7.2.2 Data collection methods

The typical data-collection process consists of compiling data from different sources into one database where the type and the format of the data are pre-defined. The most common method is as follows.

a) Address all the data sources that are available, and extract the relevant "raw" data into an intermediate storage. If the information is contained in a computerized database, use any suitable methods for extracting the relevant information; viz. extraction of targeted information by specific software methods or printing reports with desired information.

b) Interpret this information and translate it into the type and format desired for the target database. In most cases, this is done by manual interpretation.

c) Transfer the data from the source(s) to the reliability data bank using any suitable method. Suitable "off-the-shelf" software can be used to transfer data from one database to another with the desired "language" conversion done by software algorithms. This is, however, feasible only as long as a conversion algorithm sufficiently robust to make a confident conversion can be defined. These methods do require some extra effort upfront and, therefore, are only cost-effective for large quantities of data or repetitive data collection of the same category. It may also be used for maintenance when transferring data from one CMMIS to another.

d) Data-collection methods significantly impact the cost-benefit analysis for data-collection and shall, therefore, be carefully planned and tested before the main data-collection process is started.

7.2.3 Organization and training

Data collection may be done either within the company using internal sources or as a task done by more specialized companies or personnel. As data are, by nature, “historical”, it evidently takes some time before sufficient data are accumulated to draw valid conclusions based on statistics only. The cost-benefit analysis for collecting data can take some time to become evident but annual tracking of equipment performance captures a useful history.

Data collection can require skills from several categories, viz. IT, reliability/statistics, maintenance, operation and data collection. Key personnel shall be familiar, in particular, with the data-collection concept and any specific software for the data-collection activity, and, to a reasonable extent, know the technical, operational and maintenance aspects of the equipment for which data are collected. Proper training of key personnel on these issues is necessary in order to obtain quality data. The personnel who check the quality of the data shall be different from those doing the data collection. Data collectors shall, as a pre-requisite, know this International Standard and give feedback as appropriate.

Before data collection starts, it is useful to do a pilot exercise to check the available population, the quality of source information and the feasibility of the data-collection methods. This serves as a model for what can be achieved within a given time and budget.

A system for dealing with deviations encountered in the data-collection process, such as ambiguous definitions, lack of interpretation rules, inadequate codes, etc., shall be established and problems solved as soon as possible. It can be a major task to correct corrupt data after many data have been collected.

A data-collection exercise shall also provide feedback by summarizing and evaluating all quality lessons learned during the planning and execution of the data-collection effort. Recommendations shall then be fed back to the relevant personnel for improvement on definitions, maintenance systems (e.g. CMMIS-systems) and the data-collection process and personnel.

8 Equipment boundary, taxonomy and time definitions

8.1 Boundary description

A clear boundary description is imperative for collecting, merging and analysing RM data from different industries, plants or sources. It also facilitates communication between operators and equipment manufacturers. Otherwise, the merging and analysis is based on incompatible data.

For each equipment class, a boundary shall be defined indicating what RM data are to be collected. This may be given by using a figure, a text definition or a combination of both.

An example of a boundary diagram is shown in Figure 2 and an example of a definition to accompany the diagram is as follows:

EXAMPLE The boundary applies to both general-service and fire pumps. Inlet and outlet valves and suction strainer are not within the boundary. Furthermore, the pump drivers along with their auxiliary systems are not included. Driver units are recorded as separate inventories (electric motor, gas turbine or combustion engine) and it is important that the failures on the driver, if recorded, be recorded as part of the driver units. A number in the pump inventory gives a reference to the appropriate driver inventory.

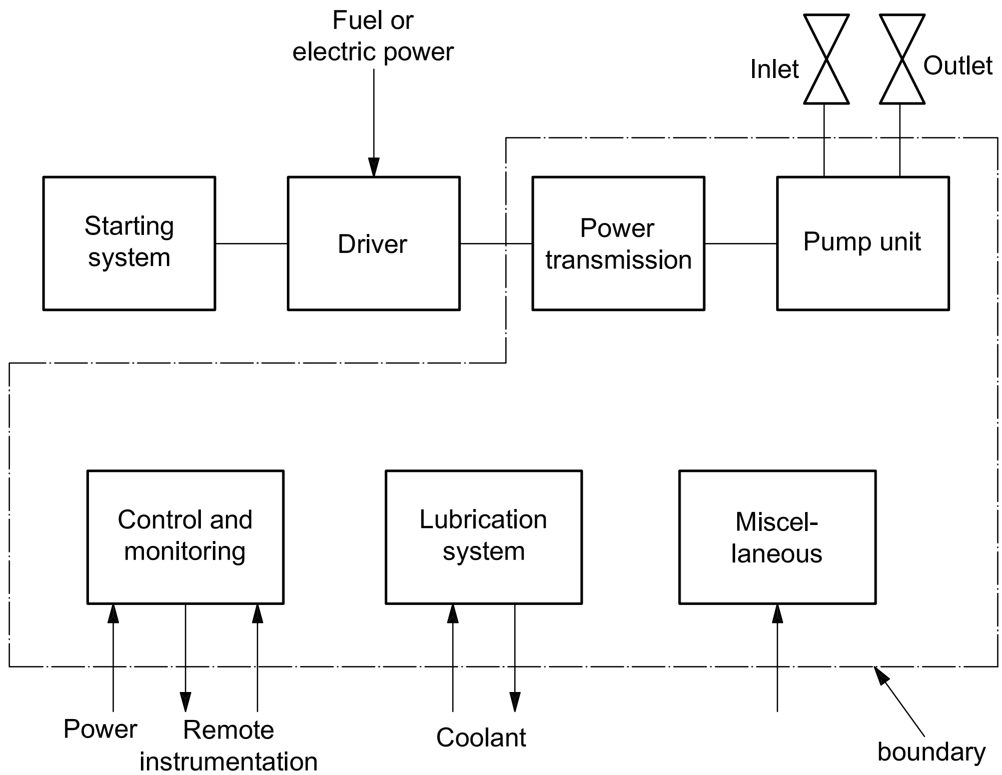


Figure 2 — Example of boundary diagram (pumps)

Due attention shall be paid to the location of the instrument elements. In the above example, the central control and monitoring items are typically included within the “control and monitoring” subunit, while individual instrumentation (trip, alarm, control) is typically included within the appropriate subunit, e.g. lubrication system.

The boundary diagram shall show the main lower-level items and the interfaces to the surroundings. Additional textual description shall, when needed for clarity, state in more detail what shall be considered inside and outside the boundaries (see the Example associated with Figure 2). When referring to this International Standard, it is vital that any deviation from the boundaries given in this International Standard, or new boundaries not given by this International Standard, be specified.

Boundaries shall avoid overlapping among different equipment classes. For example, when collecting data on instruments as separate equipment units, one shall avoid including those instruments that are also included within the boundaries of other equipment units on which data are being collected. Some overlapping can be difficult to avoid; however, such case(s) shall be identified and treated appropriately during the data analyses.

Recommended boundary diagrams for some selected equipment units are given in Annex A.

8.2 Taxonomy

The taxonomy is a systematic classification of items into generic groups based on factors possibly common to several of the items (location, use, equipment subdivision, etc.). A classification of relevant data to be collected in accordance with this International Standard is represented by a hierarchy as shown in Figure 3. Definitions of each segment are provided below, in addition to examples of different business streams and equipment types, as illustrated in Table 2.

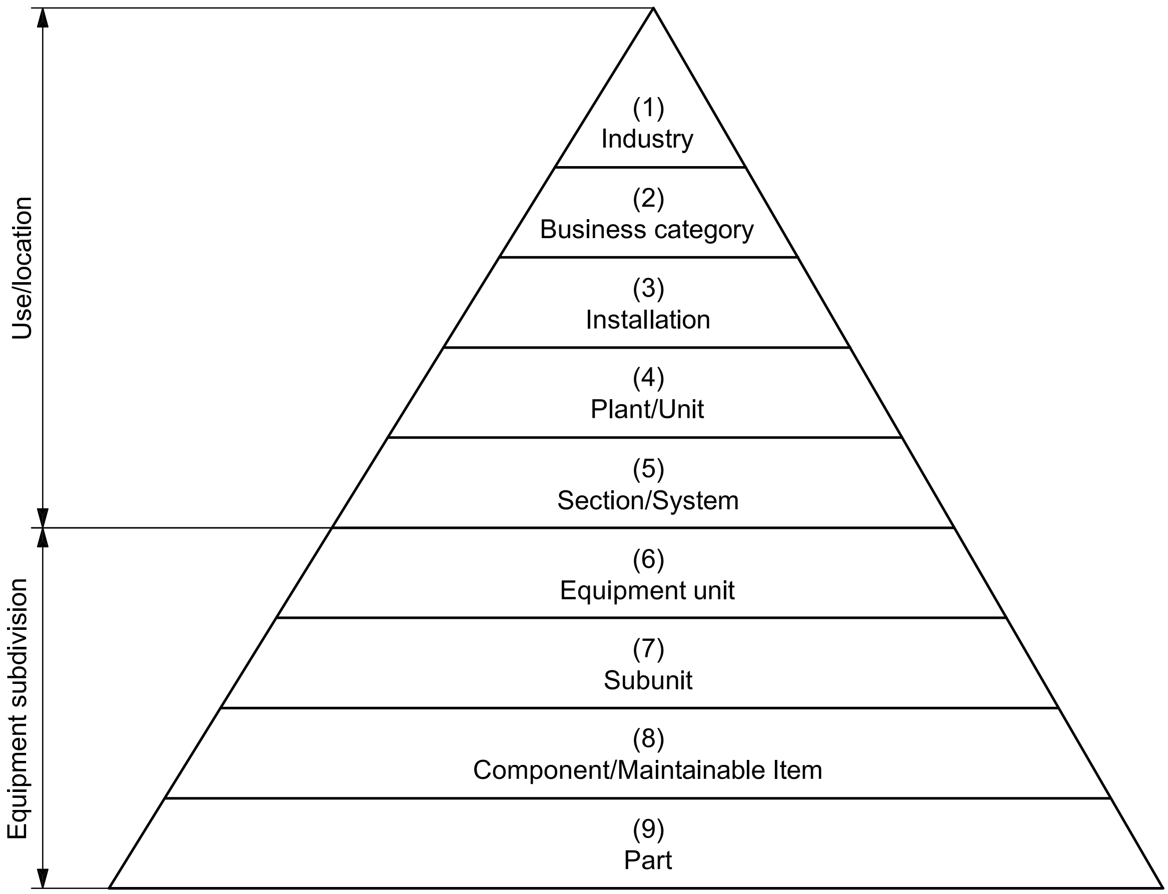


Figure 3 — Taxonomy

Levels 1 to 5 represent a high-level categorization that relates to industries and plant application regardless of the equipment units (see level 6) involved. This is because an equipment unit (e.g. pump) can be used in many different industries and plant configurations and, for analysing the reliability of similar equipment, it is necessary to have the operating context. Taxonomic information on these levels (1 to 5) shall be included in the database for each equipment unit as "use/location data" (see Table 2).

Levels 6 to 9 are related to the equipment unit (inventory) with the subdivision in lower indenture levels corresponding to a parent-child relationship. This International Standard focuses on the equipment unit level (level 6) for the collection of RM data and also indirectly on the lower indenture items, such as subunits and components. The number of subdivision levels for the collection of RM data depends on the complexity of the equipment unit and the use of the data. A single instrument might need no further breakdown, while several levels can be required for a large compressor. For data used in availability analyses, the reliability at the equipment-unit level can be the only data required, while an RCM analysis and root-cause analysis can require data on failure mechanism at the component/maintainable item, or parts, level. This International Standard does not specifically address level 9.

It is necessary that RM data be related to a certain level within the taxonomic hierarchy in order to be meaningful and comparable. For example, a failure mode shall be related to the equipment unit, while a failure mechanism shall be related to the lowest achievable level in the item hierarchy. Table 3 gives guidance on this.

Table 2 — Taxonomic examples

Main category	Taxonomic level	Taxonomy hierarchy	Definition	Examples
Use/location data	1	Industry	Type of main industry	Petroleum, natural gas, petrochemical
	2	Business category	Type of business or processing stream	Upstream (E and P), midstream, downstream (refining), petrochemical
	3	Installation category	Type of facility	Oil/gas production, transportation, drilling, LNG, refinery, petrochemical (see Table A.1)
	4	Plant/Unit category	Type of plant/unit	Platform, semi-submersible, hydrocracker, ethylene cracker, polyethylene, acetic acid plant, methanol plant (see Table A.2)
	5	Section/System	Main section/system of the plant	Compression, natural gas, liquefaction, vacuum gas oil, methanol regeneration, oxidation section, reaction system, distillation section, tanker loading system (see Table A.3)
Equipment subdivision	6	Equipment class/unit	Class of similar equipment units. Each equipment class contains comparable equipment units (e.g. compressors).	Heat exchanger, compressor, piping, pump, boiler, gas turbine extruder, agitator, furnace, Xmas tree, blow-out preventer (see Table A.4)
	7	Subunit	A subsystem necessary for the equipment unit to function	Lubrication subunit, cooling subunit, control and monitoring, heating subunit, pelletizing subunit, quenching subunit, refrigeration subunit, reflux subunit, distributed control subunit
	8	Component/ Maintainable item (MI) [a]	The group of parts of the equipment unit that are commonly maintained (repaired/restored) as a whole	Cooler, coupling, gearbox, lubrication oil pump, instrument loop, motor, valve, filter, pressure sensor, temperature sensor, electric circuit
	9	Part [b]	A single piece of equipment	Seal, tube, shell, impeller, gasket, filter plate, bolt, nut, etc.

[a] For some types of equipment, there might not be a MI; e.g. if the equipment class is piping, there might be no MI, but the part could be “elbow”.

[b] While this level can be useful in some cases, it is considered optional in this International Standard.

8.3 Timeline issues

8.3.1 Surveillance and operating period

The equipment surveillance period is typically used as the time period for determining time-related reliability parameters, e.g. MTBF, component life, etc. For many equipment units, the operating, or in-service, period is less than the surveillance period due to maintenance, sparing of equipment or intermittent operation of the equipment (e.g. tank-transfer pumps).

When equipment is in an idle state or in “hot” standby, i.e. being ready for immediate operation when started, it is considered to be operating (or “in-service”) by the definitions in this International Standard. Equipment on standby, which would require some activities to be performed before being ready for operation (“cold” standby), is not considered to be in an operating state. The various time-period definitions are illustrated in Table 4.

Table 3 — Reliability and maintenance parameters in relation to taxonomy levels

Recorded RM data	Hierarchy level [a]				
	4 Plant/Unit	5 Section/ System	6 Equipment unit	7 Subunit	8 Component/ Maintainable item
Impact of failure on safety	X [b]				
Impact of maintenance on safety	X				
Impact of failure on operations	X	(X) [c]			
Impact of maintenance with regard to operations	X	(X)			
Failure impact on equipment			X	(X)	(X)
Failure mode		(X)	X	(X)	(X)
Failure mechanism			(X)	(X)	X
Failure cause				(X)	X
Detection method		(X)	X	(X)	(X)
Subunit failed				X	
Component/maintainable item failed					X
Down time	(X)	(X)	X		
Active maintenance time			X	(X)	(X)

[a] See Figure 3.

[b] X = default.

[c] (X) = possible alternatives.

Table 4 — Timeline definitions

Total time												
Down time								Up time				
Planned down time					Unplanned down time			Operating time				Non-operating time
Preventive maintenance		Other planned outages			Corrective maintenance		Other unplanned outages					
Prepar-ation and/or delay	Active preventative maintenance (item being worked on)	Reserve [a]	"Cold " stand-by	Modifi-cation [b]	Prepar-ation and/or delay	Active corrective maintenance (item being worked on) [c]	Shutdown, [d] operational problems/ restrictions etc.	Run-down	Ramp-up	Run-ning	"Hot" stand-by	Idle

[a] Means that item is available for operation, but not required for some time. Does not include items considered as "spare parts" or items taken out of service on a more permanent basis.

[b] Modification can change the reliability characteristics of an item and can, therefore, require that the collection of reliability data for the surveillance period be terminated before the modification and be re-started with a new surveillance period after the modification.

[c] Includes fault diagnosis, repair action and testing (as required).

[d] Shutdown of machinery (trip and manual shutdown) is defined in C.1.8.

Data may also be collected for actual preventive maintenance if one wants the full picture of down time caused by all maintenance actions (see Table 4). Periods when equipment is deliberately taken out of service for an extended period, or is being modified, are not considered to be relevant for data collection.

The surveillance period may also cover several states in the life of the item. For example, in the subsea environment, equipment can be installed and functioning, i.e. a barrier to the escape of downhole hydrocarbons, but the well might not start producing for several months. Failures can occur on the equipment during this phase, requiring it to be repaired with a potential delay to start-up. Likewise, equipment can fail during a refinery turnaround, which is not a “production” phase, again requiring repair and possible delay to start-up.

8.3.2 Data collection periods

Depending on use and feasibility, data may be recorded for the whole equipment lifetime or for shorter intervals. The latter is common due both to cost and to getting data within a reasonable time frame. As shown in Annex C, the lifetime of many items is assumed to follow the so-called “bathtub” curve. If only the RM data for the steady-state operating part of an item are required, data collection shall start after the burn-in period is considered to have ended. The length of this period can vary among equipment categories from no burn-in to several months. Data recorded during the steady-state operating period often follows, or is assumed to follow, the exponential lifetime curve (constant failure rate). For some equipment, it is also useful and essential to collect data from “day one” in order to accumulate experience on burn-in failures. In this case, data collected from what may be considered as an initial burn-in period shall be distinguished from data collected from the subsequent steady-state operating period.

The length of the data-collection period shall be balanced against the expected failure rate, size of population and access to data. For equipment of high importance (safety) and equipment where one knows that few failures normally occur (subsea), a longer surveillance period is desirable (e.g. the whole lifetime history). It is even useful to collect data for equipment with no failures during the surveillance period because, by observing no failures in a given period, it is possible to estimate the failure rate by “censoring” the data. Methods within statistics shall be used to estimate the confidence of the data (upper/lower confidence limits), as shown in Annex C.

While the surveillance period is just an interval in calendar time between two specific times and can, therefore, be defined exactly, operating time is not always that straightforward to determine. For some rotating equipment, the operating time is recorded on a counter and can be read exactly. For other equipment, this might not be true. Hence, it is often necessary to estimate operating time based on knowledge from the operating and/or maintenance staff. As the “true” failure rate for an item shall be calculated based on actual operation, high priority should be given to collecting or estimating this parameter.

8.3.3 Maintenance times

Two main calendar times during maintenance are recommended to be collected, viz. down time and active repair time. The difference between the two is illustrated in Figure 4.

Down time includes the calendar time from the time the equipment is stopped for a repair until it is reconnected to its intended service after having been tested.

Active maintenance time is the calendar time during which maintenance work on the item is actually being performed. By this definition, active repair time cannot normally be greater than the down time.

NOTE Exceptionally, active repair time can be greater than down time if the maintenance can be performed with the equipment unit operating.

The operational time required to run down the equipment before repair and ramp up after the repair is not considered to be part of the down time.

NOTE See also definitions in 3.2 and 3.10.

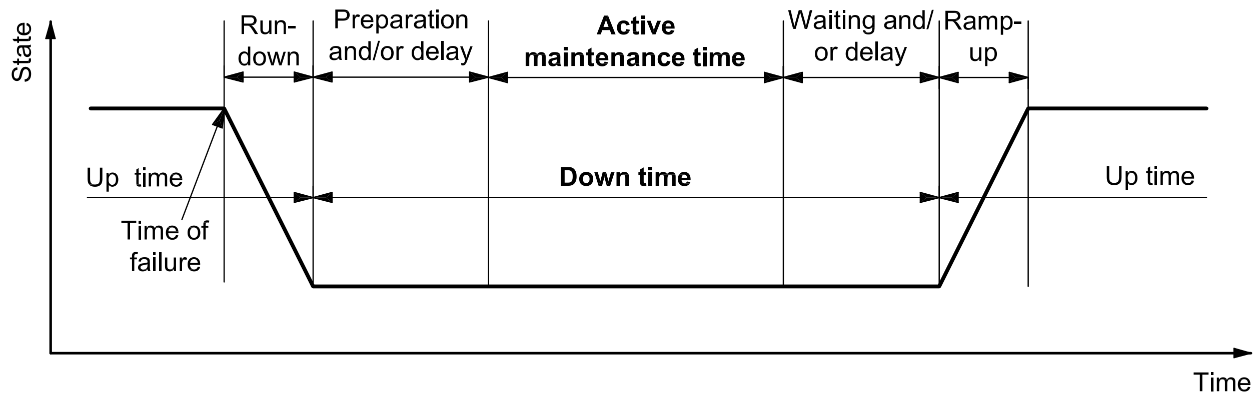


Figure 4 — Maintenance times

9 Recommended data for equipment, failures and maintenance

9.1 Data categories

The RM data shall be collected in an organized and structured way. The major data categories for equipment, failure and maintenance data are the following.

a) Equipment unit data (inventory data)

The description of an equipment unit (level 6 in Figure 3) is characterized by the following:

1) classification data, e.g. industry, plant, location, system;

2) equipment attributes, e.g. manufacturer's data, design characteristics;

3) operation data, e.g. operating mode, operating power, environment.

These data categories shall be general for all equipment classes. Additionally, some data specific for each equipment class (e.g. number of stages for a compressor) are required. Recommended data for some equipment classes are given in Annex A.

b) Failure data

These data are characterized by the following:

1) identification data, e.g. failure record number and related equipment that has failed;

2) failure data for characterizing a failure, e.g. failure date, items failed, failure impact, failure mode, failure cause, failure detection method.

c) Maintenance data

These data are characterized by the following:

1) identification data, e.g. maintenance record number, related failure and/or equipment record;

2) maintenance data, parameters characterising a maintenance action, e.g. date of maintenance, maintenance category, maintenance activity, impact of maintenance, items maintained;

3) maintenance resources, maintenance man-hours per discipline and total, utility equipment/ resources applied;

4) maintenance times, active maintenance time, down time.

The type of failure and maintenance data shall normally be common for all equipment classes, with exceptions where it is necessary to collect specific types of data, e.g. subsea equipment.

Corrective-maintenance events shall be recorded in order to describe the corrective action following a failure. Preventive-maintenance records are required to retain the complete lifetime history of an equipment unit.

9.2 Data format

Each record, e.g. a failure event, shall be identified in the database by a number of attributes. Each attribute describes one piece of information, e.g. failure mode. It is recommended that each piece of information be coded where possible. The advantages of this approach versus free text are

— facilitation of queries and analysis of data,

— ease of data input,

— consistency check undertaken at input, by having predefined code lists,

— minimization of database size and response time of queries.

The range of predefined codes shall be optimized. A short range of codes is too general to be useful. A long range of codes gives a more precise description, but slows the input process and might not be used fully by the data collector. Selected codes shall, if possible, be mutually exclusive.

The disadvantage of a predefined list of codes versus free text is that some detailed information can be lost. For all categories mentioned in 9.1 a), b) and c), it is recommended to include some additional free text giving more explanatory information as available and deemed relevant, e.g. to include a narrative of the occurrence leading to a failure event. This would assist in quality checking the information and browsing through single records to extract more detailed information.

Examples of codes are given in Annexes A and B for different equipment types and reliability data.

9.3 Database structure

9.3.1 Description

The data collected shall be organized and linked in a database to provide easy access for updates, queries and analysis. Several commercial databases are available that can be used as main building blocks for designing a reliability database. Two aspects of organizing the structure of data shall be addressed as described in 9.3.2 and 9.3.3.

9.3.2 Logical structure

The logical structure defines the logical links among the main data categories in the database. This model represents an application-oriented view of the database. The example in Figure 5 shows a hierarchical structure with failure and maintenance records linked to the equipment unit (inventory). Records describing preventive maintenance (PM) are linked to the inventory description in a many-to-one relation. The same applies for failures, which additionally have related corrective-maintenance records linked to each failure record. Each record (e.g. failure) may consist of several attributes (e.g. failure date, failure mode, etc.).

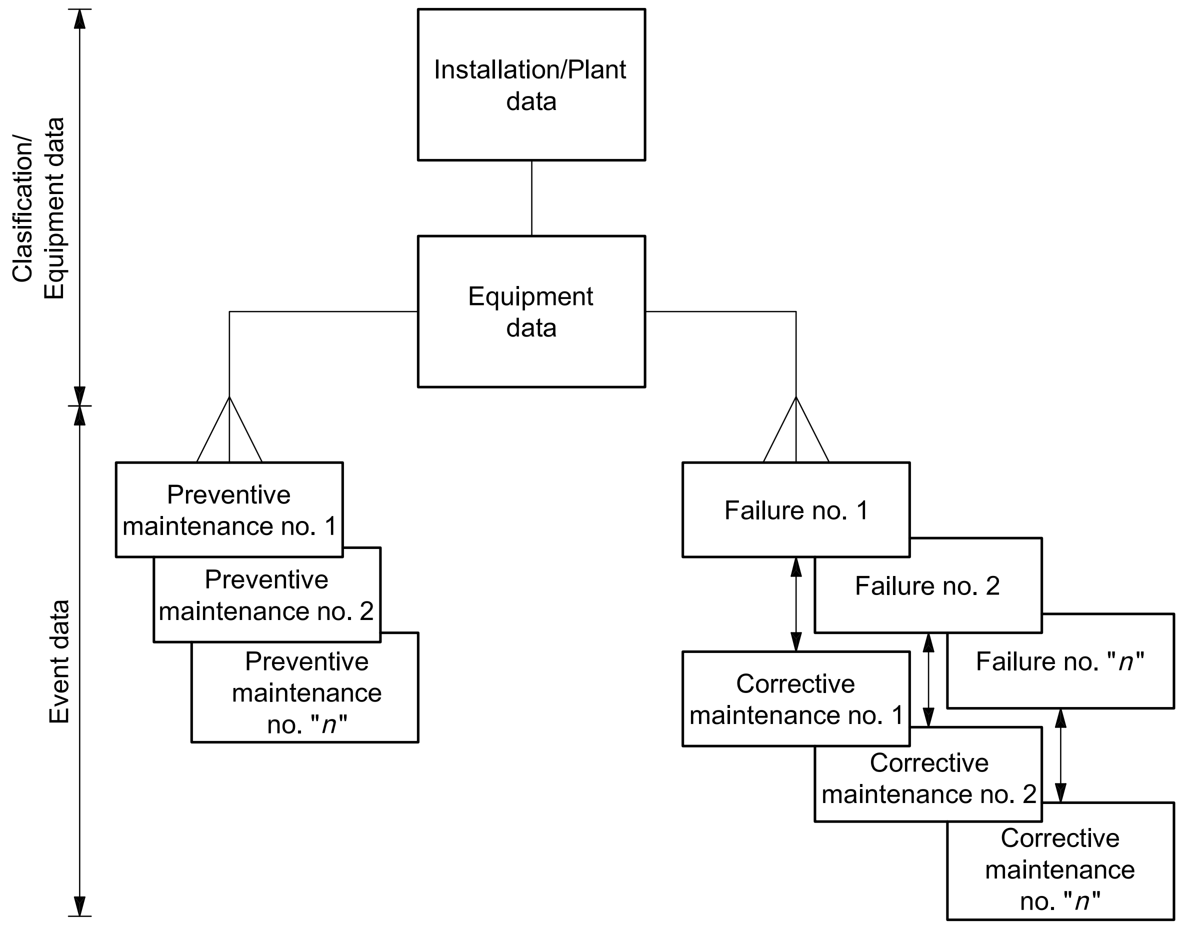


Figure 5 — Logical data structure (example)

9.3.3 Database architecture

This defines the design of the database as to how the individual data elements are linked and addressed. The following four model categories are commonly available, ranked in order of complexity and versatility.

a) Hierarchical model: Data fields within records are related by a “family tree” relationship. Each level represents a particular attribute of data.

b) Network model: This is similar to the hierarchical model; however, each attribute can have more than one parent.

c) Relational model: The model is constructed from tables of data elements, which are called relations. No access path is defined beforehand; all types of manipulation of the data in tabular form are possible. The majority of database designs use this concept.

d) Object model: The software is considered as a collection of objects, each of which has (1) a structure and (2) an interface. The structure is fixed within each object while the interface is the visible part that provides the link address between the objects. Object modelling enables the database design to be very flexible, extendable, reusable and easy to maintain. This model seems to be popular in new database concepts.

9.4 Equipment data

The classification of equipment into technical, operational and environmental parameters is the basis for the collection of RM data. This information is also necessary to determine whether the data are suitable or valid for various applications. Some data are common to all equipment classes and other data are specific to a particular equipment class.

To ensure that the objectives of this International Standard are met, a minimum of data shall be collected. These data are identified by an asterisk (*) in Tables 5, 6 and 8. However, the addition of certain other data categories can significantly improve the potential usability of the RM data (see Annex D).

Table 5 contains the data common to all equipment classes. In addition, some data that are specific for each equipment class shall be recorded. Annex A gives examples of such data for some equipment classes. In the examples in Annex A, the priority data are suggested, but they can vary according to each case or application.

9.5 Failure data

A uniform definition of failure and a method of classifying failures are essential when it is necessary to combine data from different sources (plants and operators) in a common RM database.

A common report, as given in Table 6 (see also Table 3), for all equipment classes shall be used for reporting failure data. For some equipment classes, e.g. subsea equipment, minor adaptations can be necessary.

The minimum data needed to meet the objectives of this International Standard are identified by (*). However, the addition of certain other data categories can significantly improve the potential usability of the RM data; see Annex D.

Table 5 — Equipment data common to all equipment classes

Data category	**Data**	**Taxonomic level** [a]	**Business category** (examples)			
			Upstream (E & P)	**Midstream**	**Downstream** (refining)	**Petro-chemical**
Use/ Location attributes	Industry	1	Petroleum	Natural gas	Petroleum	Petrochemical
	Business category (*)	2	E & P	Midstream	Refining	Petrochemical
	Installation category	3	Oil/gas production	Pipeline	Refinery	Petrochemical
	Installation code or name (*)	3	Delta	Beta gas line	Charlie refinery	Delta chemical
	Owner code or name	4	Smith Ltd.	Johnsen Inc.	JPL Corp.	ABC ASA
	Geographic location	3	UKCS	Europe	Mid-west USA	UK
	Plant/Unit category (*)	4	Oil/gas platform	Compressor station	Hydro-cracker	Ethylene cracker
	Plant/Unit code or name (*)	4	Alpha 1	CS 3	HH 2	EC 1
	Section/System (see Annex A) (*)	5	Oil processing	Compression	Reaction	Reaction system
	Operation category	5	Remote control	Remote control	Manned	Manned

Table 5 (*continued*)

Data category	Data	Taxonomic level [a]	Business category (examples)			
			Upstream (E & P)	**Midstream**	**Downstream** (refining)	**Petro-chemical**
Equipment attributes	Equipment class (see Annex A) (*)	6	Pump	Compressor	Heat exchanger	Heater
	Equipment Type (see Annex A) (*)	6	Centrifugal	Centrifugal	Shell and tube	Fired
	Equipment identification/ Location (e.g. tag number) (*) [b]	6	P101-A	C1001	C-21	H-1
	Equipment description (nomenclature)	6	Transfer	Main compressor	Reactor effluent	Charge heater
	Unique equipment identification number [b]	6	12345XL	10101	Cxy123	909090
	Manufacturer's name (*)	6	Johnson	Wiley	Smith	Anderson
	Manufacturer's model designation	6	Mark I	CO_2	GTI	SuperHeat A
	Design data relevant for each equipment class and subunit/component as applicable, e.g. capacity, power, speed, pressure, redundancy, relevant standard(s) (see also Annex A)	6	Equipment-specific	Equipment-specific	Equipment-specific	Equipment-specific
Operation (normal use)	Normal operating state/Mode (*)	6	Running	Active standby	Intermittent	Running
	Initial equipment commissioning date	6	2003.01.01	2003.01.01	2003.01.01	2003.01.01
	Start date of current service (*)	6	2003.02.01	2003.02.01	2003.02.01	2003.02.01
	Surveillance time, h (calculated) (*)	6	8 950	8 000	5 400	26 300
	Operational time, h (measured/calculated)	6	3 460	100	5 200	4 950
	Number of demands during the surveillance period as applicable (includes both operational and test activation) (*)	6	340	2	N.A.	N.A.
	Operating parameters as relevant for each equipment class; e.g. ambient conditions, operating power (see Annex A)	6	Equipment-specific	Equipment-specific	Equipment-specific	Equipment-specific
Additional information	Additional information in free text as applicable	6	Specify as needed	Specify as needed	Specify as needed	Specify as needed
	Source of data, e.g. P & ID, data sheet, maintenance system	6	Specify as needed	Specify as needed	Specify as needed	Specify as needed

a See definitions in Figure 3.

b The serial number is required for potential change-out at the equipment level. The tag number identifies only the physical location of equipment in the plant. If the equipment is replaced with, e.g. an overhauled unit, the tag number remains the same but the serial number changes.

(*) indicates the minimum data that is required to be collected.

Table 6 — Failure data

Category	Data to be recorded	Description
Identification	Failure record (*)	Unique failure record identification
	Equipment identification/Location (*)	E.g. tag number (see Table 5)
Failure data	Failure date (*)	Date of failure detection (year/month/day)
	Failure mode (*)	Usually at equipment-unit level (level 6) (see B.2.6) [a]
	Failure impact on plant safety (e.g. personnel, environment, assets) [b]	Usually zero, partial or total
	Failure impact on plant operations (e.g. production, drilling, intervention) [b]	Usually zero, partial or total
	Failure impact on equipment function (*)	Effect on equipment-unit function (level 6): critical, degraded, or incipient failure [c]
	Failure mechanism	The physical, chemical or other processes which have led to a failure (see Table B.2)
	Failure cause [d]	The circumstances during design, manufacture or use which have led to a failure (see Table B.3)
	Subunit failed	Name of subunit that failed (see examples in Annex A)
	Component/Maintainable item(s) failed	Name of the failed maintainable item(s) (see Annex A)
	Detection method	How the failure was detected (see Table B.4)
	Operating condition at failure	Running, start-up, testing, idle, standby
Remarks	Additional information	Give more details, if available, on the circumstances leading to the failure: failure of redundant units, failure cause(s) etc.

[a] For some equipment categories such as subsea equipment, it is recommended to also record failure modes on taxonomic levels lower than the equipment-unit level.

[b] See example of failure consequence classification in Table B.2.

[c] For some equipment categories and applications it may be sufficient to record critical and non-critical (degraded + incipient) failures only.

[d] The failure cause and sometimes the failure mechanism are not known when the data are collected, as they commonly require a root cause analysis to be performed. Such analysis shall be performed for failures of high consequence, high repair/down time cost, or failures occurring significantly more frequent than what is considered "normal" for this equipment unit class ("worst actors").

(*) indicates the minimum data that shall be collected.

9.6 Maintenance data

9.6.1 General

Maintenance is carried out for the following reasons:

a) to correct a failure (corrective maintenance); the failure shall be reported as described in 9.5;

b) as a planned and normally periodic action to prevent failure from occurring (preventive maintenance).

A common report for all equipment classes shall be used for reporting maintenance data. The data required are given in Table 8. For some equipment classes, minor adaptations can be required (e.g. subsea equipment).

The minimum data needed to meet the objectives of this International Standard are identified by (*). However, the addition of other data categories can significantly improve the potential usability of the RM data; see Annex D.

9.6.2 Maintenance categories

There are two basic categories of maintenance:

a) that done to correct an item after it has failed (corrective maintenance);

b) that done to prevent an item from failing (preventive maintenance); part of this can be simply the checks (inspections, tests) to verify the condition of the equipment to decide whether or not any preventive maintenance is required.

NOTE "Modification" is not defined as a maintenance category but is a task often performed by the maintenance organization. A modification can have an influence on the reliability and performance of an item.

Figure 6 shows the main maintenance categories in more detail. Table B.5 presents the main types of maintenance activities commonly performed.

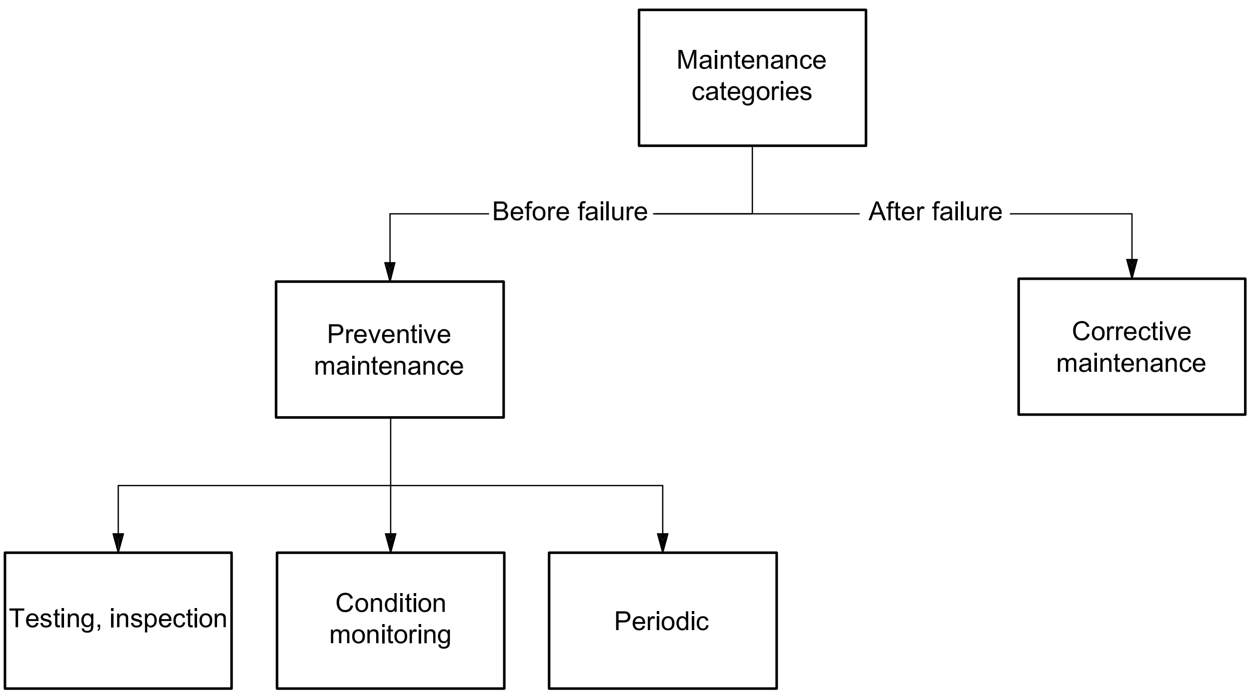


Figure 6 — Maintenance categorization

9.6.3 Reporting maintenance data

9.6.3.1 Corrective maintenance

As a minimum for recording the reliability of an item, it is required that the corrective maintenance to correct a failure shall be recorded.

9.6.3.2 Preventive maintenance

It is recommended that the recording of the actual preventive maintenance (PM) be done essentially in the same way as for corrective actions. This can give the following additional information:

a) full lifetime story of an item (all failures and maintenance);

b) total resources used on maintenance (man-hours, spare parts);

c) total down time and, hence, total equipment availability, both technical and operational; see Annex C;

d) balance between preventive and corrective maintenance.

Recording PM actions is useful mainly for the maintenance engineer, but is also useful for the reliability engineer wanting to record or estimate the availability of equipment. A lifetime analysis takes into account not only failures but also maintenance actions intended to restore the item to "as-good-as-new" condition. PMs are often performed on a higher indenture level (e.g. "package" level); hence there might not be any data available that can be related to the items on the lower indenture level (subunit, maintainable item). It is necessary to consider this restriction when defining, reporting and analysing PM data.

During the execution of PM actions, impending failures can be discovered and corrected as part of the PM activities. In this case, the failure(s) shall be recorded as any other failure with the subsequent corrective action done, even though it initially was considered to be a PM-type activity. The failure-detection method shall, in this case, be considered as the type of PM being done. It is, however, realized that some failures, generally of minor character, can be corrected as part of the PM and not recorded individually. The practice on this can vary among companies and should be addressed by the data collector(s) in order to reveal the possible type and amount of failures being included within the PM program.

9.6.3.3 Preventive maintenance programme

A final option is to record the planned PM programme as well. In this case, it is possible to additionally record the differences between the planned PM and the PM actually performed (backlog). An increasing backlog indicates that control of the conditions of the plant is being jeopardized and can, in adverse circumstances, lead to equipment damage, pollution or personnel injury.

Table 7 shows a summary of data to be collected and possible added value for different data categories. Annex D contains a more detailed survey of data requirements for various applications.

Table 7 — Usefulness of maintenance data

Data to be collected	Priority with regard to data collection	Examples
Corrective maintenance	Required (see Table 8)	• Repair time (MTTR) • Amount of corrective maintenance • Replacement/repair strategy
Actual preventive maintenance	Recommended	• Full lifetime story of the equipment • Total resources used on maintenance • Total down time • Effect of PM on failure rate • Balance between corrective and preventive maintenance
Planned preventive maintenance (maintenance programme)	Optional	• Difference between real and planned PM (backlog) • Updating programme based on experiences (methods, resources, intervals)

Table 8 —Maintenance data

Category	Data to be recorded	Description [a]
Identification	Maintenance record (*)	Unique maintenance identification
	Equipment identification/location (*)	e.g. tag number (see Table 5)
	Failure record (*)	Corresponding failure identification record (not relevant for preventive maintenance)
Maintenance data	Date of maintenance (*)	Date when maintenance action was undertaken or planned (start date)
	Maintenance category (*)	Main category (corrective, preventive)
	Maintenance priority	High, medium or low priority
	Interval (planned)	Calendar or operating interval (not relevant for corrective maintenance)
	Maintenance activity	Description of maintenance activity, see Annex B, Table B.5
	Maintenance impact on plant operations	Zero, partial or total
	Subunit maintained	Name of subunit maintained (see Annex A) [b] (May be omitted from preventive maintenance).
	Component/maintainable item(s) maintained	Specify the component/maintainable item(s) that were maintained (see Annex A) (May be omitted from preventive maintenance).
	Spare part location	Availability of spares (e.g. local/distant, manufacturer)
Maintenance resources	Maintenance man-hours, per discipline [c]	Maintenance man-hours per discipline (mechanical, electrical, instrument, others)
	Maintenance man-hours, total	Total maintenance man-hours
	Maintenance equipment resources [c]	e.g. intervention vessel, crane
Maintenance times	Active maintenance time [d] (*)	Time duration for active maintenance work being done on the equipment (see also definitions in Table 4)
	Down time [d] (*)	Time duration during which an item is in a down state (see also Table 4 and Figure 4)
	Maintenance delays/problems	Prolonged down time causes, e.g. logistics, weather, scaffolding, lack of spares, delay of repair crew
Remarks	Additional information	Give more details, if available, on the maintenance action and resources used

[a] Records to be entered for both corrective and preventive maintenance, except where shown.

[b] For corrective maintenance, the subunit maintained is normally identical to the one specified on the failure event report (see Table 6).

[c] For subsea equipment, the following apply:

- type of main resource(s) and number of days used, e.g. drilling rig, diving vessel, service vessel;
- type of supplementary resource(s) and number of hours used, e.g. divers, ROV/ROT, platform personnel.

[d] This information is desirable for RAM and RCM analyses. It is currently infrequently recorded in the maintenance-management systems. It is necessary to improve the reporting of this information to capture reasons for long down times.

(*) indicates the minimum data that shall be collected.

Annex A
(informative)

Equipment-class attributes

A.1 Advisory notes

A.1.1 General

Annex A provides examples on how typical equipment used in the petroleum, petrochemical and natural gas industries can be categorized as to their taxonomy, boundary definition, and inventory data. These data are informative for each equipment unit. Normative data, e.g. failure modes, for the equipment examples are shown in Annex B.

A standardized approach has been applied for some of the subunits that are used on a majority of equipment classes (e.g. control and monitoring, lubrication system, cooling system). The result that is the total number of tables required to describe the different data categories and definitions is reduced and, at the same time, there are fewer tailor-made definitions and codes for each individual equipment unit. The user should, therefore, apply those categories and codes that are applicable to the equipment for which data are being collected. Equipment having a unique design can require a more tailor-made categorization instead of that shown in these examples.

In the tables that describe the “equipment-unit subdivision" for the equipment, it is recommended to also include the following:

a) “Maintainable items/Parts” on an as-needed basis, e.g. to include instrumentation;

b) “Others”, if defined “Maintainable items/Parts” are lacking; or

c) “Unknown” category, if sufficient information is not available.

The priority classes given in this annex are high, medium and low. When interpreting or assessing the value of these classes, they can be equated to compulsory (high), highly desirable (medium) and desirable (low).

