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Petroleum and natural gas industries — Well integrity

Part 1: Life cycle governance (ISO 16530-1:2017)



National foreword

This British Standard is the UK implementation of EN ISO 16530-1:2017.

The UK participation in its preparation was entrusted to Technical Committee PSE/17/-/4, Drilling and production equipment for petroleum and natural gas industries.

A list of organizations represented on this committee can be obtained on request to its secretary.

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English Version

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1: Life cycle governance (ISO 16530-1:2017)**

Pétrole et industries du gaz naturel - Intégrité du puits
- Partie 1: Gouvernance du cycle de vie (ISO 16530-
1:2017)

Erdöl- und Erdgasindustrie - Bohrungsintegrität - Teil
1: Leitlinien zur Lebenszykluslenkung (ISO 16530-
1:2017)

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European foreword

This document (EN ISO 16530-1:2017) has been prepared by Technical Committee ISO/TC 67 "Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries" in collaboration with Technical Committee CEN/TC 12 "Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries" the secretariat of which is held by NEN.

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The text of ISO 16530-1:2017 has been approved by CEN as EN ISO 16530-1:2017 without any modification.

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Foreword

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

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 4, *Drilling and production equipment*.

A list of all parts in the ISO 16530 series can be found on the ISO website.

Introduction

This document has been developed by oil and gas producing operating companies and is intended for use in the petroleum and natural gas industries worldwide. This document is intended to provide guidance to the well operator on managing well integrity throughout the well life cycle. Furthermore, this document addresses the minimum compliance requirements for the well operator in order to claim conformity with this document.

It is necessary that users of this document are aware that requirements over and above those outlined herein may be needed for individual applications.

This document addresses the process of managing well integrity during each of the well life cycle phases, namely: basis of design; design; construction; operation; intervention (including work-over) and abandonment.

The following terminology, in line with ISO/IEC Directives, is used in this document:

- a) The term “shall” denotes a minimum requirement in order to conform to this document.
- b) The term “should” denotes a recommendation or that which is advised but not required in order to conform to this document.
- c) The term “may” is used to indicate a course of action permissible within the limits of this document.
- d) The term “can” is used to express possibility or capability.

In addition, the term “consider” is used to indicate a suggestion or to advise.

The phases of a well life cycle have separate and distinct requirements for achieving well integrity management objectives, but all phases have common elements and techniques. [Clause 5](#) discusses these common elements and techniques. [Clauses 6](#) to [11](#) discuss each individual phase and its requirements. Additionally, each clause highlights the aspects to be considered within the common elements and techniques as applicable to that phase.

[Figure 1](#) summarizes the elements which are common among phases, and the relation between the phases.

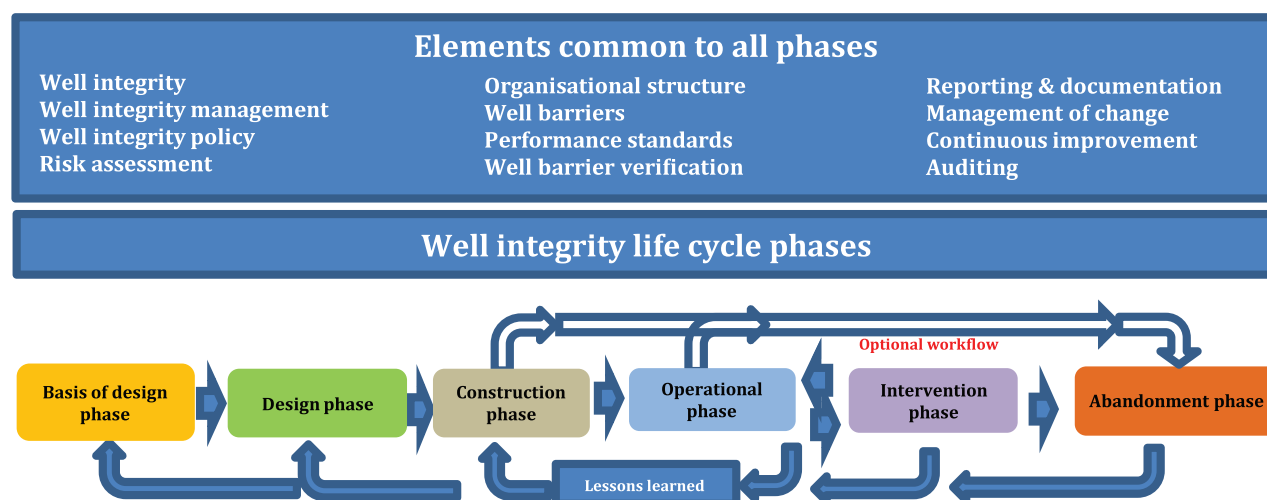


Figure 1 — Elements common to the phases of well integrity management

Petroleum and natural gas industries — Well integrity —

Part 1: Life cycle governance

1 Scope

This document is applicable to all wells that are operated by the petroleum and natural gas industry. This document is applicable to any well, or group of wells, regardless of their age, location (including onshore, subsea and offshore wells) or type (e.g. naturally flowing, artificial lift, injection wells).