A.1.2 Boundary definitions

The purpose of the boundary definition is to ensure a common understanding of the “subunit/component” and “maintainable item/part” included within the boundary of a particular equipment unit and, hence, which failure and maintenance events to record. For definition of the boundaries, the following rules are recommended.

a) Do not include items of unique design or configuration-dependant items. Include only those items that are considered to be generic for the equipment class being considered in order to compare “like with like.”

b) Exclude connected items from the equipment-class boundary, unless specifically included by the boundary specification. Failures that occur in a connection (e.g. leak), and that cannot be solely related to the connected item, should be included within the boundary definition.

c) If a driver and the driven unit use a common subunit (e.g. lubrication system), relate failure and maintenance events on this subunit, as a general rule, to the driven unit;

d) Include instrumentation only where it has a specific control and/or monitoring function for the equipment unit in question and/or is locally mounted on the equipment unit. Control and supervisory instrumentation of more general use (e.g. SCADA-systems) should not, as a rule, be included.

In A.2.2 to A.2.9 examples of boundary diagrams for different equipment classes are presented. This list is not exhaustive for the equipment categories covered by this International Standard, but includes examples on how taxonomies may be defined for typical equipment found in the petroleum, petrochemical and natural gas industries.

A.1.3 Common equipment data

This International Standard recommends some common equipment data that should be collected for all equipment classes as shown in Table 5.

Additionally, some equipment-specific data for equipment classes are presented in this annex. These data have been found to be useful when comparing performance, or benchmarking, of equipment.

Such design features specific for each equipment class should be considered depending on how far down in equipment categorization the data collector wants, or is required, to go. Collection of data is a trade-off between the cost of obtaining it, which often can be high, and the value of the data in relation to the specific requirements to define each equipment class for the intended analyses. The accessibility of the data in the source(s) also sets a limit on the data that can be collected. An indication of the importance of each data type is indicated. This importance ranking can differ among different users and applications.

A.1.4 Equipment classification and application

Tables A.1 to A.4 provide a methodology for grouping different equipment examples and their application as covered by this International Standard. These lists are not meant to be exhaustive but are intended to show the main types of equipment classes and systems and how they can be grouped in categories. Any applied categorization should be appropriate for the intended use and purpose of the data being collected (see 7.1.2). Tables A.1 to A.4 show a categorization related to the taxonomic levels shown Figure 3.

— Table A.1 shows a recommendation for grouping equipment on installation level (level 3 in the taxonomic hierarchy).

— Table A.2 shows a recommendation for how equipment can be classified on plant/unit level (level 4), as shown in Table 5.

— Table A.3 shows a list of relevant sections/systems (level 5) within the petroleum, natural gas and petrochemical industries where equipment as covered by this International Standard can be used. The systems where the equipment is applied should be recorded as one parameter in the general equipment data shown in Table 5 (category “Use/Location”).

— Table A.4 lists typical examples of equipment units used in the petroleum, natural gas and petrochemical industry as covered by this International Standard (level 6). Table A.4 also indicates those equipment taxonomies that are illustrated by examples, as described in A.2.1. B.2.6 contains the associated failure modes for the same equipment examples.

In the classification shown in Tables A.1 to A.3, the terms “upstream,” “midstream,” “downstream” and “petrochemical” are used. The interpretation of these terms in this International Standard is as follows:

a) upstream — business category of the petroleum industry involving exploration and production (e.g. offshore oil/gas production facility, drilling rig, intervention vessel);

b) midstream — business category involving the processing, storage and transportation sectors of the petroleum industry (e.g. LNG, LPG and GTL; see Table A.1);

c) downstream — business process most commonly used in the petroleum industry to describe post-production processes (e.g. refining, transportation and marketing of petroleum products);

d) petrochemicals — business category producing petrochemical, i.e. chemicals derived from petroleum and used as feedstock for the manufacture of a variety of plastics and other related products (e.g. methanol, polypropylene).

Table A.1 — Installation category — Level 3

Business category			
Upstream (E & P)	**Midstream**	**Downstream**	**Petrochemical**
Oil/gas production facility (offshore/ onshore) Gas processing Drilling rig Intervention vessel Terminal Pipeline	Liquefied natural gas plant (LNG) Liquefied petroleum gas plant (LPG) Gas to liquids plant (GTL) Combined heating and power (CHP) Terminal Storage Shipping (LNG, Oil) Pipeline	Refinery Gas Processing Pipeline Shipping Terminal	Petrochemical complex Shipping Terminal

Table A.2 — Plant/Unit level classification — Level 4

Business category			
Upstream (E & P)	**Midstream**	**Downstream (refining)**	**Petrochemical**
Offshore platform Onshore production plant Floating production storage and offloading (FPSO) Floating drilling, production storage and offloading (FDPSO) Floating storage unit (FSU) Compliant tower Semi-submersible Subsea production Tension leg platform (TLP) Jack-up Subsea intervention and support vessel (SISV)	Pipeline compressor station Pipeline pump station	Process Utility Offsite and support facilities	Methanol plant Ethylene plant Acetic Acid plant Polyethylene plant Polypropylene plant Polyvinylchloride plant

Table A.3 — Section/System classification — Level 5

Business category			
Upstream (E & P)	**Midstream**	**Downstream (refining)**	**Petrochemical**
Process — General	**LNG process**	**Process — General**	**Process — General**
Oil process/treatment	CO_2/H_2S removal	Cracking	Hydrodesulfurization
Gas process/treatment	Dehydration/ Mercaptonization	Crude distillation	Hydrogen steam reforming
Water process/treatment	Liquefaction	Catalytic de-waxing	Hydrotreating
Oil/condensate-export systems	Mercury removal	Catalytic reforming	Isomerization
Gas-export systems	Fractionation	Lubes de-waxing	Kerosene hydroteater
Utilities [a]	Refrigeration	Lubes hydro-finishing	Naphtha hydrotreater
Chemical injection	LNG storage	Merox treating	Phenol extraction
Cooling system	LNG loading/unloading	Selective hydro-treating	Polymerization unit
Flare system	Boil-off gas (BOG) recovery	Sour-water stripping	Solvent deasphalting
Heating system	Vaporizers	Sulfur-recovery unit	Solvent dewaxing
Oily-water treatment	Recondensing	Tail-gas treating	Solvent extraction
Steam	**LNG utilities**	Vacuum distillation	Steam
Water injection	Fuel gas	Visbreaking	Steam cracking
Methanol	Cooling system	**Utilities**	Steam-methane reforming
Compressed air	Heating system	Steam	Sulfur recovery
Main power [b]	Main power	Power	Sweetening
Emergency power [b]	Blow-down and relief system	Instrument air	Vacuum distillation
Essential power [b]	Refrigerant storage	Utility air	Visbreaking
Fuel gas	Fiscal metering	Cooling water	**Utilities**
Materials handling		Nitrogen	Steam
HVAC		Emergency shutdown	Power
Fresh water systems		Fire and gas detection	Instrument air
Safety and control systems		Analysers	Utility air
Emergency/process shutdown			Cooling water
Fire and gas detection			Nitrogen
Fire water systems			Fire and gas detection
Fire-fighting systems			Analysers
Process control			Emergency shutdown
PA/alarm system			
Emergency preparedness systems			
Offshore installations			
Ballast water			
Seawater lift			
Position keeping			
Evacuation means			
Well and subsea systems			
Completion fluid			
Manifold control			
Multi-well manifold control			
Satellite well control			
Well servicing			
Combined function			

[a] These sections/systems may also be applicable for downstream and petrochemical unless defined specifically for these categories.

[b] Includes both power generation and distribution.

Table A.4 — Equipment class — Level 6

Equipment category	Equipment class — Level 6	Example included in Annex A
Rotating	Combustion engines	Yes
	Compressors	Yes
	Electric generators	Yes
	Electric motors	Yes
	Gas turbines	Yes
	Pumps	Yes
	Steam turbines	Yes
	Turboexpanders	Yes
	Blowers and fans	No
	Liquid expanders	No
	Mixers	No
Mechanical	Cranes	Yes
	Heat exchangers	Yes
	Heaters and boilers	Yes
	Vessels	Yes
	Piping	Yes
	Winches	Yes
	Swivels	Yes
	Turrets	Yes
	Pipeline	No
	Storage tanks	No
	Loading arms	No
	Filters and strainers	No
	Steam ejectors	No
	Xmas trees (topside/onshore)	No
Electrical	Uninterruptible power supply	Yes
	Power transformers	Yes
	Switchgears/switchboards and distribution boards	No
	Frequency converters	No
	Power cables and terminations	No
Safety and control	Fire and gas detectors	Yes
	Input devices	Yes
	Control units	Yes
	Valves	Yes
	Nozzles	Yes
	Evacuation equipment	No
	Fire-fighting equipment	No
	Inert-gas equipment	No

Table A.4 (*continued*)

Equipment category	Equipment class — Level 6	Example included in Annex A
Subsea production	Subsea production control	Yes
	Xmas trees	Yes
	Risers	Yes
	Subsea pumps	Yes
	Subsea processing equipment	No
	Templates	No
	Manifolds	No
	Pipelines	No
	Flowlines	No
	Subsea isolation equipment	No
	Intervention tools	No
	Electric-power distribution	No
Drilling	Blowout preventer [a]	Yes
	Top drive	Yes
	Derrick [b]	No
	Drawworks	No
	Mud pumps	No
	Mud-treatment equipment	No
	Diverter	No
	Choke manifold	No
	String-motion compensator	No
	Riser compensator	No
	Cementing equipment	No
	Drilling and completion risers	No
	Crown and travelling blocks	No
Well completion (downhole)	Downhole safety valves	Yes
	Casing	Yes
	Tubing	Yes
	Hangers	No
	Packers	No
	Electrical submersible pumps	No
	Downhole sensors	No
	Wellheads	No
Well intervention	Coiled tubing, surface equipment	No
	Coiled tubing, BOPs and control systems	No
	Coiled tubing, other pressure-control equipment and systems	No
	Coiled tubing, string and mechanical bottom hole assembly	No
	Coiled tubing, string and electrical bottom hole assembly	No

Table A.4 (*continued*)

Equipment category	Equipment class — Level 6	Example included in Annex A
Well intervention	Wireline, surface equipment	No
	Wireline, BOPs and control systems	No
	Wireline, other pressure-control equipment and systems	No
	Wireline, slickline/braided cable and bottom-hole assembly	No
	Wireline, electric cable and bottom-hole assembly	No
	Rig-assisted snubbing (RAS), surface equipment	No
	Rig-assisted snubbing (RAS), BOPs and control systems	No
	Rig-assisted snubbing (RAS), other pressure-control equipment and systems	No
	Rig-assisted snubbing (RAS), tubing and bottom-hole assemblies	No
Marine	Anchor windlasses and mooring equipment	No
	Thrusters	No
	Dynamic positioning equipment	No
	Towing equipment	No
	Jacking equipment	No
	De-icing equipment	No
	Helicopter deck with equipment	No
Utilities [c]	Hydraulic power units	No
	Air-supply equipment	No
	De-superheaters	No
	Nitrogen-supply equipment	No
	Heating/cooling media	No
	HVACs	No

a Subsea blowout preventer.

b Including heave compensation.

c Utilities may be associated with a number of equipment classes in this International Standard (e.g. pumps, valves, instrumentation).

A.2 Equipment-specific data

A.2.1 General

The equipment examples, indicated by a "yes" in the last column of Table A.4, are presented in A.2.2 to A.2.8 and include a detailed description of the following:

— equipment-type classification;

— boundary definitions;

— subdivision into lower indenture levels;

— equipment-specific data.

This information should be used to identify the data necessary to be collected for each equipment example presented and define the structure for a database for the relevant taxonomic elements. Many of the recommended parameters can be common across many equipment classes (e.g. capacity, rotational speed). The examples should not be considered exhaustive.

Examples of failure coding, such as failure modes, failure mechanism etc., are given in Annex B. For safety equipment, some specific failure definitions are given in Annex F.

A.2.2 Rotating-equipment data

A.2.2.1 Combustion engines

Table A.5 — Type classification — Combustion engines

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Combustion engines — piston (diesel/gas engines)	CE	Diesel engine	DE
		Otto (gas) engine	GE

Table A.6 — Equipment-class subdivision — Combustion engines

Equipment class Level 6	Combustion engines					
Subunit/ Component	**Start system**	**Combustion engine unit**	**Control and monitoring**	**Lubrication system**	**Cooling system [a]**	**Miscel-laneous**
Maintainable item/Part	Start energy (battery, air) Starting unit Start control	Air inlet Ignition system Turbocharger Fuel pumps Injectors Fuel filters Exhaust Cylinders Pistons Shaft Thrust bearing Radial bearing Seals Piping Valves	Actuating device Control unit Internal power supply Monitoring Sensors [b] Valves Wiring Piping Seals	Reservoir Pump Motor Filter Cooler Valves Piping Oil Temperature-control sensor	Heat exchanger Fan Motor Filter Valves Piping Pump Temperature-control sensor	Hood Flange joints

[a] May include water-cooled or air-cooled systems.

[b] Specify type of sensor, e.g. pressure, temperature, level, etc.

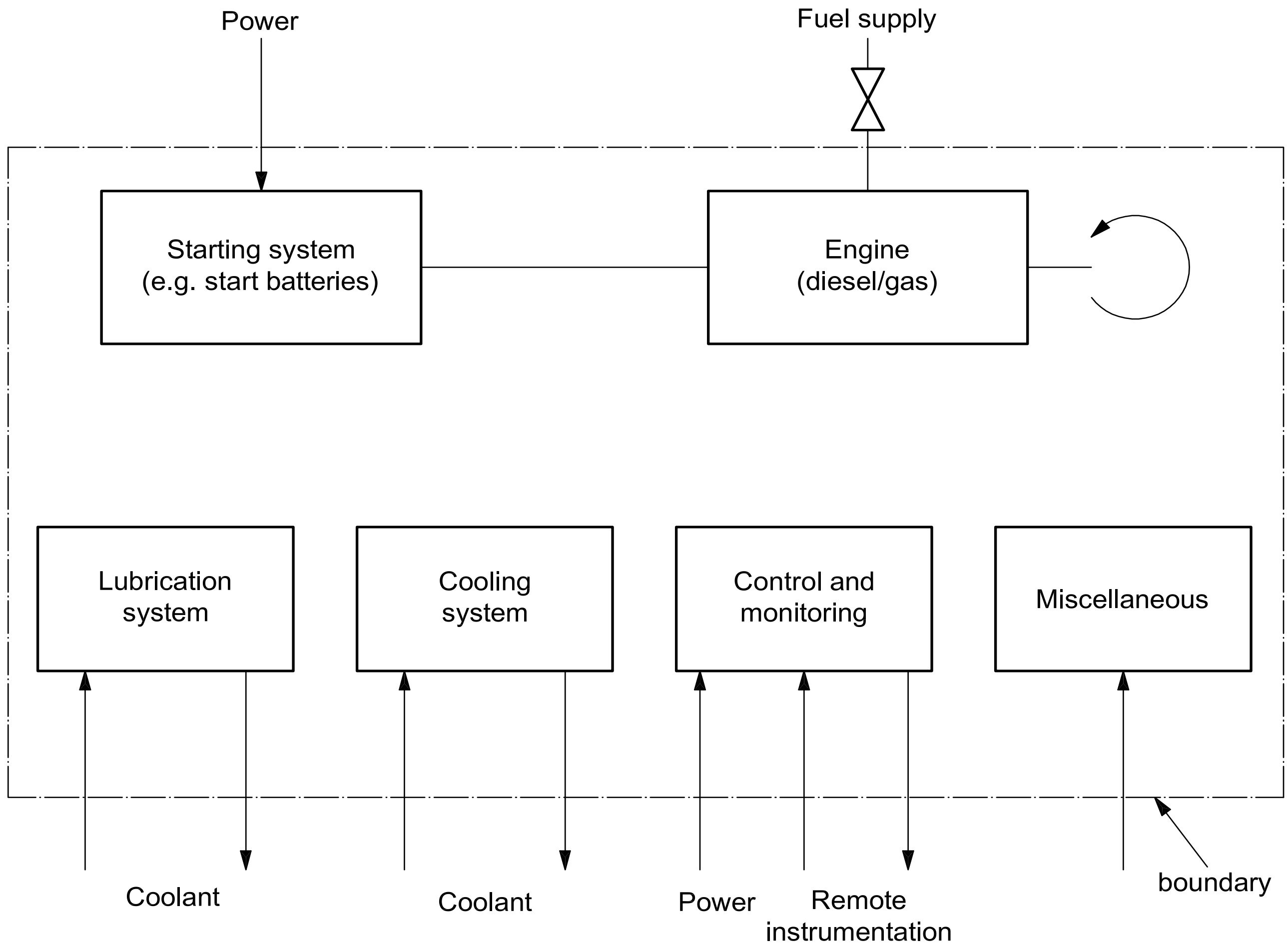


Figure A.1 — Boundary definition — Combustion engines

Table A.7 — Equipment-specific data — Combustion engines

Name	Description	Unit or code list	Priority
Driven unit	Driven unit (equipment class, type and identification code)	Specify	High
Power - design	Maximum rated output (design)	Kilowatt	High
Power - operating	Specify the approximate power at which the unit has been operated for most of the surveillance time	Kilowatt	High
Speed	Design speed	Revolutions per minute	High
Number of cylinders	Specify number of cylinders	Integer	Low
Cylinder configuration	Type	Inline, vee, flat	Low
Starting system	Type	Electric, hydraulic, pneumatic	Medium
Ignition system	Otto, diesel	Compression ignition (diesel), spark plugs	Medium
Fuel	Type	Gas, light oil, medium oil, heavy oil, dual	Low
Air-inlet filtration type	Type	Free text	Low
Engine-aspiration type	Type of engine aspiration	Turbo, natural	Medium

A.2.2.2 Compressors

Table A.8 — Type classification — Compressors

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Compressor	CO	Centrifugal	CE
		Reciprocating	RE
		Screw	SC
		Blowers/fans	BL
		Axial	AX

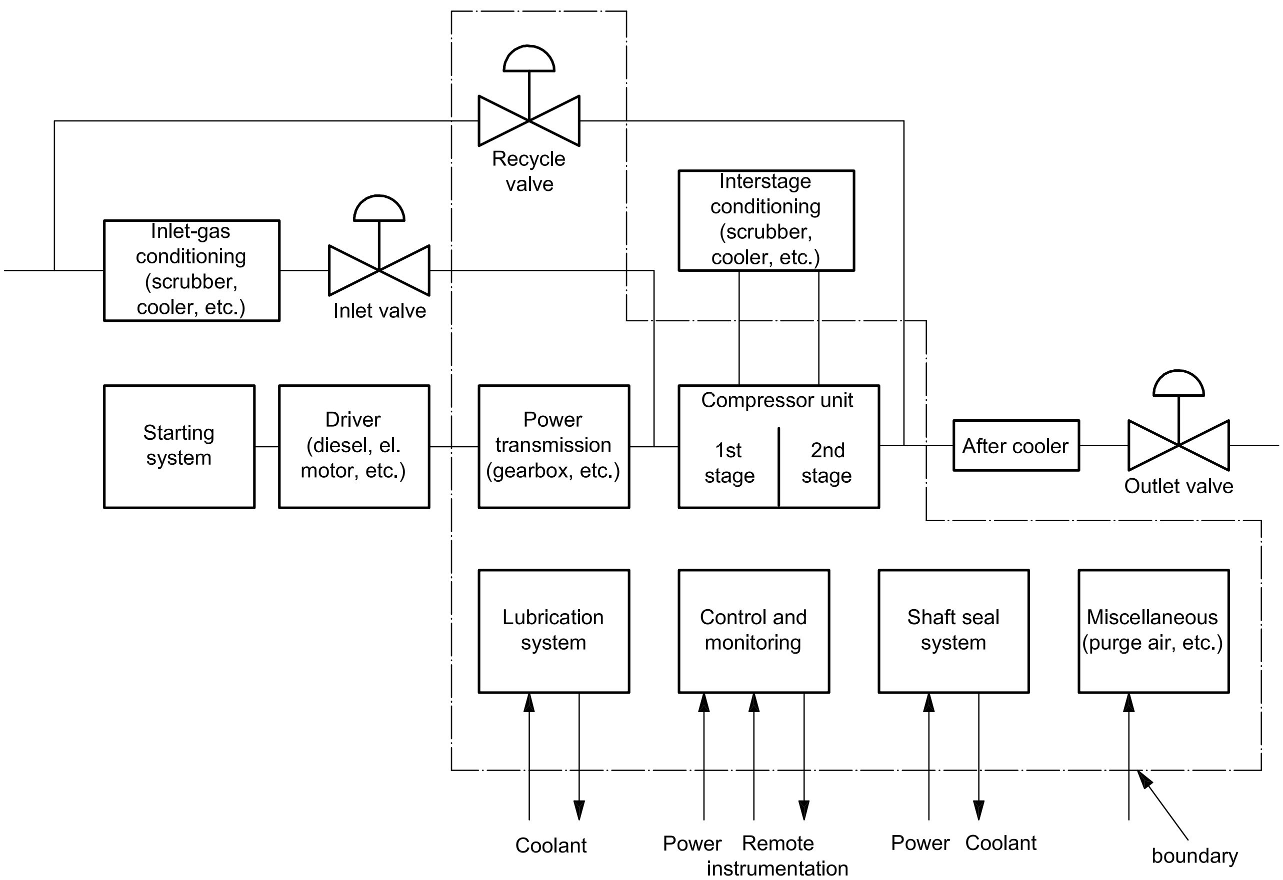


Figure A.2 — Boundary definition — Compressors

A.2.2.2.1 Equipment boundary definition for compressors

Figure A.2 shows the boundary definition for compressors. Inlet and outlet valves, and the compressor driver with connected auxiliaries, are not included within the boundary. Driver units are recorded as separate inventories (electric motor, gas turbine or combustion engine) and the failures on the driver, if recorded, should be recorded separately for the driver. A number in the compressor inventory shall give a reference to the appropriate driver inventory.

Compression is normally done in stages where a number of subunits are connected into a train.

A compressor train is considered as one inventory. Each compressor train can consist of up to four compressor stages. Recompression trains on an offshore oil platform normally perform compression in four stages. Each compression stage is usually performed by one compressor unit (casing) but in some cases one compressor unit can perform two stages. Each compressor (stage) normally contains several impellers that are the physical assembly of rotating blades that raise the pressure one step in the compressor unit.

If there are subunits that are common to the driver (e.g. a gas turbine) and the driven unit (i.e. the compressor), these are regarded as a part of the driven unit. For compressors with common lubrication-oil and seal-oil systems, failures should, as a general rule, be assigned to the subunit that is assumed to be the one most affected. Otherwise, the failure should be assigned to the lubrication-oil system.

Table A.9 — Equipment subdivision — Compressors

Equipment class	Compressors					
Subunit	**Power transmission**	**Compressor**	**Control and monitoring**	**Lubrication system**	**Shaft seal system**	**Miscellaneous**
Maintainable item/Part	Gearbox/ variable drive Bearings Coupling to the driver Coupling to the driven unit Lubrication Seals	Casing Rotor with impellers Balance piston Interstage seals Radial bearing Thrust bearing Shaft seals Internal piping Valves Antisurge system [b] Piston Cylinder liner Packing	Actuating device Control unit Cables and junction boxes Internal power supply Monitoring Sensors [a] Valves Wiring Piping Seals	Oil tank with heating system Pump Motor Check valves Coolers Filters Piping Valves Lube oil	Oil tank with heating Reservoir Pump Motor Gear Filters Valves Seal oil Dry gas seal Mechanical seal Scrubber	Base frame Piping, pipe support and bellows Control valves Isolation valves Check valves Coolers Silencers Purge air Magnetic-bearing control system Flange joints

[a] Specify type of sensor, e.g. pressure, temperature, level, etc.

[b] Including recycle valve and controllers.

Table A.10 — Equipment-specific data — Compressors

Name	Description	Unit or code list	Priority
Type of driver	Driver unit (equipment class, type and identification code)	Specify	High
Gas handled	Average molar mass (specific gravity × 28.96)	Grams per mole	Medium
Suction pressure	Design – first stage	Pascal (bar)	Medium
Suction pressure	Operating – first stage	Pascal (bar)	Low
Discharge pressure	Design – last stage	Pascal (bar)	High
Discharge pressure	Operating – last stage	Pascal (bar)	Medium
Flow rate	Design	Metres cubed per hour	High
Flow rate	Operating	Metres cubed per hour	Low
Discharge temperature	Design	Degrees Celsius	Medium
Discharge temperature	Operating	Degrees Celsius	Low
Power	Design power	Kilowatt	High
Utilization	Percent utilization compared to design	Percent	Medium
Polytropic head	—	Kilojoules per kilogram	Low
Number of casings	Number of casings in the train	Integer	High
Number of stages	Number of compressor stages (not impellers) in this train	Integer	Medium
Body type	Type	Vertical split case (barrel type), axial split case	Low
Shaft sealing	Type	Mechanical, oil, dry gas-packed, dry gland, labyrinth, combined	Low
Intercooler fitted	Specify if cooler is fitted	Yes/no	Medium
Shaft seal system	Separate, combined, dry, etc.	Separate, combined, dry	High
Radial bearing	Type	Antifrictional, journal, magnetic	Low
Thrust bearing	Specify as relevant in comment field whether any thrust pressure regulator is installed	Antifrictional, journal, magnetic	Low
Speed	Design speed	Revolutions per minute	Low
Coupling	Type	Fixed, flexible, hydraulic, disconnect	Low
Reciprocating compressors only			
Cylinder configuration	—	Inline, opposed, V, W	Low
Cylinder orientation	—	Horizontal, vertical, inclined	Low
Working principle	—	Single-acting, double-acting	Low
Packing type	—	Lubricated, dry	Low

A.2.2.3 Electric generators

Table A.11 — Type classification — Electric generators

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Electric generator	EG	Gas-turbine driven	TD
		Steam-turbine driven	SD
		Turboexpander	TE
		Engine driven, e.g. diesel engine, gas engine	MD

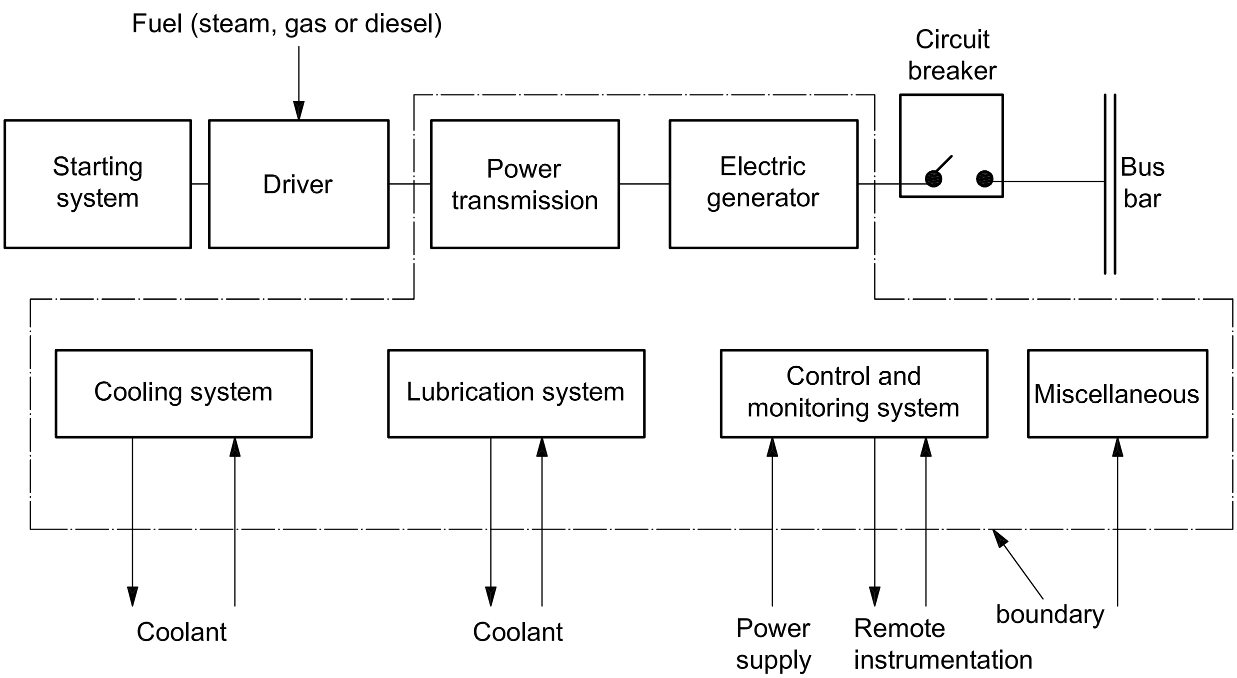


Figure A.3 — Boundary definition — Electric generators

Table A.12 — Equipment subdivision — Electric generators

Equipment unit	Electric generators					
Subunit	**Power transmission**	**Electric generator**	**Control and monitoring** [a]	**Lubrication system**	**Cooling system**	**Miscellaneous**
Maintainable items	Gearbox Radial bearing Thrust bearing Seals Lubrication Coupling to driver Coupling to driven unit	Stator Rotor Radial bearing Thrust bearing Excitation Cabling and junction boxes	Actuating device Control unit (e.g. AVR) Internal power supply Monitoring Sensors [b] Valves Wiring Piping Seals	Reservoir Pump Motor Filter Cooler Valves Piping Oil	Heat exchanger Fan Motor Filter Valves Piping Pump	Hood Purge air

[a] The automatic voltage regulator (AVR) is an element within “Control”. Temperature and vibration surveillance are elements within “Monitoring”.

[b] Specify type of sensor, e.g. pressure, temperature, level, etc.

Table A.13 — Equipment-specific data — Electric generators

Name	Description	Unit or code list	Priority
Type of driver	Equipment class, type and identification code	Specify	High
Coupling	Specify (fixed, flexible, etc.)	Fixed, flexible, hydraulic, disconnect	Low
Speed	Synchronous	Revolutions per minute	Medium
Frequency	Design frequency	Hertz	Low
Voltage	Design voltage	Kilovolts	High
Power – design	Design power	Kilovolts	High
Power factor	$\cos\varphi$	Number	Low
Excitation control	Type	Automatic, manual	Medium
Excitation type	Brushless/slip-ring	Brushless, slip-ring	Medium
Degree of protection	Protection class in accordance with IEC 60529	IP	Low
Insulation class – stator	Insulation class in accordance with IEC 60034-1	Y, A, E, B, F, H	Medium
Temperature rise – stator	Temperature rise in accordance with IEC 60034-1	Y, A, E, B, F, H	Low
Insulation class – rotor	Insulation class in accordance with IEC 60034-1	Y, A, E, B, F, H	Medium
Temperature rise – rotor	Temperature rise in accordance with IEC 60034-1	Y, A, E, B, F, H	Medium
Radial bearing	Type	Antifrictional, journal, magnetic	Low
Thrust bearing	Type	Antifrictional, journal, magnetic	Low
Lubrication of bearings	Type of bearing lubrication	Grease, oil bath, pressurized oil, oil ring	Low
Generator cooling	Type	Air/air, air/water, open ventilated	Low

A.2.2.4 Electric motors

Table A.14 — Type classification — Electric motors

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Electric motor	EM	Alternating current	AC
		Direct current	DC

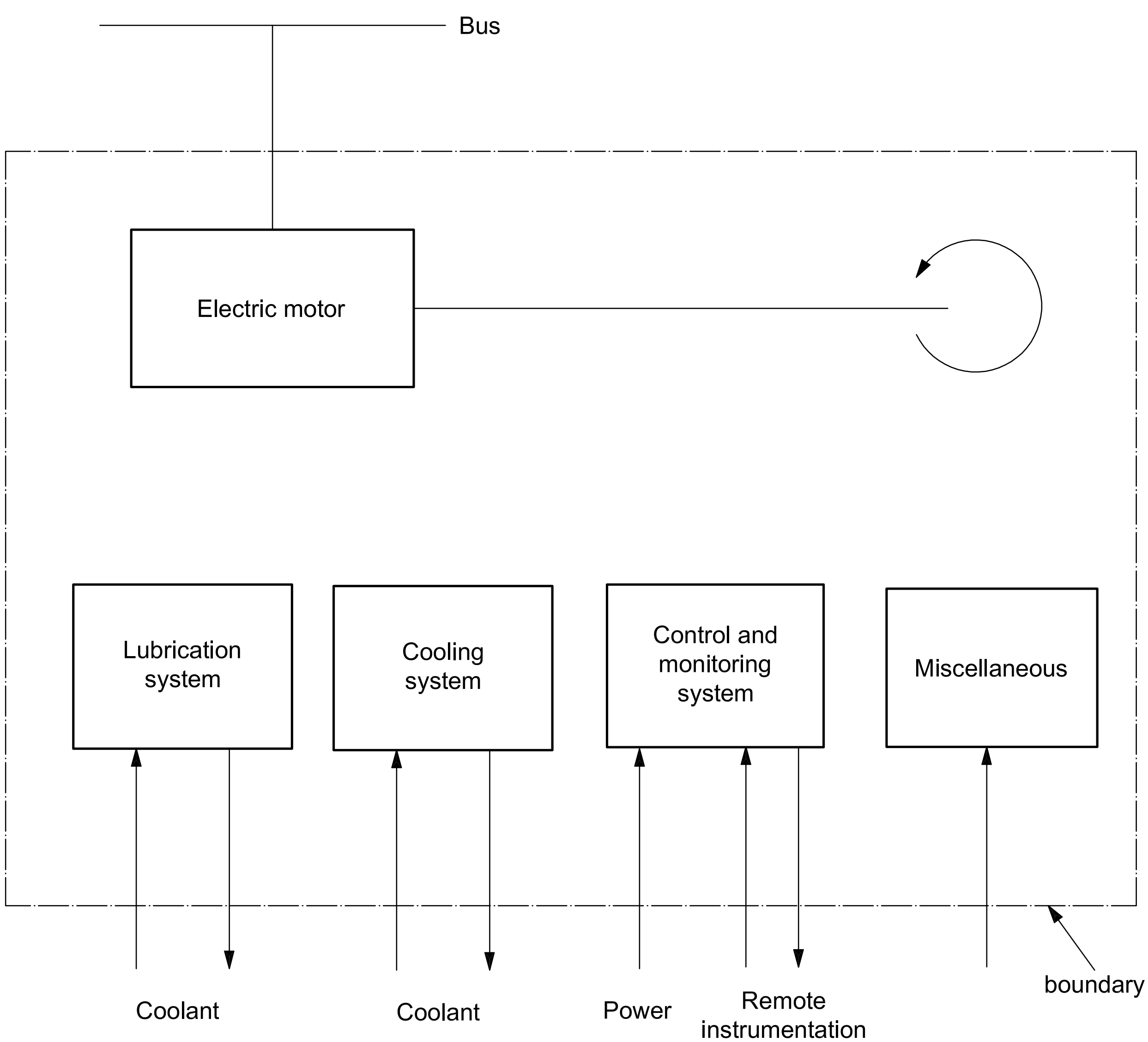


Figure A.4 — Boundary definition — Electric motors

Table A.15 — Equipment subdivision — Electric motors

Equipment unit	Electric motors				
Subunit	**Electric motor**	**Control and monitoring** [a]	**Lubrication system**	**Cooling system**	**Miscellaneous**
Maintainable items	Stator Rotor Excitation Radial bearing Thrust bearing	Actuating device Control unit Internal power supply Monitoring Sensors [b] Valves Wiring Piping Seals	Reservoir Pump Motor Filter Cooler Valves Piping Oil	Heat exchanger Filter Valves Piping Pump Motor Fan	Hood

[a] Normally, there is no extra control system for motors. For motors of Ex(p) class (pressurized), the internal pressure is monitored. Temperature can be monitored on large motors.

[b] Specify type of sensor, e.g. pressure, temperature, level, etc.

Table A.16 — Equipment-specific data — Electric motors

Name	Description	Unit or code list	Priority
Type of driven unit	Equipment class, type and identification code	Specify	High
Power – design	Max. output (design)	Kilowatt	Medium
Power – operating	Specify the approximate power at which the unit has been operated for most of the surveillance time	Kilowatt	Low
Variable speed	Specify if installed or not	Yes/No	Low
Speed	Design speed	Revolutions per minute	Medium
Voltage	Design voltage	Volts	Medium
Motor type	Type	Induction, commutator (d.c.), synchronous	Medium
Insulation class – stator	Insulation class in accordance with IEC 60034-1	Y, A, E, B, F, H	Medium
Temperature rise – stator	Temperature rise in accordance with IEC 60034-1	Y, A, E, B, F, H	Low
Insulation class – rotor [a]	Insulation class in accordance with IEC 60034-1	Y, A, E, B, F, H	Medium
Temperature rise – rotor [a]	Temperature rise in accordance with IEC 60034-1	Y, A, E, B, F, H	Medium
Degree of protection	Protection class in accordance with IEC 60529	Specify	Medium
Type of Ex protection	Explosion classification category, e.g. Ex(d), Ex(e) [b]	e.g. Ex(d), Ex(e)	High

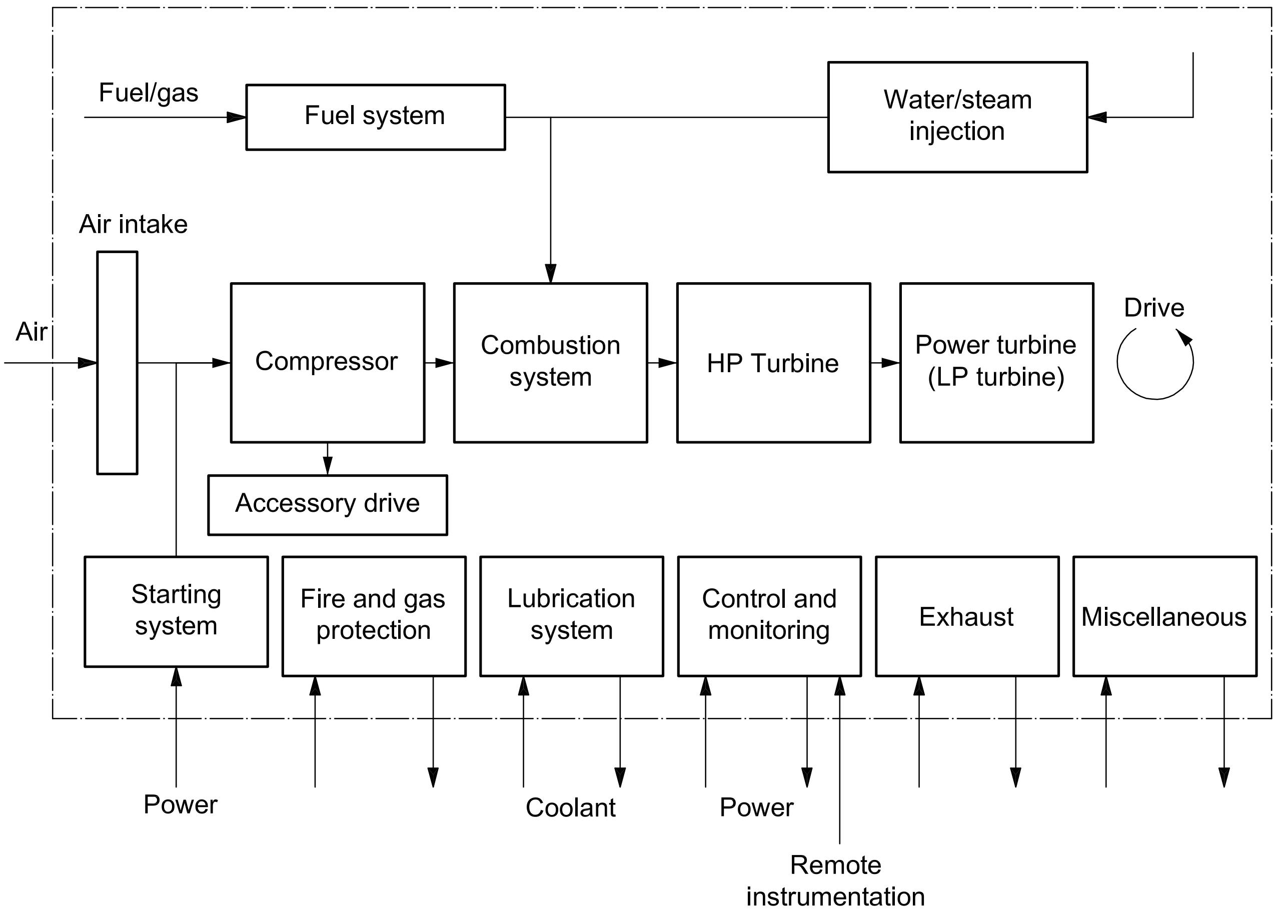
[a] Not relevant for induction motors.

[b] See IEC 60079 (all parts).

A.2.2.5 Gas turbines

Table A.17 — Type classification — Gas turbines

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Gas turbine	GT	Industrial	IN
		Aero-derivative	AD



NOTE This boundary drawing shows a typical layout frequently used for mechanical drive or power generation. However, gas turbines can be configured in different ways with regards to the layout of some subsystems. The compressor and the turbine can be mechanically coupled, single-shaft GT. Other alternatives are when one or more parts of the turbine are mechanically decoupled (multi-spool GT).

Figure A.5 — Boundary definition — Gas turbines

Table A.18 — Equipment subdivision — Gas turbines

Equipment unit	**Gas turbines**					
Subunit	**Starting system**	**Air intake**	**Combustion system**	**Compressor**	**Power turbine H P turbine**	**Control and monitoring**
Maintainable items	Starting motor Start control Piping Filter(s) Valve(s) Pump(s) Start energy (e.g. battery, air)	Air cooling Anti-icing Filters Intake duct Inlet vanes	Combustor Fuel nozzles Seals	Rotor Stator Cooling system VGV system Anti-surge valve Aux. bleeding system Anti-icing valve Casing Radial bearing Thrust bearing Seals Piping	Rotor Stator Casing Radial bearing Thrust bearing Seals Valves Piping	Control unit Sensors [a] Wires Actuating devices Monitoring Valves Internal power supply Seals

	Lubrication system	**Fuel system**	**Water/Steam injection [b]**	**Fire and gas protection**	**Accessory drive**	**Exhaust**	**Miscel-laneous**
	Heater Reservoir(s) Pump(s) Motor Filter Temperature control Valves Piping Oil cooler Oil Sensors Wires	Fuel control Piping Valves Seals Pump(s)/Gas compressor Filter(s)/ Separators Wires Fuel properties measurement	Pump(s) Piping Valves Filter(s) Seals Wires	Control unit Pipes Valves Sensors Wires Tank(s)/ Storage	Gearbox Bearing Seals Casing	Diffuser Exhaust collector Compensator /bellows Ducting Emission monitoring Silencer Thrust bearing Valves Waste heat recovery unit	Enclosure Hood Purge air Flange joints Ventilation fan Water-wash system

[a] Specify type of sensor, e.g. pressure, temperature, level, etc.

[b] Only relevant for gas turbines with NO_x-abatement control with steam or water.

Table A.19 — Equipment-specific data — Gas turbines

Name	Description	Unit or code list	Priority
Type of driven unit	Characteristics of the driven subsystem	Generator drive, mechanical drive, auxiliaries, other	High
Power – design	ISO power rating	Kilowatt	High
Power – operating	Specify the approximate power at which the unit has been operated for most of the surveillance time.	Kilowatt	Medium
Operating profile	Utilization profile	Base load, peak load, load-sharing backup, emergency/reserve	High
De-rating	Specify if permanently de-rated or not	Yes/No	Medium
Speed	Design speed (power shaft)	Revolutions per minute	Medium
Number of shafts	Specify number	1, 2, 3	Medium
Starting system	Specify main starting system	Electric, hydraulic, pneumatic	High
Backup starting system	Specify if relevant	Electric, hydraulic, pneumatic	Low
Fuel	Fuel type	Gas, oil-light, oil-medium, oil-heavy, dual	Medium
NO_x abatement	Type of abatement control	Steam, water, dry (e.g. dry low emission), none (e.g. single annular combustor)	High
Air inlet filtration type	Type	Free text	Low

A.2.2.6 Pumps

Table A.20 — Type classification — Pumps

Equipment class		Type	
Description	Code	Description	Code
Pump	PU	Centrifugal	CE
		Reciprocating	RE
		Rotary	RO

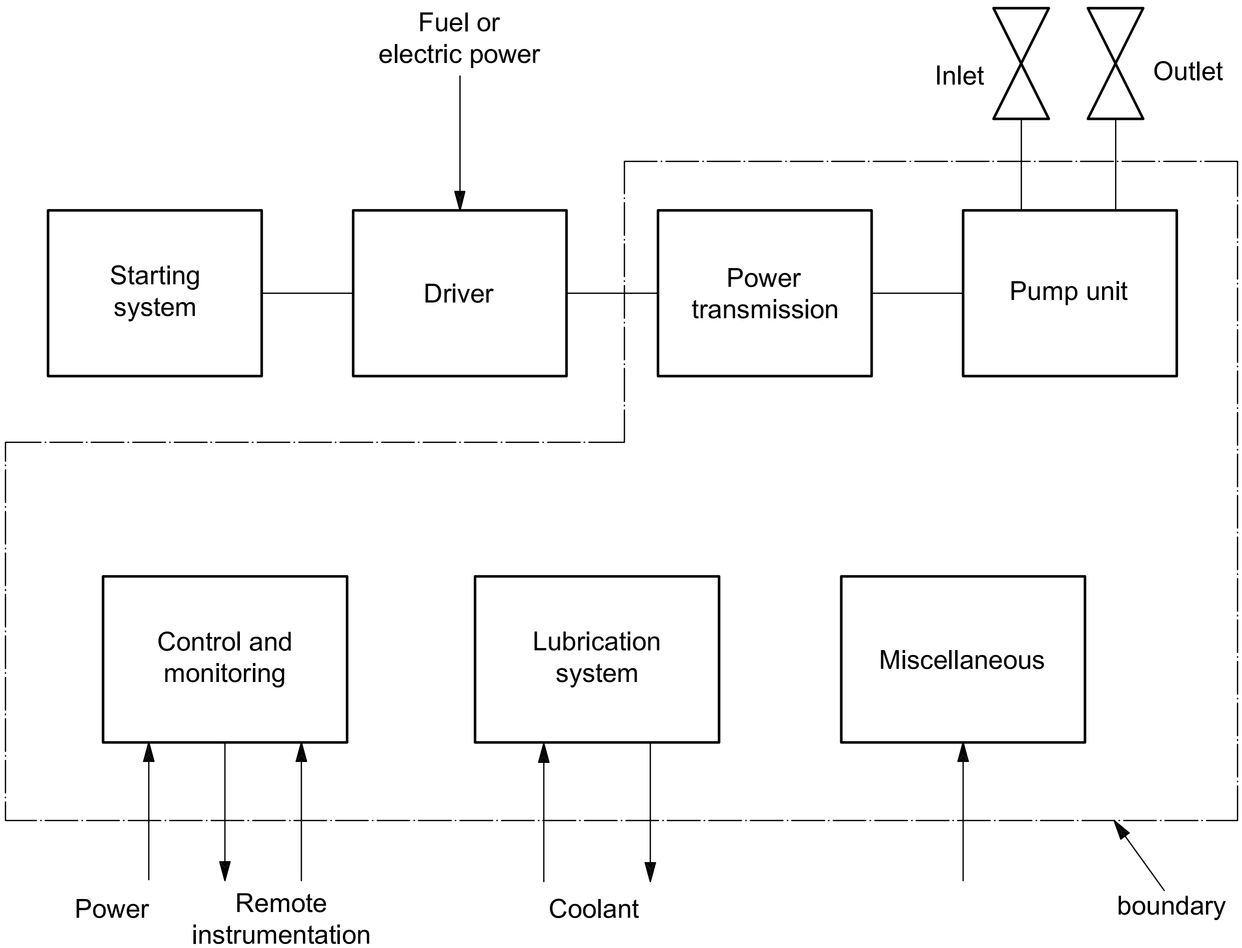


Figure A.6 — Boundary definition — Pumps

Table A.21 — Equipment subdivision — Pumps

Equipment unit	**Pumps**				
Subunit	**Power transmission**	**Pump unit**	**Control and monitoring**	**Lubrication system**	**Miscellaneous**
Maintainable items	Gearbox/ variable drive Bearing Seals Coupling to driver Coupling to driven unit	Support Casing Impeller Shaft Radial bearing Thrust bearing Seals Valves Piping Cylinder liner Piston Diaphragm	Actuating device Control unit Internal power supply Monitoring Sensors [a] Valves Wiring Piping Seals	Reservoir Pump Motor Filter Cooler Valves Piping Oil Seals	Purge air Cooling/heating system Cyclone separator Pulsation damper Flange joints

[a] Specify type of sensor, e.g. pressure, temperature, level, etc.

Table A.22 — Equipment-specific data — Pumps

Name	Description	Unit or code list	Priority
Type of driver	Equipment class, type and identification code	Specify	High
Fluid handled	Type	Oil, gas, condensate, freshwater, steam, sea water, crude oil, oily water, flare gas, fuel gas, water/glycol, methanol, nitrogen, chemicals, hydrocarbon-combined, gas/oil, gas/condensate, oil/water, gas/oil/water, LNG	High
Fluid corrosive/erosive	Classify as shown in footnote [a]	Benign, moderate, severe	Medium
Application – pump	Where applied	Booster, supply, injection, transfer, lift, dosage, disperse	Medium
Pump – design	Design characteristic	Axial, radial, composite, diaphragm, plunger, piston, screw, vane, gear, lobe	Medium
Power – design	Design/rated power of pump	Kilowatt	High
Utilization of capacity	Normal operating/design capacity	Percent	Medium
Suction pressure – design	Design pressure	Pascal (bar)	Medium
Discharge pressure – design	Design pressure	Pascal (bar)	High
Speed	Design speed	Revolutions per minute or strokes per minute	Medium
Number of stages	Centrifugal: number of impellers (in all stages) Reciprocating: number of cylinders Rotary: number of rotors	Number	Low
Body type	Barrel, split casing, etc.	Barrel, split case, axial split, cartridge,	Low
Shaft orientation	—	Horizontal, vertical	Low
Shaft sealing	Type	Mechanical, oil seal, dry gas, packed, gland, dry seal, labyrinth, combined	Low
Transmission type	Type	Direct, gear, integral	Low
Coupling	Coupling	Fixed, flexible, hydraulic, magnetic, disconnect	Low
Environment	Submerged or dry-mounted	—	Medium
Pump cooling	Specify if separate cooling system is installed	Yes/No	Low
Radial bearing	Type	Antifrictional, journal, magnetic	Low
Thrust bearing	Type	Antifrictional, journal, magnetic	Low
Bearing support	Type	Overhung, between bearings, pump casing, split sleeve	Low

[a] Benign (clean fluids, e.g. air, water, nitrogen).

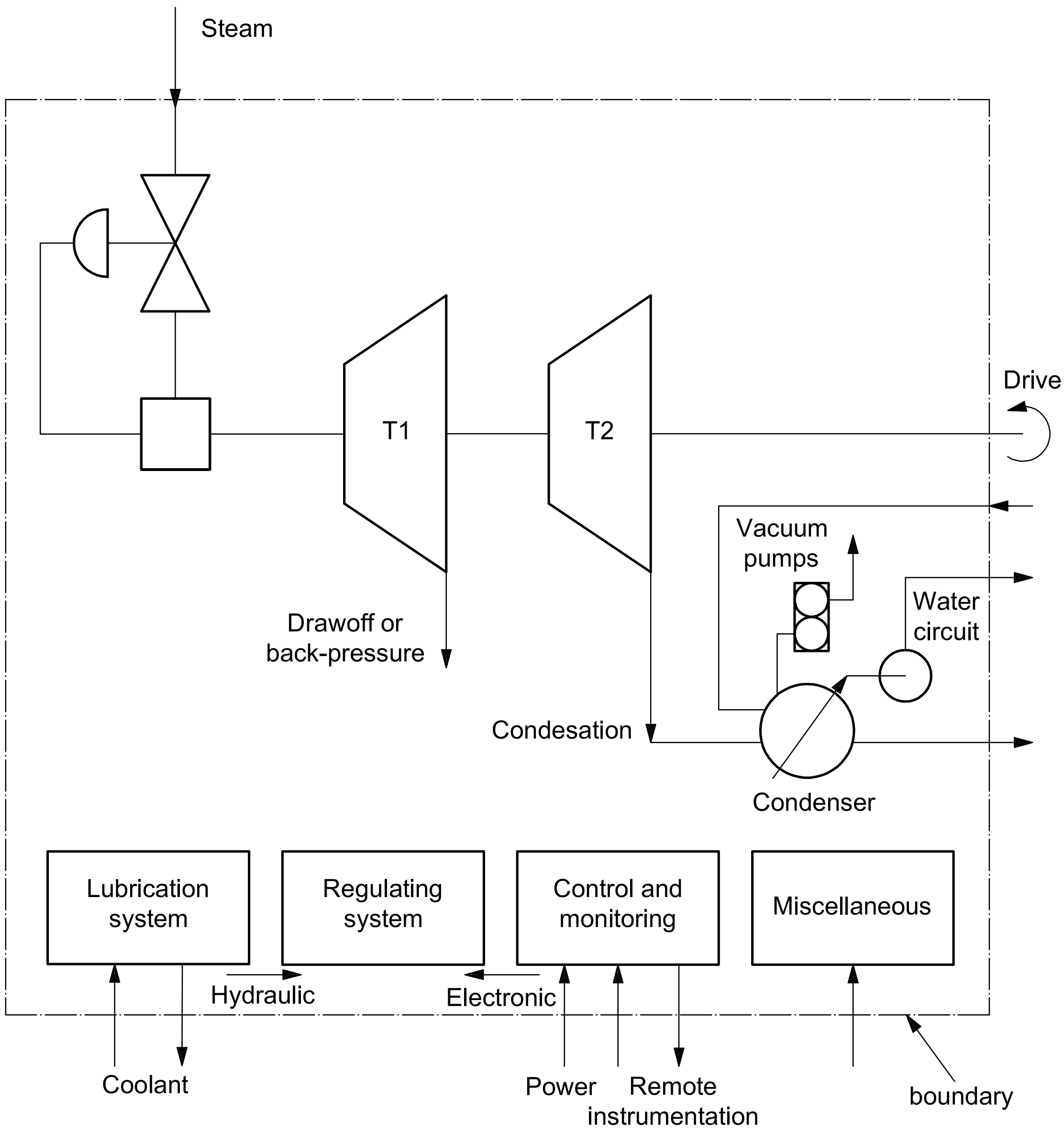
Moderately corrosive/erosive (oil/gas not defined as severe, sea water, occasionally particles).

Severely corrosive/erosive [sour gas/oil (high H_2S), high CO_2, high sand content].

A.2.2.7 Steam turbines

Table A.23 — Type classification — Steam turbines

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Steam turbines	ST	Multi-stage	MS
		Single-stage	SS



T1 turbine stage 1

T2 turbine stage 2

Figure A.7 — Boundary definition — Steam turbines

Table A.24 — Equipment subdivision — Steam turbines

Equipment unit	Steam turbines					
Subunit	**Power turbine**	**Condenser**	**Regulating system**	**Lubrication system**	**Control and monitoring**	**Miscellaneous**
Maintainable items	Piping Radial bearing Rotor Seals Stator/casing Steam reg. valves Thrust bearing	Condenser Reg. pump Vacuum pump	Filter Pump	Cooler Filter Oil Oil seal pump Piping Pump Motor Reservoir Valves	Actuating device Control unit Internal power supply Monitoring Sensors [a] Valves Wiring Piping Seals	Cranking system Hood

[a] Specify type of sensor, e.g. pressure, temperature, level etc.

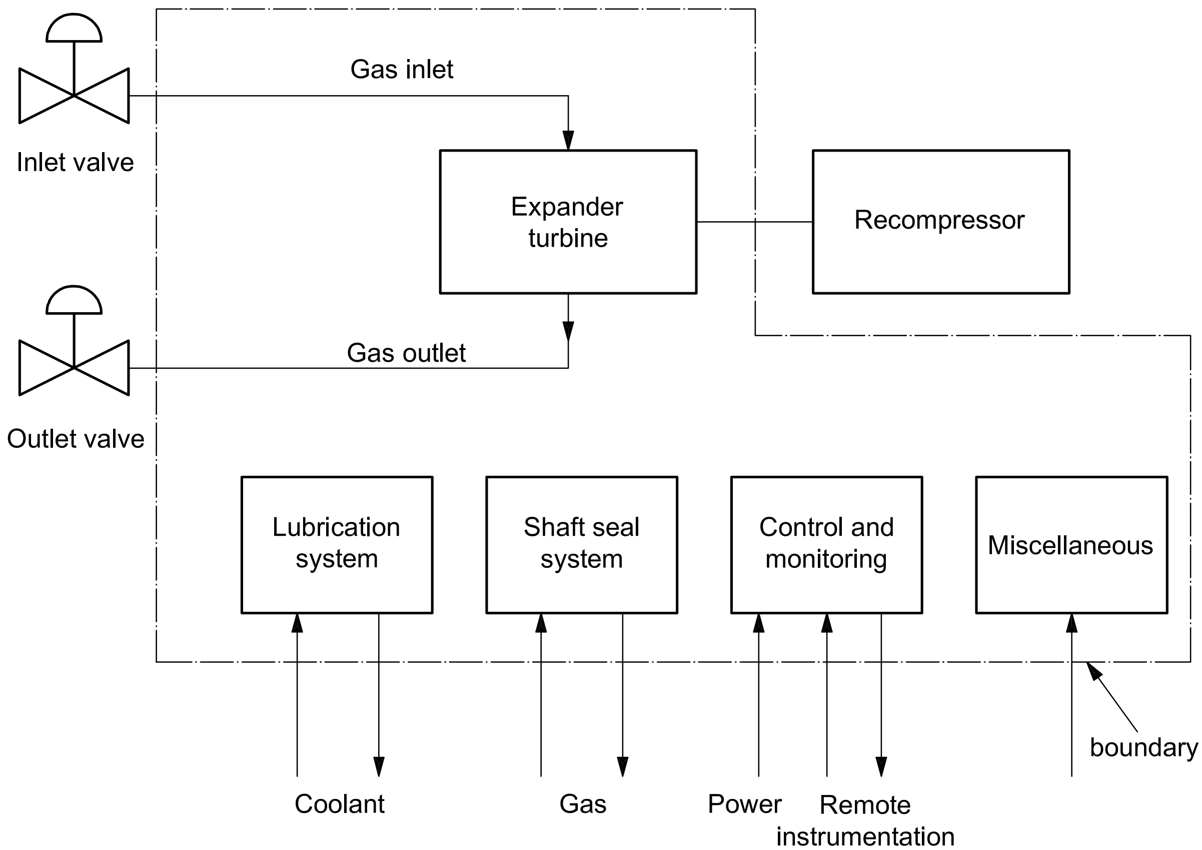
Table A.25 — Equipment-specific data — Steam turbines

Name	Description	Unit or code list	Priority
Driven unit	Equipment class, type and identification code	Compressor, crane, generator, pump, winch, etc.	High
Power – design	ISO power rating	Kilowatt	High
Power – operating	Specify the approximate power at which the unit has been operated for most of the surveillance time.	Kilowatt	Medium
Speed	Design speed (power shaft)	Revolutions per minute	Medium
Number of shafts	Specify number	Number	Medium
Regulating system	Specify type	Electronic, hydraulic	Medium
Backup starting system	Specify if relevant	Electric, hydraulic, pneumatic	Low
Fuel	Fuel type	Gas, oil-light, oil-medium, oil-heavy, dual	Medium
Air inlet filtration type	Type	Free text	Low

A.2.2.8 Turboexpanders

Table A.26 — Type classification — Turboexpanders

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Turboexpander	TE	Centrifugal	CE
		Axial	AX



NOTE Driven units other than recompressors (e.g. pumps or generators) are also outside the boundary.

Figure A.8 — Boundary definition — Turboexpanders

Table A.27 — Equipment subdivision — Turboexpanders

Equipment unit	**Turboexpanders**				
Subunit	**Expander turbine**	**Control and monitoring**	**Lubrication system**	**Shaft seal system**	**Miscellaneous**
Maintainable items	Rotor w/impellers Inlet vanes Casing Radial bearing Thrust bearing Seals Inlet screen Valves Piping	Actuating device Control unit Internal power supply Monitoring Sensors [a] Valves Wiring Piping Seals	Reservoir Pump Motor Filter Cooler Valves Piping Oil	Seal-gas equipment Seal gas	Others

[a] Specify type of sensor, e.g. pressure, temperature, level, etc.

Table A.28 — Equipment-specific data — Turboexpanders

Name	Description	Unit or code list	Priority
Type of driven unit	Equipment class, type and identification code	Specify	High
Power – design	Max. design output power	Kilowatt	High
Power – operating	Specify the approximate power at which the unit has been operated for most of the surveillance time.	Kilowatt	Low
Speed	Design speed	Revolutions per minute	Medium
Inlet flow	Design inlet flow, turbine	Kilograms per hour	Medium
Inlet temperature	Design inlet temperature, turbine	Degrees Celsius	Medium
Inlet pressure	Design inlet pressure, turbine	Pascal (bar)	Medium
Gas handled	Average molar mass (specific gravity × 28.96)	Grams per mole	Low
Gas corrosiveness/ erosiveness	Specify as shown in the footnote [a]	Benign, moderate, severe	Medium
Type of design	Type	Centrifugal, axial	Medium
Number of stages	Number of stages (in series)	Number	Low
Casing-split type	Type	Horizontal/vertical	Low
Shaft sealing	Type	Mechanical, oil, seal, dry gas, packed, gland, dry seal, labyrinth, combined	Low
Flow-control turbine	Type	Variable nozzles, nozzle-group valves, throttle valve, fixed inlet	Low
Radial bearing	Type	Antifrictional, journal, magnetic	Low
Thrust bearing	Type	Antifrictional, journal, magnetic	Low

[a] Benign (clean and dry gas).

Moderately corrosive/erosive (some particles or droplets, some corrosiveness).

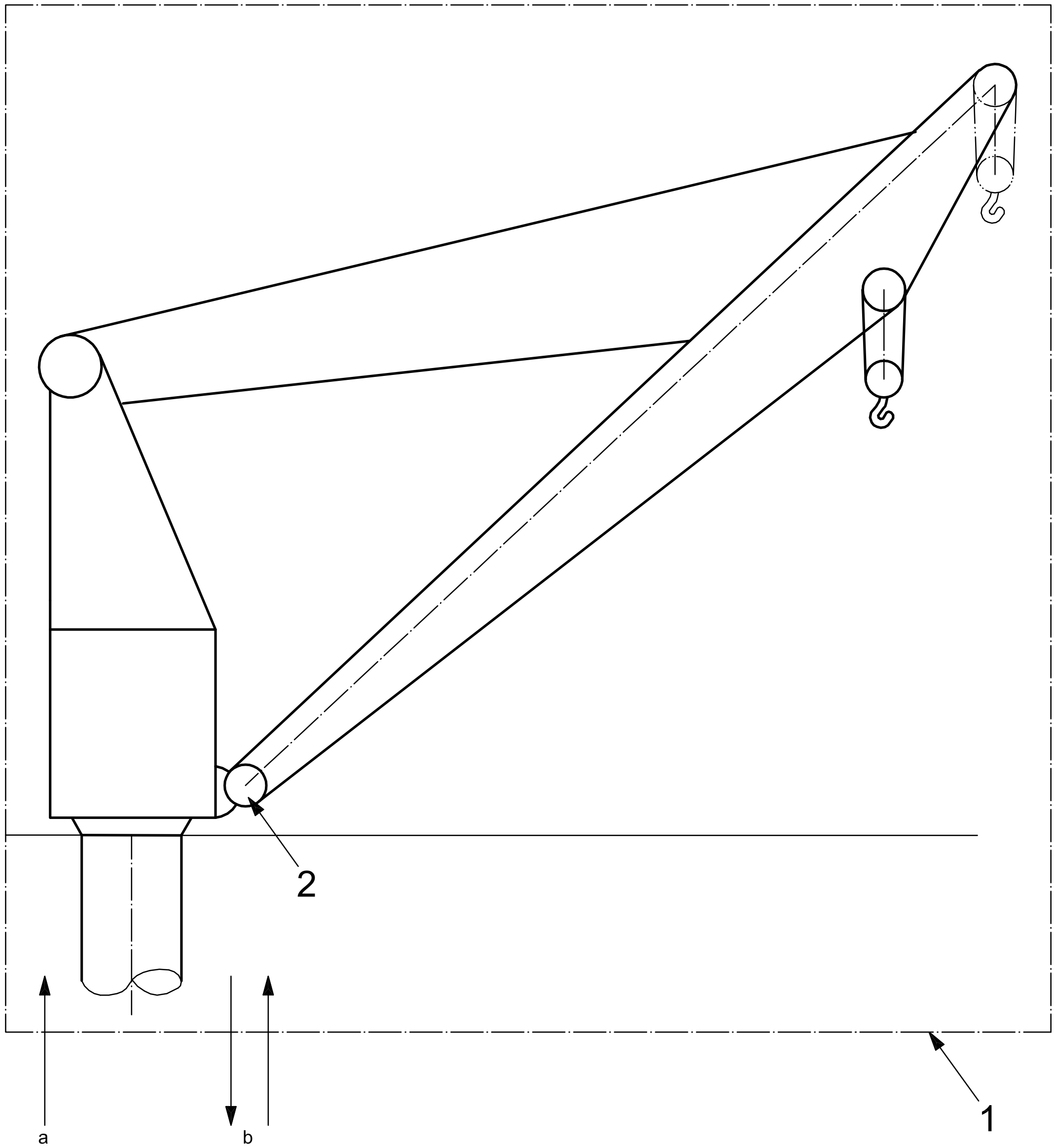
Severe corrosive/erosive (sour gas, high CO_2 content, high content of particles).

A.2.3 Mechanical Equipment

A.2.3.1 Cranes

Table A.29 — Type classification — Cranes

Equipment class — Level 6		Equipment type	
Description	Code	Description	Code
Cranes	CR	Electro-hydraulic operated	HO
		Diesel hydraulic operated	DO



Key

1 boundary

2 crane base (u/s slew ring)

a Power supply.

b Communication signal in/out.

NOTE The boundary drawing illustrates one type of crane commonly used offshore. Several other categories exist, viz. traversing cranes, gantry cranes etc. It is necessary to adapt the taxonomy for these categories to each category.

Figure A.9 — Boundary definition — Cranes

Table A.30 — Equipment subdivision — Cranes

Equipment unit	Cranes						
Subunit	**Crane structure**	**Boom system**	**Hoist system**	**Swing system**	**Power system**	**Control and monitoring**	**Miscel-laneous**
Maintainable items	A-frame/king Drivers cabin Engine room Pedestal Crane frame	Boom Boom bearing Hydraulic cylinder Luffing winch Luffing wire Luffing sheaves Boom stop cylinder	Hoist winch Hoist sheaves Hook Lifting wire Shock damper	Slew bearing Slew ring Slew motor Slew pinion	Hydraulic pumps Electric engine Diesel engine Proportional valves Hydraulic tank Hydraulic filters Hydraulic oil	PC/PLS Control valves Internal power supply (UPS) Amplifiers Joysticks Load indicator	Others

Table A.31 — Equipment-specific data — Cranes

Name	Description	Unit or code list	Priority
Type of driver	Driver unit (equipment class, type and identification code)	Specify	High
Overall maximum height	Specify	Metres	Low
Main boom length	Specify	Metres	Medium
A-frame height	Specify	Metres	Low
Boom, min. angle	Specify	Degrees	Low
Boom, max. angle	Specify	Degrees	Low
Slew bearing type	Specify	Conical, roller	High
Hydraulic operating medium	Hydraulic fluid type	Oil-based, synthetic-based, water-based	Low
Hydraulic operating pressure	Specify	Pascal (bar)	Low
Total unit weight	Specify	Metric tonnes	Medium
Boom total weight	Specify	Metric tonnes	Low
Safe working load (SWL)	Crane's safe working load	Metric tonnes	High
Max. operating swing	Turning range (total)	Degrees	Medium
Max. moment	Crane's max. moment	Tonne·metre	High
Hoist speed 1	At max. load	Metres per second	Medium
Hoist speed 2	At no load	Metres per second	Low
Slewing speed 1	At max. load	Degrees per second	Medium
Slewing speed 2	At no load	Degrees per second	Low
WHIP crane	Installed or not	Yes/No	Low
Heave compensation system	Installed or not	Yes/No	Low
Automatic overload protection system (AOPS)	Installed or not	Yes/No	High
Manual overload protection system (MOPS)	Installed or not	Yes/No	High
Constant tension	Installed or not	Yes/No	Low

A.2.3.2 Heat exchangers

NOTE Heat exchangers include coolers, condensers and re-vaporizers, etc.

Table A.32 — Type classification — Heat exchangers

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Heat exchanger	HE	Shell and tube	ST
		Plate	P
		Plate fin	PF
		Double pipe	DP
		Bayonet	BY
		Printed circuit	PC
		Air-cooled	AC
		Spiral	S
		Spiral-wound	SW

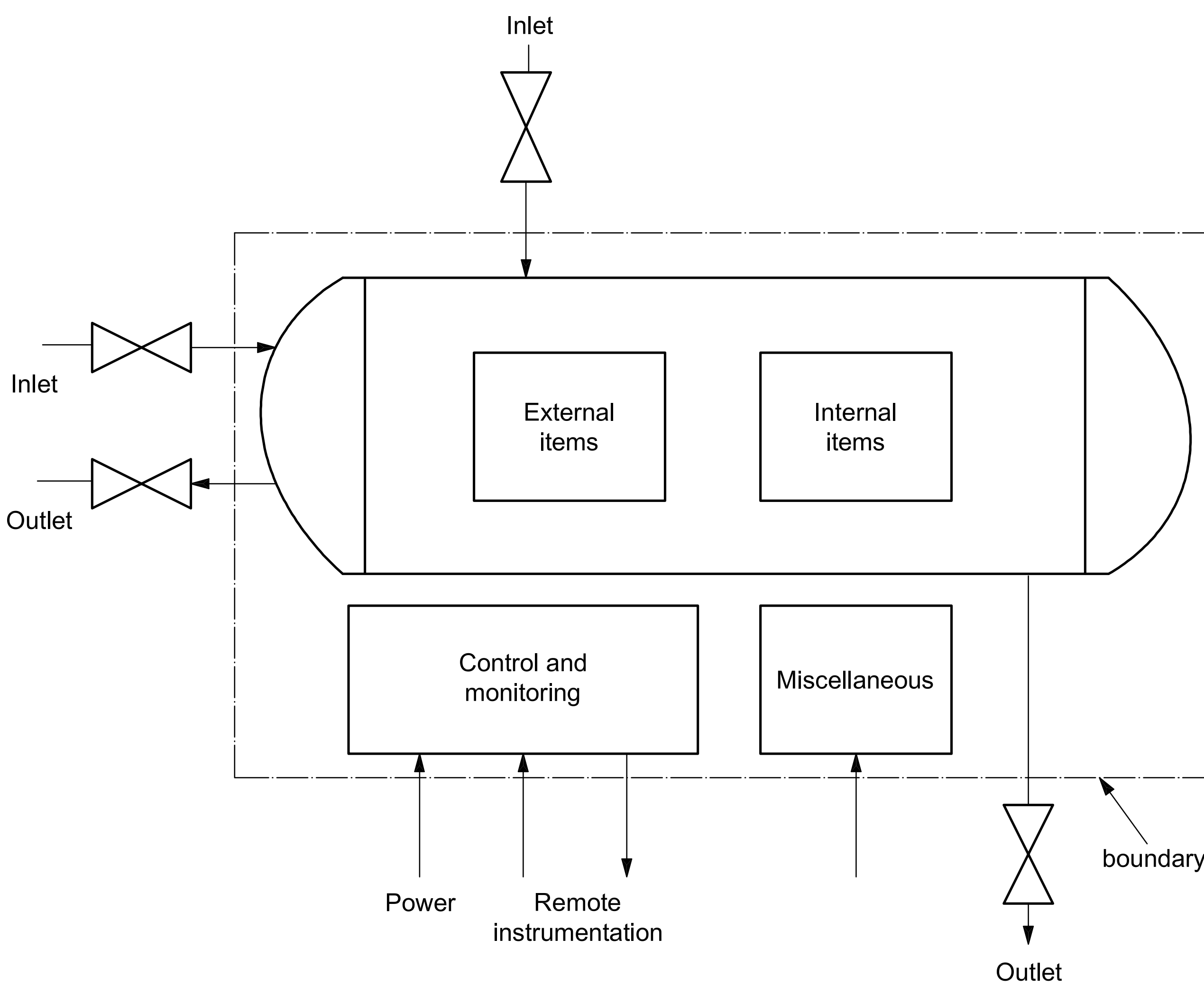


Figure A.10 — Boundary definition — Heat exchangers

Table A.33 — Equipment subdivision — Heat exchangers

Equipment unit	Heat exchangers			
Subunit	**External**	**Internal**	**Control and monitoring**	**Miscellaneous**
Maintainable items	Support Body/shell Valves Piping	Body/shell Tubes Plates Seals (gaskets)	Actuating device Control unit Internal power supply Monitoring Sensors [b] Valves Wiring Piping Seals	Fan [a] Motor

[a] Applicable for air-cooled heat exchangers only.

[b] Specify type of sensor, e.g. pressure, temperature, level, etc.

Table A.34 — Equipment-specific data — Heat exchangers

Name	Description	Unit or code list	Priority
Fluid, hot side	Fluid type	Oil, gas, condensate, freshwater, steam, sea water, crude oil, oily water, flare gas, water/glycol, methanol, nitrogen, chemicals, hydrocarbon, air	High
Fluid, cold side	Fluid type	Oil, gas, condensate, freshwater, steam, sea water, crude oil, oily water, flare gas, water/glycol, methanol, nitrogen, chemicals, hydrocarbon, air	High
Rated heat transfer	Design value	Kilowatt	Medium
Heat-transfer area	—	Metres squared	Medium
Utilization	Used/rated heat transfer	Percent	Medium
Pressure, hot side	Design pressure	Pascal (bar)	Medium
Pressure, cold side	Design pressure	Pascal (bar)	Medium
Temperature drop, hot side	Operating	Degrees Celsius	Low
Temperature rise, cold side	Operating	Degrees Celsius	Low
Size – diameter	External	Millimetres	Medium
Size – length	External	Metres	Medium
Number of tubes/plates	—	Number	Low
Tube/plate material	Specify material type in tubes/plates.	Free text	Medium

A.2.3.3 Heaters and boilers

A.2.3.3.1 Boundary definitions for heaters and boilers

The boundary definition applies to hydrocarbon- (HC-) fired heaters and boilers. The layout of heaters and boilers can vary considerably; however, they all apply the same principle supplying energy to heat or boil a medium. The energy can be supplied through combustion of hydrocarbons, through supply of a high-temperature medium (e.g. steam) or by electricity.

The heater and boiler components may vary significantly in design, but will typically include a vessel/shell in which the heating process is performed. For heaters and HC-fired boilers, a burner device and exhaust system are included. Unlike most boilers, the heaters contain a tube coil through which the medium being heated flows.

For HC-fired heaters and boilers, the fuel-control valve is inside the equipment boundary, while the fuel-conditioning equipment (e.g. scrubbers) and ESD/PSD valves are outside the boundary.

Inlet, outlet, pressure-relief and drain valves are specifically excluded. Valves and instruments included are those locally mounted and/or which form a pressure boundary (e.g. block valves, calibration valves, local indicators/gauges).

Table A.35 — Type classification — Heaters and boilers

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Heaters and boilers	HB	Direct-fired heater	DF
		Electric heater	EH
		Indirect HC-fired heater	IF
		Heater treater	HT
		Non-HC-fired boiler	NF
		Electric boiler	EB
		HC-fired boiler	FB

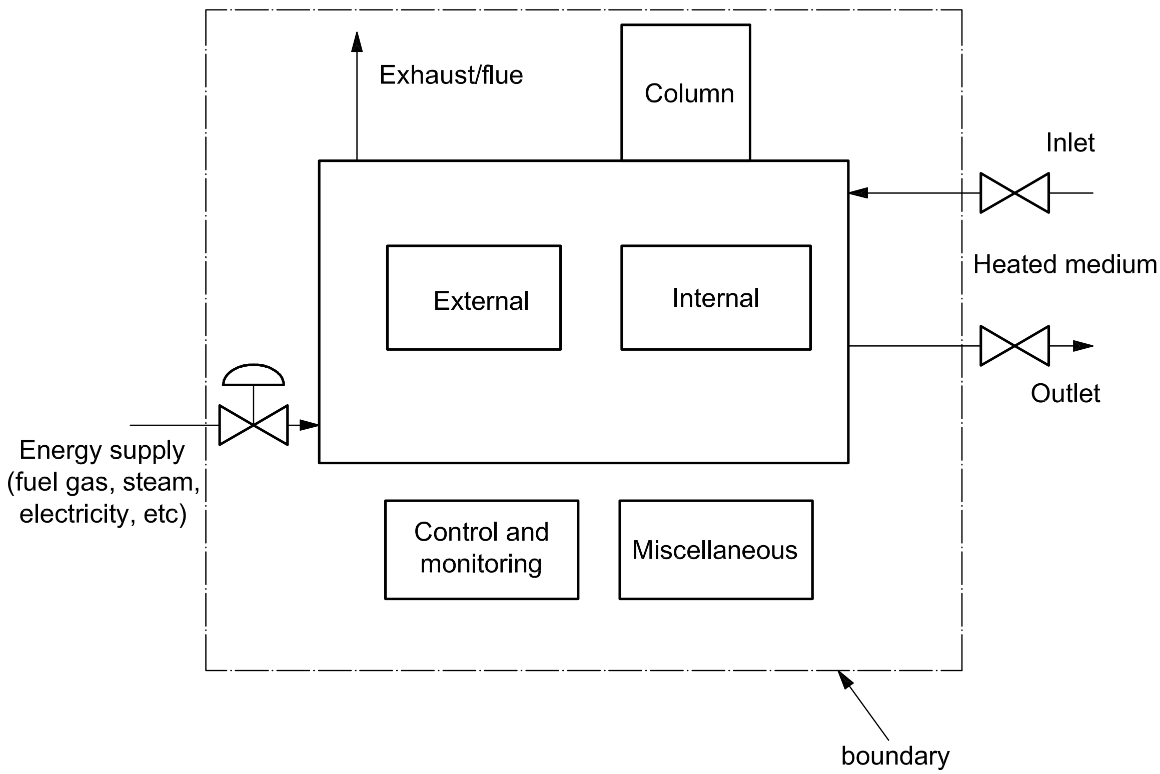


Figure A.11 — Boundary definition — Heaters and boilers

Table A.36 — Equipment subdivision — Heaters and boilers

Equipment unit	Heaters and (re)boilers				
Subunit	**Column**	**Externals**	**Internals**	**Control and monitoring**	**Miscellaneous**
Maintainable items	Body/shell Packing Reflux coil/ condenser	Body/shell Piping Support Valves	Body/shell Burner Firetube Exhaust stack Tube coil Support	Actuating device Control unit Internal power supply Monitoring Sensors [a] Valves Wiring Piping Seals	Fan Others

[a] Specify type of sensor, e.g. pressure, temperature, level, etc.

Table A.37 — Equipment-specific data — Heaters and boilers

Name	Description	Unit or code list	Priority
Energy source	Type of heating energy	Electricity, exhaust gas, fuel gas, hot oil, liquid fuel, steam	High
Heated/boiled medium	Type of fluid being heated/boiled	MEG, TEG, HC-based heating medium, water, water/TEG	High
Rated heat transfer	Design value	Kilowatt	High
Inlet temperature	Design value	Degrees Celsius	Medium
Outlet temperature	Design value	Degrees Celsius	Medium
Size – diameter	Specify	Millimetres	Medium
Size – length	Specify	Metres	Medium
Number of tubes	Specify	Number	Medium
Tube material	Specify	Specify	Low
Tube coil configuration	Specify	Helical, horizontal, single-pass, spiral, split-pass, vertical	Low
Packing type	—	Specify	High
Heater type	Direct-fired only	Box, cabin, cylindrical	Low
Number of burners	—	Number	Low

A.2.3.4 Vessels

NOTE Vessels include separators, scrubbers, cyclones, etc.

Table A.38 — Type classification — Vessels

Equipment class — Level 6		Equipment type	
Description	Code	Description	Code
Vessel	VE	Stripper	SP
		Separator	SE
		Coalescer	CA
		Flash drum	FD
		Scrubber	SB
		Contactor	CO
		Surge drum	SD
		Hydrocyclone	HY
		Slug catcher	SC
		Adsorber	AD
		Dryer	DR
		Pig trap	PT
		Distillation column	DC
		Saturator	SA
		Reactor	RE
		De-aerator	DA

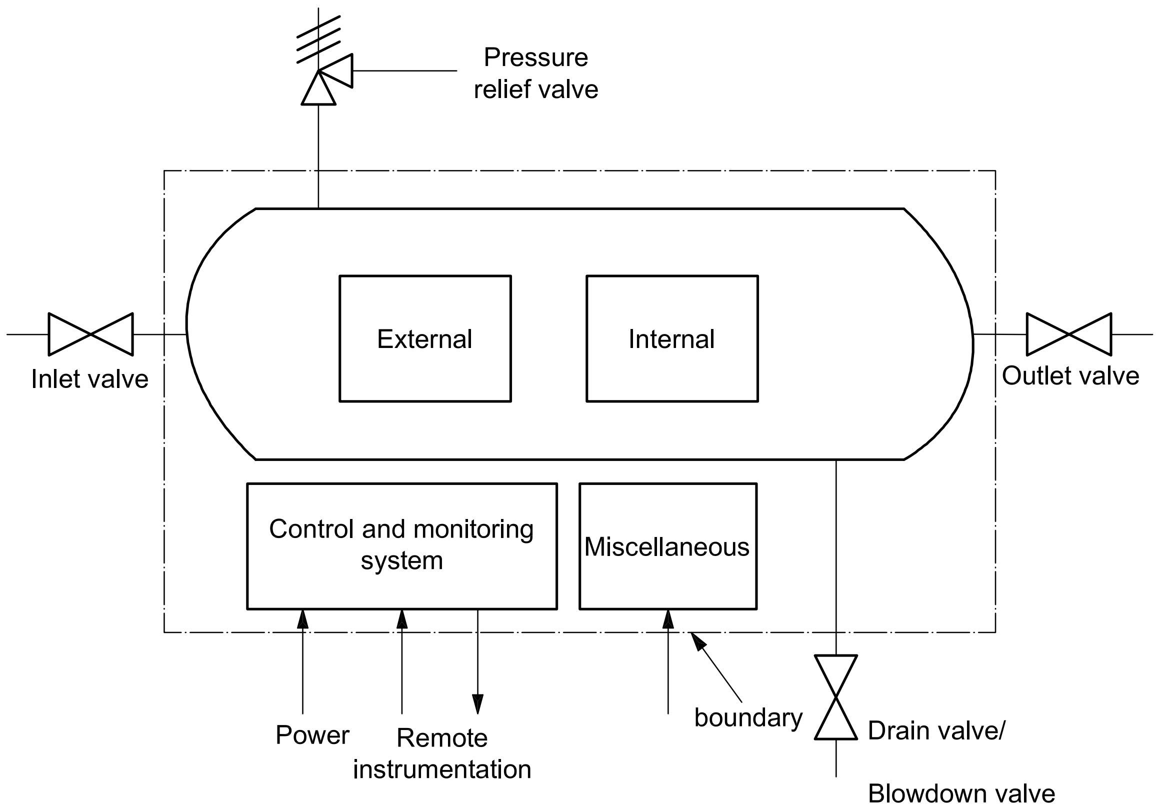


Figure A.12 — Boundary definition — Vessels

Table A.39 — Equipment subdivision — Vessels

Equipment unit	**Vessels**			
Subunit	**External items**	**Internal items**	**Control and monitoring**	**Miscellaneous**
Maintainable items	Support Body/Shell Valves Piping	Body/Shell Plates, trays, vanes, pads Nozzle Sand-trap system Heater Corrosion protection Distributor Coil	Actuating device Control unit Internal power supply Monitoring Sensors [a] Valves Wiring Piping Seals	Others

[a] Specify type of sensor, e.g. pressure, temperature, level, etc.

Table A.40 — Equipment-specific data — Vessels

Name	Description	Unit or code list	Priority
Fluid(s)	Main fluid	Oil, gas, condensate, freshwater, steam, sea water, crude oil, oily water, flare gas, fuel gas, water/glycol, methanol, nitrogen, chemicals, hydrocarbon combined, gas/oil, gas/condensate, oil/water, gas/oil/water	High
Pressure – design	Design pressure	Pascal (bar)	High
Temperature – design	Design temperature	Degrees Celsius	Low
Pressure – operating	Operating pressure	Pascal (bar)	Medium
Temperature – operating	Operating temperature	Degrees Celsius	Low
Size – diameter	External	Millimetres	Medium
Size – length	External	Metres	Medium
Body material	Specify type or code	Free text	Low
Orientation	—	Horizontal/vertical	Low
Number of branches	Pressurized connections only	Number	Low
Internals	Design principle	Baffles, trays, grid plate, demister, heat coil, diverter, de-sander, combined	Low

A.2.3.5 Piping

Table A.41 — Type classification — Piping

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Piping	PI	Carbon steels	CA
		Stainless steels	ST
		High-strength low-alloy steels	LO
		Titanium	TI
		Polymers including fibre-reinforced	PO

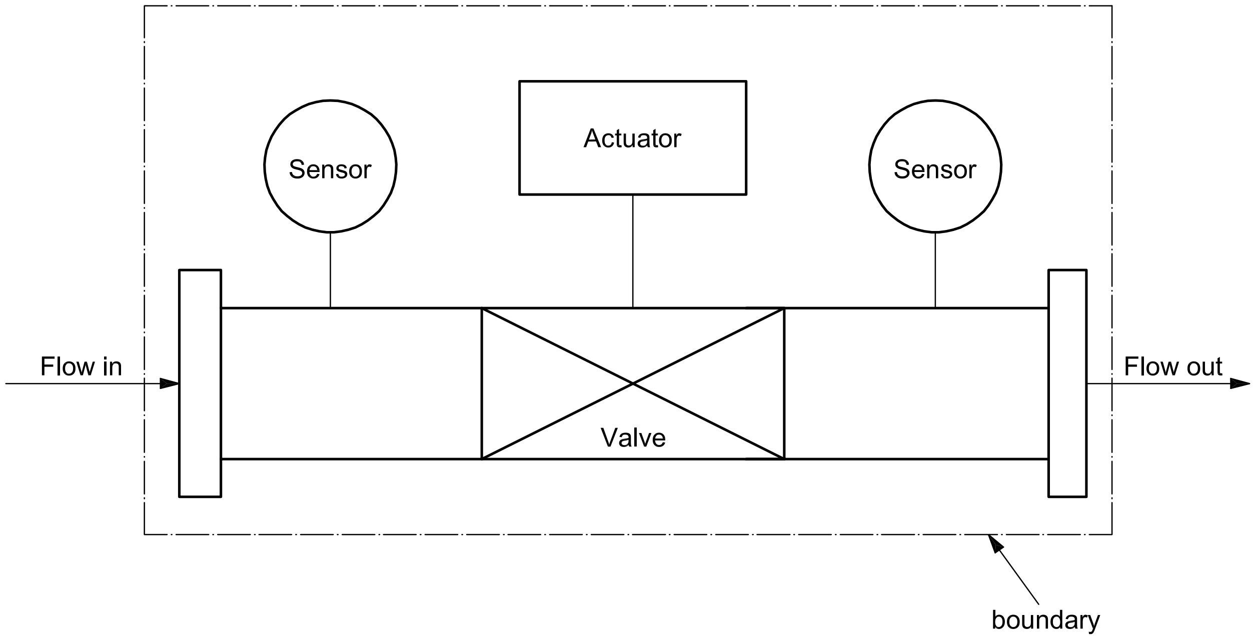


Figure A.13 — Boundary definition — Piping

Table A.42 — Equipment subdivision — Piping

Equipment unit	Piping			
Subunit	**Pipe**	**Valve** [a]	**Control and monitoring**	**Miscellaneous**
Maintainable items	Fastener/ bolts Fitting Flange Header Lining Pipe element Plug	Valve body Valve seals Actuator Bonnet Accessories	Actuating device Control unit Internal power supply Monitoring Sensors [b] Valves Wiring Piping Seals	Pipe support Others

[a] It should be marked if the valve(s) is/are registered as (a) separate equipment units(s) in the database (see also A.2.5.4).

[b] Specify type of sensor, e.g. pressure, temperature, level, etc.

Table A.43 — Equipment-specific data — Piping

Name	Description	Unit or code list	Priority
Diameter	Outer diameter	Millimetres	High
Wall thickness	Specify	Millimetres	Medium
Length	Total length	Metres	High
Design pressure	Max. allowable pressure	Pascal (bar)	High
Fluid handled	Type	Oil, gas, condensate, freshwater, steam, sea water, crude oil, oily water, flare gas, fuel gas, water/glycol, methanol, nitrogen, chemicals, hydrocarbon-combined, gas/oil, gas/condensate, oil/water, gas/oil/water	High
Fluid corrosive/erosive	Classify as shown in the footnote [a]	Benign, moderate, severe	Medium
Pipe material	Specify	Carbon steel, stainless steel, alloy type, composite, titanium etc.	Medium
Insulated	Specify	Yes/No	Low
Number of valves	Number of valves installed on the pipe length considered	Number	Medium
Type of valves	Specify valve category	PSV, ESD, HIPPS, manual, etc.	Low
Number of flanges	Specify	Number	Low

[a] Benign (clean fluids, e.g. air, water, nitrogen).

Moderately corrosive/erosive (oil/gas not defined as severe, sea water, occasionally particles).

Severely corrosive/erosive [sour gas/oil (high H_2S), high CO_2, high sand content].

A.2.3.6 Winches

Table A.44 — Type classification — Winches

Equipment class — Level 6		Equipment type	
Description	Code	Description	Code
Winches	WI	Electric winch	EW
		Hydraulic winch	

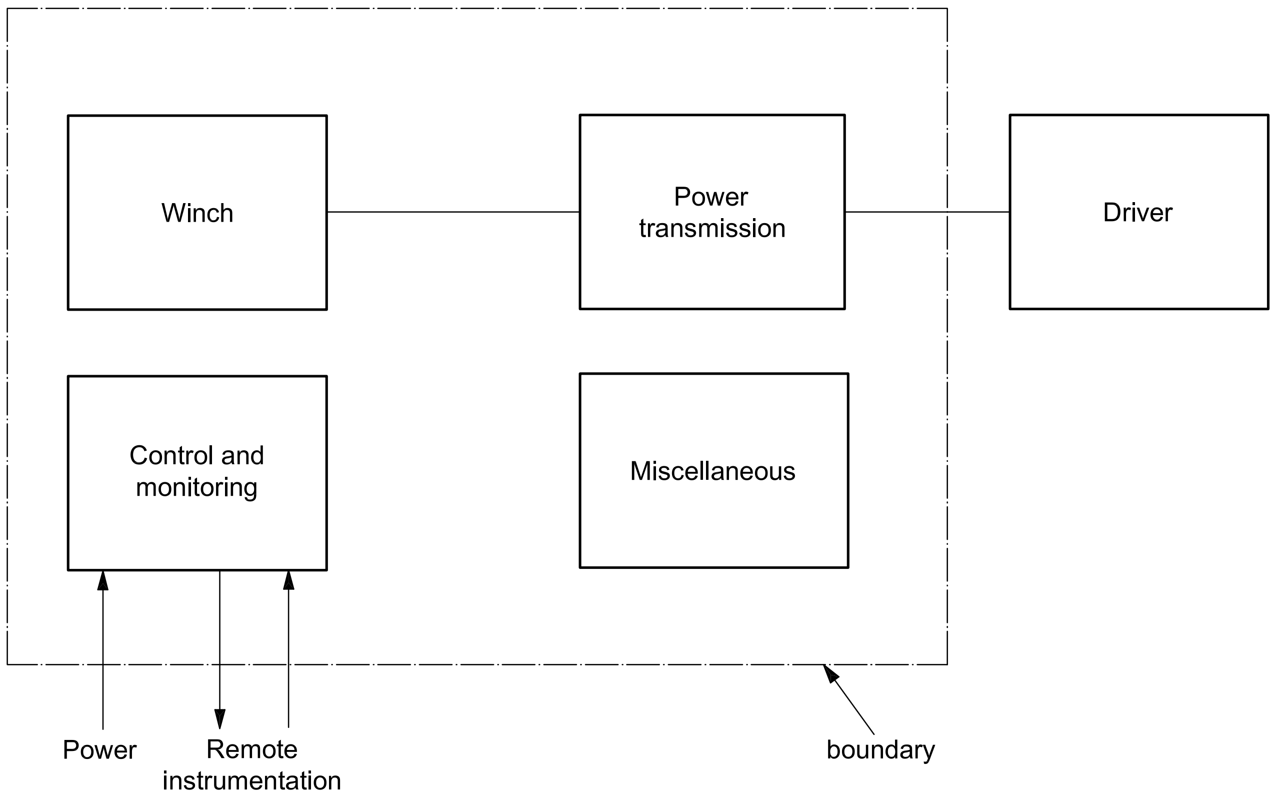


Figure A.14 — Boundary definition — Winches

Table A.45 — Equipment subdivision — Winches

Equipment unit	Winches			
Subunit	**Winch**	**Power transmission**	**Control and monitoring**	**Miscellaneous**
Maintainable items	Bearing Chain Drum Lubrication Reel Speedbrake Spool Structure Tensioning and motion compensation Wire	Bearing Coupling Gear Shaft	Actuating device Control unit Internal power supply Monitoring Sensors [a] Valves Wiring Piping Seals	Hood Others

[a] Specify type of sensor, e.g. pressure, temperature, level, etc.

Table A.46 — Equipment-specific data — Winches

Name	Description	Unit or code list	Priority
Type of driver	Equipment class, type and code	Specify	High
Wire/chain type	Type of hoisting line	Cable, chain, rope, umbilical, wire	High
Max. output	Max. input power – design	Kilowatt	High
Max. capacity	Max. load capacity	Metric tonnes	Medium
Drum capacity	Max. drum capacity	Metres	Low
Drum diameter	—	Metres	Low
Wire diameter	Wire/line thickness	Millimetres	Low
Speed – design	Max. operating speed	Revolutions per minute	High
Transmission type	Type	Direct, gear, integral	Low
Coupling	Type	Disconnect, fixed, flexible, hydraulic	Low
Lubrication of bearings	Type	Specify	Low
Radial bearing	Type	Antifrictional, journal, magnetic	Low
No. of drums	Number	Number	Low
Spooling device	As applicable	Yes/No	Low
Constant tensioning system	As applicable	Yes/No	Low
Heave compensation system	As applicable	Yes/No	Low
Regeneration of power	As applicable	Yes/No	Low
Remote control	As applicable	Yes/No	Low

A.2.3.7 Turrets

Table A.47 — Taxonomy classification — Turrets

Equipment class — Level 6		Equipment type	
Description	Code	Description	Code
Turrets	TU	Disconnectable turrets	DT
		Permanent turrets	PT

A.2.3.7.1 Boundary definitions for turrets

A.2.3.7.1.1 The disconnectable turret boundary is defined as follows:

a) interfaces between the ship hull and the turret or buoy;

b) mooring lines and anchors down to seabed included within boundary;

c) interface between turret and turret compartment (boundary includes riser termination);

d) manifold piping and valves between the riser termination and the swivel or dragged chain outside the boundary;

e) control and monitoring equipment excluded from the boundary.

The boundary definition for permanent turrets is focused on the marine structures and dedicated turret systems.

A.2.3.7.1.2 The permanent turret boundary is defined as follows.

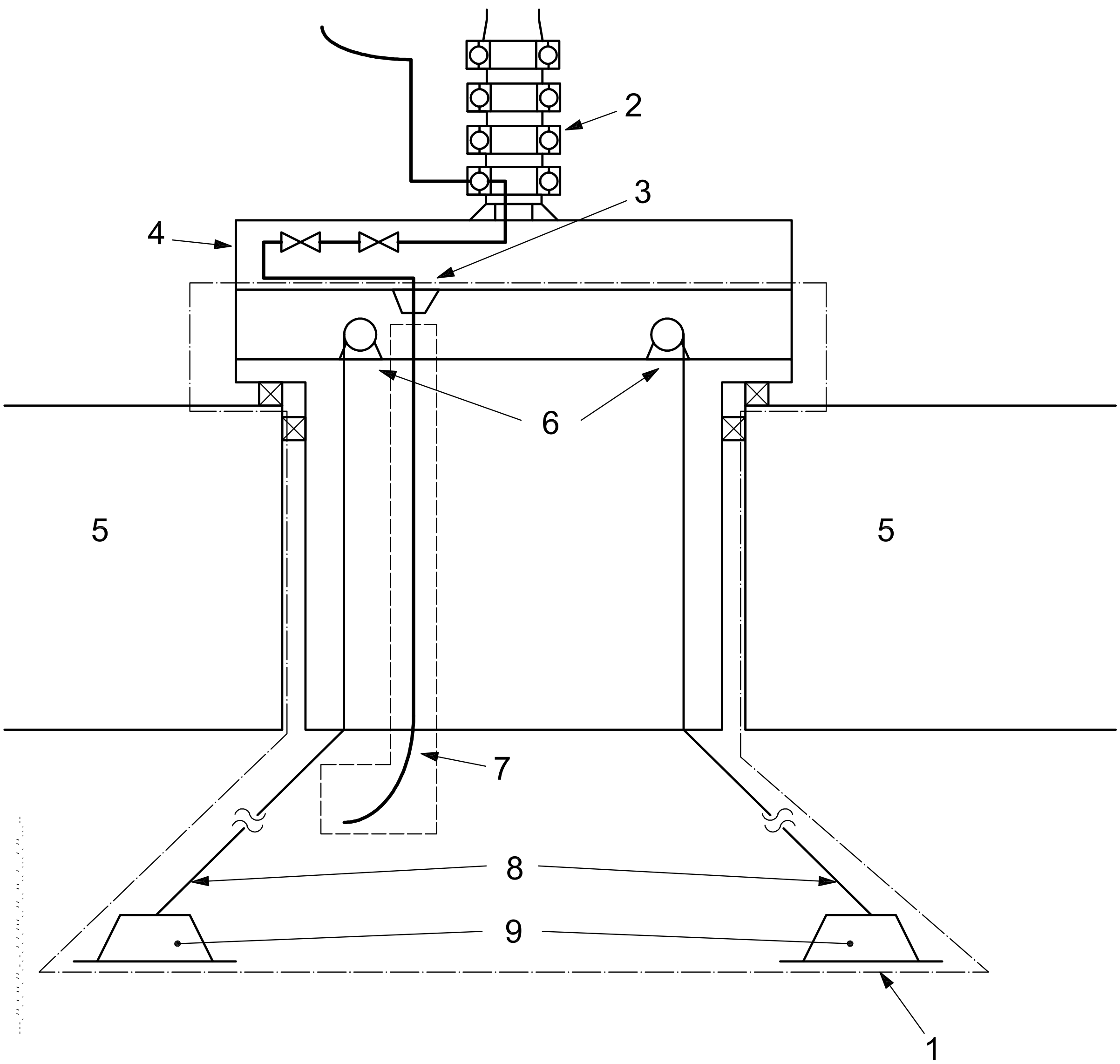
a) The interface between the ship hull and the outer diameter of the turret defines the boundary between the ship structure and the turret.

b) Mooring lines and anchors down to the seabed are included within the boundary.

c) The interface between turret and turret compartment defines the upper boundary of the turret.

d) The riser and umbilical termination is inside the equipment boundary.

e) The risers are outside the boundary (covered as a separate equipment class).



Key

1 boundary
2 swivel
3 riser termination
4 production manifold
5 ship
6 anchor winches
7 riser
8 mooring lines
9 anchors

Figure A.15 — Boundary definition — Turrets

Table A.48 — Equipment subdivision — Turrets

Equipment unit	Turrets			
Subunit	**Turret**	**Mooring**	**Riser and umbilical termination**	**Utility systems**
Maintainable items	Bearing-roller Bearing-slide Bearing-wheel Structure Turning and locking system	Anchor Buoy [a] Chain Synthetic rope Connection to structure Winch Wire	Bend-restrictor lock Hang-off	Ballast system Bilge system Lock buoy/ship system [a] Power system Pull-in [a] Ventilation

[a] Only relevant for disconnectable turrets.

Table A.49 — Equipment-specific data — Turrets

Name	Description	Unit or code list	Priority
Application	Main use	External loading, external production/injection, internal loading, internal production/injection	High
Turret location	Where installed on the vessel	Bow, stern, behind living quarter	High
Fluid transmission	Fluid-transfer method	Dragged chain, jumper, swivel	High
Rotation system	—	Active, passive	High
Riser termination	Type	Flanged, quick connect, quick disconnect, welded	High
Number of risers	—	Number	High
Number of umbilicals	—	Number	High
Number of anchor lines	—	Number	High
Wave height	Significant height – design value	Meters	Medium
Vessel displacement	—	Metric tonnes	Medium

A.2.3.8 Swivels

Table A.50 — Type classification — Swivels

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Swivels	SW	Axial	AX
		Toroidal	TO
		Electric/signal	ES

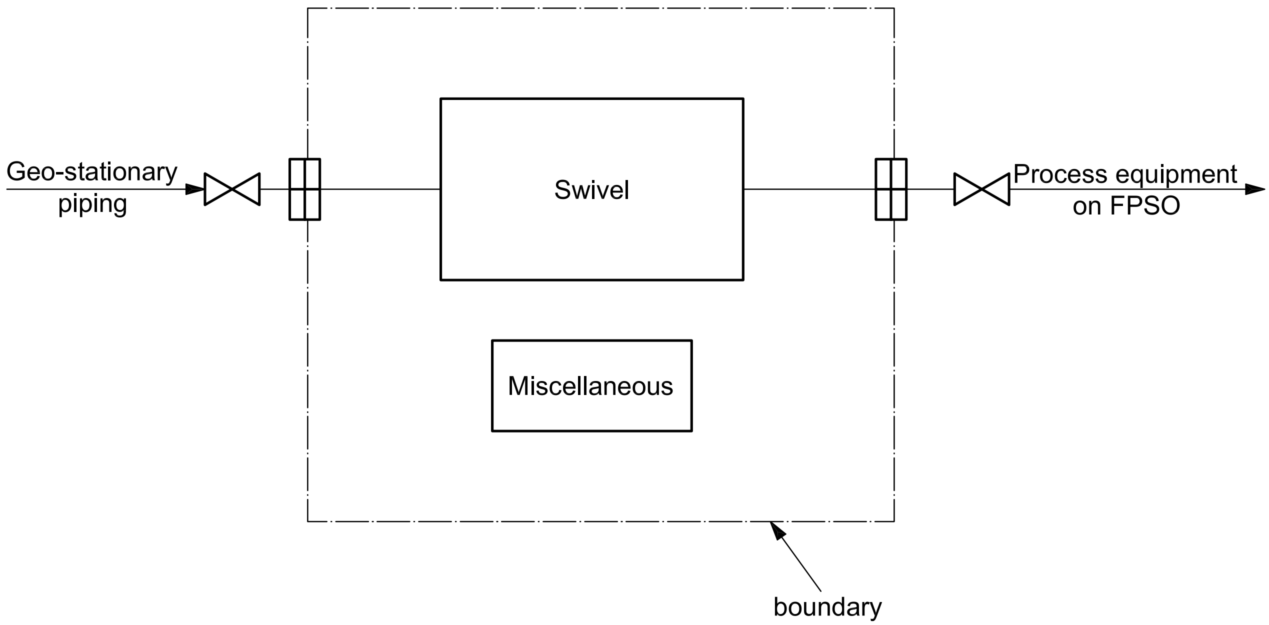


Figure A.16 — Boundary definition — Swivels

Table A.51 — Equipment subdivision — Swivels

Equipment unit	**Swivels**	
Subunit	**Swivel**	**Miscellaneous**
Maintainable items	Dynamic seals Bearing Liquid barrier system Bolting (incl. both structural and pressure connections) Casing Brushes [a]	Tensioners Common items

[a] Only for electric swivels.

Table A.52 — Equipment-specific data — Swivels

Name	**Description**	**Unit or code list**	**Priority**
Number of paths	For power and signal swivels no. of paths is defined as no. of services	Number	High
Design pressure	—	Pascal (bar)	Medium
Design temperature	—	Degrees Celsius	Low
Enclosure	Type of enclosure	Closed compartment, naturally ventilated	Medium
Produced-fluid corrosiveness	Type of service	Sweet service, sour service	Medium
Sand production	Measured or estimated sand production	Grams per cubic metre	Low
Electric power	Power swivels only	Kilowatt	Medium
Voltage – power	Power swivels only [a]	Volt	Medium
Voltage signal	Signal swivels only [a]	Volt	Medium

[a] If several levels exist, record the most dominating and add further explanation as “Remarks”.

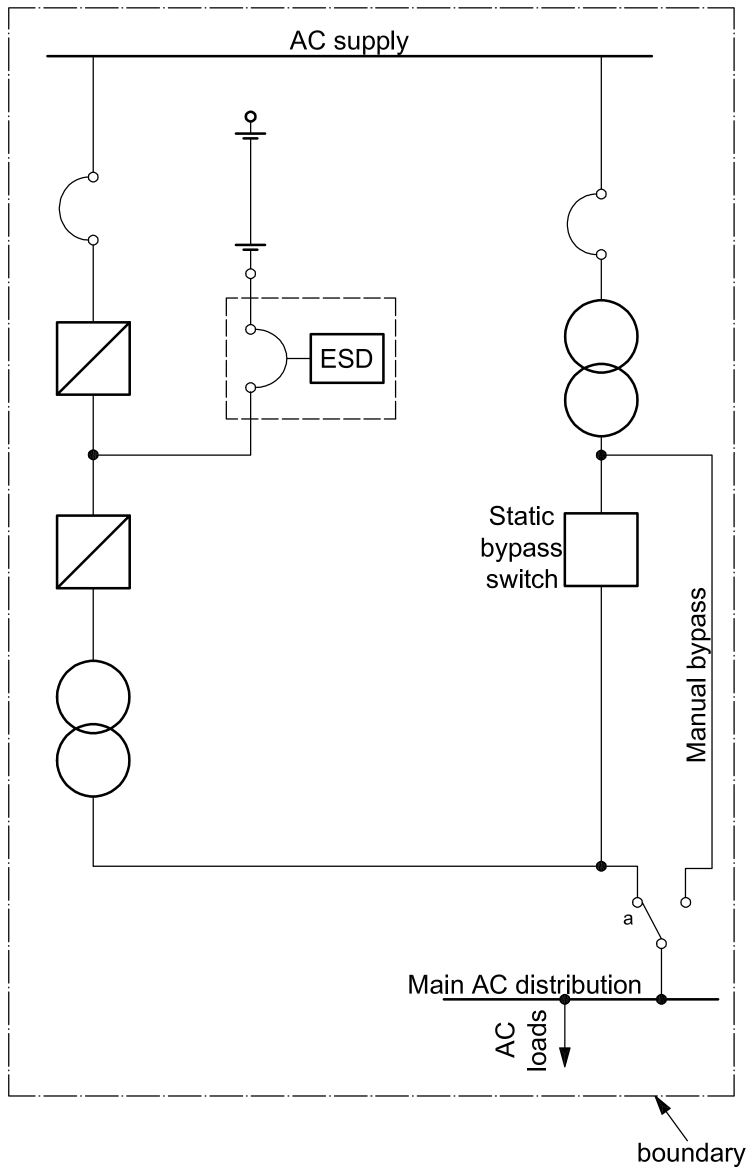
A.2.4 Electrical equipment

A.2.4 presents examples of typical plant/unit-level applications for electrical equipment.

A.2.4.1 Uninterruptible power supplies (UPS)

Table A.53 — Type classification — UPS

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
UPS	UP	Dual UPS with standby bypass Rectifier supplied from emergency power Bypass from main power system	UB
		Dual UPS without bypass Rectifier supplied from emergency power	UD
		Single UPS with bypass Rectifier supplied from emergency power Bypass from main power system	US
		Single UPS without bypass Rectifier supplied from emergency power	UT



[a] Make-before-break switch.

Figure A.17 — Boundary definition (typical) **— UPS**

Table A.54 — Equipment subdivision — UPS

Equipment unit	UPSs					
Subunit	**Battery unit**	**Bypass unit**	**Inverter unit**	**Rectifier unit/ DC supply**	**Control and monitoring**	**Miscellaneous**
Maintainable items	Battery breaker Battery bank Cabling Circuit breaker Connection/ socket Instrument	Bypass switch Bypass transformer Contactor feeder [a] Fuse(s) Instrument Static switch	Bypass switch Cabling Connection/ socket Fuse(s) Instrument Inverter Static switch Inverter transformer	Cabling Contactor feeder [a] Fuse(s) Fused switch Instrument Rectifier Rectifier transformer	Actuating device Control unit Internal power supply Monitoring Sensors [b] Valves Wiring Piping Seals	Cabinet Insulation Cooling fans Others

[a] Normally located in the supplying switchboard.

[b] Specify type of sensor, e.g. pressure, temperature, level, etc.

Table A.55 — Equipment-specific data — UPS

Name	Description	Unit or code list	Priority
Application	What equipment the UPS is applied for	Circuit breaker, control systems, safety systems, telecommunication	High
System input voltage	Input voltage	Volt	High
Input frequency	Rated input	50 Hz or 60 Hz	High
Number of phases input voltage	1-phase or 3-phase	Number	High
Voltage variation	Input voltage	Percent	Low
Frequency variation	Input frequency	Percent	Low
System output voltage	Output voltage	Volt	High
Output frequency	Rated output	50 Hz, 60 Hz or DC	High
Number of phases output voltage	1-phase or 3-phase	Number	High
Rated output load and power factor	Apparent power and power factor in nominal operations	Kilovolt·amperes/cosφ	High
Degree of protection	Protection class in accordance with IEC 60529	IP code	Medium
Ambient temperature	Operating temperature range	Minimum and maximum temperature in degrees Celcius	Low
Cooling method	Specify	Water, air, others	Medium
UPS string system	The numbers of UPS systems which are working in parallel	Dual, single, triple	Medium
Rectifier/inverter bypass system	The type of bypass switch	Manual, static	Medium

Table A.55 (*continued*)

Name	Description	Unit or code list	Priority
Battery backup time	The time during which the battery can supply rated output power to the inverter	Minutes	Medium
Recharge time	The time to recharge the battery to 90 % capacity	Hours	Medium
Battery technology	Type of	NiCd, Pb-acid, other	Medium
Battery earth-fault monitoring	Specify	Common, individual, N.A.	Low
Method of ventilation	Specify	Forced, natural	Low
Number of battery banks	Specify	Number	Medium

A.2.4.2 Power transformers

Table A.56 — Type classification — Power transformers

Equipment class — level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Power Transformer	PT	Oil immersed	OT
		Dry	DT

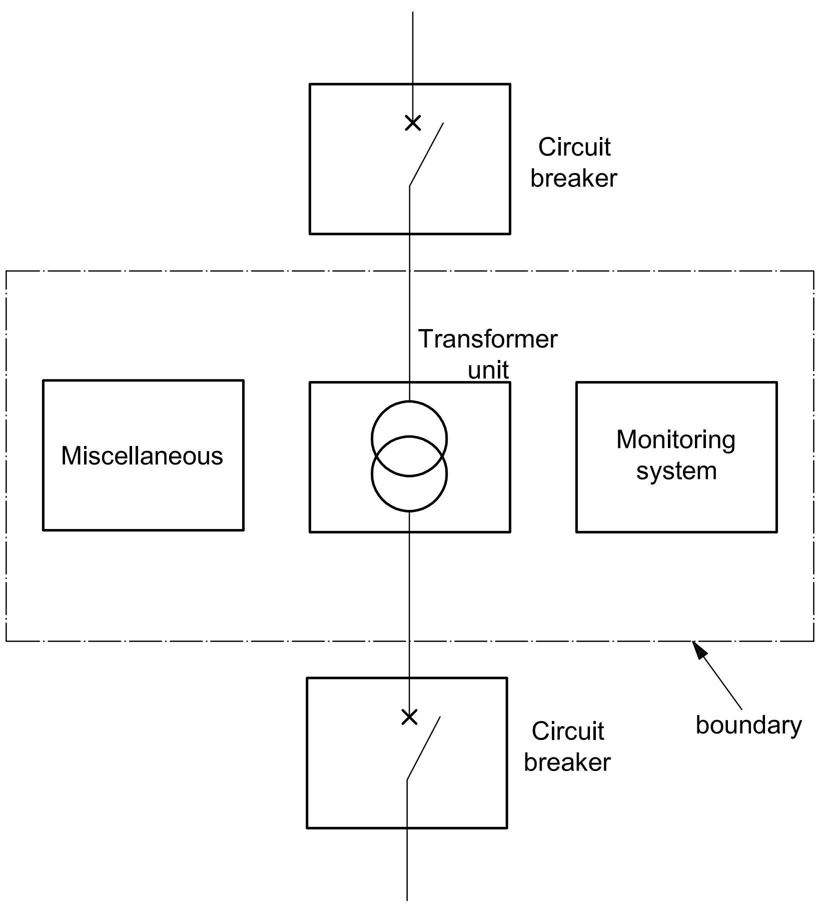


Figure A.18 — Boundary definition (typical) **— Power transformer**

Table A.57 — Equipment Subdivision — Power transformers

Equipment Unit	Power transformers		
Subunit	**Transformer unit**	**Monitoring system**	**Miscellaneous**
Maintainable items	Oil Tank Windings Fan Core Expansion tank Radiator Tap changer Neutral impedance Outer tank [a]	Bucholz relay Level indicator Thermometer Relief valve Pressure relay Current transformers	Bushing insulators Terminal blocks Connectors Wiring Grounding Junction box Silica-gel device Dampers Penetrator [a]

[a] Subsea application.

Table A.58 — Equipment-specific data — Power transformers

Name	Description	Unit or Code list	Priority
Frequency	Rated frequency	Hertz	Low
Primary voltage	Rated voltage	Kilovolts	High
Secondary voltage	Rated voltage	Kilovolts	High
Voltage additional windings	Rated voltage tertiary or further windings	Kilovolts	High
Power – design	Rated power	Kilovolt·amperes	High
Power factor	Cos φ	Number	Low
Efficiency	Efficiency factor (η)	Number < 1	Medium
Degree of protection	Protection class in accordance with IEC 60529	Code as in IEC 60529:2001, Clause 4	Low
Thermal class designation	Thermal class in accordance with IEC 62114	Y, A, E, B, F, H, 200, 220, 250	Medium
Temperature rise	In accordance with IEC 60076-2	Degrees Celsius	Low
Transformer cooling	Type in accordance with IEC 60076-2	Code as in IEC 60076-2:1993, Clause 3	High
Number of phases	1-phase or 3-phase	Number	High
Level of insulation	Insulation in accordance with IEC 60076-3	Kilovolts	High
Three-phase transformer connection	Type and combination of connections (vector groups) as star, delta, etc. in accordance with IEC 60076-1	Code as recommended in IEC 60076-1:2000, Annex D	High
Water depth [a]	Water depth for location of subsea transformer	Metres	High
Type of dry transformer winding	Specify if the windings are encapsulated in solid insulation. Cast resin is an example of solid insulation.	Encapsulated/not encapsulated	Medium

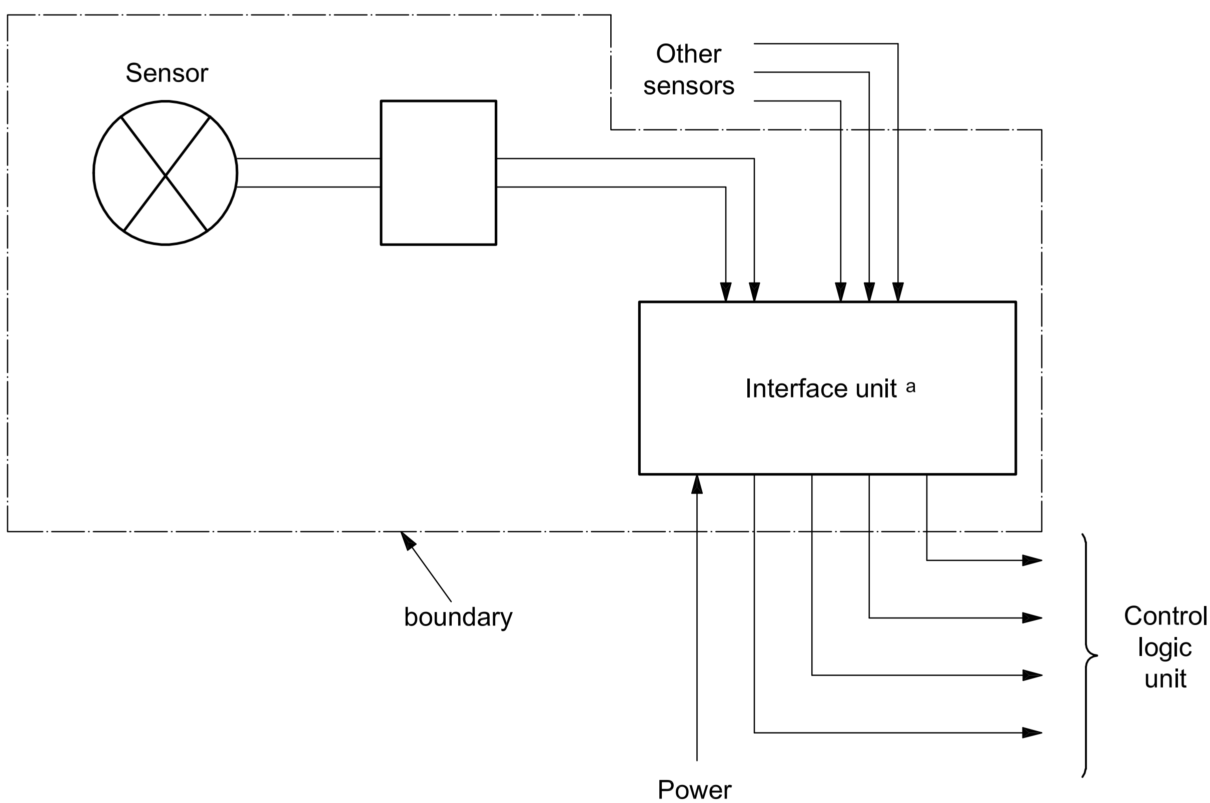
[a] Relevant for subsea installations only.

A.2.5 Safety and Control

A.2.5.1 Fire and gas detectors

Table A.59 — Type classification — Fire and gas detectors

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Fire and gas detectors	FG	**Fire detection**	
		Smoke/Combustion	BS
		Heat	BH
		Flame	BF
		Manual pushbutton	BM
		Others	BA
		Gas detection	
		Hydrocarbon	AB
		Toxic gases	AS
		Others	AO



[a] Not applicable for all fire and gas sensors.

Figure A.19 — Boundary definition — Fire and gas detectors

A.2.5.1.1 Boundary definitions for fire and gas detectors

Field input devices such as fire and gas detectors are usually connected to a fire and gas control logic unit (CLU), which is not included in the boundary of fire and gas detectors (see Figure A.19). Monitoring/interface units may be used between detector and CLU, and this is part of the fire and gas detectors. The purpose of these units is, among others, to monitor the detectors, their interface connections and cables, analyzing the incoming data by different algorithms and initiating fault or alarm signals. The basic principle of data communication between field equipment and such interface systems can be based on multiplexing and sequential polling of data.

Table A.60 — Equipment subdivision — Fire and gas detectors

Equipment unit	Fire and gas detectors		
Subunit	**Sensor**	**Interface unit** [a]	**Miscellaneous**
Maintainable items	Cabling Cover Detector (incl. head and associated electronics) Mounting socket	Cabinet Control card Display	Others

[a] Not applicable for all fire and gas sensors.

Table A.61 — Equipment-specific data — Fire and gas detectors

Name	Description	Unit or code list	Priority
Functional characteristics			
Location on installation	Where installed	Drill floor, wellhead, process, auxiliary, mud processing, power generation, utility, control room, auxiliary room, living quarter	High
Environment	Exposure	Severe, moderate, low, unknown [a]	High
Item characteristics			
Sensing principle	Type	Fire: Ionization, optical, IR, UV, IR/UV, rate rise, rate comp., fixed temp., fusible plug, camera, multisensor (optical/heat) Gas: Catalytic, electrochemical, photoelectrochemical, photoelectric beam, IR, UV, acoustic, camera, aspirating, optical beam, solid state	High
Detector communication	Type	Conventional, addressable (one-way), smart (two-way)	Medium
Fault tolerance [b]	Response at failure	Yes/No	Medium
Self-test feature	Degree of self-testing	No self-test, automatic loop test, built-in test, combined	Medium
Type of Ex protection	Explosion classification category, e.g. Ex(d), Ex(e) [c]	Ex(d), Ex(e), Ex(i), none	Low

[a] Environment classification:

severe — not enclosed and/or outdoor; heavily exposed (vibration, heat, dust, salt);

moderate — partly enclosed and/or moderately exposed (vibration, heat, dust, salt); naturally ventilated;

low — enclosed and/or indoor; minor exposure (vibration, heat, dust, salt); mechanically ventilated.

[b] Design based on de-energized principle is compatible with fail-safe philosophy. A safety-instrumented system operating in “normally energized” mode can be designed to fail-safe on loss of power or signal.

[c] See IEC 60079 (all parts).

A.2.5.2 Input devices

Input devices are, in general, sensors that convert process parameters into an electric signal that can be monitored. Typical main categories of input devices are the following:

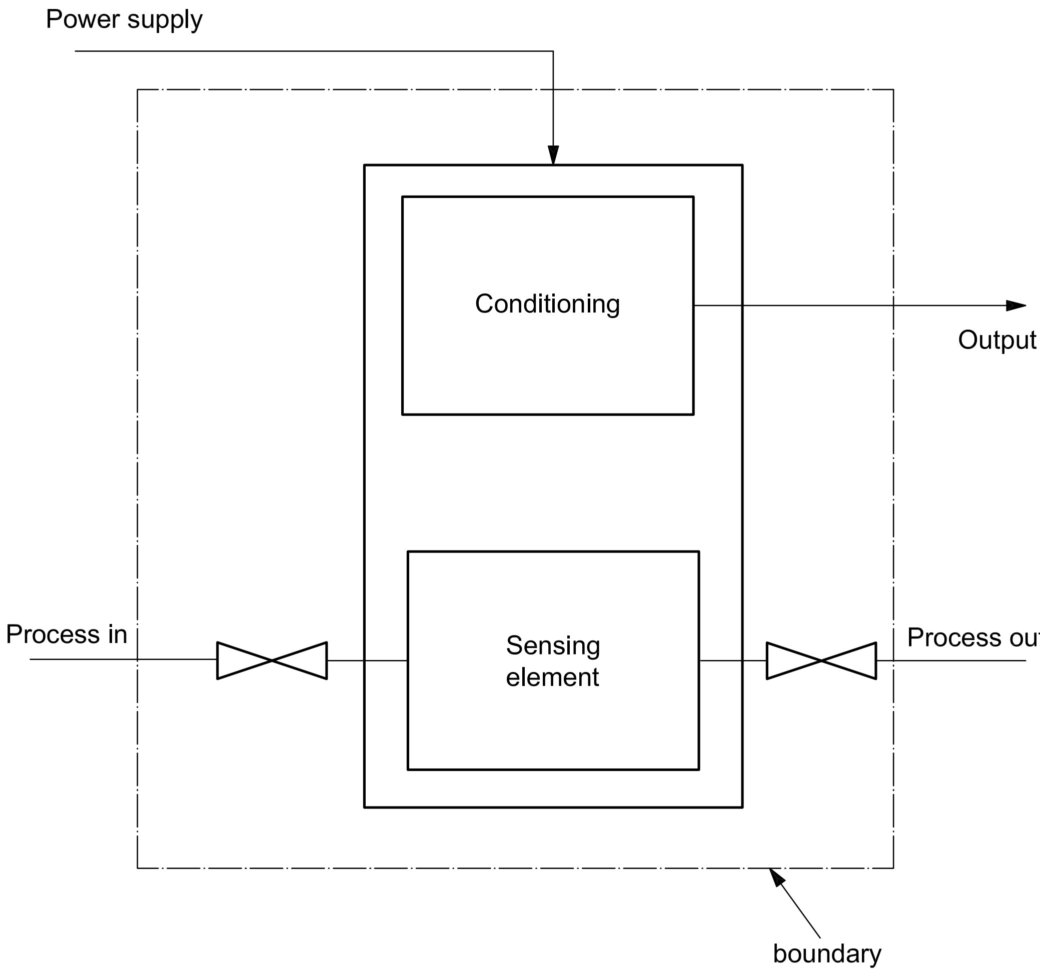
a) transmitter: converts process parameter, e.g. pressure, into proportional electrical signals, typically 4 mA to 20 mA or 0 V to 10 V (see IEC 60381-2);

b) transducer: converts process parameters, e.g. pressure, into proportional electrical signals, typically unamplified output;

c) switch: converts process parameters, e.g. pressure, typically into on/off electrical signals.

Table A.62 — Type classification — Input devices

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Input devices	IP	Pressure	PS
		Level	LS
		Temperature	TS
		Flow	FS
		Speed	SP
		Vibration	VI
		Displacement	DI
		Analyser	AN
		Weight	WE
		Corrosion	CO
		Limit switch	LP
		On/off (pushbutton)	PB
		Others	OT



This boundary drawing does not apply for switches and pushbuttons.

Figure A.20 — Boundary definition — Input devices

Table A.63 — Equipment subdivision — Input devices

Equipment unit	**Input devices**	
Subunit	**Sensor and electronics**	**Miscellaneous**
Maintainable items	Sensing element Conditioning (electronics)	Cabling Piping Others

Table A.64 — Equipment-specific data — Input devices

Name	Description	Unit or code list	Priority
Functional characteristics			
Location on installation	Where installed	Drill floor, wellhead, process, auxiliary, mud processing, power generation, utility, control room, auxiliary room, living quarter	High
Application	Where applied	Process control, emergency shutdown, process shutdown, pressure reduction, bypass, blowdown, monitoring, combined	High
Fluid/gas corrosiveness/ erosiveness	Classify as explained in footnote [a]	Benign, moderate, severe	Medium
Item characteristics			
Category	Main category	Transmitter, transducer, switch, pushbutton	High
Sensing principle	Applicable for pressure sensors only	Bonded strain, semiconductor, strain, piezoelectric, electromechanical, capacitance, reluctance, oscillating wire	High
	Applicable for level sensors only	Differential-pressure cell, capacitance, conductive, displacement, diaphragm, sonic, optical, microwave, radio frequency, nuclear	High
	Applicable for temperature sensors only	Resistance temperature detector (PT), thermocouple, capillary	High
	Applicable for flow sensors only	Displacement, differential head (closed conduit/pipe, open channel), velocity, mass	High
	Insert additional types as relevant (e.g. speed, vibration)	To be defined by user as required	High
Sensor voting, k out of Y (only as relevant)	At least k out of the total number, Y, of sensors shall provide signal to initiate control/safety action. k and Y shall be entered; if no voting, leave blank.	k = “xx” (integer) Y = “yy” (integer)	Low
Fault tolerance	Response at failure	Yes/No	High
Detector communication	Type	Conventional, addressable (one-way), smart (two-way)	Medium
Self-test feature	Degree of self-testing	No self-test, automatic loop test, built-in test, combined	High
Type of protection	Explosion classification category, e.g. Ex(d), Ex(e) [b]	Ex(d), Ex(e), Ex(i), None	Low

[a] Benign (clean fluids, e.g. air, water, nitrogen).

Moderately corrosive/erosive (oil/gas not defined as severe, sea water, occasionally particles).

Severely corrosive/erosive [sour gas/oil (high H_2S), high CO_2 content, high sand content].

[b] See IEC 60079 (all parts).

A.2.5.3 Control logic units (CLU)

Table A.65 — Type classification — Control logic units

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Control logic units	CL	Programmable logic controller (PLC)	LC
		Computer	PC
		Distributed control unit	DC
		Relay	RL
		Solid state	SS
		Single-loop controller	SL
		Programmable automation controller (PAC)	PA

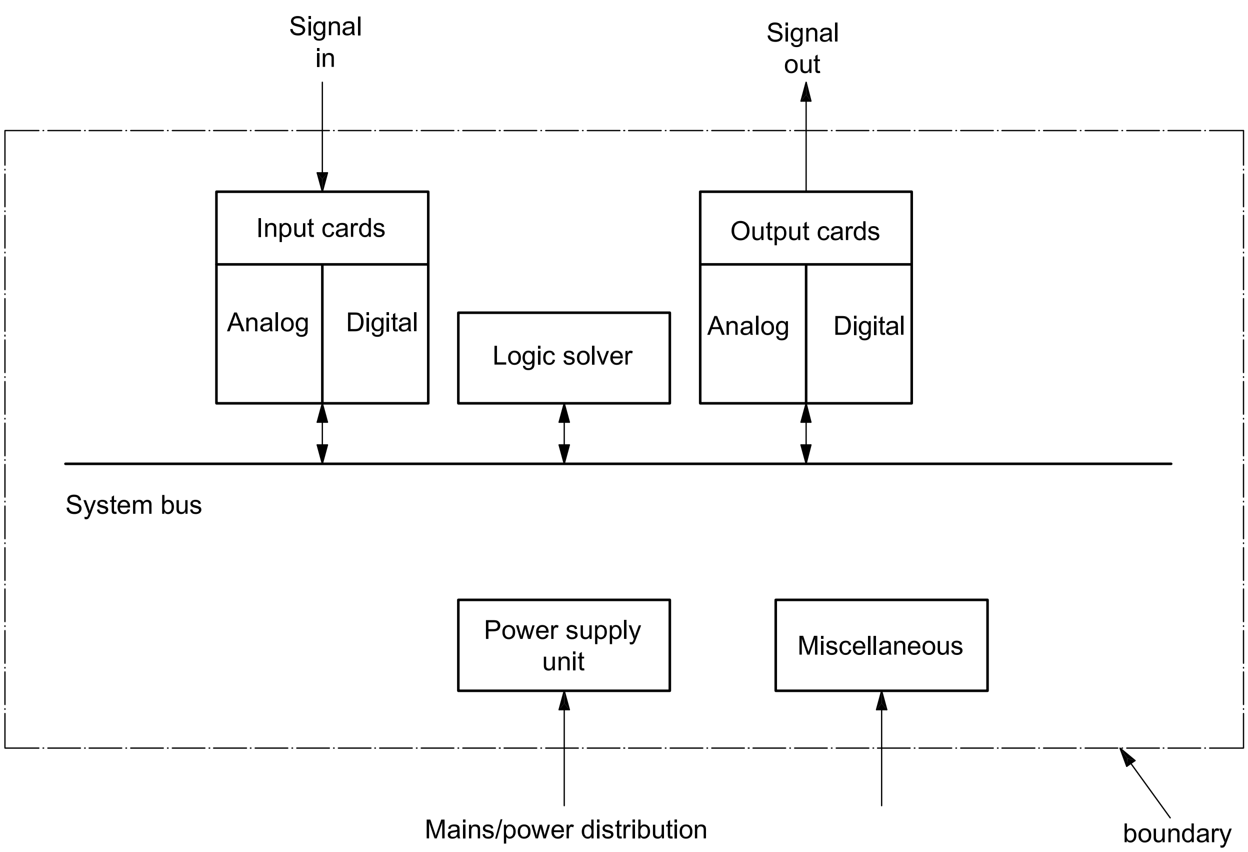


Figure A.21 — Boundary definition — Control logic units

Table A.66 — Equipment subdivision — Control logic units

Equipment unit	Control logic unit							
Subunit	**Analog input cards**	**Digital input cards**	**Analog output cards**	**Digital output cards**	**Logic solver**	**System bus**	**Power supply**	**Miscel-laneous**
Maintainable items	Input card Connection unit	Input card Connection unit (X-wiring)	Output card Connection unit (X-wiring) Relay	Output card Connection unit (X-wiring) Relay	Central processor unit (CPU) Random access memory (RAM) Watchdog/ diagnostic Software	No subdivision	No subdivision	Galvanic barriers Others

Table A.67 — Equipment-specific data — Control logic units

Name	Description	Unit or code list	Priority
Application – control logic	Where used	Centralized, distributed, man-machine interface	Medium
CLU redundancy configuration	Specify if there are redundant CLUs installed	Yes/No	Low
Self-test feature	Degree of self-testing	No self-test, automatic-loop test, built-in test, combined	High
Fault tolerance	Response at failure	Yes/No	High

A.2.5.4 Valves

NOTE: The valves described in the taxonomy classification given in Table A.68 do not apply for valves used for specific upstream purposes like subsea valves and valves used in downhole completion. These valves are covered in the specific chapters in Annex A on this type of equipment (see A.2.6 and A.2.7). Dry Xmas trees and wellheads are, however, considered as topside valves.

Table A.68 — Type classification — Valves

Equipment class — Level 6		Type	
Description	**Code**	**Description**	**Code**
Valves	VA	Ball	BA
		Gate	GA
		Globe	GL
		Butterfly	BP
		Plug	PG
		Needle	NE
		Check	CH
		Diaphragm	DI
		Flapper	FL
		Multiple orifice	MO
		Three-way	WA
		PSV-conventional	SC
		PSV-conventional with bellow	SB
		PSV-pilot operated	SP
		PSV-vacuum relief	SV
		Plug and cage	PC
		External sleeve	ES
		Disc	DI
		Axial flow	AF
		Pinch	PI
		Others	OH

NOTE 1 Pilot valves are normally non-tagged components used for self-regulation. PSV solenoid valves are normally a sub-tag of a valve tag used for all ESD/PSD. Quick-exhaust dump valves are specific valves used if quick response is required (e.g. HIPPS function). Relief valves are normally PSV valves.

NOTE 2 Valves of a specific type not defined in Table A.68 should be coded as “Others” with a comment specifying type description. Example: Clack- or Elastomer-type Deluge valves).

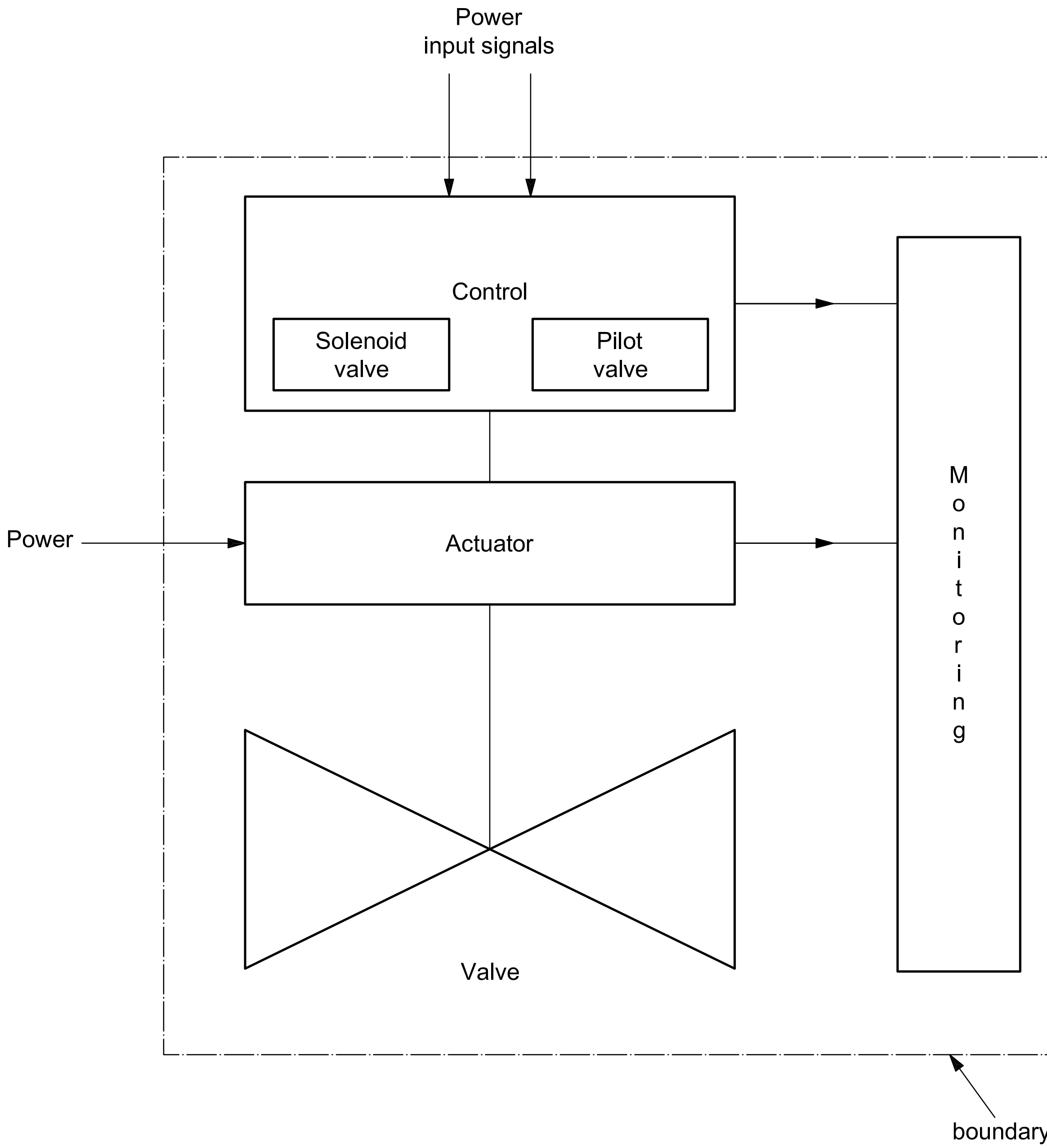


Figure A.22 — Boundary definition — Valves

Table A.69 — Equipment subdivision — Valves

Equipment unit	Valves			
Subunit	**Valves**	**Actuator [a]**	**Control and monitoring [a]**	**Miscellaneous**
Maintainable items	Valve body Bonnet Flange joints Seat rings Packing/stem seal Seals Closure member Stem	Diaphragm Spring Case Piston Stem Seals/gaskets Electrical motor [b] Gear Travel stop	Wiring Indicator Instrument, general Instrument, position Monitoring Solenoid valve Pilot valve [c] Quick exhaust dump valve Internal power supply Limit switch	Accumulator Others

a Not applicable for all valve categories.

b Electric-motor actuator only.

c Applicable for hydraulic/pneumatically actuated valves.

Table A.70 — Equipment-specific data — Valves

Name	Description	Unit or code list	Priority
Main function	Main functional category	Flow control, on/off, non-return, pressure safety valves, instrument or hydraulic control	High
Application	Specify function in the process	Annulus (Xmas tree), blowdown, bypass, injection, X-over, Deluge, ESD, ESD/PSD, PSD, HIPPS, swab, wing, relief, control, choke	High
Where mounted	Equipment on which the valve is installed	Wellhead, Xmas tree, wellhead flow line, wellhead injection line, pump, turbine, generator, separator, heat exchanger, vessel, header, electric motor, diesel motor, turboexpander, drilling, pipeline, mud process, utility, living quarter, air inlet, riser	High
Size	Internal diameter	Millimetres (inches)	Medium
Fluid handled	Main fluid only	Oil, gas, condensate, freshwater, steam, sea water, crude oil, oily water, flare gas, fuel gas, water/glycol, methanol, nitrogen, chemicals, hydrocarbon combined, gas/oil, gas/condensate, oil/water, gas/oil/water, NGL, LPG, LNG, slurry, etc.	High
Fluid temperature	Operating temperature main fluid	Degrees Celsius	Medium
Fluid corrosiveness/ erosiveness	Classify as shown in the footnote [a]	Benign, moderate, severe	Medium
Flowing pressure	Normal operating pressure (inlet)	Pascal (bar)	Medium
Shut-off pressure	Maximum differential pressure when valve closed (design) For PSVs: set-point opening pressure	Pascal (bar)	Low

Table A.70 (*continued*)

Name	Description	Unit or code list	Priority
Valve material	Type	Carbon steel (CS), stainless steel (SST), duplex, alloy type, composite, titanium	High
Stem sealing	Type	Stuffing box, duplex, lip seal, O-ring	High
Seat design	Type of seat design	Soft seated, metal-to-metal seated	Medium
Actuation principle [b]	Actuator operating principle	Single-acting, double-acting, actuation by line/process pressure, actuation by gravity	Medium
Actuation – opening	Type of actuation force	Electrical, hydraulic, pneumatic, mechanical (spring), manual, combinations, none	High
Actuation – closing	Type of actuation force	Electrical, hydraulic, pneumatic, mechanical (spring), manual, combinations, none	Medium
Manufacturer – actuator	Name of actuator manufacturer	Specify	Low
Manufacturer – pilot valve	Name of pilot-valve manufacturer	Specify	Low
Manufacturer – solenoid valve	Name of solenoid-valve manufacturer	Specify	Low
Pilot-valve configuration	Number and configuration (applicable for pilot-operated valves only)	Specify, e.g. 1 × 3/2 (= single 3/2 pilot valve), 2 × 4/3 (= double 4/3 pilot valve)	Low
Fail-safe principle pilot valve	Fail-safe principle	Energized, de-energized	Low
Solenoid-valve configuration	Number and configuration (applicable for solenoid-operated valves only)	Specify, e.g. 1 × 3/2 (= single 3/2 pilot valve), 2 × 4/3 (= double 4/3 pilot valve)	Low
Fail-safe principle solenoid valve	Fail-safe principle	Energized, de-energized	Low
Trim type	Type (applicable for control valves only)	Noise reduction, anti cavitation, multi-stage, single-stage	High
Valve leakage class	Specify according to applicable reference standard (e.g. for valves complying with API 6D, see ISO 5208)	ISO 5208:1993, Annexes A, B, C and D	High

[a] Benign (clean fluids, e.g. air, water, nitrogen).

Moderately corrosive/erosive (oil/gas not defined as severe, sea water, occasionally particles).

Severe corrosive/erosive [sour gas/oil (high H_2S), high CO_2 content, high sand content].

[b] Primary actuation principle:

a) single-acting = actuation force by gas (air) or hydraulic fluid for either opening or closing the valve;

b) double-acting = actuation force by gas (air) or hydraulic fluid for both opening and closing the valve;

c) actuation by line/process pressure or actuation by gravity = no actuation apart from possible backup actuation.

A.2.5.5 Nozzles

Table A.71 — Type classification — Nozzles

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Nozzles	NO	Deluge	DN
		Sprinkler	SR
		Water mist	WM
		Gaseous	GA

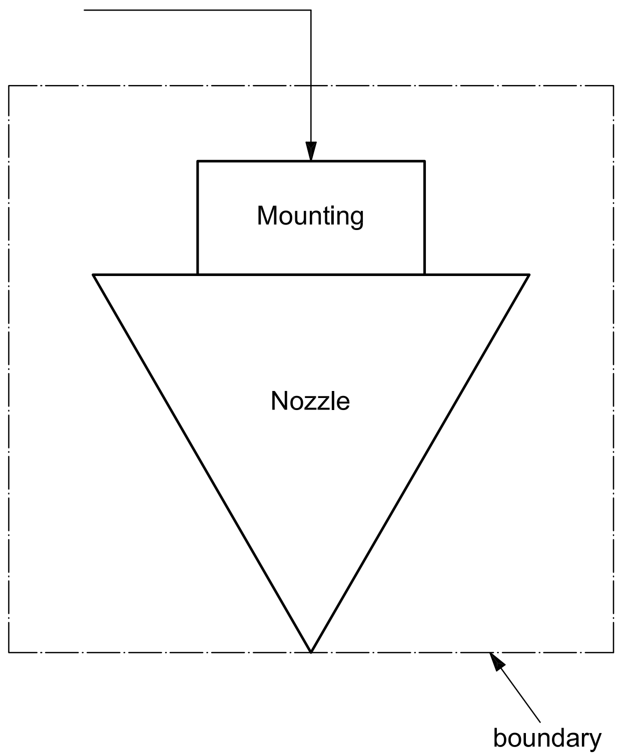


Figure A.23 — Boundary definition — Nozzles

Table A.72 — Equipment subdivision — Nozzles

Equipment unit	Nozzles		
Subunit	**Nozzle**	**Mounting assembly**	**Miscellaneous**
Maintainable items	Fusible bulb Nozzle body with internals Nozzle head Protective coating Screen Solder	Mounting connector Seals	Others

Table A.73 — Equipment-specific data — Nozzles

Name	Description	Unit or code list	Priority
Application	Where in the process applied	Deluge, sprinkler	High
Hazards protection	Type of protection	Electrical, Ex, fuel oil, glycol, HC gas, hydrogen gas, lubricants, methanol, combustibles, radioactivity, toxic gas, toxic liquid	High
Location on plant	Where located in the plant	Air inlet, compressor, diesel engine, drilling, electric motor, FW inlet, gas-metering, generator, header, heat exchanger, living qt., mud-processing, pigging station, pipeline, pump, separator, turbine, utility, vessel, wellhead, wellhead flowline, wellhead injection line, Xmas tree	High
Nozzle material	Specify	Brass, chrome-plated, electrode-less nickel-plated, lead-coated, stainless steel	High
Nozzle length	Specify	Millimetres	High
Nozzle width	Specify	Millimetres	High
Installation category	How installed	Concealed, horizontal sidewall, pendent, recessed, upright, vertical sidewall	Low
Fluid handled – nozzles	Main fluid only	Potable water, sea water, Inergen, CO_2	Medium
Fluid corrosiveness/ erosiveness	Classify as shown in the footnote [a]	Benign, moderate, severe	Medium
Discharge temperature	At operating condition	Degrees Celsius	Low
Flowing pressure	Specify	Pascal (bar)	Medium
Flow rate	Specify	Litres per minute	Medium
Shut-off pressure	Maximum differential pressure when valve closed (design) For safety pressure-relief valves: set-point opening pressure	Pascal (barg)	Low
Fluid temperature	Specify	Degrees Celsius	Low
Connection size	Specify	Millimetres (inches)	High
Type of nozzle end	Specify	Bolted flange, clamped flange, screwed, welded	Medium
Spray angle	Specify	Degrees	Medium
Spray type	Specify	Droplets, mist	Medium
Actuation	Specify	Fusible bulb, solder, external	Medium
Nozzle screen	Whether or not installed	Yes/No	Low

[a] Benign (clean fluids, e.g. air, water, nitrogen).

Moderately corrosive/erosive (oil/gas not defined as severe, sea water, occasionally particles).

Severe corrosive/erosive [sour gas/oil (high H_2S), high CO_2 content, high sand content].

A.2.6 Subsea production

NOTE Valves used on subsea equipment are considered as specific valves within the taxonomy examples shown in chapter A.2.6 for this equipment class. Valves used on dry Xmas trees and wellheads are considered as topside valves (see chapter A.2.5.4)

A.2.6.1 Subsea production control

Table A.74 — Type classification — Subsea production control

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Subsea-production-control system	CS	Direct hydraulic	DH
		Direct electro-hydraulic	EH
		Multiplexed electro-hydraulic	MX
		Discrete pilot hydraulic	PH
		Sequential piloted hydraulic	SH
		Telemetric hydraulic	TH

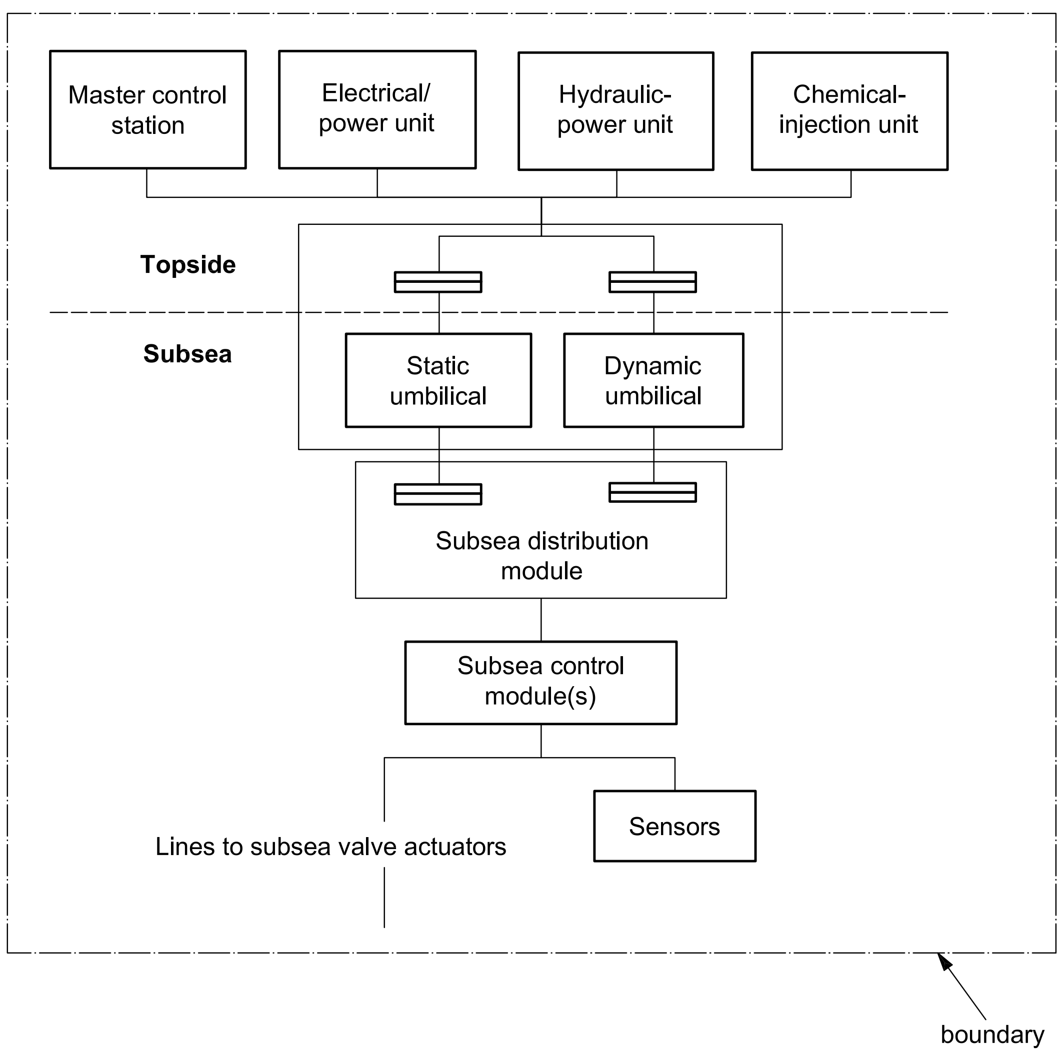


Figure A.24 — Boundary definition — Subsea production control

Table A.75 — Equipment subdivision — Subsea production control

Equipment unit	Subsea production control								
Subunit	**Chemical Injection (topside)**	**Dynamic umbilical**	**Static umbilical**	**Electric-power unit (topside)**	**Hydraulic-power unit (topside)**	**Master control (topside)**	**Subsea control module**	**Subsea distr. module**	**Sensors**
Maintainable items	Number breakdown	Bend restrictor Buoyancy device Hydraulic/ chemical line J/I-tube seal Power/signal line Sheath/ armour Stabilizer Tension- and motion-compensation equilibrium	Hydraulic/ chemical line Power/signal line Sheath/ armour Subsea umbilical-termination unit Topside umbilical-termination unit	No breakdown	No breakdown	No breakdown	Accumulator subsea Module base plate Chemical inj. coupling Fibre optic coupler Filter Hydr. coupling Power supply unit Power/signal coupler Subsea electronic module Solenoid valve	Accumulator subsea Subsea bypass panel Chemical inj. coupling Fibre-optic coupler Fibre optic jumper Hose Hydr./ chemical jumper Hydr. coupling Piping Power/signal coupler Power/signal jumper Subsea cabling	Flow Leak Level Position Combined pressure and temp. Pressure Temp. Sand

Table A.76 — Equipment-specific data — Subsea production control

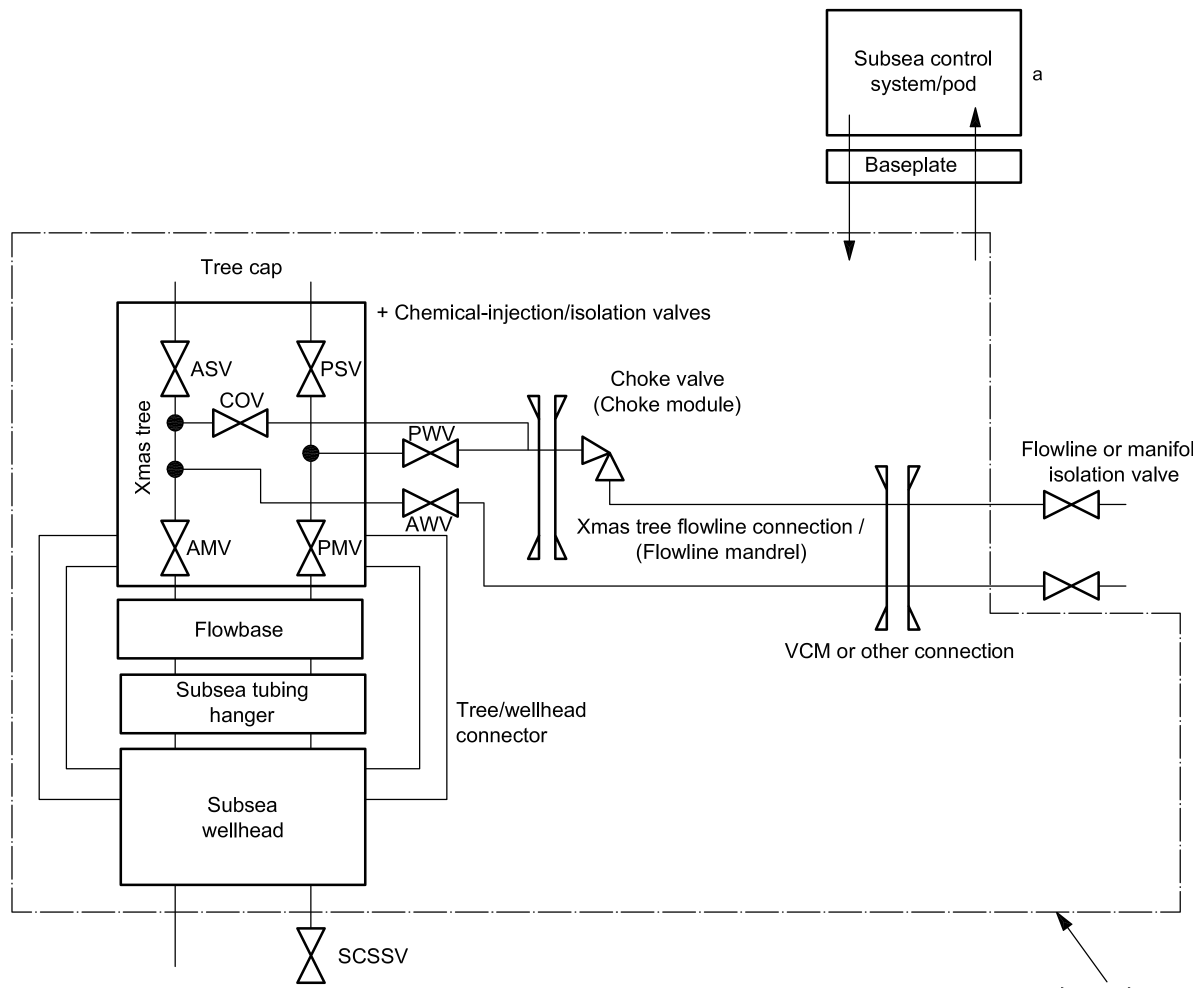
Name	Description	Unit or code list	Priority
Well identification number	Operator description	Number or name	High
Application	Where used	HIPPS, manifold, SSIV, pump, wellhead, Xmas tree, multi-purpose	Medium
Type of control fluid	—	Oil-based, water-based	Medium
Type of control system	—	Closed, open	Medium
Redundancy	—	Yes/no	Medium
Manufacturer	Specify	Free text	High
Model type	Specify	Free text	Low
Multilateral wells	—	Yes/no	Low

A.2.6.2 Xmas trees

NOTE Applies mainly for (wet) subsea Xmas trees.

Table A.77 — Type classification — Xmas trees

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Wellhead and Xmas trees	WC	Vertical	VE
		Horizontal	HO



ASV/PSV: Annulus/Production swab valve
AMV/PMV: Annulus/Production master valve
AWV/PWV: Annulus/Production wing valve
COV: Crossover valve
SCSSV: Surface-controlled subsurface safety valve

[a] Sensors mounted on the tree.

Figure A.25 — Boundary definition — Xmas trees

Table A.78 — Equipment subdivision — Xmas trees

Equipment unit	Wellhead and Xmas trees [a]					
Subunit	**Subsea wellhead**	**Subsea Xmas tree**	**Tubing hanger**	**Flowbase**	**Flow control module [b]**	**Vertical connection module (VCM)**
Maintainable items	Permanent guide base (PGB) Temporary guide base (TGB) Conductor housing Wellhead housing (high-pressure housing) Casing hangers Annulus seal assemblies (packoffs)	Chem. inj. coupling Flowspool Piping (hard pipe) Hoses (flexible piping) Debris cap Tree-guide frame Connector Internal isolation cap Internal tree-cap valve Internal tree-cap plug Tree cap [c] Valve, check Valve, choke Valve, control Valve, other Valve, process isolation Valve, utility isolation Valve, workover	Chem. inj. coupling Hydr. coupling Power/signal coupler Tubing-hanger body Tubing-hanger isolation plug	Frame Hub/mandrel [d] Valve, check Valve, process isolation Valve, utility isolation	Chem. inj. coupling Connector Flow loop Frame Hoses Hydr. connector Piping Valve, check Valve, choke Valve, control	VCM connector Valve and actuator Control system compensation Swivel Funnel guide ROV-panel override system ROV panel

[a] SCM (subsea control module) as well as other control-system parts can also be considered as subunits or maintainable items of the Xmas tree and failure data collected within this equipment class.

[b] This can also be designated as choke module.

[c] The tree cap, which is able to be replaced independently, can also be considered as a subunit of the Xmas tree.

[d] This can also be designated as flowline mandrel as well as be considered as a subunit of the Xmas tree.

Table A.79 — Equipment-specific data — Xmas trees

Name	Description	Unit or code list	Priority
Well identification number	Operator description	Number or name	High
Install/retrieve guide	Guideline/guideline-less, diver-assisted and diver-less lay-away	Guideline, guideline-less	High
Well type	Production, injection	Production, injection	High
Protection type	Over-trawlable, trawl-catching, etc.	Trawl-catching, trawl-deflecting, none	High
Water depth	—	Metres	High
Manufacturer	Specify	—	High
Model type	Specify	—	Low
Number of connections	Number of lines connected to the tree block	Number	Low
Control principle	Defines the control principle for Xmas tree functions and actuators	—	Low
Piggable	Specify if piggable or not	Yes/no	Low
Size of tree	Dimensions and mass	Metres, kilograms	Low
Mudline suspension system	Define whether a mudline suspension system exists	Yes/no	Low
Multilateral well	Define	Yes/no	Low
Fluid produced/injected	Main fluid only: oil, gas, condensate, injection water	Oil, gas, condensate, injection water, oil and gas, gas and condensate, oil/gas/water, CO_2, gas and water, produced water	High
Fluid corrosiveness	Classify as shown in the footnote [a]	Neutral, sweet, sour	High
Asphaltenes	Specify	Yes/no	Low
Scale formation	Specify	Yes/no	Low
Wax formation	Specify	Yes/no	Low
Hydrate formation	Specify	Yes/no	Low
Sand production	Specify	Yes/no	Low

[a] Neutral (clean fluids with no corrosive effects).
Sweet [moderately corrosive/erosive (oil/gas not defined as severe, raw sea water, occasional particles)].
Sour {severely corrosive/erosive [sour gas/oil (high H_2S), high CO_2, high sand content]}.

A.2.6.3 Risers

Table A.80 — Type classification — Risers

Equipment class — Level 6		Equipment type	
Description	Code	Description	Code
Risers	PR	Rigid	RI
		Flexible	FL

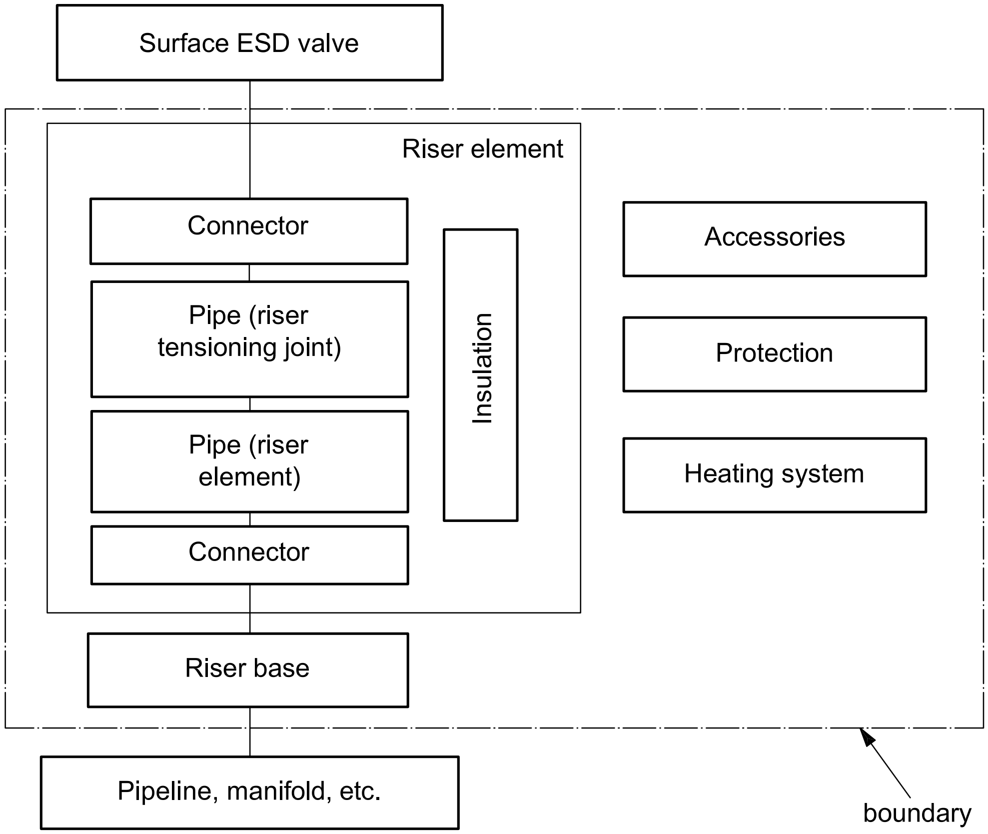


Figure A.26 — Boundary definition — Risers

Table A.81 — Equipment subdivision — Risers

Equipment unit	Risers				
Subunit	**Riser**	**Riser base**	**Heating system**	**Protection**	**Accessories**
Maintainable items	Connector Insulation Pipe	Gas lift Structure Valve, process isolation Valve, utility isolation	Topside part Subsea part	Anode Coating – external	Bend restrictor Buoyancy device J/I-tube seal Stabilizing and guiding equipment Tension- and motion-compensation equipment

Table A.82 — Equipment-specific data — Risers

Name	Description	Unit or code list	Priority
Well identification number	Operator description	Number or name	High
Application	What type of platform	Fixed, floating, buoy	Medium
Riser length	—	Metres	High
Working pressure	—	Pascal (bar)	Medium
Coating	External and internal	Specify	Low
Corrosion inhibitor	—	Yes/no	Low
Temperature	Design value	Degrees Celsius	Low
Manufacturer	Specify	—	High
Gas lift	If installed or not	Yes/no	Low
Pipe diameter	—	Millimetres	Medium
Pipe material	Specify	Steel, composite, titanium, clad/lined	Medium
Protection, corrosion	Specify	Active, passive	Medium
Protection, mechanical	Specify	I-tube, J-tube, riser shaft penetration	Medium
Riser layout	Specify	Free hanging, Lazy S, lazy wave, pliant wave, steep S, steep wave	Medium
Wall thickness	Specify	Millimetres	Low
Fluid conducted	Main fluid only: oil, gas, condensate, injection water	Oil, gas, condensate, injection water, oil and gas, gas and condensate, oil/gas/ water, CO_2, gas and water, produced water	High
Fluid corrosiveness	Classify as shown in footnote [a]	Neutral, sweet, sour	High
Asphaltenes	Specify	Yes/no	Low
Scale formation	Specify	Yes/no	Low
Wax formation	Specify	Yes/no	Low
Hydrate formation	Specify	Yes/no	Low
Sand production	Specify	Yes/no	Low

[a] Neutral (clean fluids with no corrosive effects).

Sweet [moderately corrosive/erosive (oil/gas not defined as severe, raw sea water, occasional particles)].

Sour {severely corrosive/erosive [sour gas/oil (high H_2S), high CO_2, high sand content]}.

A.2.6.4 Subsea pumps

Table A.83 — Type classification — Subsea pumps

Equipment class — Level 6		Equipment type	
Description	Code	Description	Code
Subsea (ESP) pumps	SP	Centrifugal	CE
		Reciprocating	RE
		Rotary	RO

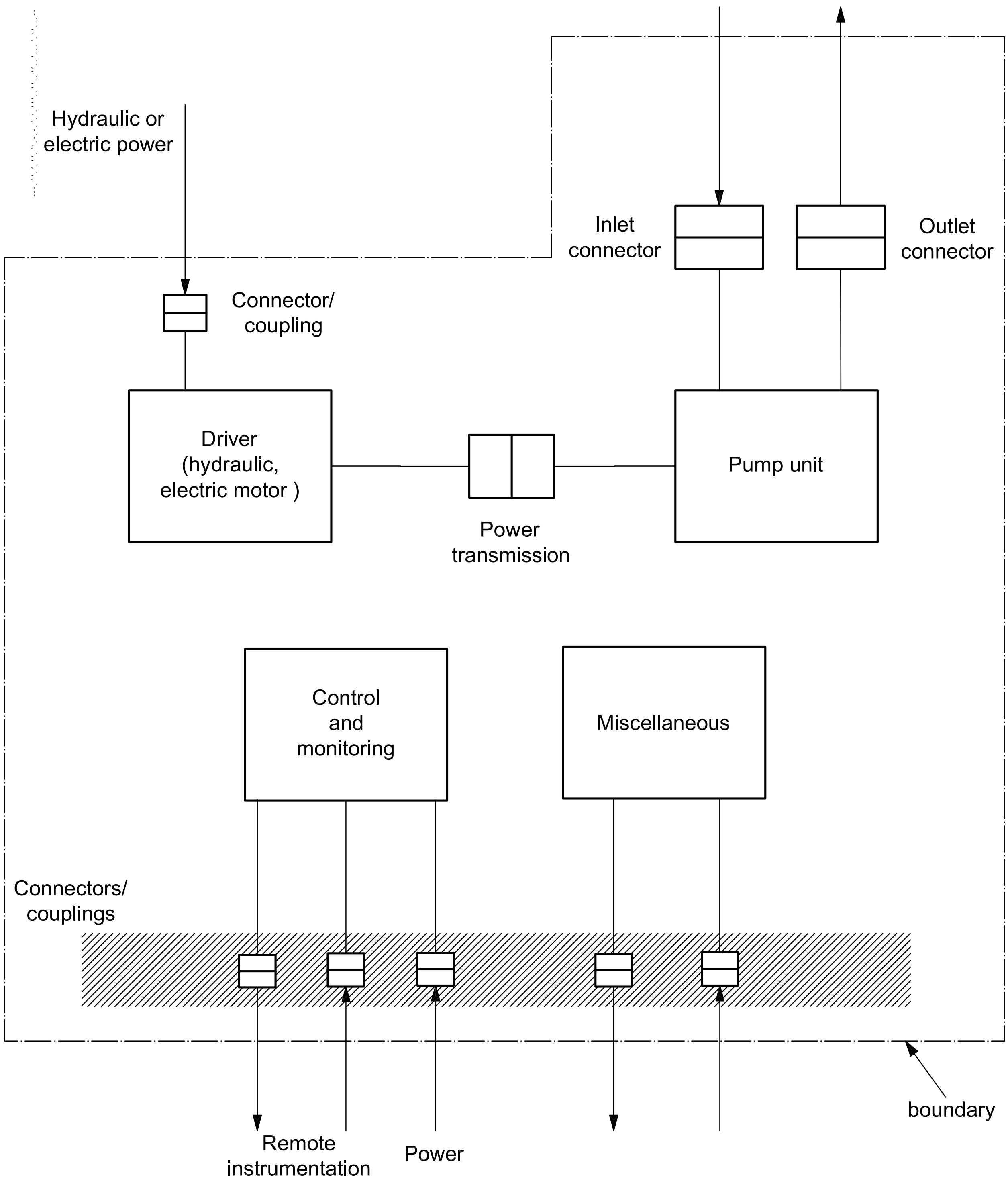


Figure A.27 — Boundary definition — Subsea pumps

Table A.84 — Equipment subdivision — Subsea pumps

Equipment unit	Subsea pumps					
Subunit	**Pump**	**Driving unit**	**Power transmission**	**Lubrication**	**Control and monitoring**	**Miscellaneous**
Maintainable items	Bearing, radial Bearing, thrust Casing Connector Cyl. liner Impeller Piping Piston Seal Shaft Structure, protect Structure, support Valve, control Valve, process isolation Valve, other	Bearing, radial Bearing, thrust Casing Connector Control unit Impeller Rotor Seal Stator Support	Bearing, radial Bearing, thrust Coupling Gearbox Seal	Accumulator s.s. Connector Cooling/heating Cooler Filter Lub. oil Piping Lub. oil pump incl. driver Reservoir Valve, check	Cable Junction box Leak sensor Level sensor Power supply Pressure sensor Power/signal coupler Speed sensor Temperature sensor Vibration sensor Valve, other	Connector Cooling/heating Lubrication Piping Pulsation damper Purge system

Table A.85 — Equipment-specific data — Subsea pumps

Name	Description	Unit or code list	Priority
Well identification number	Operator description	Number or name	High
Discharge pressure – design	—	Pascal (barg.)	High
Suction pressure – design	—	Pascal (barg.)	Medium
Pump driver	Type of driver	Electric motor, turbine, hydraulic motor	High
Power – design	Driver power	Kilowatt	High
Speed	Design value	Revolutions per minute	Low
Number of stages	—	Number	Low
Pump coupling	—	Disconnectable, fixed, flexible, hydraulic	Low
Manufacturer	Specify	Free text	High
Model type	Specify	Free text	Low
Fluid handled	Main fluid only: oil, gas, condensate, injection water	Oil, gas, condensate, injection water, oil and gas, gas and condensate, oil/gas/water, CO_2, gas and water, produced water	High
Fluid corrosiveness	Classify as shown in footnote [a]	Neutral, sweet, sour	High
Radial bearing type	Specify	Magnetic, roller, sliding	Low
Thrust bearing type	Specify	Magnetic, roller, sliding	Low
Shaft orientation	Specify	Horizontal, vertical	Low
Shaft seal type	Specify	Dry, gland, labyrinth, mechanical, oil, packed combined	Low
Transmission type	Specify	Direct, gear, integral	Low

[a] Neutral (clean fluids with no corrosive effects).
Sweet [moderately corrosive/erosive (oil/gas not defined as severe, raw sea water, occasional particles)].
Sour {severely corrosive/erosive [sour gas/oil (high H_2S), high CO_2, high sand content]}.

A.2.7 Well-completion equipment

NOTE Valves used on well-completion equipment are considered as specific valves within the taxonomy examples shown in this equipment class. Valves used on dry Xmas trees and wellheads are considered as topside valves (see A.2.5.4)

A.2.7.1 Item categories

Well-completion equipment in this context refers to equipment below wellhead level. All major completion-equipment items are included, from tubing hanger at the top end to equipment at the bottom of the well.

The following item categories are defined for well-completion equipment.

a) String items

String items are defined as items that are all integral parts of the conduit ("string") used for production or injection of well effluents. The string is built by screwing together a variety of equipment items.

b) Accessories

Accessories are items that are required to be tied to a "host" string item to define a system. This is done to be able to logically represent string items which are too complex to be given as just a stand-alone item of the string. Only two such "host" string items, or string items with accessories, have been defined to date. These are the electrical submersible pump (ESP) and downhole permanent gauge (DHPG) systems.

c) Inserted items

Inserted items are defined as items which can be attached (set) inside string items. A typical example is the combination of a lock and wireline-retrievable downhole safety valve set inside a safety valve nipple.

d) Control line/cable

The control line/cable category allows information to be stored for control lines and cables and a variety of parts that are normally associated with control lines or cables. Examples of such parts are packer penetrators, electric connectors for gauges, electric wellhead connectors, etc. This category provides the opportunity to build control line/cable "systems" consisting of the hydraulic control line or cable itself and all associated parts. Reliability analysis is then subsequently possible for the control-line system once the system has been tied to a specific string item in a completion.

Each control line/cable shall always be connected to one or more string items.

e) Casing

The casing category is included to store information on individual casing-string sections and associated casing failures. The casing category represents full lengths of individual casing sections and does not represent individual items threaded into the casing string, compared with the production/injection string.

Sealing elements that are designed to seal off against leakage of hydrocarbons between the various sections of casing string (casing pack-offs) are not included.

A.2.7.2 Standard equipment specifications

Table A.86 — Item database format and name specification

Item category	Data-collection format	Predefined item name
String item	Annulus safety valve	Tubing-retrievable, surface-controlled annular subsurface safety valve (TR-SCASSV)
	Default	Adjustable union
		Landing nipple
		Millout extension
		Muleshoe
		Nipple for wireline SCSSV
		Gravel pack screen
		Perforated pup joint
		Pup joint
		Sliding sleeve
		Tubing anchor
		Wireline re-entry guide
	Electrical submersible-pump system with accessories	Electrical submersible pump unit (straight)
		Electrical submersible pump unit (y-tool)
	Expansion joint	Expansion joint
	Flow coupling	Flow coupling
	Gauge mandrel with accessories	Permanent gauge mandrel
	Packer type	Production packer
		Downhole packer/hanger
	Seal assembly	Seal assembly (conventional)
		Seal assembly (overshot)
	Side-pocket mandrel	Side-pocket mandrel (for valve)
	Spacer type	Spacer
	Tubing type	Tubing
	Tubing safety valve	Tubing-retrievable, surface-controlled subsurface safety valve (TR-SCSSV) (ball)
		Tubing-retrievable, surface-controlled subsurface safety valve (TR-SCSSV) (flapper)
	X-over	X-over
	Y-block	Y-block
Accessories	Default	None defined
	Downhole gauge	Permanent gauge
	Intake section	Intake section
	Motor	Electrical submersible pump motor
	Motor lead extension	Motor lead extension

Table A.86 (*continued*)

Item category	Data-collection format	Predefined item name
	Motor seal system	Motor seal system
	Pump	Pump with electric drive
Inserted item	Annulus safety valve	Wireline surface-controlled subsurface safety valve (SCSSV)
	Default	Brain (sideguard)
		Lock for wireline surface-controlled annular subsurface safety valve (SCASSV)
	Gas lift valve	Gas lift valve
		Chemical-injection valve
	Safety valve	Wireline SCSSV
Control line/cable	Default	None defined
	Electric connector, gauge	Electric-connector downhole gauge
	Electric connector, hanger	Electric-connector tubing hanger
	Hydraulic line	Hydraulic control line
	Penetrator	Wellhead penetrator
		Hanger penetrator
		Packer penetrator
	Power cable	Power cable
	Signal cable	Signal/instrument cable
	Surface controller	Surface controller
Casing	Casing	

An example of data-collection format with associated data field definitions and registration alternatives is shown for downhole safety valves below.

A.2.7.3 Downhole safety valves (DHSV)

This valve is available in two main types:

a) tubing-retrievable installed as an integral part of the tubing/completion string;

b) wireline-retrievable run on wireline toolstring for installation inside the tubing/completion string, set in a dedicated landing nipple/profile.

Table A.87 — Tubing-retrievable, surface-controlled subsurface safety valve (TR-SCSSV)

Item: Tubing safety valve (TR)		Category: String item	Priority
Name	**Description**	**Unit or code list**	
Model	Give unique item model designation	Characters (25)	High
Part number (operator)	—	—	Medium
Part number (manuf.)	—	—	High
Manufacturer	—	All major oilfield equipment manufacturers	High
Effective length	Length occupied by the item in the string, exclusive of pin/box	Metres	High
Valve type	—	Tubing-retrievable Tubing-retrievable with wireline-retriev. brain Other Unknown	Medium
Closure principle	—	Ball Flapper (conventional) Flapper (curved) Poppet Other Unknown	Medium
Valve configuration	—	Single valve (s.v.) Single valve with insert capability within valve Single v. with sep. nipple/contr.l. for insert v. Upper valve in “hot” backup tandem concept Lower valve in “hot” backup tandem concept Upper valve in “cold” backup tandem concept Lower valve in “cold” backup tandem concept Upper valve in hybrid tandem concept	Low
Equalizing feature	—	With equalizing feature Without equalizing feature Unknown	Low
Nominal size	—	—	High
Maximum OD	—	—	Medium
Minimum ID	—	—	Medium
Pressure rating	—	—	Low

Table A.87 (*continued*)

Item: Tubing safety valve (TR)		**Category: String item**	**Priority**
Name	**Description**	**Unit or code list**	
Piston type	—	Rod Concentric Rod and concentric Other Unknown	High
Number of pistons	Total number of pistons in valve.	Numeric	Low
Number of control lines	Total number of control lines attached to valve	Numeric	Low
Secondary control line function	—	Not installed Balance line Permanent lockout Temporary lockout Normal operation Other Unknown	Low
Seal configuration and type	Describe configuration and materials used in dynamic and static seals	Character field	Low
Material spec. for — closure device — seat — flowtube/piston	Material used for the most vital valve parts. 'Seat' here means seat for closure device.	Code list of metallic materials	High
Control principle	—	Hydraulic Hydraulic with nitrogen charge as add-on power source Hydraulic with balance line for deep setting Electromagnetic with downhole power source Solenoid-operated with electric cable Other Unknown	Medium
Remarks	—	Character field	Low

Table A.88 — Wireline-retrievable (WR) type DHSV/WR-SCSSV

Item: Downhole safety valve (WR)		Category: Inserted item	Priority
Name	**Description**	**Unit or code list**	
Model	Give unique item model designation	Characters (25)	High
Part number (operator)	—	—	Medium
Part number (manuf.)	—	—	High
Manufacturer	—	All major oilfield equipment manufacturers	High
Length	—	Metres	High
Closure principle	—	Ball Flapper (conventional) Flapper (curved) Poppet Other Unknown	Medium
Valve configuration	—	Single valve (s.v) Single valve with insert capability within valve Single v. with sep. nipple/contr.l. for insert v. Upper valve in “hot” backup tandem concept Lower valve in “hot” backup tandem concept Upper valve in “cold” backup tandem concept Lower valve in “cold” backup tandem concept Upper valve in hybrid tandem concept	Low
Equalizing feature	—	With equalizing feature Without equalizing feature Unknown	Low
Nominal Size	—	—	High
Maximum OD	—	—	Medium
Minimum ID	—	—	Medium
Pressure rating	—	—	Low
Piston type	—	Rod Concentric Rod and concentric Other Unknown	High
Number of pistons	Total number of pistons in valve	Number	Low
Number of control lines	Total number of control lines attached to valve	Number	Low
Secondary control line function	—	Not installed Balance line Permanent lockout Temporary lockout Normal operation Other Unknown	Low

Table A.88 (*continued*)

Item: Downhole safety valve (WR)		Category: Inserted item	Priority
Name	**Description**	**Unit or code list**	
Seal configuration and type	Describe configuration and materials used in dynamic and static seals	Character field	Low
Material spec. for — closure device — seat — flowtube/piston	—	Code list of metallic materials	High
Control principle	—	Hydraulic Hydraulic with nitrogen charge as add-on power source Hydraulic with balance line for deep setting Electromagnetic with downhole power source Solenoid-operated with electric cable Other Unknown	Medium
Remarks	—	Character field	Low

A.2.7.4 Production/injection data

Operational data that should be collected for well-completion equipment are listed in Table A.89. The data are well-specific and provide a generic reference to the working environment for all equipment in the well. The production/injection data should be collected on a monthly basis.

Table A.89 — Production/injection operational data

Data	Description	Unit or code list
Year	—	—
Month	—	—
Wellhead pressure	Flowing wellhead pressure	Pascal (bar)
Wellhead temperature	Temperature at wellhead under flowing conditions	Degrees Celsius
Daily flow, gas	Representative daily flow of gas	Standard cubic metres per day
Daily flow, oil	Representative daily flow of oil	Standard cubic metres per day
Daily flow, condensate	Representative daily flow of condensate	Standard cubic metres per day
Daily flow, water	Representative daily flow of water	Standard cubic metres per day
H_2S concentration	Representative daily concentration of H_2S	Mole percent or grams per metric tonne [a]
CO_2 concentration	Representative daily concentration of CO_2	Mole percent or grams per metric tonne [a]
Remarks	Other information considered relevant	—

[a] Grams per metric tonne is the equivalent of parts per million (ppm), a unit that is deprecated by ISO.

A.2.7.5 Failure and maintenance data

The permanently installed well-completion equipment is normally run to failure. Preventive replacement may be performed for some string items, such as wireline-retrievable, surface-controlled subsurface safety valves (SCSSV).

In rare cases, items may be repaired downhole. This typically may be the case with casing- or tubing-retrievable, surface-controlled subsurface safety valves (SCSSV).

If a downhole repair action actually succeeds in restoring the function of an item, this can be reported by identifying the failure record for the item that initially failed. Depending on item category, the item-failure record can be assessed as described in Table 8. The downhole repair action is reported by changing the remedial action code and giving the remedial action date. Should a failure occur on the same item at a later stage, a new failure record should be entered as described previously.

Information on downhole testing of valves should be collected, as this provides valuable information concerning interpretation of downhole failure trends.

A.2.8 Drilling

A.2.8.1 Top drives

Table A.90 — Type classification — Top drives

Equipment class — Level 6		Equipment type	
Description	**Code**	**Description**	**Code**
Drilling equipment	DE	Hydraulically driven	HD
		Electrically driven	ED

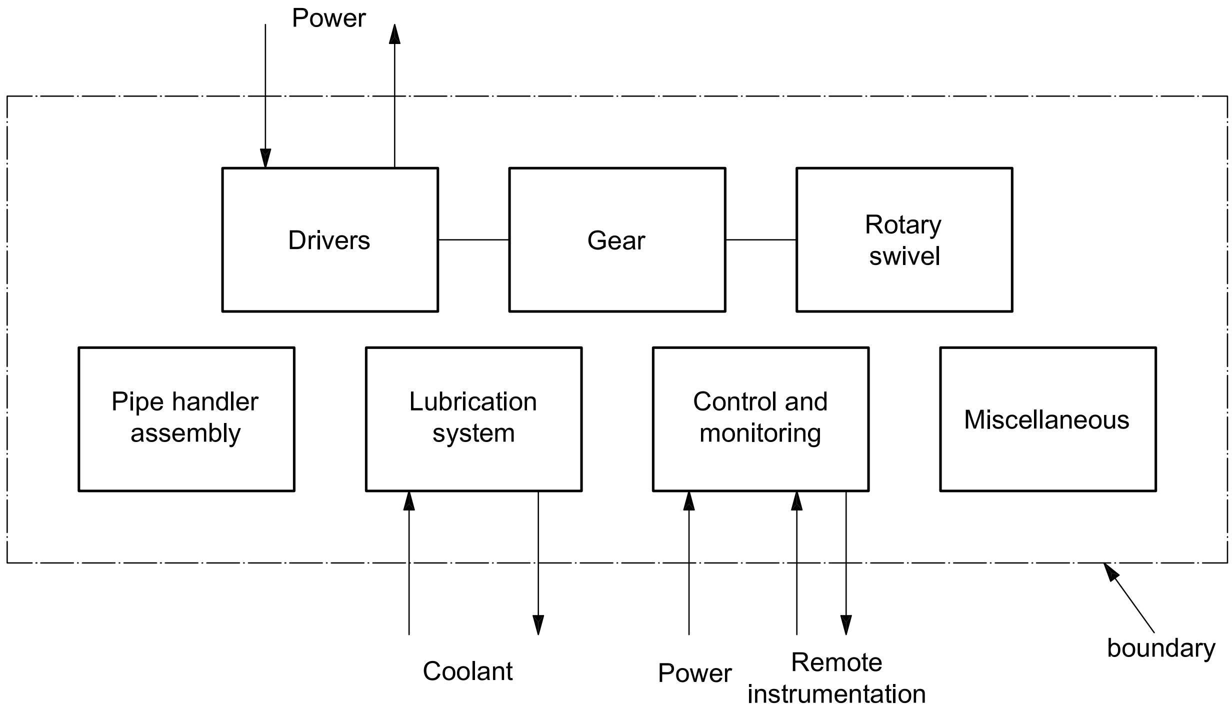


Figure A.28 — Boundary definition — Top drives

A top drive (frequently also referred to as a power swivel) is a piece of equipment that serves the following functions:

- rotating the drill string (formerly undertaken by the rotary table);
- providing a conduit for drilling mud (formerly undertaken by the rotary swivel);
- disconnecting/connecting pipe (formerly undertaken by the iron roughneck);
- closing in the drill pipe by an integrated kelly valve (formerly undertaken by the kelly valve in connection with the rotary table);
- lifting/lowering drill string by use of standard elevator (formerly undertaken by the hook by using same kind of elevator).

Top drives may be either electrically or hydraulically driven. If they are hydraulically driven, several hydraulic motors are normally used.

Elevator links and elevators are not regarded as a part of the top drive (standard drilling equipment).

Table A.91 — Equipment subdivision — Top drives

Equipment unit	Top drive/power swivel						
Subunit	**Drivers**	**Gear**	**Rotary swivel**	**Pipe-handler assembly**	**Lubrication**	**Control and monitoring**	**Miscellaneous**
Maintainable items	Electric driver Hydraulic driver Radial, thrust and axial bearing	Bearings Packing/ seals Coupling to driver Coupling to swivel Pinions Gearwheels	Gooseneck Packing/ seals Axial, radial and thrust bearing Swivel housing Swivel stem	Link hanger incl. tilt actuators Pipe-handler position motor Swivel coupling Torque wrench	Oil tank Heaters Coolers Pump with motor Valves Filters Lube oil	Control panel Control Electric and/or hydraulic solenoid cabinet Service loops Manifolds Junction box	Guide dolly frame Internal blow-out preventers (kelly valves) Counter-balance compensator/ read-saver system

Table A.92 — Equipment-specific data — Top drives

Name	Description	Unit or code list	Priority
Type of driver	Specify type	Electric, hydraulic	High
Number of drives (applicable for hydraulic drives only)	Specify number	Number	High
Hydraulic power requirements (applicable for hydraulic drives only)	Pressure	Pascal (bar)	High
	Flow rate	Litres per minute	
Motor category (applicable for electric drives only)	Specify type	Induction, synchronous	High
Electrical supply requirements (applicable for electric drives only)	Voltage	Volt	High
	Current	Ampere	
Rated power	Max. output	Kilowatt	High
Normal operating power	Power	Kilowatt	High
Speed	Max. speed	Revolutions per minute	High
	Normal speed	Revolutions per minute	
Torque	Max. torque	Newton·metre	High
	At normal speed	Newton·metre	
	At max. speed	Newton·metre	
Pressure utilities	Hydraulic pressure	Pascal (bar)	Low
	Air pressure	Pascal (bar)	
Flow utilities	Hydraulic flow	Litres per minute	Low
	Air flow	Litres per minute	
Retractable dolly frame	Specify	Yes/no	Low
Mud pressure capacity	Pressure	Pascal (bar)	Low
Inside BOP design pressure	Pressure	Pascal (bar)	Low
Torque wrench capacity	Diameter	Millimetres	Low
	Torque	Newton·metre	
Elevator link hanger capacity	Capacity	Kilogram	High

A.2.8.2 Blowout Preventer (BOP)

Table A.93 — Type classification — Blowout preventer (BOP)

Equipment class — Level 6		Type	
Description	Code	Description	Code
Drilling equipment	DE	Surface BOP	BT
		Subsea BOP	BS

A.2.8.2.1 Description of blowout preventer (BOP)

There are two main types of BOPs used for drilling:

a) surface BOPs are used for land operations or for structures that are fixed to the seafloor;

b) subsea BOPs are used for drilling from a floating unit; this BOP is fixed to the seafloor wellhead.

In principle, a surface BOP is similar to a subsea BOP. The main differences are related to the control of the BOP functions and that the surface BOP, in general, has fewer functions than the subsea BOP. In addition, a subsea BOP has a flexible joint at the top to allow variation in the riser angle.

In normal drilling operations, the drilling-fluid pressure is higher than the reservoir pressure. This prevents an uncontrolled influx of formation fluids to the well bore.

The reservoir pressure can, from time to time for various reasons, exceed the drilling-fluid pressure. This results in an uncontrolled influx of formation fluids to the well bore. The main function of the BOP is, then, to close in the wellbore in order to circulate drilling fluid with a higher density to regain the hydrostatic control of the well.

The BOP can also be used for other purposes, such as testing casing, testing leak-off pressure, squeeze cement, etc.

The example of BOP taxonomy given in Figure A.29 relates to subsea-mounted BOPs used for drilling.

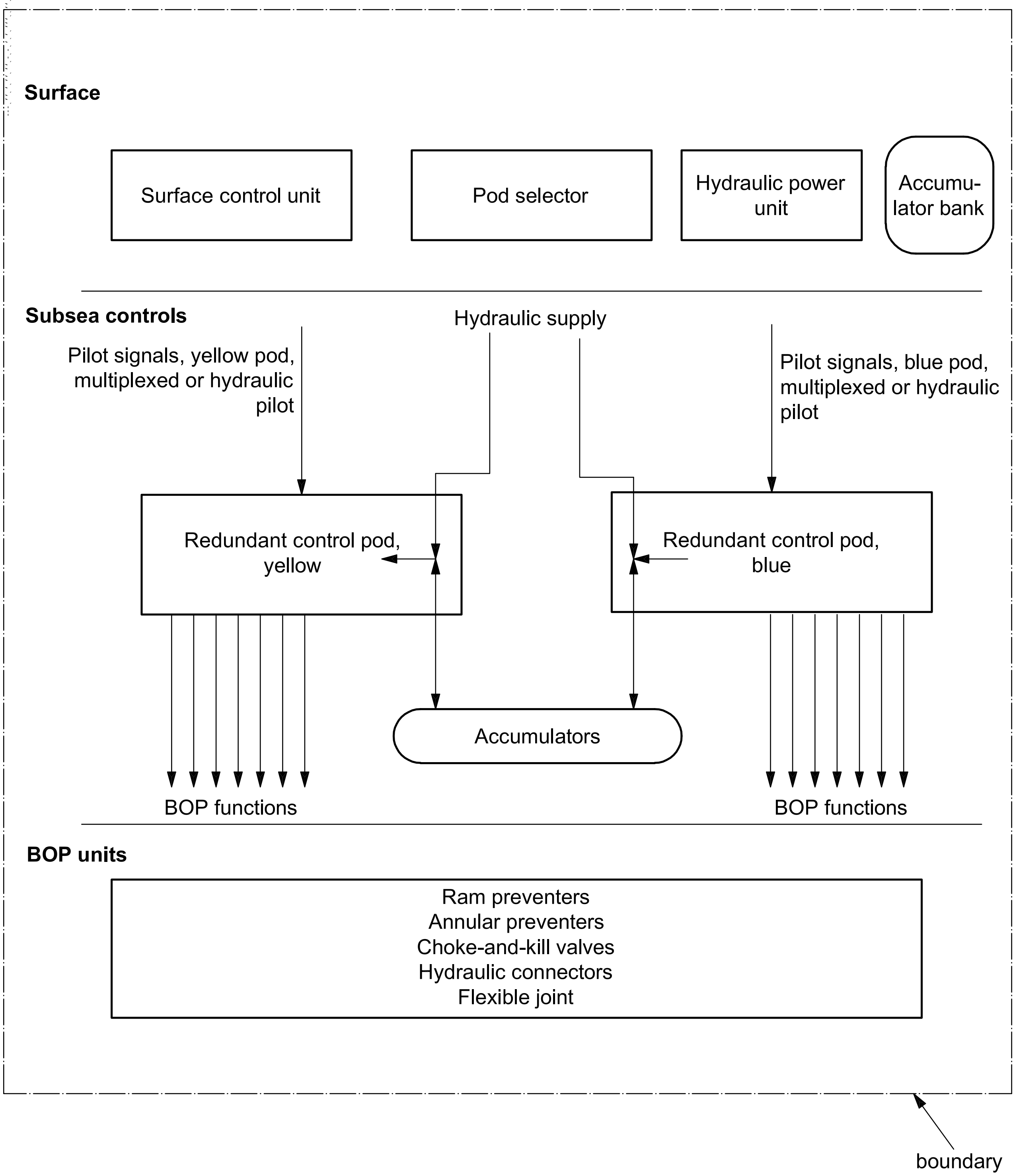


Figure A.29 — Boundary definition — Subsea BOP

A.2.8.2.2 Boundary definitions for BOP

A BOP typically consists of the following main components:

a) one or two annular preventers that seal around any tubular in the well;

b) three to six ram preventers that, depending on dressing, can seal around various pipes in the well, shear pipe and seal an empty hole;

c) a main connector that connects the BOP to the wellhead and, in addition, for a subsea BOP, a lower marine riser package (LMRP) connector that can disconnect the riser from the BOP;

d) four to ten choke-and-kill valves that can be operated in order that the contained pressure in the BOP can be observed, pressurized fluid circulated out of the well and pressurized fluid pumped in the well.

Table A.94 — Equipment subdivision — Blowout preventer (BOP)

Equipment unit	**Blowout preventer (BOP)**				
Subunit	**Preventers, valves and lines**	**Hydraulic connectors**	**Flexible joint (subsea BOP)**	**Control system**	**Backup control system**
Maintainable items	**Annular preventers** Body Flanges Packing element Hydraulic piston Seals **Ram preventers** Body Flanges Ram block Ram seals Shear blade Piston Seals **Kill-and-choke valves** Actuator Gooseneck house Gate Seals **Kill-and-choke lines** Riser-attached line Couplers Seals	**LMRP and wellhead connector** Body Locking mechanism Piston Main-bore seal ring Seals	Flexible element Housing Flanges	**Subsea** Pod stingers Pilot valves Shuttle valves Accumulators Pressure regulator valves Hydraulic control fluid Seals Piping Hydraulic bundles (pilot lines and main supply) Multiplex cables Rigid hydraulic supply line **Surface** Control panels Surface control unit Hydraulic power unit Pod reels Pod selector valve	**Subsea** Solenoid valves Pilot valves Shuttle valves Accumulators Subsea control unit Battery Transducers **Surface** Surface control unit Transducers

Table A.95 — Equipment-specific data — Blowout preventer (BOP)

Name	Description	Unit or code list	Priority
Rig type	Specify	Floating with DP-system, anchored, jack-up etc.	High
BOP manufacturer/supplier	Specify	Free text	High
Dimension	Specify (inner diameter)	Millimetres (inches)	High
Size	Height and mass	Millimetres (inches), kilograms (tons)	Low
Pressure rating	Specify	Pascal (pounds per square inch)	High
Ram preventers – manufacturer (and model)	Specify	Free text	High
Ram preventers, pressure rating	Specify	Pascal (pounds per square inch)	High
Number of ram preventers	Specify	Number	High
Annular preventers – manufacturer (and model)	Specify	Free text	High
Annular preventers, pressure rating	Specify	Pascal (pounds per square inch)	High
Number of annular preventers	Specify	Number	High
LMRP connector – manufacturer and model	Specify	Free text	Medium
LMRP connector pressure rating	Specify	Pascal (pounds per square inch)	High
Wellhead connector – manufacturer (and model)	Specify	Free text	Medium
Wellhead connector pressure rating	Specify	Pascal (pounds per square inch)	High
Choke-and-kill valve – manufacturer (and model)	Specify	Free text	Medium
Number of choke-and-kill valves	Specify	Number	Medium
Type of control fluid	Specify	Oil-based, water-based	Medium
Type of control system	Specify	Multiplexed, pilot hydraulic, other	Medium
Redundancy control system	Specify	Free text	High
Backup control system	Specify	Free text	Medium

A.2.9 Utilities

No examples are included in Annex A.

NOTE Utilities can include anything from single equipment units (e.g. pumps) to more complex assemblies (packages).

EXAMPLES Fire water system, HVAC, hydraulic power supply, etc.

Depending on the application, data can be collected on single-unit level and the reliability estimated by calculating the total reliability for the utility assembly. Alternatively, data can be collected for the complete utility system as a whole. It is necessary to establish the taxonomic definition defined or adapted to the selected alternative.

Annex B
(normative)

Interpretation and notation of failure and maintenance parameters

B.1 Failure interpretation

When planning to collect data (see 7.1.2 and B.2.6), be aware that a failure can occur in one of a number of failure modes, e.g. complete loss of function, function degradation below an acceptable limit or an imperfection in the state or condition of an item (incipient failure) that is likely to result in a functional failure if not corrected.

Also be aware that it can be useful to make a distinction between the collection of data for reliability purposes and for availability purposes as follows.

a) For reliability purposes, it is mainly the intrinsic failures of the equipment unit that are of interest, i.e. physical failures that occur on the equipment being considered and that normally require some restoration (corrective maintenance) that it is necessary to record.

b) For the full lifetime story of equipment, it is necessary to record all actual preventive maintenance actions in a way similar to that for the corrective maintenance.

c) For availability purposes, all failures that have caused some equipment outage should be recorded. This can include stoppages due to operational limits being exceeded (e.g. trips) where no physical failure of the equipment occurred.

d) Even if no failures are experienced within the surveillance time, it is possible to estimate the failure rate by properly censored data (see C.3.3). Hence, recording the reliability history may also be useful for equipment in periods with no failures.

Table B.1 gives some guidance on this issue by distinguishing between data collected as reliability data and additional data collected as availability data.

Annex F and IEC 61508 also give guidance on what to consider as a failure for safety equipment. Such definition can be related to functional loss, reduced capacity or operation outside prescribed limits.

The full description of a failure might not be possible before a corrective action is carried out. In some cases (incipient failures), the corrective action may deliberately be deferred (e.g. opportunity maintenance). In this case, it can be necessary to record both the date of failure detection and the date of the corrective action. For analysis purposes, the latter date should normally be used.

Table B.1 — Failure in relation to reliability and availability

Type of failure/maintenance to record	Reliability	Availability
Failures that require some corrective maintenance action to be carried out (repair, replacement)	Yes	Yes
Failure discovered during inspection, testing and/or preventive maintenance that requires repair or replacement of typically non-wear items (seals, bearings, impellers, etc.)	Yes	Yes
Failure of safety devices or control/monitoring devices that necessitates shutdown (trip) or reduction of the items capability below specified limits	Yes	Yes
Shutdown (trip) of the item (whether automatically or manually controlled) due to external conditions or operating errors, where no physical failure condition of the item is revealed	No	Yes
Failure of the equipment caused by external impact (e.g. lack of power supply, structural impact, etc.)	No	Yes
Periodic replacement of consumables and normal wear parts	No	No
Minor planned maintenance services, such as adjustments, lubrication, cleaning, oil replacement, filter replacement or cleaning, painting, etc.	No	Yes
Testing and inspections	No	Yes
“On-demand” activations	Yes	Yes
Preventive or planned maintenance [a]	Yes (No)	Yes
Modifications, new work, upgrades [b]	No	Yes/No

[a] To get the full lifetime history of the equipment, the actual preventive maintenance should be recorded. For recording failures only, this can be skipped.

[b] Modifications are normally not a part of maintenance but are frequently done by maintenance personnel.

B.2 Failure and maintenance data notations

B.2.1 General

In order to limit database size and make it easier to analyse the data, it is recommended that coded information be used wherever applicable. A drawback with codes is that potentially useful information can be lost and that selecting inappropriate codes can lead to non-informative information. The availability of too many codes can be confusing and the codes can overlap, while too few codes might not sufficiently describe the area one is aiming to cover. A unified definition and interpretation of codes is necessary for obtaining highly reliable information.

In all cases, it is recommended to supplement the coding with some additional free-text capability in order to improve interpretation of single events, both for quality purposes before the data are entered into the database and for subsequent detailed analysis of single records (e.g. failure events).

Annex B.2 presents a method of coding that has been found to be useful when collecting RM data within the petroleum and natural gas industry, and should be equally applicable for similar equipment classes in the petrochemical industry. For some specific equipment and/or specific uses, supplementary codes may be used.

Design a method of reporting failure (see 7.1.2) that records the time and date of failure together with details of the failure mode (see B.2.6), the failure mechanism (see B.2.2) and the failure cause (root cause) (see B.2.3). Also, record the detection method (see B.2.4) and the maintenance activity (see B.2.5). Use the codes given in the tables wherever practicable and additional free text where necessary.

Take care to distinguish between failure mechanism and failure mode.

Failure modes are presented in this Annex B in Tables B.6 to B.12 for those equipment examples included in Annex A as shown in Table A.4.

Subdivision codes for failure mechanisms and failure causes, e.g. numbers 1.1, 1.2, etc., should be preferred before the general category failure code, e.g. 1, and so on (see Tables B.2. and B.3).

How failure mode, failure mechanism and failure cause are related to different taxonomy levels is shown in Table 3.

B.2.2 Failure mechanism

The failure mechanism is the physical, chemical or other process or combination of processes that leads to the failure. It is an attribute of the failure event that can be deduced technically, e.g. the apparent, observed cause of the failure. The failure mechanism's root cause(s) is/are coded whenever this information is available. (A separate field for this is recommended in this International Standard.)

The codes on failure mechanism are basically related to one of the following major categories of failure types:

a) mechanical failures;

b) material failures;

c) instrumentation failures;

d) electrical failures;

e) external influence;

f) miscellaneous.

This categorization is rather coarse and within each category a more detailed categorization is recommended as shown in Table B.2. If there is not sufficient information to apply codes at this sublevel, then codes on the main level as listed above may be used. This implies that descriptive codes for mechanical failures, numbered 1.1, 1.2, etc., should be preferred to the general category failure code, 1.0, and so on (see Table B.2).

The failure mechanism should normally be related to a lower indenture level (subunit or maintainable-item level). In practical terms, the failure mechanism represents a failure mode at maintainable item level.

Care should be taken to distinguish between failure mechanism and failure mode.

EXAMPLE It is recorded that a valve started leaking hydrocarbons to the environment but no further causes are recorded. Here, the failure mode should be coded ELP (external leak of process medium) and the failure mechanism coded unknown (6.4), not leakage (1.1).

Failure mechanism is also related to the failure cause (see B.2.3); the latter aimed at revealing the underlying root cause of the failure.

Six categories of failure mechanism are identified in Table B.2, together with subdivisions and related codes to be used in data bases.

Table B.2 — Failure mechanism

Failure mechanism		Subdivision of the failure mechanism		Description of the failure mechanism
Code number	**Notation**	**Code number**	**Notation**	
1	Mechanical failure	1.0	General	A failure related to some mechanical defect but where no further details are known
		1.1	Leakage	External and internal leakage, either liquids or gases: If the failure mode at equipment unit level is coded as “leakage”, a more causally oriented failure mechanism should be used wherever possible.
		1.2	Vibration	Abnormal vibration: If the failure mode at equipment level is vibration, which is a more causally oriented failure mechanism, the failure cause (root cause) should be recorded wherever possible.
		1.3	Clearance/ alignment failure	Failure caused by faulty clearance or alignment
		1.4	Deformation	Distortion, bending, buckling, denting, yielding, shrinking, blistering, creeping, etc.
		1.5	Looseness	Disconnection, loose items
		1.6	Sticking	Sticking, seizure, jamming due to reasons other than deformation or clearance/alignment failures
2	Material failure	2.0	General	A failure related to a material defect but no further details known
		2.1	Cavitation	Relevant for equipment such as pumps and valves
		2.2	Corrosion	All types of corrosion, both wet (electrochemical) and dry (chemical)
		2.3	Erosion	Erosive wear
		2.4	Wear	Abrasive and adhesive wear, e.g. scoring, galling, scuffing, fretting
		2.5	Breakage	Fracture, breach, crack
		2.6	Fatigue	If the cause of breakage can be traced to fatigue, this code should be used.
		2.7	Overheating	Material damage due to overheating/burning
		2.8	Burst	Item burst, blown, exploded, imploded, etc.
3	Instrument failure	3.0	General	Failure related to instrumentation but no details known
		3.1	Control failure	No, or faulty, regulation
		3.2	No signal/ indication/alarm	No signal/indication/alarm when expected
		3.3	Faulty signal/ indication/alarm	Signal/indication/alarm is wrong in relation to actual process. Can be spurious, intermittent, oscillating, arbitrary
		3.4	Out of adjustment	Calibration error, parameter drift
		3.5	Software failure	Faulty, or no, control/monitoring/operation due to software failure
		3.6	Common cause/ mode failure	Several instrument items failed simultaneously, e.g. redundant fire and gas detectors; also failures related to a common cause.

Table B.2 (*continued*)

Failure mechanism		Subdivision of the failure mechanism		Description of the failure mechanism
Code number	Notation	Code number	Notation	
4	Electrical failure	4.0	General	Failures related to the supply and transmission of electrical power, but where no further details are known
		4.1	Short circuiting	Short circuit
		4.2	Open circuit	Disconnection, interruption, broken wire/cable
		4.3	No power/voltage	Missing or insufficient electrical power supply
		4.4	Faulty power/voltage	Faulty electrical power supply, e.g. overvoltage
		4.5	Earth/isolation fault	Earth fault, low electrical resistance
5	External influence	5.0	General	Failure caused by some external events or substances outside the boundary but no further details are known
		5.1	Blockage/plugged	Flow restricted/blocked due to fouling, contamination, icing, flow assurance (hydrates), etc.
		5.2	Contamination	Contaminated fluid/gas/surface, e.g. lubrication oil contaminated, gas-detector head contaminated
		5.3	Miscellaneous external influences	Foreign objects, impacts, environmental influence from neighbouring systems
6	Miscellaneous [a]	6.0	General	Failure mechanism that does not fall into one of the categories listed above
		6.1	No cause found	Failure investigated but cause not revealed or too uncertain
		6.2	Combined causes	Several causes: If there is one predominant cause this should be coded.
		6.3	Other	No code applicable: Use free text.
		6.4	Unknown	No information available

[a] The data acquirer should judge which is the most important failure mechanism descriptor if more than one exist, and try to avoid the 6.3 and 6.4 codes.

B.2.3 Failure cause

The objective of these data is to identify the initiating event ("root causes") in the sequence leading up to a failure of an equipment item. Five categories of failure cause are identified in Table B.3 together with sub divisions and related codes to be used in data bases.

The failure causes are classified in the following categories:

1) design-related causes;

2) fabrication/installation-related causes;

3) failures related to operation/maintenance;

4) failures related to management;

5) miscellaneous.

As for failure mechanism, the failure cause can be recorded at two levels depending on how much information is available. If the information is scarce, only a coarse classification, i.e. codes 1, 2, 3, 4 and 5, can be possible, while a more detailed subdivision code number can be recorded if more information is available.

Failure causes are commonly not known in depth when the failure is observed and, in order to reveal the root cause of a failure, a specific root cause analysis can be useful. This is in particular relevant for failures of a more complex nature and where the failure is important to avoid due to its consequences. Examples are failures with serious safety and/or environmental consequences, abnormally high failure rates compared to the average and failures with a high repair cost.

Due care is required so as not to confuse failure mechanism (describing the apparent, observed cause of failure) with failure cause (describing the underlying or "root" cause of a failure).

Table B.3 — Failure causes

Code number	Notation	Subdivision code number	Subdivision of the failure cause	Description of the failure cause
1	Design-related causes	1.0	General	Inadequate equipment design or configuration (shape, size, technology, configuration, operability, maintainability, etc.), but no further details known
		1.1	Improper capacity	Inadequate dimensioning/capacity
		1.2	Improper material	Improper material selection
2	Fabrication/ installation-related causes	2.0	General	Failure related to fabrication or installation, but no further details known
		2.1	Fabrication error	Manufacturing or processing failure
		2.2	Installation error	Installation or assembly failure (assembly after maintenance not included)
3	Failure related to operation/ maintenance	3.0	General	Failure related to operation/use or maintenance of the equipment but no further details known
		3.1	Off-design service	Off-design or unintended service conditions, e.g. compressor operation outside envelope, pressure above specification, etc.
		3.2	Operating error	Mistake, misuse, negligence, oversights, etc. during operation
		3.3	Maintenance error	Mistake, errors, negligence, oversights, etc. during maintenance
		3.4	Expected wear and tear	Failure caused by wear and tear resulting from normal operation of the equipment unit
4	Failure related to management	4.0	General	Failure related to management issues, but no further details known
		4.1	Documentation error	Failure related to procedures, specifications, drawings, reporting, etc.
		4.2	Management error	Failure related to planning, organization, quality assurance, etc.
5	Miscellaneous [a]	5.0	Miscellaneous - general	Causes that do not fall into one of the categories listed above
		5.1	No cause found	Failure investigated but no specific cause found
		5.2	Common cause	Common cause/mode
		5.3	Combined causes	Several causes are acting simultaneously. If one cause is predominant, this cause should be highlighted.
		5.4	Other	None of the above codes applies. Specify cause as free text.
		5.5	Unknown	No information available related to the failure cause

[a] The data acquirer should judge which is the most important cause if more than one exist, and try to avoid the 5.4 and 5.5 codes.

B.2.4 Detection method

This is the method or activity by which a failure is discovered. This information is vitally important when evaluating the effect of maintenance, e.g. to distinguish between failures discovered by a planned action (inspection, PM maintenance) or by chance (casual observation). Nine categories of detection methods are identified in Table B.4, together with related codes to be used in the databases.

Table B.4 — Detection method

Number	Notation [a]	Description	Activity
1	Periodic maintenance	Failure discovered during preventive service, replacement or overhaul of an item when executing the preventive maintenance programme	Scheduled activities
2	Functional testing	Failure discovered by activating an intended function and comparing the response against a predefined standard. This is one typical method for detecting hidden failures	
3	Inspection	Failure discovered during planned inspection, e.g. visual inspection, non-destructive testing	
4	Periodic condition monitoring [b]	Failures revealed during a planned, scheduled condition monitoring of a predefined failure mode, either manually or automatically, e.g. thermography, vibration measuring, oil analysis, sampling	
5	Continuous condition monitoring [b]	Failures revealed during a continuous condition monitoring of a predefined failure mode	Continuous monitoring
6	Production interference	Failure discovered by production upset, reduction, etc.	
7	Casual observation	Casual observation during routine or casual operator checks, mainly by senses (noise, smell, smoke, leakage, appearance etc.)	Casual occurrences
8	Corrective maintenance	Failure observed during corrective maintenance	
9	On demand	Failure discovered during an on-demand attempt to activate an equipment unit (e.g. safety valve fails to close on ESD-signal, fail to start a gas turbine on demand, etc.)	
10	Other	Other observation method and/or combination of several methods	Other

[a] Specific notation for fire and gas detectors, process sensors and control logic units: The codes above should be interpreted as follows:

functional test	periodic functional testing
casual observation	field observation
periodic CM	abnormal state discovered by control room personnel (no fault annunciation)
continuous CM	fault annunciation in control room (audible and/or visible alarm)

[b] Condition monitoring implies use of specific equipment and/or algorithms to monitor the condition of the equipment with respect to predefined failure modes (note that "test" and "inspection" are separate codes). Condition monitoring (CM) can be further divided into either 1) periodic monitoring or 2) continuous monitoring as follows:

1) periodic CM: periodic condition monitoring includes techniques such as thermography, off-line vibration measuring, oil analyses, calibration checks and sampling;

2) continuous CM: continuous instrumental surveillance of process parameters and equipment condition, e.g. temperature, pressure, flow, RPM, to detect abnormal operating conditions.

B.2.5 Maintenance activity

Twelve categories of maintenance activity are identified in Table B.5 together with related codes to be used in databases for both corrective maintenance and preventive maintenance.

Table B.5 — Maintenance activity

Code Number	Activity	Description	Examples	Use [a]
1	Replace	Replacement of the item by a new or refurbished item of the same type and make	Replacement of a worn-out bearing	C, P
2	Repair	Manual maintenance action performed to restore an item to its original appearance or state	Repack, weld, plug, reconnect, remake, etc.	C
3	Modify [b]	Replace, renew or change the item, or a part of it, with an item/part of a different type, make, material or design	Install a filter with smaller mesh diameter, replace a lubrication oil pump with another type, reconfiguration etc.	C, P
4	Adjust	Bringing any out-of-tolerance condition into tolerance	Align, set and reset, calibrate, balance	C, P
5	Refit	Minor repair/servicing activity to bring back an item to an acceptable appearance, internal and external	Polish, clean, grind, paint, coat, lube, oil change, etc.	C, P
6	Check [c]	The cause of the failure is investigated, but no maintenance action performed, or action is deferred. Able to regain function by simple actions, e.g. restart or resetting.	Restart, resetting, no maintenance action, etc. Particularly relevant for functional failures, e.g. fire and gas detectors, subsea equipment	C
7	Service	Periodic service tasks: Normally no dismantling of the item	e.g. cleaning, replenishment of consumables, adjustments and calibrations	P
8	Test	Periodic test of function or performance	Function test of gas detector, accuracy test of flow meter	P
9	Inspection	Periodic inspection/check: a careful scrutiny of an item carried out with or without dismantling, normally by use of senses	All types of general check. Includes minor servicing as part of the inspection task	P
10	Overhaul	Major overhaul	Comprehensive inspection/overhaul with extensive disassembly and replacement of items as specified or required	C, P
11	Combination	Several of the above activities are included	If one activity dominates, this may alternatively be recorded	C, P
12	Other	Maintenance activity other than specified above	may dominates	C, P

[a] C: used typically in corrective maintenance; P: used typically in preventive maintenance.

[b] Modification is not defined as a maintenance category, but is often performed by persons trained in the maintenance disciplines. Modification to a major extent can have influence on the operation and reliability of an equipment unit.

[c] "Check" includes the circumstances both where a failure cause was revealed but maintenance action was considered either not necessary or not possible to carry out and where no failure cause could be found.

For corrective maintenance, this information describes the type of restoration action that was performed. In general, the predominant restoration activity should be coded when several activities are involved. The code categories "repair", "replace", "overhaul" and "modify" should have a priority relative to the code categories "refit" and "adjust" when a combination of the two categories are involved (e.g. repair consisting of "repair" and "refit" should be coded as “repair”). If there are several repair activities involved, none of which is predominant, the code “combined” may be used.

“Modify” means a modification of the original equipment unit where the original design has been altered or the item in question replaced with one of a different type/make. If the modification is of significant character, it is not considered as a maintenance action, but may be carried out by, or in co-operation with, the maintenance staff. A “repair” is meant to be an action to correct a single failure or a few failures, normally on-site. “Overhaul” means a comprehensive repair of several failures, or one major failure requiring extensive work, or complete refurbishment of an equipment subunit. Typically, such maintenance is undertaken in a workshop.

If the complete equipment unit has been replaced with a new and/or modified one, it is recommended to rewind the time parameters (e.g. operating time) for this unit. This does not apply if the equipment unit is of low complexity and a complete replacement is considered as a normal part of the maintenance.

For preventive maintenance, this information describes the type of preventive action being performed. In general, the most predominant maintenance activity should be coded when several activities are involved. If there is no predominant task, again this should be coded as “combined” and additional information on the various activities listed in a free-text field if provided.

NOTE These maintenance codes do not, as such, reflect the effectiveness of the maintenance action as to restoring the condition of the item (e.g. “good-as-new” or “bad-as-old” condition).

B.2.6 Failure modes

Failure modes should normally relate to the equipment-class level in the hierarchy. For subsea equipment, however, it is recommended to also record failure modes on lower levels in the equipment hierarchy (e.g. “maintainable-item” level). The failure modes can be categorized into three types:

a) desired function is not obtained (e.g. failure to start);

b) specified function lost or outside accepted operational limits (e.g. spurious stop, high output);

c) failure indication is observed but there is no immediate and critical impact on the equipment-unit function [these are typically non-critical failures related to some degradation or incipient fault condition (e.g. initial wear)].

Failure modes are presented in Tables B.6 to B.12 for each main equipment category shown in Table A.4.

Recommended failure modes are presented for each main equipment category (see also list of equipment presented in Table A.4):

— rotating (compressors, combustion engines, electric generators, gas turbines, etc.);

— mechanical (cranes, heat exchangers, heaters and boilers, vessels, storage tanks, piping, etc.);

— electrical (UPS, power transformers, frequency converters, etc.);

— safety and control (fire and gas detectors, sensors, valves, nozzles, fire fighting equipment, etc.);

— subsea production (subsea control systems, Xmas trees, templates, manifolds, risers, etc.);

— well completion (downhole safety valves, wellheads, tubing, casing, packers, etc.);

— drilling (derrick, top drive, drawworks, mud pump, BOP, etc.).

Table B.6 — Rotating equipment — Failure modes

Equipment class [a]								Failure modes			
Combustion engine	Compressor	Electric generator	Electric motor	Gas turbine	Pump	Steam turbine	Turbo expander	Description	Examples	Code [b]	Type [c]
X	X	X	X	X	X	X	X	Failure to start on demand	Doesn't start on demand	FTS	1
X	X	X	X					Failure to stop on demand	Doesn't stop on demand	STP	1
X	X	X	X	X	X	X	X	Spurious stop	Unexpected shutdown	UST	2
X	X	X	X	X	X	X	X	Breakdown	Serious damage (seizure, breakage)	BRD	3
X	X		X	X	X	X	X	High output	Overspeed/output above acceptance	HIO	2
X	X	X	X	X	X	X	X	Low output	Delivery/output below acceptance	LOO	2
X	X		X	X	X	X	X	Erratic output	Oscillating, hunting, instability	ERO	2
X				X		X		External leakage – fuel	External leakage of supplied fuel/gas	ELF	3
	X			X	X	X	X	External leakage – process medium	Oil, gas, condensate, water	ELP	3
X	X	X	X	X	X	X	X	External leakage – utility medium	Lubricant, cooling water	ELU	3
X	X			X	X	X	X	Internal leakage	Leakage internally of process or utility fluids	INL	3
X	X	X	X	X	X	X	X	Vibration	Abnormal vibration	VIB	3
X	X	X	X	X	X	X	X	Noise	Abnormal noise	NOI	3
X	X	X	X	X	X	X	X	Overheating	Machine parts, exhaust, cooling water	OHE	3
X	X			X	X	X	X	Plugged/choked	Flow restriction(s)	PLU	3 (2)
X	X	X	X	X	X	X	X	Parameter deviation	Monitored parameter exceeding limits, e.g. high/low alarm	PDE	2 (3)

Table B.6 (*continued*)

Equipment class [a]								Failure modes			
Combustion engine	**Compressor**	**Electric generator**	**Electric motor**	**Gas turbine**	**Pump**	**Steam turbine**	**Turbo expander**	**Description**	**Examples**	**Code [b]**	**Type [c]**
X	X	X	X	X	X	X	X	Abnormal instrument reading	False alarm, faulty instrument indication	AIR	2 (3)
X	X	X	X	X	X	X	X	Structural deficiency	Material damages (cracks, wear, fracture, corrosion)	STD	3
X	X	X	X	X	X	X	X	Minor in-service problems	Loose items, discoloration, dirt	SER	3
X	X	X	X	X	X	X	X	Other	Failure modes not covered above	OTH	—
X	X	X	X	X	X	X	X	Unknown	Too little information to define a failure mode	UNK	—

a See Table A.4. The codes shown apply to equipment classes marked with “X”.

b A proposed abbreviated code for the failure-mode.

c One of the three failure-mode types listed below; depending on type of failure, more than one of these categories can apply (e.g. a severe leakage can lead to stoppage of the equipment):

1) desired function is not obtained (e.g. failure to start);

2) specified function lost or outside accepted operational limits (e.g. spurious stop, high output);

3) failure indication is observed, but there is no immediate and critical impact on equipment-unit function. These are typically non-critical failures related to some degradation or incipient fault condition.

Table B.7 — Mechanical Equipment — Failure modes

Equipment class [a]								Failure modes			
Cranes	Heat exchangers	Heaters and boilers	Piping	Vessels	Winches	Turrets	Swivels	Description	Examples	Code [b]	Type [c]
X	X	X	X	X	X	X	X	Abnormal instrument reading	False alarm, faulty instrument indication	AIR	2 (3)
X			X		X			Breakdown	Breakdown	BRD	3 (1)
	X			X				Insufficient heat transfer	Cooling/heating below acceptance	IHT	2
	X	X	X	X			X	External leakage – process medium	Oil, gas, condensate, water	ELP	3
X	X	X		X	X		X	External leakage – utility medium	Lubricant, cooling water, barrier oil	ELU	3
						X	X	Failure to connect	Failure to connect	FCO	1
X						X	X	Failure to function as intended	General operation failure	FTI	1(2)
X					X	X	X	Failure to rotate	Failure to rotate	FRO	1
X					X			Failure to start on demand	Failure to start on demand	FTS	1
					X			Failure to stop on demand	Failure to stop on demand	STP	1
						X		Failure to disconnect	Failure to disconnect when demanded	FDC	2
		X						Insufficient heat transfer	Missing, or too low, heat transfer	IHT	2
X	X	X	X				X	Internal leakage	Leakage internally of process or utility fluids	INL	3
							X	Low oil supply pressure	Low oil supply pressure	LBP	2
					X			Low output	Performance below specifications	LOO	2
X					X			Load drop	Load drop	LOA	2
						X		Loss of buoyancy	Loss of buoyancy in idle position	LOB	2
						X		Mooring failure	Mooring failure	MOF	2

Table B.7 (*continued*)

Equipment class [a]								Failure modes			
Cranes	Heat exchangers	Heaters and boilers	Piping	Vessels	Winches	Turrets	Swivels	Description	Examples	Code [b]	Type [c]
X			X		X	X		Noise	Excessive noise	NOI	3
X		X	X		X			Overheating	Overheating	OHE	3
	X	X	X	X			X	Plugged/choked	Flow restriction due to contamination, objects, wax, etc.	PLU	3
			X				X	Power/signal transmission failure	Power/signal transmission failure	PTF	2
X					X			Slippage	Wire slippage	SLP	2
X					X			Spurious operation	Unexpected operation	SPO	2
X	X	X	X	X	X	X	X	Structural deficiency	Material damages (cracks, wear, fracture, corrosion)	STD	3
X	X	X	X	X	X	X	X	Parameter deviation	Monitored parameter exceeding limits, e.g. high/low alarm	PDE	2 (3)
X			X		X			Vibration	Excessive vibration	VIB	3
X	X	X	X	X	X	X	X	Minor in-service problems	Loose items, discoloration, dirt	SER	3
X	X	X	X	X	X	X	X	Other	Failure modes not covered above	OTH	—
X	X	X	X	X	X	X	X	Unknown	Too little information to define a failure mode	UNK	—

a See Table A.4. The codes shown apply to equipment classes marked with “X”.

b A proposed abbreviated code for the failure mode.

c One of the three failure-mode types listed below; depending on type of failure, more than one of these categories can apply (e.g. a severe leakage can lead to stoppage of the equipment):

1) desired function is not obtained (e.g. failure to start);

2) specified function lost or outside accepted operational limits (e.g. spurious stop, high output);

3) failure indication is observed, but there is no immediate and critical impact on equipment-unit function. These are typically non-critical failures related to some degradation or incipient fault condition.

Table B.8 — Electrical equipment — Failure modes

Equipment class [a]		Failure modes			
UPS	**Power transformers**	**Description**	**Examples**	**Code [b]**	**Type [c]**
X	X	Failure to function on demand	Doesn't start on demand	FTF	1
X		Faulty output frequency	Wrong/oscillating frequency	FOF	2
X	X	Faulty output voltage	Wrong/unstable output voltage	FOV	2
X		Loss of redundancy	One or more redundant units not functioning	LOR	2
X		Erratic output	Oscillating, hunting, instability	ERO	2
X	X	Overheating	Machine parts, exhaust, cooling water	OHE	3
X	X	Parameter deviation	Monitored parameter exceeding limits, e.g. high/low alarm	PDE	2 (3)
X		Spurious operation	Unexpected operation	SPO	2
	X	Abnormal instrument reading	Wrong oil level indication	AIR	3
	X	Plugged/choked	Obstructed piping	PLU	2
	X	External leakage utilities	Oil leakage	ELU	1
	X	Structural deficiency	Reservoir rupture	STD	1
	X	Internal leakage	Oil leakage	INL	2
X	X	Minor in-service problems	Loose items, discoloration, dirt	SER	3
X	X	Other	Failure modes not covered above	OTH	—
X	X	Unknown	Too little information to define a failure mode	UNK	—

[a] See Table A.4. The codes shown apply to equipment classes marked with “X”.

[b] A proposed abbreviated code for the failure mode.

[c] One of the three failure-mode types listed below; depending on type of failure, more than one of these categories can apply (e.g. a severe leakage can lead to stoppage of the equipment):

1) desired function is not obtained (e.g. failure to start);

2) specified function lost or outside accepted operational limits (e.g. spurious stop, high output);

3) failure indication is observed, but there is no immediate and critical impact on equipment-unit function. These are typically non-critical failures related to some degradation or incipient fault condition.

Table B.9 — Safety and control equipment — Failure modes

Equipment class [a]					Failure modes			
Fire detectors [b]	Gas detectors [b]	Input devices	Control logic units	Valves	Description	Examples	Code [c]	Type [d]
X		X	X		Failure to function on demand	Failure to respond on signal/ activation	FTF	1
				X	Failure to open on demand	Doesn't open on demand	FTO	1
				X	Failure to close on demand	Doesn't close on demand	FTC	1
				X	Delayed operation	Opening/closing time below spec.	DOP	2
X	X	X	X	X	Spurious operation	e.g. false alarm	SPO	2
X	X [e]	X	X	X	High output	Overspeed/output above acceptance	HIO	2
X	X [f]	X	X	X	Low output	Delivery/output below acceptance	LOO	2
	X [g]				Very low output		VLO	2
X		X	X		Erratic output	Oscillating, hunting, instability	ERO	2
X	X [h]	X			No output	No output	NOO	1
X	X				Spurious high alarm level	e.g. 60 % of Lower Explosion Limit (LEL)	SHH	2
X	X				Spurious low alarm level	e.g. 20 % of Lower Explosion Limit (LEL)	SLL	2
				X	Plugged/choked	Partial or full flow restriction	PLU	1
		X		X	External leakage – process medium	Oil, gas, condensate, water	ELP	3
		X		X	External leakage – utility medium	Lubricant, cooling water	ELU	3
				X	Internal leakage	Leakage internally of process or utility fluids	INL	3
				X	Leakage in closed position	Leak through valve in closed position	LCP	
				X	Abnormal instrument reading	False alarm, faulty instrument indication	AIR	2 (3)

Table B.9 (*continued*)

Equipment class [a]					Failure modes			
Fire detectors [b]	**Gas detectors [b]**	**Input devices**	**Control logic units**	**Valves**	**Description**	**Examples**	**Code [c]**	**Type [d]**
				X	Structural deficiency	Material damages (cracks, wear, fracture, corrosion)	STD	3
X		X	X	X	Minor in-service problems	Loose items, discoloration, dirt	SER	3
X	X	X		X	Other	Failure modes not covered above	OTH	—
X	X	X	X	X	Unknown	Too little information to define a failure mode	UNK	—

a See Table A.4. The codes shown apply to equipment classes marked with an "X".

b Failure coding for fire and gas detectors: For fire and gas detectors, it is important that all failures are recorded; also those detected during scheduled testing and those detected in operation, e.g. replacement of a detector head should be recorded, even if this is done as part of the preventive maintenance programme. Typical failure modes are the following:

— failure to function: The detector does not respond when exposed to its relevant stimulus (e.g. gas or heat). This failure mode is normally observed during functional testing;

— spurious operation: The detector gives an alarm signal when it is not exposed to relevant stimulus. This failure mode is normally observed during operation and logged by control-room personnel;

— others: Additionally, some failure modes related to low/high output, adjustments and overhauls will typically be found in the log books.

c A proposed abbreviated code for the failure mode.

d One of the three failure-mode types listed below; depending on type of failure, more than one of these categories can apply (e.g. a severe leakage can lead to stoppage of the equipment):

1) desired function is not obtained (e.g. failure to start);

2) specified function lost or outside accepted operational limits (e.g. spurious stop, high output);

3) failure indication is observed, but there is no immediate and critical impact on equipment-unit function. These are typically non-critical failures related to some degradation or incipient fault condition.

e e.g. reading 10 % LEL to 20 % LEL without test gas; reading above 80 % LEL on test gas.

f e.g. reading between 31 % LEL to 50 % LEL upon test gas (assuming a nominal set point of 65 % LEL).

g e.g. reading between 11 % LEL to 30 % LEL upon test gas.

h e.g. reading less than 10 % LEL upon test gas.

Table B.10 — Subsea equipment — Failure modes

Equipment class [b]				Failure modes [a]			
Subsea control systems	Xmas trees	Subsea pumps	Risers	Description	Examples	Code [c]	Type [d]
X		X		Failure to function on demand	Failure to respond on signal/activation	FTF	1
	X			Failure to open on demand	Doesn't open on demand	FTO	1
	X			Failure to close on demand	Doesn't close on demand	FTC	1
	X			Failure to lock/unlock	Doesn't lock or unlock when demanded	FTL	1
	X			Failure to set/retrieve	Failed set/retrieve operations	SET	1
X	X	X		Spurious operation	Fails to operate as demanded	SPO	2
		X		High output	Overspeed/output above acceptance	HIO	2
X		X		Low output	Delivery/output below acceptance	LOO	2
X	X			Insufficient power	Lack of or too low power supply	POW	1
X				Loss of redundancy	One or more redundant units failed	LOR	2
	X			Loss of barrier	One or more barriers against oil/gas escape lost	LOB	2
	X		X	Plugged/choked	Partial or full flow restriction	PLU	1
X	X	X	X	External leakage – process medium	Oil, gas, condensate, water	ELP	3
X	X		X	External leakage – utility medium	Lubricant, cooling water	ELU	3
X	X	X	X	Internal leakage – utility medium	Leakage internally of process or utility fluids	INL	3
X		X		Abnormal instrument reading	False alarm, faulty instrument indication	AIR	2 (3)
	X		X	Structural deficiency	Material damages (cracks, wear, fracture, corrosion)	STD	3
X			X	No immediate effect	No effect on function	NON	1
X	X	X	X	Other	Failure modes not covered above	OTH	—

a Although not a requirement of this International Standard, it is recommended that, for subsea equipment, failure modes are also recorded at a lower hierarchical level, e.g. "maintainable item".

b See Table A.4. The codes shown apply to equipment classes marked with "X".

c A proposed abbreviated code for the failure mode.

d One of the three failure-mode types listed below; depending on type of failure, more than one of these categories can apply (e.g. a severe leakage can lead to stoppage of the equipment):

1) desired function is not obtained (e.g. failure to start);
2) specified function lost or outside accepted operational limits (e.g. spurious stop, high output);
3) failure indication is observed, but there is no immediate and critical impact on equipment-unit function. These are typically non-critical failures related to some degradation or incipient fault condition.

Table B.11 — Well-completion equipment — Failure modes

Equipment class [a]	Failure modes			
DHSV	**Description**	**Examples**	**Code [b]**	**Type [c]**
X	Failure to open on demand	Does not open on demand	FTO	1
X	Failure to close on demand	Does not close upon demand signal	FTC	2
X	Leakage in closed position	Leakage through valve exceeding acceptance criteria when closed	LCP	2
X	Well-to-control-line communication	Influx of well fluids into valve control line	WCL	2
X	Control-line-to-well communication	Loss of hydraulic control fluids into the well bore	CLW	3
X	Premature closure	Spurious closure of valve without command	PCL	2
X	Other	Failure modes not covered above	OTH	—
X	Unknown	Too little information to define a failure mode	UNK	—

a See Table A.4. The codes shown apply to equipment classes marked with an “X”.

b A proposed abbreviated code for the failure mode.

c One of the three failure-mode types listed below; depending on type of failure, more than one of these categories can apply (e.g. a severe leakage can lead to stoppage of the equipment):

1) desired function is not obtained (e.g. failure to start);

2) specified function lost or outside accepted operational limits (e.g. spurious stop, high output);

3) failure indication is observed, but there is no immediate and critical impact on equipment unit function. These are typically non-critical failures related to some degradation or incipient fault condition.

Table B.12 — Drilling equipment — Failure modes

Equipment class [a]		Failure modes			
Top drive	**Blowout preventer**	**Description**	**Examples**	**Code [b]**	**Type [c]**
	X	Failure to function on demand	Failure to respond on signal/activation (e.g. failure to shear)	FTF	1
	X	Failure to open	Doesn't open on demand	FTO	1
	X	Failure to close	Doesn't close on demand	FTC	1
X	X	Abnormal instrument reading	False alarm, faulty instrument indication	AIR	2 (3)
X	X	External leakage – utility medium	Hydraulic oil, lubrication oil, coolant, mud, water, etc.	ELU	3
X	X	Erratic output	Oscillating or instable operation	ERO	2
X		Failure to start on demand	Failure to start top drive	FTS	1
X		Failure to stop on demand	Failure to stop top drive or incorrect shutdown process	STP	1
X	X	Internal leakage	Leakage internally of process or utility fluids	INL	3
	X	Leakage in closed position	Leakage through a valve (e.g. ram-valve) in closed position	LCP	2 (3)
X		High output	Output torque above specifications	HIO	2
X		Low output	Output torque below specifications	LOO	2
X		Noise	Excessive noise	NOI	3
X		Overheating	Overheating	OHE	3
X	X	Spurious operation	Unexpected operation	SPO	2
X		Structural deficiency	Material damages (cracks, wear, fracture, corrosion)	STD	3
X		Vibration	Excessive vibration	VIB	3 (2)
	X	Loss of redundancy	Loss of one or more redundancies (e.g. main control system, backup system)	LOR	2
	X	Loss of functions on both pods	Both pods are not functioning as desired	POD	1
	X	Plugged/choked	Choke or kill line plugged	PLU	3
	X	Fails to connect	Failure to connect upper connector	FCO	1
	X	Fails to disconnect	Failure to disconnect upper connector	FTD	1
X	X	Minor in-service problems	Loose items, discoloration, dirt	SER	3
X	X	Other	Failure modes not covered above	OTH	—
X	X	Unknown	Too little information to define a failure mode	UNK	—

[a] See Table A.4. The codes shown apply to equipment classes marked with "X".

[b] A proposed abbreviated code for the failure mode.

[c] One of the three failure-mode types listed below; depending on type of failure, more than one of these categories can apply (e.g. a severe leakage can lead to stoppage of the equipment):

1) desired function is not obtained (e.g. failure to start);
2) specified function lost or outside accepted operational limits (e.g. spurious stop, high output);
3) failure indication is observed, but there is no immediate and critical impact on equipment-unit function. These are typically non-critical failures related to some degradation or incipient fault condition.

Annex C
(informative)

Guide to interpretation and calculation of derived reliability and maintenance parameters

C.1 Interpretation rules for commonly used failure and maintenance parameters

C.1.1 Introduction

Though this International Standard does not cover data analysis in the broad sense, this annex includes some recommended interpretation rules and basic calculation equations commonly used when analysing reliability and maintenance data. For a more in-depth assessment of this subject, we recommend textbooks on the subject and some of the standards listed in the Bibliography at the end of this International Standard.

In addition to the definitions given in Clause 3, Annex C gives some interpretation rules for commonly used terms encountered in data collection and projects.

C.1.2 Redundancy definitions

Redundancy may be applied as follows:

a) passive (cold) standby: redundancy wherein part of the means for performing a required function is needed to operate, while the remaining part(s) of the means are inoperative until needed;

b) active (hot) standby: redundancy wherein all means for performing a required function are intended to operate simultaneously;

c) mixed: redundancy where a part of the redundant means “is on standby” and another part is “active” (example: three means, one active, one in hot standby, one in cold standby).

EXAMPLE 1 Redundancy can be expressed as a quantitative measure, viz. equipment redundancy factor (ERF).

EXAMPLE 2 3 units times 50 % gives an ERF of 1.5.

(See also definition of redundancy in Clause 3 and definitions of “hot” and “cold” standby versus “up time/down time” in 8.3.1).

For redundant systems, parts can fail without a failure of the system. This should be taken into account when estimating required spare parts and repair capacity (where these failures are counted) and estimates of availability (where these failures are not counted).

C.1.3 On-demand data

For some equipment, collected reliability data are used to estimate the on-demand failure probability (e.g. start probability of an emergency generator). In this case, the total number of demands should be recorded including those where failures are experienced. Two types of demands should be included:

a) test activation of the item normally done as part of preventive maintenance (e.g. function test of a fire and gas detector);

b) automatic, or manual, activation of an on-demand function during operation (e.g. closure of an ESD valve).

The probability of failure on demand is calculated as the average fraction of time spent in the failed state, as shown in C.6.2.

C.1.4 Independent failures

Most of the basic probabilistic calculations and most of the models used in the reliability field are relevant only for independent events.

Two events, A and B, are independent if the occurrence of A is independent of that of B. Mathematically speaking, that means that the conditional probability of occurrence of B given the occurrence of A, $P(\mathrm{B/A})$, is simply equal to $P(\mathrm{B})$.

Therefore, by using the definition of conditional probability:

$$P(\mathrm{B/A}) = P(\mathrm{A} \cap \mathrm{B})/P(\mathrm{A}) = P(\mathrm{B}) \qquad \text{(C.1)}$$

This implies that

$$P(\mathrm{A} \cap \mathrm{B}) = P(\mathrm{A}) \cdot P(\mathrm{B}) \qquad \text{(C.2)}$$

When two events have the above property, that means that they behave independently from each other and they are said to be stochastically independent.

Independent failures are, of course, a particular case of independent events.

C.1.5 Dependent failures

When the occurrence of one event depends of the occurrence of one or several other events, these events are said to be dependent.

In this case, the above Equation (C.2) is no longer valid and it is necessary to replace it by Equation (C.3):

$$P(\mathrm{A} \cap \mathrm{B}) > P(\mathrm{A}) \cdot P(\mathrm{B}) \qquad \text{(C.3)}$$

Therefore, when the dependencies are not taken under consideration, the results are underestimated. As they are no longer conservative, this cannot be acceptable, especially for safety studies. This is why the concepts of common-cause failure and common-mode failure have been introduced.

Components that fail due to a shared cause normally fail in the same functional mode. The term common mode is, therefore, sometimes used. It is, however, not considered to be a precise term for communicating the characteristics that describe a common-cause failure.

C.1.6 Common-cause failure (CCF)

A common-cause failure is the simultaneous or concomitant failure of several components due to the same cause. Therefore, each time the failures are not completely independent there is a possibility of CCF.

The CCF can be split into several categories:

a) failure of utilities (electricity, compressed air, etc.) or external aggressions (environment, fire, etc.);

b) internal failures (design error, installation error, bad set of components, etc.);

c) cascade failures (the failure of A leads to the failure of B, which leads to the failure of C, etc.).

Items listed in a) are considered as CCF only if the level of analysis is not sufficient in order to identify them explicitly.

Items listed in b) are more difficult to analyse: experience proves their existence but their causes are generally not identified very easily.

Items listed in c) are generally related to the process itself and can be difficult for the reliability analyst to identify.

When the analysis is too difficult or not possible, a β-factor is generally introduced to split the basic failure rate, λ, of a component into an independent part, $(1 - \beta) \times \lambda$, and a CCF part, $\beta \times \lambda$. This avoids an unrealistic result, but is only an estimate in order to take into account the existence of a potential CCF.

It should be noted that the individual failures due to a CCF arise not necessarily exactly at the same time but within a certain period of time.

C.1.7 Common-mode failure

The notion of common-mode failure, CMF, is often confused with the notion of CCF, although it is a little bit different: a CMF occurs when several components fail in the same way (same mode). Of course, this can be due, in turn, to a CCF.

C.1.8 Trip definitions

Shutdown of machinery refers to the situation when the machinery is shut down from normal operating condition to full stop. Two types of shutdown exist.

a) Trip — The shutdown is activated automatically by the control/monitoring system:

- real trip — The shutdown is effectuated as a result of a monitored (or calculated) value in the control system exceeding a pre-set limit;
- spurious trip — Unexpected shutdown results from error(s) in the control/monitoring system or error(s) imposed on the control/monitoring system originating from the environment or people.

b) Manual shutdown — The machinery is stopped by an intended action of the operator (locally or from the control room).

For some equipment, “spurious stop” is defined as a failure mode that can be either a real trip or a spurious trip as defined above depending on cause.

C.1.9 Failure consequence classification

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

Failure consequence ranking is an essential part of data applications used to assess the risk level (see Annex D). It is, therefore, useful to classify the consequence of failures as to overall impact. A classification of failure consequences, with classes represented by numbers I to XVI, is illustrated in Table C.1. Note that this classification is primarily intended for assessing the consequences of failures that have occurred. For more detailed recommendations on risk classification, see relevant standards, e.g. ISO 17776 and IEC 60300-3-9.

The recording of failure and maintenance impact data for failure events is addressed in Tables 6 and 8.

Table C.1 — Failure-consequence classification

Consequences	Category			
	Catastrophic Failure that results in death or system loss	**Severe** Severe injury, illness or major system damage (e.g. < USD 1 000 000)	**Moderate** Minor injury, illness or system damage (e.g. < USD 250 000)	**Minor** Less than minor injury, illness or system damage (e.g. < USD 50 000)
Safety	I — Loss of lives — Vital safety-critical systems inoperable	V — Serious personnel injury — Potential for loss of safety functions	IX — Injuries requiring medical treatment — Limited effect on safety functions	XIII — Injuries not requiring medical treatment — Minor effect on safety function
Environmental	II Major pollution	VI Significant pollution	X Some pollution	XIV No, or negligible, pollution
Production	III Extensive stop in production/operation	VII Production stop above acceptable limit [a]	XI Production stop below acceptable limit [a]	XV Production stop minor
Operational	IV Very high maintenance cost	VIII Maintenance cost above normal acceptable [a]	XII Maintenance cost at or below normal acceptable [a]	XVI Low maintenance cost

[a] It is necessary to define acceptable limits for each application.

C.1.10 Analysis of failures

Failures that occur and that are judged to be in the unacceptable category in Table C.1 require that specific reporting and analyses be done in order to find measures to prevent such failure from re-occurring (e.g. improved maintenance, inspections, modifications, replacements etc.). Some useful analytical methods are summarized below.

a) Reliability system modelling (e.g. Monte Carlo simulation, Markov analysis, reliability growth modelling etc.) is recommended for all critical-service equipment for the comparison of reliability for various proposed system configurations to provide input to concept selection in the development of the design basis. Specifically,

   — sensitivity studies to identify the component failures or human errors, or both, having the greatest impact on system reliability (this information can be used to improve the reliability of individual components or to provide a basis for modifying the system configuration during the project proposal),

   — evaluation of operational inspection intervals that have direct impact on predicted system reliability,

   — establishment of the amount of inspection and testing required for certain system elements.

b) Pareto analysis can be utilized to establish the plant's list of "bad actors" based on the highest failure rates or total maintenance cost.

c) Root-cause analysis is recommended in the following cases:

   — failures of severity types I to VIII;

   — systems defined as "bad actors" by the operating facility.

d) Equipment lifetime analysis, such as Weibull analysis, is recommended on equipment types having five or more common-mode failures with severity levels I to XII.

NOTE Common causes of failures can be classified as follows.

1) Infant-mortality failures (Weibull-shape parameter $\beta < 1$) are usually induced by external circumstances and are typically due to poor installation, solid-state electronic failures, manufacturing defects, misassembly, or incorrect start-up procedures.

2) Random failures ($\beta = 1$) most often result from maintenance errors, human errors, foreign-object failures or computational errors in the Weibull analysis (e.g. combining data from different failure modes, combining common failure modes from differing equipment types, etc.). Random failures are best addressed by improved predictive-maintenance programmes (more rigorous condition monitoring).

3) Early wear-out failures ($1.0 < \beta < 4.0$) can occur in the normal design life of the equipment and most often include low cycle fatigue, most bearing failures, corrosion and erosion. Preventive maintenance resulting in repair or replacement of critical components can be cost effective. The period for overhaul is read off the Weibull plot at the appropriate β life.

4) Old age wear-out failures (β W 4.0) most often occur outside the normal design life. The steeper the slope, β, the smaller the variation in the times to failure and the more predictable the results. Typical failure modes with old age wear include stress corrosion, erosion, material property issues, etc. Preventive maintenance to replace parts that produce significant failures can be cost effective. The period for overhaul is read off the Weibull plot at the appropriate β life.

C.1.11 Safety critical equipment

For some equipment, like safety-critical equipment, more specific definitions for a failure and its consequences can be useful. Some recommendations on this are given in Annex F.

C.2 Availability

C.2.1 Normalized definition

Note that the definition of availability given in IEC 60050-191:1990, 3.1.1, can be misleading because it can lead one to think that “availability” and “reliability” are the same concepts. This is not true because the meaning of “over a given time interval” is not at all the same for the concepts of “availability” and “reliability”. Even if the definitions of “availability” and “reliability” seem very close, these concepts are completely different, specifically:

— availability: item working at a given instant (no matter what has happened before);

— reliability: item working continuously over a whole period of time.

“Availability” characterizes a function that can be interrupted without any problem and “reliability,” a function that cannot be interrupted over a whole period of time.

C.2.2 Mathematics of availability

It is with the mathematical definitions that the situation is clarified. In fact, there are several mathematical expressions for "availability" concepts.

— Pointwise or instantaneous availability, $A(t)$, is the probability that an item is in a state to perform a required function under given conditions at a given instant of time, assuming that the required external resources are provided. (This is the definition given in IEC 61508.)

The instantaneous availability, $A(t)$, at time, t, is given by Equation (C.4):

$$A(t) = P_{\mathrm{S}}(t) \tag{C.4}$$

where $P_{\mathrm{S}}(t)$ is the probability that item S does not have a critical failure at time, t.

— Mean availability for a given mission (over a given period of time), $A_{m(t1,t2)}$, is the average of the pointwise availabilities over the time period, $t_1 \le t \le t_2$. This is given mathematically by Equation (C.5):

$$A_{m(t1,t2)} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} A(t) \mathrm{d}t \qquad \text{(C.5)}$$

— Mean availability is the limit of the mean availability for a given mission when the time period goes to infinity, as given by Equation (C.5):

$$A_m = \lim_{t \to \infty} \frac{1}{t} \int A(t) \mathrm{d}t \qquad \text{(C.6)}$$

These definitions show clearly the difference between the various “availabilities,” specifically:

a) for the pointwise availability, we are interested only in the fact that the item works well when it is required (no matter if it has failed at some previous moment, provided it has been repaired since and has not failed again);

b) for the mean availability, we are interested in the same, but averaged over a given period of time. This corresponds to the ratio of the effective working time over the whole duration under interest.

Note that in most, but not all, of the cases, after a certain time, the pointwise availability reaches an asymptotic value called “steady state” availability, which is equal to the above “mean availability”.

Example For a simple repairable item with only two reliability parameters [failure rate (λ; see Clause C.3) and repair rate (μ)], the pointwise availability is equal to Equation (C.7):

$$A(t) = 1 - \frac{\lambda}{\lambda + \mu} \left\{ 1 - \exp\left[-(\lambda + \mu)t \right] \right\} \qquad \text{(C.7)}$$

When t goes to infinity, we obtain the asymptotic value, as given by Equation (C.8), which is also the mean availability:

$$A_m = \frac{\mu}{\lambda + \mu} \qquad \text{(C.8)}$$

This availability is the “technical” or “intrinsic” or “inherent” availability of the item (see also C.2.3.2).

C.2.3 Measures and estimates of mean availability data records

C.2.3.1 Mathematics of measures and estimates of mean availability data records

The interest of the availability concept within the ISO 14224 application areas is the relationship existing between data collected in the field and the mathematical meaning of the mean availability over a given period.

When planning to collect measures and estimates of mean availability (see 3.1 and 7.1.2), two types of mean availability and the sum of the two should be considered.

a) Operational availability, A_o, is given by Equation (C.9):

$$A_o = \frac{t_{MU}}{t_{MU} + t_{MD}} \qquad \text{(C.9)}$$

where

t_{MU} is the mean up time, estimated by using the actual up time observed in the field;

t_{MD} is the mean down time, estimated by using the actual up and down times observed in the field.

b) Intrinsic availability, A_I, is given by Equation (C.10):

$$A_I = \frac{t_{MTF}}{t_{MTF} + t_{MTR}} \quad (C.10)$$

where

t_{MTR} is the mean time to repair, estimated by using the actual repair times observed in the field;

t_{MTF} is the mean time to failure, estimated by using the actual up times observed in the field.

c) Mean time between failures, t_{MBF}, is given by Equation (C.11):

$$t_{MBF} = t_{MTF} + t_{MTR} \quad (C.11)$$

where t_{MTF} and t_{MTR} are as defined above.

C.2.3.2 Uses of measures and estimates of mean availability data records

A_I and A_o are not equivalent, except when t_{MD} is equal to t_{MTR}. Generally, A_I is of interest to reliability engineers, while A_o is of interest to maintenance people.

These estimations explain why the unit of availability is expressed as the proportion of time(s) the item is in the up state.

Be aware that through t_{MD}, which is made of several delays (detection, isolation, spare parts, stand-by, repair duration, re-instatement, etc.), and t_{MU}, which is normally close to the t_{MTF}, the operational availability depends on the combined aspects of the reliability performance, the maintenance performance, the maintainability performance and the maintenance support performance. Therefore, this is not an intrinsic property of the item itself but a property of that item within the context (the whole installation, procedures, maintenance policy, etc.) where it is used.

Depending on the interest of the user, only a part of the down time may be considered. Extra delays due to required external resources other than maintenance resources may be excluded from the estimation in order to perform a more intrinsic estimation, such as given in Equation (C.12):

$$A_1 = \frac{t_{MTF}}{t_{MTF} + t_{MTR}} \quad (C.12)$$

which is an estimate of the theoretical equation given in Equation (C.13):

$$A_m = \frac{\mu}{\lambda + \mu} \quad (C.13)$$

In the same way, the time spent for preventive maintenance can be included or not in the evaluations.

The above single equation for evaluating the two reliability parameters, λ and μ, is not sufficient. It is necessary to evaluate λ and μ separately based on the observed t_{MTF} (or t_{MU}) for the failure rate, and the observed t_{MTR} (a part of the t_{MD}) for the repair rate.

As the amount of data collected increases, the estimations become closer and closer to the true mathematical values. The uncertainties can be managed through classical statistical analyses.

It is quite common to define the operational availability based on the down time related to the sum of both corrective and preventive maintenance. The term “technical availability” is also sometimes used as an alternative to “intrinsic availability.” In the latter case, down time related to corrective maintenance only shall be included in the calculations. The operational availability per year, $A_{o,y}$, and the technical availability per year, $A_{T,y}$, can then be calculated as given in Equations (C.14) and (C.15), respectively:

$$A_{o,y} = \frac{8\,760 - (t_{CM} + t_{PM})}{8\,760} \quad (C.14)$$

$$A_{T,y} = \frac{8\,760 - t_{CM}}{8\,760} \quad (C.15)$$

where

t_{CM} is the time for condition monitoring

t_{PM} is the time for preventive maintenance

C.3 Failure rate estimation

C.3.1 General

C.3.1.1 Mathematics for failure rate and hazard rate estimation

The “failure rate” is a classical reliability parameter traditionally denoted by the Greek letter, λ (lambda).

The failure rate is an average frequency, λ, of failure (i.e. a number of failures per unit of time). It is easy to calculate an estimator, $\hat{\lambda}$, of this frequency from historical RM data by dividing the number of observed failures, n, of the considered item by its cumulative working time (operational time) during the same period of time, as given by Equation (C.16):

$$\hat{\lambda} = n \Big/ \sum t_{TFi} \quad (C.16)$$

where

n is the number of observed failures;

t_{TFi} is the ith time to fail (i.e. ith duration of functioning observed from the field).

NOTE 1 λ is a function of time t and it asymptotically approaches $1/t_{MTF}$.

In Equation (C.16), t_{TFi} means the ith “time to fail” (i.e. the ith duration of functioning) observed from the field. So, this is actually the estimator of 1/MTTF for a repairable item (component/system). This λ is usually a function of time *t*, but asymptotically it approaches $1/t_{TFi}$.

In practice, the term $\sum t_{TFi}$ in Equation (C.16) is often replaced by the total operational time of the units investigated; see the example below.

NOTE 2 Equation (C.16) is true only if an exponential failure distribution (constant hazard rate for the system) is assumed. In case a component does not have constant hazard rate, the asymptotic rate for the system is not reached until after several changes of the component (renewal process). Such an interpretation means that the number of failures over a (long) time period (0, t) “on the average” is equal to $\lambda \times t$. Or, more generally: if a number of items with the same constant “failure rate,” λ, are observed over a total operational time, t, then the mean number of failures observed over this period asymptotically equals $\lambda \times t$.

EXAMPLE A failure rate of 3×10^{-4} failures per hour means that on the average 30 failures will occur during an operational period of 100 000 h. It is emphasized that we are talking here about repairable units, i.e. units that are repaired immediately after failure.

In the above example, we state that in the long run the mean time between two failures of a unit equals $1/\lambda = 3\ 333$ h. It is important not to confuse this t_{TFi} of 3 333 h with expected time to failure. Since the failure rate is assumed constant, the probability of a failure is the same from 0 h to 100 h, from 3 300 h to 3 400 h and from 9 900 h to 10 000 h.

However, the term "failure rate" is usually defined (e.g. in text books) quite differently. It is used synonymously with the term "hazard rate." Also, this rate is generally a function of time, t, (since the start of operation of the unit). Then, $\lambda(t)\mathrm{d}t$ is the probability that the item fails between t and $t + \mathrm{d}t$, provided that it is working at t. This function, $\lambda(t)$, then defines the lifetime distribution of the units (i.e. the statistical distribution of the time to first failure). This distribution can also be expressed in terms of the probability, $F(t)$, that the item will fail before it has been operating a time, t, as given in Equation (C.17):

$$F(t) = 1 - R(t) \tag{C.17}$$

where $R(t)$ is the probability that the item will survive a time period, t.

Nevertheless, it can be demonstrated mathematically that when the hazard rate, $\lambda(t)$, is constant over time, t, then the "failure rates," λ, in both interpretations have the same estimator as given in Equations (C.16) and (C.17). In that case, we can use the term "failure rate" without causing too much confusion (but we still have two different interpretations).

The assumption that the failure rate (hazard rate) is constant ($= \lambda$) over the whole life of the concerned item means that the probability of the item to survive a period, t, is given by Equations (C.18) and (C.19):

$$R(t) = \exp(-\lambda \times t) \tag{C.18}$$

$$F(t) = 1 - \exp(-\lambda \times t) \tag{C.19}$$

In this case, $\lambda = 1/t_{MTF}$.

C.3.1.2 Uses of failure rate and hazard rate estimation

In the general situation, the hazard rate, $\lambda(t)$, of the item's lifetime is often assumed to reflect three periods: early failures, useful life and wear-out failures (see Figure C.1). During the early failure period, the $\lambda(t)$ is normally decreasing, during the useful life it is more or less constant and during the wear-out period it is increasing, i.e. the curve, $\lambda(t)$, has the so-called bathtub form (see Figure C.1).

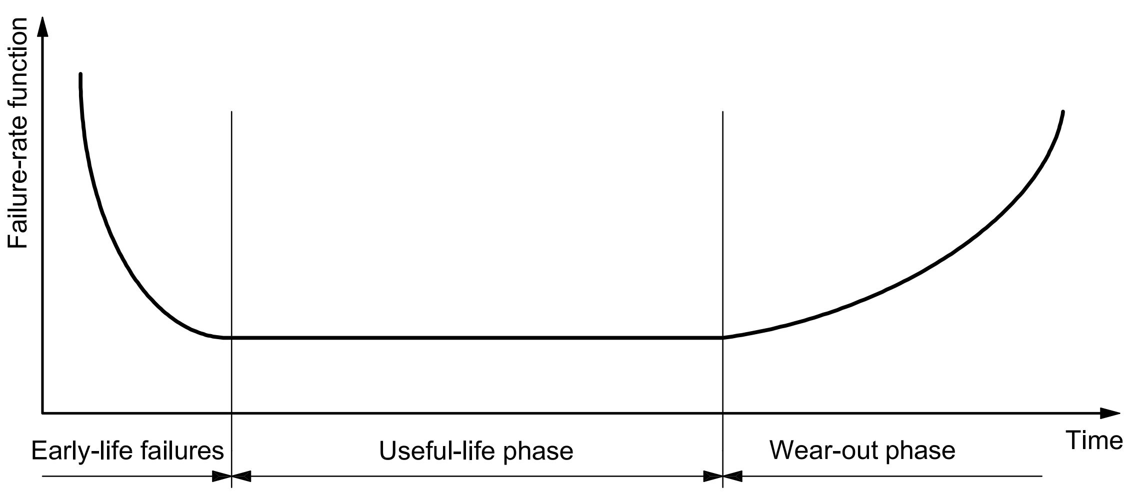


Figure C.1 — Bathtub curve for hazard rate ("failure rate") of a unit

If early failures are treated separately and units are taken out of service before they arrive at wear-out, the assumption of constant hazard rate can be reasonable. This estimator gives no information on the form of the hazard-rate curve. Assuming that the hazard rate is constant, this is also an estimator for the constant hazard rate. If a constant hazard rate is assumed where wear-out failures are present in the components or spare parts, the reliability is underestimated for low operating time and overestimated for high operating time. With regards to the time to first failure, t_{TFF}, the constant hazard rate estimate is totally misleading. Nevertheless, a more sophisticated statistical analysis can be performed to determine if the hazard rate is decreasing, constant or increasing and to evaluate the parameters with another reliability model such as Weibull for components or the Power law for repaired systems.

In that case, it is necessary to take into consideration the various durations of the t_{TFi}s.

The standard methods for estimation of a constant failure rate based on the observed number of failures over a given time of operation are described in C.3.2 and C.3.3.

C.3.2 Maximum likelihood estimator of a constant failure rate

The maximum likelihood estimator, $\hat{\lambda}$, of λ is given by Equation (C.20):

$$\hat{\lambda} = \frac{n}{\tau} \qquad \text{(C.20)}$$

where

n is the number of failures observed;

τ is the aggregated time in service, measured either as surveillance time or operating time.

Note that this approach is valid only in the following situations.

— The number of failures for a specified number of items with the same constant failure rate, λ, are available for a given aggregated time, τ, in service;

— At least one failure is observed ($n \geq 1$) over time, τ.

In "classical" statistical theory, the uncertainty of the estimate $\hat{\lambda}$ may be presented as a 95 % confidence interval with a lower limit, L_{Lower}, and an upper limit, L_{Upper}, as given by Equations (C.21) and C(22), respectively:

$$L_{\text{Lower}} = \frac{1}{2\tau} z_{0,95;\nu} \qquad \text{(C.21)}$$

$$L_{\text{Upper}} = \frac{1}{2\tau} z_{0,05;\nu} \qquad \text{(C.22)}$$

where

$z_{0,95;\nu}$ is the upper 95th percentile of the χ^2-distribution (chi-square) with ν degrees of freedom;

$z_{0,05;\nu}$ is the lower 5th percentile of the χ^2-distribution (chi-square) with ν degrees of freedom.

NOTE 1 The chi-square distribution can be found in most textbooks on statistics or in Reference [67].

NOTE 2 Other confidence limits can also be used depending on application.

EXAMPLE Assume that $n = 6$ failures have been observed during an aggregated time in service $\tau = 10\ 000$ h.

The failure rate estimate, $\hat{\lambda}$, expressed as failures per hour as given in Equation (C.20), is calculated as

$$\hat{\lambda} = n / \tau = 6 \times 10^{-4}$$

The 95 % confidence interval, from Equations (C.21) and (C.22), is calculated as

$$\left[\frac{1}{2\tau} z_{0,95;2N}, \frac{1}{2\tau} z_{0,05;2(N+1)}\right] = \left(\frac{1}{20\,000} z_{0,95;12}, \frac{1}{20\,000} z_{0,05;14}\right) = (2{,}6 \times 10^{-4},\ 11{,}8 \times 10^{-4})$$

The estimate and the confidence interval are illustrated in Figure C.2.

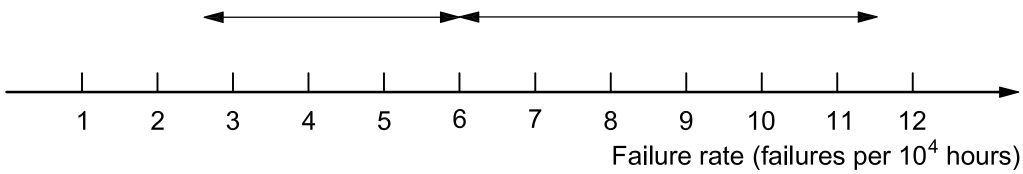


Figure C.2 — Estimate and 95 % confidence interval for the example calculation of the failure rate

C.3.3 Estimation of failure rate with zero failures — Bayesian approach

C.3.3.1 General

NOTE The Bayesian approach is not always accepted by safety authorities (e.g. in the nuclear field).

The classical approach described above has difficulties when the observed number of failures is zero. An alternative approach which handles the situation with zero failures is to use a Bayesian approach with non-informative prior distribution. When n failures have been observed during time, t, the failure rate estimate, $\hat{\lambda}$, in the posteriori distribution is given by Equation (C.23):

$$\hat{\lambda} = \frac{2n+1}{2t} \qquad \text{(C.23)}$$

which, in the case with zero failures, reduces to Equation (C.24):

$$\hat{\lambda} = \frac{1}{2t} \qquad \text{(C.24)}$$

C.3.3.2 Constant confidence-level estimator

The failure rate is estimated from Equation (C.25):

$$\hat{\lambda} = \frac{n + 0{,}7}{t} \qquad \text{(C.25)}$$

C.3.3.3 Advantages

The advantages of this estimator are the following.

— It works in the zero failure case.

— It is homogeneous from a confidence level point of view.

— It uses the median of the failure rate.

— It is easy to use.

C.4 Maintainability

C.4.1 Normalized definitions

Several normalized definitions of the concept of "maintainability" exist in normalization documents, specifically

— ability, under given conditions, of an item to be maintained in or restored to, over a given period of time, a state where it is able to perform its function when the maintenance is achieved under prescribed conditions, procedures and means;

— measure of the ability of an item to be maintained in or restored in specified conditions when the maintenance is achieved by personnel with a specified level of skill and using prescribed procedures and resources at all the prescribed levels of maintenance and repair.

C.4.2 Mathematical meaning

C.4.2.1 Maintainability concepts

There is a probabilistic version of "maintainability", similar to that for the concepts of reliability and availability, as follows:

probability that an item can be restored to a condition within a prescribed period of time when maintenance is performed by personnel having specific skill levels using prescribed procedures and resources.

C.4.2.2 Maintainability performance

This is a probability method to measure maintainability performance, in addition to a lot of other indicators.

The maintainability, $M(t)$, can be expressed by Equation (C.26):

$$M(t) = P(t_{TR} \leq t) \quad \text{(C.26)}$$

where

t_{TR} is the time to repair item S;

$P(t_{TR} \leq t)$ is the probability that t_{TR} is less than time t.

Therefore, $M(t)$ is the cumulative distribution function (CDF) of the t_{TR}s of item S. By definition of the CDFs, $M(t)$ is a non-decreasing function varying from 0 to 1 as t varies from 0 to infinity. That means any repairable item is likely to be repaired (restored) if we wait long enough.

As a property of the CDF, it is possible to express $M(t)$ by using the "hazard rate" of the distribution, which, in this case, is the so-called "repair rate" $\mu(t)$.

When this rate is constant, we obtain the classical equation for the maintainability, $M(t)$, given in Equation (C.27):

$$M(t) = 1 - \exp(-\mu \times t) \quad \text{(C.27)}$$

where μ is the so-called repair rate, which is equivalent to the hazard rate and which is designated t_{MTR}.

Note that, depending on what we actually want to evaluate, the whole down time, a part of it or only the active maintenance time can be used as t_{TR} in Equation (C.26).

C.4.2.3 Repair rate

The repair rate, μ, is a reliability parameter that allows the evaluation of the probability that the item is repaired within a certain delay after having failed (this is the probabilistic version of the "maintainability" of the item).

This parameter plays a role for the t_{TR} (time to repair) analogous to that of the failure rate for the t_{TF} (time to failure).

The estimate is given by Equation (C.28):

$$\mu = \frac{n}{\sum t_{\text{TR}i}} = \frac{1}{t_{\text{MTR}}} \quad \text{(C.28)}$$

where

n is the number of repairs;

$t_{\text{TR}i}$ is the length of the ith repair

t_{MTR} is the mean time to repair.

All data can be collected from the field.

This parameter can be used to evaluate the maintainability of the item using an exponential law as given in Equation (C.29):

$$M(t) = 1 - \exp(-\mu \times t) \quad \text{(C.29)}$$

More sophisticated probabilistic laws are often used for modelling repairs. In these cases, the repair rate becomes a non-constant $\mu(t)$ and the simple estimate in Equation (C.29) no longer applies. For example, it is necessary to take into consideration the length of the various $t_{\text{TR}i}$s in order to evaluate the parameter of a log-normal law.

C.4.2.4 Measures and estimates

An indicator of the maintainability performance is the t_{MTR} (mean time to repair) of the concerned item. This t_{MTR} is the part of the t_{MD} (mean down time) due to the repair itself. It can be estimated from the sum of the observed "times to repair" (from data feedback) divided by the number of repairs, as given in Equation (C.30):

$$t_{\text{MTR}} = \sum \frac{t_{\text{TR}_i}}{n} \quad \text{(C.30)}$$

NOTE When the analytical form of $M(t)$ is known or has been chosen, a link can be made between the parameters of the exponential law and the t_{MTR}s estimated from the field.

The estimation in the classical case, when Equation (C.29) holds and when μ, the so-called "repair rate," is constant, is easy. As the amount of data collected increases, the estimation becomes closer and closer to the true mathematical values. The uncertainties can be managed through classical statistical analyses.

For more complicated repair laws (e.g. log-normal), it is necessary to take into consideration the length of the various observed t_{TF}s and to do a statistical fitting.

When planning to collect data (see 7.1.2), it is necessary to consider the various methods of recording down times (see Table 4) and the appropriate parts of the down time to be included need to be chosen. Depending on what is done, several parts of the down time can be included within the t_{MTR}.

C.4.3 Maintainability — Intrinsic and extrinsic factors

For comparison purposes, it is important to identify what is intrinsic (only related to the item) and extrinsic (context-dependent) in the maintainability of single items.

— Intrinsic maintainability considers only the built-in characteristics designed to help the maintenance of an item.

— Extrinsic maintainability considers all that is context-dependent: logistics, support, task organisation, isolation, de-isolation.

“Extrinsic” maintainability changes from site to site while “intrinsic” maintainability does not. For reliability studies, it is very important to be able to analyse and model separately these two definitions of the maintainability.

For comparison purposes, it is useful to be able to identify those factors of maintainability that relate only to the item itself, e.g. lubrication or ease of dismantling, which can be called intrinsic maintainability, and those related to its location, e.g. logistics, support, task organisation, isolation, de-isolation, which can be called extrinsic maintainability.

C.4.4 Procedure for compiling data records for maintainability

When planning to collect measures and estimates of failure maintainability (see 7.1.2), choose appropriate measures from Clause C.5 for the information required.

C.5 “Mean time” definitions

C.5.1 Principle

The mean time during which the item is in certain states can be measured by use of mean down time, mean time between failures, mean time to failure, mean time to repair, mean up time, etc. Mean values are a good approximation when limited data are available or when there is no clear trend in the data. However, if there is a trend, as there often is, in maintenance data, e.g. increasing hazard rate (wear-out) or decreasing hazard rate (“run in”), mean values can be misleading and can result in incorrect decisions.

C.5.2 Mean down time (MDT)

Mean down time is defined as the mean time during which the item is in its down state.

This includes all the delays between the failure and the restoration of the function of the concerned item: detection, spare parts, logistics, stand-by, maintenance policy, active maintenance time, re-instatement, etc.

This is not an intrinsic parameter, as it depends on the context within which the item is used.

Therefore, only a specific part of this down time can be of interest to an analyst performing a reliability study (i.e. t_{MTR}). See also Figure 4.

C.5.3 Mean time between failures (MTBF)

C.5.3.1 Definition

Mean time between failures is defined as the mean time between two consecutive failures.

C.5.3.2 Mathematics of MTBF

The general expression for the mean time between failures, t_{MBR}, can be expressed as given in Equation (C.31):

$$t_{MBF} = t_{MU} + t_{MD} \tag{C.31}$$

where

t_{MU} is the mean up time;

t_{MD} is the mean down time.

which, in simple cases, can be expressed as given in Equation (C.32):

$$t_{MBF} = t_{MTF} + t_{MTR} \tag{C.32}$$

where

t_{MTF} is the mean time to failure;

t_{MTR} is the mean time to repair.

Like the MDT, this is not an intrinsic parameter, but depends on the context within which the item is used.

C.5.3.3 Uses for MTBF

MTBFs are calculated and used for different purposes (for item and equipment, service, site, etc.). The "item" and "equipment" are of interest mainly to reliability engineers and the others to the maintenance people.

C.5.4 Mean time to failure (MTTF)

C.5.4.1 Definition

Mean time to failure is defined as the mean time before the item fails.

C.5.4.2 Mathematics of MTTF

This parameter, mean time to fail, t_{MTF}, is linked to the failure rate, λ, of the concerned item by Equation (C.33)

$$t_{MTF} = \frac{1}{\lambda} \tag{C.33}$$

where λ is the failure rate.

C.5.4.3 Use of MTTF

Rigorously, this parameter concerns only the first failure of a new item before any maintenance task has been performed. If the repair is perfect, i.e. the repaired item is "as good as new", t_{MTF} is exactly the same as t_{MU}.

Take care to understand this term and be aware that in practice, t_{MTF} and t_{MU} are often confused (see definition of t_{MU}).

NOTE t_{MTF} is normally associated with the assumption of an exponential distribution (e.g. a constant hazard rate). t_{MTF} is also used for other distributions as, for example, the normal distribution or the Weibull distribution. Equations (C.31) to (C.33) are valid only for the assumption of an exponential distribution for both t_{MBF} and t_{MTF}. Further, it is a prerequisite that all the time is measured in the same time dimension (global or local time).

C.5.5 Mean time to repair (MTTR)

C.5.5.1 Definition

Mean time to repair is defined as the mean time before the item is repaired.

C.5.5.2 Mathematics of MTTR

This parameter, mean time to repair, t_{MTR}, is linked to the repair rate, μ, of the concerned item by Equation (C.34)

$$t_{MTR} = \frac{1}{\mu} \tag{C.34}$$

where μ is the repair rate.

C.5.5.3 Uses of MTTR

The name MTTR is generally related only to the active corrective maintenance time that is a part of the down time, but depending on the study, it can range from the active corrective maintenance time to the whole down time. In that case “restoration” can be used instead of “repair”. In the general case, however, “down time” is greater than “active maintenance time”.

If preventive maintenance is also included in addition to the corrective maintenance (repair) dealt with above, the mean time to maintain, t_{MTM}, expressed in hours, can be calculated as given in Equation (C.35):

$$t_{MTM} = \frac{\left[\left(t_{mc} \cdot M_c\right) + \left(t_{mp} \cdot M_p\right)\right]}{\left(M_c + M_p\right)} \tag{C.35}$$

where

t_{mc} is the total elapsed corrective maintenance or repair time, expressed in calendar hours;

t_{mp} is the total elapsed preventative maintenance time, expressed in calendar hours;

M_c is the total number of corrective maintenance actions (repairs);

M_p is the total number of preventative maintenance actions.

C.5.6 Mean up time (MUT)

Mean up time is defined as the mean time during which the item is in its up state.

If repairs are “perfect”, i.e. the repaired item is “as good as new,” t_{MU} is exactly the same as t_{MTF}. If repair is not perfect, or for equipment comprised of parts that have been repaired and others that have never failed, t_{MU} and t_{MTF} are two different parameters (see also C.5.4).

C.5.7 Procedure for compiling data records for mean time

When planning to collect measures and estimates of mean time (see 7.1.2), choose appropriate measures from Clause C.5 for the information.

C.6 Testing for hidden failures in safety systems

C.6.1 General principles

There are two different principles that can be used to establish the necessary test interval for a safety function with hidden failures:

— required availability

This approach is based on a risk analysis for which some absolute risk acceptance criteria have been established. Each safety function of a plant/system/item of equipment is allocated reliability requirements based on this. This approach is in line with the standards IEC 61508 (all parts) and IEC 61511 (all parts).

— cost-benefit availability

Under some circumstances, the consequence of a safety-system failure in a hazardous situation can be reduced to economic consequences only. It is, then, appropriate to establish the preventive maintenance programme by optimizing the total costs by weighing the cost of preventive maintenance against the cost of safety-system failure; see ISO 15663 (all parts).

C.6.2 Required availability

This situation is characterized by an upper limit, L_{PFD}, that the probability of failure on demand is not allowed to exceed. The necessary test interval, τ, to achieve this can be found by the approximation in Equation (C.36):

$$\tau = \frac{2L_{\text{PFD}}}{\lambda} \tag{C.36}$$

where

L_{PFD} is the upper accepted limit for probability of failure on demand;

λ is the failure rate for on-demand failures.

C.6.3 Mathematics of cost-benefit availability

When we use the term cost-benefit availability, we are considering a safety system classified as SIL 0 as defined in IEC 61508 (all parts). This means that there are no absolute requirements with respect to the availability of the system. Still, this can be an important protective system with respect to potential economic loss. An example is a vibration trip on a pump that is supposed to stop the pump if the vibration exceeds a defined level. If the vibration trip fails, the material damage to the pump can be significant. The approach to use in such a situation is to perform an economic optimization where the cost of testing is weighed against the expected cost related to failures.

Mathematically, this idea can be formulated by the approximation in Equation (C.37) for total expected cost:

$$C_{\text{TEC}} = \frac{1}{2}\lambda_{\text{fto}} \times \tau \times f \times C_{\text{f}} + \frac{C_{\text{m}}}{\tau} \tag{C.37}$$

where

C_{TEC} is the total expected cost;

λ_{fto} is the failure rate for failure mode “fail to operate”;

f is the frequency of events when the safety system is supposed to be activated;

EXAMPLE For a fire alarm, f is the frequency of fires.

C_f is the difference in cost between the consequences of the hazardous situation when the safety system works and when it does not work;

EXAMPLE For an automatic fire-extinguishing system, C_f is the difference in damage if the extinguishing system is automatically activated or not in case of a fire. In many cases, it is required to perform a coarse risk analysis to estimate C_f. In the case of a fire, for instance, one important aspect to evaluate is the probability of people being present to discover the fire and being able to manually activate the fire extinguishing equipment).

C_m is the cost of each preventive maintenance activity or test;

τ is the test interval.

The economic optimal test interval may be found by finding the derivative of the total expected cost and setting it equal to zero as given in Equation (C.38):

$$\tau = \sqrt{\frac{2C_m}{\lambda_{fto} \times f \times C_f}} \tag{C.38}$$

where the parameters are the same as those for Equation (C.37).

Annex D
(informative)

Typical requirements for data

D.1 General

There are different areas of application of RM data and it is necessary to consider carefully the collection of data (see Clause 7) so that the types of data are consistent with the intended purpose. The types of analyses considered are listed Table D.1, which also refers to other relevant international and industry standards.

Table D.1 — Areas of application and types of analyses

Areas of application	Type of analysis to be applied	Acronym	Supported by ISO 14224	Reference
Safety	A1 — Quantitative risk analysis	QRA	Yes	IEC 60300-3-9 NORSOK Z-013 ISO 17776
	A2 — Risk-based inspection	RBI	Yes	API RP 580
	A3 — Safety integrity level	SIL	Yes	IEC 61508 (all parts) IEC 61511 (all parts)
	A4 — Environmental- and social-impact assessment	ESIA	Yes	ISO 14001
LCC/Optimization/ Maintenance	B1 — Life cycle cost	LCC	Yes	IEC 60300-3-3 ISO 15663 (all parts)
	B2 — Production availability	PA	Yes	NORSOK Z-016
	B3 — Availability analysis	AA	Yes	NORSOK Z-016
	B4 — Reliability-centred maintenance	RCM	Yes	IEC 60300-3-11 NORSOK Z-008 SAE JA1011 SAE JA1012
	B5 — Spare-parts analysis	SPA	Yes	IEC 60706-4 IEC 60300-3-12
	B6 — Failure mode, effect and criticality analysis	FME	Yes	IEC 60812
	B7 — Statistical reliability data analysis	SDA	Yes	IEC 60300-3-1 IEC 60706-3
	B8 — Structural reliability	STR	Yes	ISO 19900 NORSOK N-001
General	C1 — Manning-resource planning	MRP	Yes	NORSOK Z-008
	C2 — Six sigma	6Σ	Partly	—
	C3 — Fault-tree analysis	FTA	Yes	IEC 61025
	C4 — Markov process analysis	MPA	Yes	IEC 61165
	C5 — PetriNet for Monte Carlo analysis	PNA	Yes	N/A

D.2 Business value of data collection

During the different phases of a development project from concept selection to the operational phase, it is necessary to make a lot of decisions. Many of these decisions are supported by the analysis types listed in Table D.1. These decisions normally have large impact on the project economy and safety, and they should be based on good models and high quality data in order to reach the “best” decisions. Examples of areas where such decisions are taken are shown in Clause 6.

D.3 Data requirements

During development of this International Standard, a GAP analysis was performed to reveal the requirements for data in various types of RAMS analysis. The tables below show a summary of the GAP analyses identifying the required data to be recorded for each analysis type. The data requirements have been prioritized by each analyst using the following scores:

a) normally needed; rated as 1 in Tables D.2 to D.4;

b) needed optionally; rated as 2 in Tables D.2 to D.4.

A shaded row indicates parameters for which data are already covered in this International Standard. Non-shaded rows indicate parameters identified by the GAP-analyses as possible new parameters to be included in future revisions of this International Standard.

Some recommended parameters (e.g. failure rate) cannot be recorded directly, but are required to be calculated from other data. These have been termed “derived reliability parameters” (see Annex C).

The data elements in Tables D.2 and D.4 should be seen in conjunction with data elements shown in Tables 5, 6 and 8.

D.4 Description of the analyses

A summary of analyses and relevant standards will be given in a new International Standard, ISO 20815, under development as of the publication of this International Standard.

Table D.2 — Equipment data to be recorded

Data to be recorded [a]	Type of analysis to be applied to the data recorded																	Comments
	A1	A2	A3	A4	B1	B2	B3	B4	B5	B6	B7	B8	C1	C2	C3	C4	C5	
	QRA	RBI	SIL	ESIA	LCC	PA	AA	RCM	SPA	FME	SDA	STR	MRP	6Σ	FTA	MPA	PNA	
Equipment location	1	1	2	1	1	1	1	1	1	1	1	1	2	1	2	2	2	Corresponds to equipment attributes (equipment tag number) in Table 5
Classification	1	1	2	1	1	1	2	1	1	1	1	1	1	1	2	2	2	Corresponds to classification (equipment class, equipment type and system) in Table 5
Installation data	1	1	2	2	1	1	1	1	1	1	1	1	2	1	2	2	2	Corresponds to various classification data elements in Table 5
Manufacturer's data	1	2	1	2	2	1	2	1	1	2	1	1	2	1	2	2	2	Corresponds to equipment attributes (manufacturer name and model designation) in Table 5
Design characteristics	1	2	2	2	2	1	2	1	1	2	1	1	2	1	2	2	2	—
Surveillance period	1	1	2	1	1	1	1	1	1	1	1	1	2	1	1	2	2	—
Accumulated operating period	1	1	2	1	1	1	1	1	1	1	1	1	2	1	1	2	2	—
Number of demands	1	1	1	2	1	1	1	1	1	1	1	2	2	1	1	2	2	—
Operating mode	1	1	2	1	1	1	1	1	1	1	1	2	2	1	1	2	2	—
Common-cause failure rate	2	2	1	2	2	2	2	2	2	2	2	2	2	2	1	2	2	Derived parameter; can be estimated by extracting data with failure cause "common cause/modec0148
Confidence intervals	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	Derived parameters; see Annex C
Set of spare parts	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	—

[a] For definition of acronyms A1, QRA, etc., see Table D.1.

Table D.3 — Failure data to be recorded

Data to be recorded [a]	Type of analysis to be applied to the data recorded																	Comments
	A1	A2	A3	A4	B1	B2	B3	B4	B5	B6	B7	B8	C1	C2	C3	C4	C5	
	QRA	RBI	SIL	ESIA	LCC	PA	AA	RCM	SPA	FME	SDA	STR	MRP	6Σ	FTA	MPA	PNA	
Equipment unit	1	2	2	2	1	1	1	1	1	1	1	1	1	1	2	2	2	The equipment unit, subunit and MI/component reflect the failed equipment at these levels
Subunit	2	2	2	2	1	2	1	1	1	1	1	2	1	2	2	2	2	—
Maintainable item	2	2	2	2	2	2	1	1	1	1	1	2	1	2	2	2	2	—
Failure mode	1	2	2	1	2	1	1	1	1	1	1	1	1	1	1	1	1	—
Severity class	1	2	2	2	2	1	1	1	1	1	2	1	1	2	2	2	2	Severity class in Table 6 is now renamed to "failure impact on equipment function"
Failure mechanism	2	2	2	2	2	1	2	1	1	1	2	2	1	1	2	2	2	—
Failure cause	2	2	1	2	2	1	2	1	1	1	2	1	2	2	2	2	2	—
Detection method	1	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	—
Impact of failure on operation	2	2	2	1	1	1	1	1	2	1	2	1	1	1	2	2	2	Severity class in Table 6 of main standard now divided into "Failure impact on plant with respect to safety" and "Failure impact on plant with respect to operations"
Failure date	2	2	1	1	2	2	2	2	2	2	1	1	2	2	2	2	2	Essential parameter for all lifetime analyses, e.g. TTT-plot Weibull, etc. Not recommended to discard.
External leakage rate	1	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	Hole sizes and leakage volumes may be additional data requirements in QRA, and interfaces/traceability between accidental event databases and RM databases can be beneficial in some cases.
Failure rate	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	2	Derived value; see Annex C

Table D.3 (*continued*)

Data to be recorded [a]	Type of analysis to be applied to the data recorded																	Comments
	A1	**A2**	**A3**	**A4**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**C1**	**C2**	**C3**	**C4**	**C5**	
	QRA	**RBI**	**SIL**	**ESIA**	**LCC**	**PA**	**AA**	**RCM**	**SPA**	**FME**	**SDA**	**STR**	**MRP**	**6Σ**	**FTA**	**MPA**	**PNA**	
Common-cause failure rate	2	2	2	2	2	2	2	2	2	1	2	2	2	2	1	1	2	Can be identified as one specific failure cause (see C.1.6)
Confidence interval	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	Derived value; see Annex C
Damage mechanism	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	Partly covered in failure mechanism and failure cause
Recommended action to eliminate failure cause	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	—
Spare part	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	—
Probability of failure on demand	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	2	Derived value using selected set of failure modes covered in this International Standard; see also Annex F

[a] For definition of acronyms A1, QRA, etc., see Table D.1.

Table D.4 — Maintenance data to be recorded

Data to be recorded [a]	Type of analysis to be applied to the data recorded																	Comments
	A1	A2	A3	A4	B1	B2	B3	B4	B5	B6	B7	B8	C1	C2	C3	C4	C5	
	QRA	RBI	SIL	ESIA	LCC	PA	AA	RCM	SPA	FME	SDA	STR	MRP	6Σ	FTA	MPA	PNA	
Maintenance category	2	2	2	2	1	2	2	1	1	1	1	2	1	2	2	2	2	—
Maintenance activity	2	2	1	2	1	2	2	1	1	1	1	1	1	2	2	2	2	—
Down time	2	2	1	1	1	1	1	1	1	2	1	2	1	1	1	1	1	—
Active maintenance time	2	2	2	1	1	1	1	1	1	2	1	2	1	2	1	1	1	—
Maintenance man-hours, per discipline	2	2	2	1	1	1	1	1	1	2	2	2	1	2	2	2	2	—
Maintenance man-hours, total	2	2	2	1	1	1	1	1	1	2	2	2	1	2	2	2	2	—
Date of maintenance action	2	2	1	1	2	2	2	2	2	2	2	2	1	2	2	2	2	—
Impact of maintenance on operation	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	New field proposed for this version of ISO 14224 (see Table 8)
Lead time	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	—
Spare part	2	2	2	2	2	2	2	2	1	2	1	2	2	2	2	2	1	—
Turn around time	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	—
Maintenance tools	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	1	—
Repair rate	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	2	Derived value; see Annex C
Test efficiency	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	Derived value defined as the fraction of failures discovered on test
Confidence interval	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	Derived value; see Annex C
Priority of the repair	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	—
Test interval	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	—

[a] For definition of acronyms A1, QRA, etc., see Table D.1.

Annex E
(informative)

Key performance indicators (KPIs) and benchmarking

E.1 General

Reliability and maintenance (RM) data can be used for developing and managing key performance indicators (KPIs) and for compiling Benchmark information. The objective of both Benchmarking and KPIs is to assist in the management of business improvement. This Annex gives some examples of KPIs, which can be extended, as deemed necessary, using the taxonomy classification in Figure 3. (Some of the principles described below are based on References [65] and [66].)

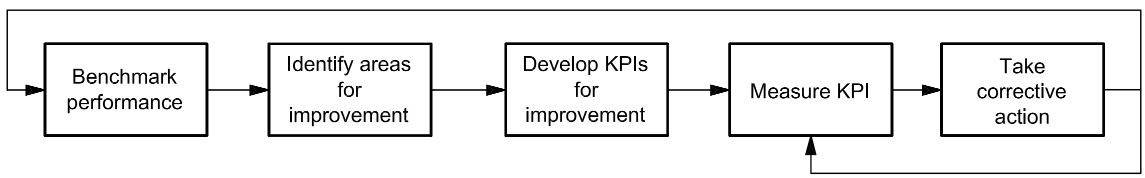


Figure E.1 — Process for using KPIs and benchmarking for improving business performance

The process depicted in Figure E.1 is a simplified version of how KPIs can be developed.

KPIs should be aligned to the objectives of the organization using them and, thus, the organization is free to define the KPIs in whatever way best contributes to the improved performance of the organization.

Improvement is an essential ingredient of successful companies. Performance indicators and benchmarking can be highly effective in identifying and improving areas of greatest opportunity.

For each of the activities in the process represented in Figure E.1 a brief description is given in the list items a) to e).

a) Benchmark performance:

   Use is made of benchmarking data to determine the performance of the organization in key areas. These benchmarks can then be used for comparison, usually external, against organizations in the same or similar industry, or against organizations in different industries that have similar business processes.

   However, measuring performance gaps with the better performers in a peer group is only half the value of benchmarking. Analyses that can be made of differences of plant profile, practices and organization (the causal factors) explaining these performance gaps are also invaluable knowledge for benchmarking study participants.

b) Identify areas for improvement:

   Based on the external benchmarks and the objectives of the organization, areas for improvement can be identified. The areas for improvement are not necessarily the areas where the performance is poor against the other benchmarks, as the areas of poor performance might not correspond with the areas that are critical for the business objectives.

   In addition, benchmarking is a tool to prove the business case for the necessary up-front management commitment and investment of the resources to be mobilized for the successful implementation of a performance-improvement project. Benchmarking can be conducted inside the company, within the industry or across industries (as long as the same business process is being dealt with). In the former case, a “best of the best” networking-type process is effective in performance upgrades. Use of benchmarking within an industry allows a company to recalibrate its performance targets and to reexamine the justification of historic policies and practices in the light of those of the better industry performers.

c) Develop KPIs for improvement

In the areas where improvement is desired, KPIs should be developed. Each KPI should have a targeted performance level. The KPI and target should, where possible, be specific, measurable, achievable (but require stretch), realistic and time-based (i.e. can track performance improvement over time). The frequency at which the KPI is measured is determined by a realistic expectation of the amount of time required for any corrective action to have an impact on the performance level. Thus, one does not want to measure and analyse the parameters when there is no change from one measurement to the next, but it is necessary to balance this against not measuring often enough, resulting in the situation that parameters can be out of control for long periods. In addition, it is necessary to consider the time, cost and resources needed to develop, maintain and manage the KPIs, as this also determines how many robust KPIs can be used.

d) Measure KPI

The KPI should be measured and reported, where possible, within existing systems. In addition to measuring the KPI, it is necessary to compare the result against the target and to identify any causes for deviations.

e) Take corrective action

The causes for deviations should be addressed and corrective actions performed, and the process should be repeated many times.

E.2 Alignment to business objectives

E.2.1 General

KPIs are aligned to the organization's objectives for the facility (or operations) and improvements are identified and implemented in order to achieve the organization's planned objectives. The alignment of KPIs to the business objectives can be represented as shown in Figure E.2.

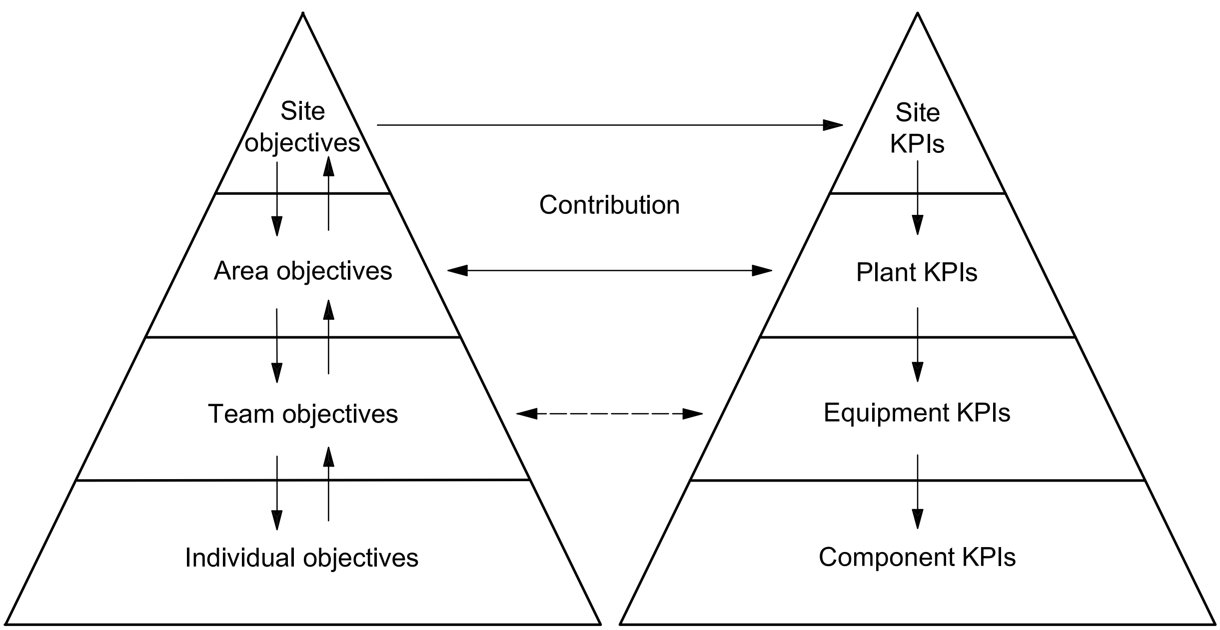


Figure E.2 — Alignment of KPIs to the business objectives

E.2.2 Differences between benchmarks and KPIs

The differences between benchmarks and KPIs are rather subtle. The major difference between a KPI and a benchmark is related to the usage. In effect, a KPI is used for managing an improvement on an ongoing basis and for determining the progress towards a predetermined target. A benchmark is used as a one-off, or low-frequency, event to determine the present performance levels against other organizations involved in the same process.

The table below provides an overview of the major differences.

Table E.1 — KPIs versus benchmarking

Characteristic	KPIs	Benchmark
Purpose	Track progress and effectiveness of management	Identify gaps in present performance level
Frequency	Reasonable expectation of change occurring	One-off/infrequent
Source of data	Internal systems	External sources
Level of control	Immediate to short-term	Longer-term
Number of influencing parameters	One or few	Many
Accuracy	Interested in trend	Interested in absolute value
Targets	Set, based on objectives	No target

E.3 Using benchmarking

E.3.1 Benchmarking principles

Benchmarking helps determine the reference point and standard from which world-class performance can be measured. The process of benchmarking can be broken down into three steps.

a) Evaluate and measure your own operation or specific process to identify weaknesses and strengths using the data collected in accordance with Clauses 7, 8, and 9. Choose a set of KPIs (see Table E.3). Align them to the organisation's objectives for the facility (or operations), identify areas for improvement, collect and analyse the data and implement improvements in order to achieve the organization's planned objectives.

b) Initiate a benchmarking study and document processes by referring to peer groups (see E.3.7) that are more productive or efficient than yours.

c) Identify best practices and implement them.

E.3.2 General

Benchmarking is most useful where there is an existing statistically significant sample population. It is necessary that those individuals involved in the exchange of information understand the inherent limitations imposed by the data they collect and the database where it is stored. For example, depending on the type, load, speed, mounting method, lubricant formulations, contamination levels, etc., a given bearing can last anywhere from 18 months to 40 years; therefore, knowing the average MTTF of all bearings in a given plant would be of only limited usefulness to a reliability engineer. For company A, who is operating with a MTTF of 18 years, to approach the reliability of company B who is operating with a MTTF of 40 years, it is necessary that there be an underlying knowledge of all of the differences in the design and operating conditions. The development of best practices cannot occur where there is not already a sound knowledge of engineering principles.

A frequent misuse of benchmarking is to consider it merely as a scorecard, that is to say, for looking backward to measure past success or failure, rather than as a map to guide forward progress to achieve goals and continue improvement.

E.3.3 Taxonomy level

Benchmarking can occur at the plant, process-unit, equipment-class, subunit or maintainable-item level. Key performance indicators for each hierarchical level (see Figure 3) provide different information. If a KPI set at one taxonomic level highlights a weakness, then the next lower taxonomy level of indicators should give further definition and clarification to the causes of the weakness. Benchmarking initiatives that rank plant or process-unit performance often look at relative levels of reliability, staffing, utilization and operating cost. KPIs for hierarchies at the level of equipment class and below include parameters that principally focus on the incidence of failure and repair. Where a “best practice” for continuous improvement on a process unit can, for example, involve the implementation of reliability-centred maintenance, the best practice at a lower hierarchy can be the implementation of more rigorous design specifications, balance or grouting requirements, etc.

E.3.4 Choice of benchmarks

KPIs that together can measure overall reliability and maintenance effectiveness within this International Standard are the following:

a) equipment-class, subunit and maintainable-item MTBF (see C.5.3);

b) availability (see C.2);

c) cost of production losses caused by unreliability and by maintenance activity;

d) direct costs (labour, contracts and materials) of maintenance work;

e) costs of maintenance support staff and of maintenance consumables.

E.3.5 Alignment of benchmark and KPI parameters across peer groups

It is important that all benchmarking contributors supply a complete set of key performance indicators that are tied to the same frame of reference. To do this, the more successful benchmarking initiatives are the following.

— Identify those elements that most affect the commercial success of the business.

— Employ generic terms for each element: the descriptions of boundaries and the collection of data should be chosen in accordance with this International Standard.

— Provide sufficiently detailed definitions to promote and enable a consistent response by each participant and ensure that all performance data apply to the same time frame.

E.3.6 Benefits of benchmarking

Benchmarking may be used to provide continuous improvement to key work-process elements of plant maintenance and reliability including

a) strategy/leadership,

b) maintenance work management,

c) predictive and preventive maintenance,

d) computerized maintenance management information systems (CMMIS),

e) training,

f) materials management,

g) contractor management,

h) reliability improvement,

i) competitive technology/benchmarking.

Confidential industry benchmarking of the reliability and maintenance function has become an essential tool for performance-improvement programmes. It has the primary objective of providing companies with useable comparative data that, at a level of detail that is actionable, helps them focus on credible opportunity targets to improve their performance.

To gain credibility and acceptance, it is necessary that these opportunity targets be seen as realistic, that is, they are understood by, and credible to, those responsible for achieving them.

Users of this International Standard are cautioned against focusing on only one or two of the KPIs and neglecting others.

E.3.7 Selection of peer groups

E.3.7.1 General

The selection of the peer group against which a participating plant compares its performance data is important. If this peer-group selection is well made, personnel in the plant will have confidence that it has the same performance opportunity as the better-performing plants in the group. Furthermore, use of a suitable method of analysis of physical causal factors, of plant characteristics and of maintenance practices within the group provide explanations of variations in performance that have greater validity.

When a plant's performance is seen to be poor compared with its peer group, the gap can be due both to differences in the plant's physical features (even within the same peer group) and also to differences in the practices and organization of the site. The characteristics of both categories of causal factor should be benchmarked using a suitable method of benchmarking, so that the relative weight of each can be judged and realistic targets set.

E.3.7.2 Selection of peer groups

A peer group's distinguishing factor is a feature of a plant that affects one or several aspects of performance and is common and intrinsic to the group of plants and also that a plant cannot change in the short/medium term.

The two peer-group distinguishing factors that have been found most significant in studies on reliability and maintenance are

— process family: for reasons of equipment types, process severity (corrosivity, toxicity, etc.) and maintenance complexity;

— geographic region: for reasons of prevailing labour hourly costs, employment and contracting practices, safety and environment-protection norms, climate, management culture and industrialization level of the region.

E.4 Examples of benchmarks and KPIs using RM data

There are a variety of benchmarks and KPIs available. Measurement of costs and failure rates provides indications of trends in the effectiveness of maintenance and reliability programmes. KPIs can also be used to gauge an organization's adherence to programmes and procedures by recording compliance with preventive or predictive schedules.

No single KPI provides the complete picture and it is, therefore, necessary to define a basket of KPIs that together indicate progress and trends in the reliable operation of plant and equipment. Trends can be shown over a period of time and can require some special attention to allow for periodical as well as accumulative reporting, for example, "last-two-years average" in the latter case.

Table E.3 gives examples of KPIs that can be developed making use of RM or other reliability-related data. Other/more KPIs can be useful depending on industry and application. In Table E.3, reference is made to the same taxonomic levels (see 8.2) as are also summarized in Table E.2.

Table E.2 — Taxonomic levels

Main category	Taxonomic level	Taxonomic hierarchy	Use/location
Use/location	1	Industry	Type of main industry
	2	Business category	Type of business or processing stream
	3	Installation category	Type of facility
	4	Plant/unit category	Type of plant/unit
	5	Section/system	Main section/system of the plant
Equipment subdivision	6	Equipment (class/unit)	Class of similar equipment units. Each equipment class contains similar pieces of equipment (e.g. compressors).
	7	Subunit	A subsystem necessary for the equipment unit to function.
	8	Component/maintainable item	The group of parts of the equipment unit that are commonly maintained (repaired/restored) as a whole
	9	Part [a]	A single piece of equipment

[a] While this level may be useful in some cases, it is considered optional in this International Standard.

Table E.3 — Examples of KPIs [a]

KPI parameter	Relevant taxonomic hierarchies [b]	Units	Explanation and calculation	Purpose and value	Involved personnel
1) MTBF Mean time between failures	6 to 8	Time (hours, days, weeks, months, years) For different classes or types of equipment Trends are shown over a period of time	Indicates the average time between failure for components, equipment or units. Definition of failure is given in Annex C (general) and Annex F (safety equipment). Use of MTBF implies that down time/repair is included. Guidelines for calculating MTBF (and MTTF) are given in Annex C.	Indication of increasing or decreasing reliability of components, equipment or unit/plant	Equipment subject-matter experts (SMEs) Reliability engineers (REs) Middle management (MM) Inspection

Table E.3 (*continued*)

KPI parameter	Relevant taxonomic hierarchies [b]	Units	Explanation and calculation	Purpose and value	Involved personnel
2) MTTF Mean time to failure	6 to 8	As above	Is similar to MTBF, but does not take into account the down time/repair time. MTBF is the sum of MTTR and MTTF. MTTF equals the reciprocal of the failure rate.	As above Note that MTTF, in principle, concerns only the first time to failure of a new item before any maintenance task has been performed	As above
3) MTBR Mean time between repairs	6 to 8	Time (hours, days, weeks, months, years) For different classes or types of equipment Trends are shown over a period of time	Indicates the average time between repairs for components, equipment or units. Although a failure typically results in a repair, this is not always the case. Repairs (e.g. major overhauls) can be undertaken on a time basis independent of failure. Calculation based on total up time between repairs divided by number of repairs over a specified time period or to date. Hence, MTBR can differ from MTBF. For subsea equipment, one may rename the KPI to “Mean time between interventions” (MTBI).	Indication of increasing or decreasing reliability of components or equipment within a plant/unit	SMEs REs MM Maintenance Inspection
4) MTTR Mean time to repair	6 to 8	Time usually in hours or days. For different classes or types of equipment Trends are shown over a period of time	The time taken to repair a component, equipment, system or unit. Total out-of-service time divided by the number of repairs. It is necessary to define the out-of-service parameters. It is necessary that MTTR follow timeline principles given in Figure 4. One may introduce MDT (Mean down time) if it is also of interest to monitor the preparation and delay times.	Indication of the productivity and work content of repair activities	SMEs and REs Maintenance
5) Worst actors List of frequently failed equipment	6 to 8	List of equipment List of frequent failure modes Frequency of failure	Clear definition of which failure types are covered is necessary (see Annex C). List of most frequently failed equipment can also be generated by frequency of repairs. Restructure as to plant impact.	Provides focus for reliability management and root cause failure analysis (RCFA) Product/quality development	As above

Table E.3 (*continued*)

KPI parameter	Relevant taxonomic hierarchies [b]	Units	Explanation and calculation	Purpose and value	Involved personnel
6) A_O Operational availability	6	% time available for operation of the equipment when all maintenance (corrective and preventive) is included in the down time	Normally on equipment-unit level.	Shows trend in equipment availability when both corrective and preventive maintenance is covered Input for production planning	SME and REs MM Operations Maintenance Inspection
7) A_T Technical availability	6	% time available for operation of the equipment when corrective maintenance only is included in the down time	Normally on equipment-unit level.	The key technical-availability indicator Shows trend in equipment availability focusing on intrinsic reliability (see C.2)	SM and MM Operations Maintenance Inspection SMEs and REs
8) Preventive maintenance (PM) man-hours ratio	4 to 6	% of total maintenance man-hours spent on PM (not including modifications)	Total PM work order (WO) man-hours divided by total WO man-hours, by equipment classification or types.	Indication of amount of proactive preventive maintenance work	SMEs and REs Operations Maintenance
9) Corrective maintenance man-hours ratio	4 to 6	% of total maintenance man-hours spent on corrective maintenance	Total CM WO man-hours divided by total WO man-hours, by equipment classification or types.	Indication of amount of corrective maintenance work	SMEs and REs Operations Maintenance
10) PMs overdue	4 to 6	Number or % of PM WOs overdue by category	Count of outstanding PM WOs by equipment classification or as a % of total PM WOs. One may also select only safety-critical equipment or production-critical equipment to differentiate into groups.	Indication of outstanding PM backlog	Operations Maintenance
11) Predictive maintenance (PdM) complete Completion of predictive maintenance (e.g. inspections, testing, periodic condition monitoring)	4 to 6	Number or % PdM data-collection activities completed	Define which predictive-maintenance activities to cover, individually or all. For example, number of data points, routes or equipment that have PdM NDT data collection carried out divided by total data points, routes or equipment, over a specified period of time. (Vibration analysis data, thickness readings, infrared scans, motor performance analysis).	Condition monitoring management	SMEs and REs Operations Maintenance Inspection

Table E.3 (*continued*)

KPI parameter	Relevant taxonomic hierarchies [b]	Units	Explanation and calculation	Purpose and value	Involved personnel
12) Predictive maintenance (PdM) overdue	4 to 6	Number or % overdue predictive maintenance (PdM) activities	Define which predictive maintenance activities to cover, individually or all. Count or % of PdM NDT data points, routes or equipment that are outstanding over a specified time period of time.	Indicates backlog of PdM type of activities, e.g. NDT	SMEs and REs Operations Maintenance Inspection
13) Turn-around duration	4	Time, usually in days	It is necessary to include run-down and start-up in connection with turn-arounds. Prolonged turn-arounds due to modifications may be separated out in order not to disturb comparison with year-to-year requirements for major maintenance.	Maintenance planning Modification opportunities Outage planning Production planning	Operations Maintenance
14) Time between turn-arounds	4 to 5	Measured on annual basis (number of months, years)	Time between turn-arounds.	As above	As above
15) Repair rework ratio	6	% of repairs where rework is required following repair	Number of WOs that are reworked divided by total number of WOs. Classified by equipment type. May be split into preventive and corrective maintenance.	Indication of work quality and productivity	REs Operations Maintenance
16) Repair workshop cycle time	6 to 8	Time, usually in hours or days	The time taken from when failed item is received at repair shop until it is ready for use again	Repair management	Maintenance
17) Total maintenance cost	4 to 6	Per plant, section or equipment for a given period (e.g. annually)	Total cost for both corrective and preventive maintenance including spare parts. Does not include costs related to down time with respect to lost production.	Trend analysis over a period of time	Plant management Operations Maintenance
18) Cost of repairs per work order	4 to 6	Cost by different equipment types for various geographical locations, units or plants.	The cost of repair to equipment as represented by the costs collected against equipment work orders. Typically, it includes labour (company and/or contract), materials and equipment hire. Overhead can also be included.	Trend in repair cost over a period of time Identification of worst actors by repair cost and/or equipment type	As above

[a] Other/more KPIs can be useful depending on industry and application.

[b] See Table E.2.

Annex F
(informative)

Classification and definition of safety-critical failures

F.1 General

The purpose of this Annex is to make the user of this International Standard aware of some specific definitions and classifications applied for safety-critical equipment. The IEC has developed the safety standards IEC 61508 (all parts) and IEC 61511 (all parts), which have been implemented by many industries including the natural gas, petroleum and petrochemical industries. The general principles described in IEC 61508 (all parts) and IEC 61511 (all parts) have been further developed by national initiatives into guidelines and analysing methods for use in the petroleum industry, for example Reference [68].

F.2 Classification of failures of instrumented safety systems

F.2.1 General definitions

Instrumented safety systems are items that exert great influence on a plant's safety and integrity, and failure of these systems is, therefore, dealt with in a more dedicated way than for other equipment. As these systems are frequently “dormant” in normal use and expected to function when called upon, it is of the utmost importance to reveal any hidden failure before the function is called upon.

Further, it is also of prime interest to know the consequences of a failure of these systems with regard to impact on safety.

Some general definitions of commonly used terms in this area are given below.

a) Dangerous failures (or unsafe failures) are failures that have the potential to prevent the safety system from achieving its safety function when there is a true demand. A single dangerous failure is generally not sufficient to prevent a redundant safety system from performing its safety function (e.g. two dangerous failures are needed for a 2-out-of-3 voting system).

b) Non-dangerous failures are failures that do not have an immediate effect on the safety function, i.e. do not prevent the safety system from achieving its dafety function or fo not cause spurious trips;

c) Safe failures (spurious trip failures) are failures that have the potential to trigger the safety function when it is not needed. A single safe failure is generally not sufficient to actually trip unexpectedly a redundant safety system (e.g. 2 safe failures are needed for a 2-out-of-3 voting system).

d) The fail-safe system is based on a design which has reduced the effect of potentially dangerous failures as far as practically possible.

e) Non-fail safe is a safety system where there remains the possibility of dangerous failures.

f) Revealed failures are failures that are detected by the system itself as soon as they occur. Failures detected by the diagnostic test of a logic solver are also considered as revealed failures.

g) Hidden failures (dormant) are failures that are not detected by themselves and that need a specific action (e.g. periodic test) to be identified.

F.2.2 Definitions from IEC 61508 (all parts) and IEC 61511 (all parts)

IEC 61508 (all parts) introduces a failure classification, as shown in Table F.1, that is adapted to instrumented safety systems.

Table F.1 — Failure classification according to IEC 61508 (all parts)

Failures				
Random hardware failures				Systematic failures
Dangerous		Safe		
Detected (DD)	Undetected (DU)	Detected (SD)	Undetected (SU)	

Here the failures are first split into the two categories:

— random hardware failures (physical);

— systematic failures (non-physical).

The random hardware failures of components are further split into the failure modes:

a) dangerous detected (DD): dangerous detected failures, i.e. failures detected either by the automatic self-test or by personnel;

b) dangerous undetected (DU): dangerous undetected failures, i.e. failures detected neither by the automatic self-test nor the personnel (control-room operator or maintenance personnel). This failure type represents safety-critical failures detected only by trying to activate the function by a function test or by function demand during normal operation. This failure contributes to the probability-of-failure-on-demand (PFD) of the component/system (“loss of safety”);

c) safe detected (SD): safe failures (i.e. not causing loss of safety) “immediately” detected by the automatic self-test;

d) safe undetected (SU): safe failures not detected by the automatic self-test.

When collecting data for safety systems, two categories of failures/events should be emphasised:

— common-cause failures (see C.1.6);

NOTE IEC 61511 (all parts) contains definitions of common-cause/common-mode failures that are specific for instrumented safety systems.

— test interval (periodic) for identifying dangerous undetected (DU) failures.

When a safety/reliability study is performed as described in IEC 61508 (all parts), it is important that the relevant failure modes be classified according to Table F.1. This supports the applicability of this International Standard to the specific analyses as described in IEC 61508 (all parts).

When recording and/or analysing failures for instrumented safety systems, it is recommended to consult IEC 61508 (all parts) and IEC 61511 (all parts) and additional national guidelines as deemed relevant.

F.3 Definition of critical/dangerous failures for safety systems

Some typical dangerous failures, mostly detectable, (see Table F.1) for some common safety systems/components are given in Table F.2. The use by operators of the standard definitions given in Table F.2 would facilitate comparison and benchmarking to enhance safety levels in the industry.

Table F.2 — Definitions of critical/dangerous failures for some safety systems/components

System/ component	Equipment class	Recommended failure definitions	Applicable failure modes [a]
Fire detection (smoke, flame, heat)	Fire and gas detectors [b]	**Detector** Fire and gas logic does not receive signal from detector, when detector is tested.	NOO, LOO, FTF
Fire detection (manual call point)	Input devices [b]	**Manual call point** Fire and gas logic does not receive a signal from the pushbutton when activated.	NOO, LOO, FTF
Gas detection	Fire and gas detectors [b]	**Detector (catalytic, optical point, H_2S and H_2)** Fire and gas logic does not receive signal equivalent to upper alarm limit when testing with prescribed test gas.	NOO, LOO
		Detector (optical line) Fire and gas logic does not receive signal equivalent to upper alarm limit when testing with prescribed test filter.	NOO, LOO
		Detector (acoustic) Fire and gas logic does not receive signal when tested.	NOO, LOO
Active fire protection (deluge)	Valves [b]	**Deluge valve** Deluge valve fails to open when tested.	FTO, DOP
	Nozzles	**Nozzle** More than 3 % of the nozzles are plugged/choked. Failures are reported per skid/loop.	PLU
Active fire protection (fire pump)	Pumps [b]	**Function** Fire pump fails to start upon signal.	FTS
		Capacity Fire pump delivers less than 90 % of design capacity.	LOO
Active fire protection (CO_2/Inergen)	Valves [b]	**Function** Release valve fails to open upon test.	FTO
Active fire protection (water mist)	Valves [b]	**Function** Release valve fails to open upon test.	FTO
Active fire protection (AFFF)	Not defined	**Function** Water/foam does not reach fire area upon test.	—
Depressurization valves (blowdown)	Valves [b]	**Valve** Valve fails to open upon signal or within specified time limit.	FTO, DOP
ESD (sectioning valves defined as safety-critical)	Valves [b]	**Function** Valve fails to close upon signal or within a specified time limit.	FTC, DOP
		Leakage Internal leakage higher than specified value.	LCP, INL

Table F.2 (*continued*)

System/ component	Equipment class	Recommended failure definitions	Applicable failure modes [a]
ESD (well isolation)	Xmas tree [b]	**Function** Valve fails to close upon signal or within a specified time limit.	FTC, DOP
		Leakage Internal leakage higher than specified value at first test.	LCP, INL
ESD (downhole safety valve)	Well completion equipment [b]	**Function** Valve fails to close upon signal or within a specified time limit.	FTC, DOP
		Leakage Internal leakage higher than specified value.	INL, LCP
ESD (riser)	Valves [b]	**Function** Valve fails to close upon signal or within a specified time limit.	FTC, DOP
		Leakage Internal leakage higher than specified value.	INL, LCP
ESD (push button)	Input devices [b]	**Function** The ESD logic does not receive a signal from the push button when activated.	NOO, LOO, FTF
Process safety (sectioning valves)	Valves [b]	**Function** Valve fails to close upon signal or within a specified time.	FTC, DOP, LCP, INL
Process safety (PSV)	Valves	**Function** Valve fails to open at the lesser of 120 % of set pressure or at 5 MPa (50 bar) above set pressure.	FTO
Input devices (pressure, temperature, level, flow, etc.)	Input devices [b]	**Function** Sensor does not give signal or gives erroneous signal (exceeding predefined acceptance limits).	NOO, ERO
Emergency power (emergency generator)	Electric Generator [b]	**Function** Emergency generator fails to start or gives wrong voltage upon start.	FTS, LOO
Emergency power (central UPS for SIS)	Uninterruptible power supply [b]	**Function** Battery capacity too low.	LOC
Emergency power (UPS for emergency lighting)	Uninterruptible power supply [b]	**Function** Battery capacity too low. For emergency lights: When one or more emergency lights within one area or circuit fails to provide lighting for minimum 30 min.	LOC
Fire damper	Not defined [b]	**Function** Damper fails to close upon signal.	—
Ballast system (valves)	Valves [b]	**Function** Valve fails to operate on signal.	FTO, FTC, DOP
Ballast system (pumps)	Pumps [b]	**Function** Pump fails to start/stop on signal.	FTS

[a] See Tables B.6 to B.12 for definition of acrynoms.

[b] IEC 61508 (all parts) and/or IEC 61511 is/are applicable.

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