This document is intended to assist the petroleum and natural gas industry to effectively manage well integrity during the well life cycle by providing:

- minimum requirements to ensure management of well integrity; and
- recommendations and techniques that well operators can apply in a scalable manner based on a well's specific risk characteristics.

Assuring well integrity comprises two main building blocks: the first is to ensure well integrity during well design and construction, and the second is to manage well integrity throughout the remaining well life thereafter.

This document addresses each stage of the well life cycle, as defined by the six phases in a) to f), and describes the deliverables between each phase within a Well Integrity Management system.

- a) The “**Basis of Design Phase**” identifies the probable safety and environmental exposure to surface and subsurface hazards and risks that can be encountered during the well life cycle. Once identified, these hazards and risks are assessed such that control methods of design and operation can be developed in subsequent phases of the well life cycle.
- b) The “**Design Phase**” identifies the controls that are to be incorporated into the well design, such that appropriate barriers can be established to manage the identified safety and environmental hazards. The design addresses the expected, or forecasted, changes during the well life cycle and ensures that the required barriers in the well's design are based on risk exposure to people and the environment.
- c) The “**Construction Phase**” defines the required or recommended elements to be constructed (including rework/repair) and verification tasks to be performed in order to achieve the intended design. It addresses any variations from the design which require a revalidation against the identified hazards and risks.
- d) The “**Operational Phase**” defines the requirements or recommendations and methods for managing well integrity during operation.
- e) The “**Intervention Phase**” (including work-over) defines the minimum requirements or recommendations for assessing well barriers prior to, and after, any well intervention that involves breaking the established well barrier containment system.
- f) The “**Abandonment Phase**” defines the requirements or recommendations for permanently abandoning a well.

The six phases of the well life cycle, as defined in this Scope, and their interrelationships, are illustrated in [Figure 1](#) in the Introduction.

This document is not applicable to well control. Well control refers to activities implemented to prevent or mitigate unintentional release of formation fluids from the well to its surroundings during drilling, completion, intervention and well abandonment operations, and involves dynamic elements, i.e. BOPs, mud pumps, mud systems, etc.

This document is not applicable to wellbore integrity, sometimes referred to as “borehole stability”. Wellbore integrity is the capacity of the drilled open hole to maintain its shape and remain intact after having been drilled.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1

A-annulus

designation of the annulus between production tubing and production casing

[SOURCE: API RP 90, modified]

3.2

acceptance criteria

specified limits of acceptability applied to process, service, or product characteristics

3.3

as low as reasonably practicable

ALARP

implementation of risk-reducing measures until the cost (including time, capital costs or other resources/assets) of further risk reduction is disproportional to the potential risk reducing effect achieved by implementing any additional measure

Note 1 to entry: See UK HSE. [27]

3.4

ambient pressure

pressure external to the wellhead

Note 1 to entry: In the case of a surface wellhead, the pressure is 0 kPa (0 psig). In the case of a subsea wellhead, it is equal to the hydrostatic pressure of seawater at the depth of the subsea wellhead.

[SOURCE: API RP 90, modified]

3.5

anomaly

condition that differs from what is expected or typical, or which differs from that predicted by a theoretical model

3.6

availability

extent to which the system/structure/equipment is capable of retaining its functional integrity

3.7

B-annulus

designation of an annulus between the production casing and the next outer casing

Note 1 to entry: The letter designation continues in sequence for each outer annulus space encountered between casing strings, up to and including the surface casing and conductor casing strings.

[SOURCE: API RP 90, modified]

3.8

breaking of containment

controlled entry into the containment system of integrity or barrier

3.9

casing liner

casing string with its uppermost point inside a previous casing string and not in the wellhead

3.10

competence

ability of an individual to perform a job properly through a combination of training, demonstrated skills, accumulated experience and personal attributes

3.11

component

mechanical part, including cement, used in the construction of a well

3.12

conductor casing

component that provides structural support for the well, wellhead and completion equipment, and often used for hole stability for initial drilling operations

Note 1 to entry: This casing string is not designed for pressure containment, but upon completion of the well it might have a casing head; therefore, it can be capable of containing low annulus pressures. For subsea and hybrid wells, the low-pressure subsea wellhead is normally installed on this casing string.

[SOURCE: API RP 90, modified]

3.13

consequence

expected effect of an event that occurs

3.14

containment

preventing release of fluid

3.15

deep-set

close to, or at, the cap rock of a reservoir or a depth where it is possible to achieve an overbalance pressure with an hydrostatic column to counter act the maximum anticipated pressure from below

3.16

deviation

departure from a standard

3.17

dispensation

approval to operate with a deviation from a requirement

3.18
extended leak off test
XLOT

application of pressure by superimposing a surface pressure on a fluid column in order to determine the pressure at which a fracture propagates into the exposed formation and also establishes the fracture closure pressure

3.19
failure
loss of ability to perform as required

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

3.21
failure modes and effects analysis
FMEA
technique which identifies failure modes and mechanisms, and their effects

3.22
failure mode, effects, and criticality analysis
FMECA
analysis usually performed after an *FMEA* ([3.21](#)) which can be based on the probability that the failure mode will result in system failure, or the level of risk associated with the failure mode, or a risk's priority

3.23
fault
abnormal, undesirable state of a system element induced by the presence of an improper command or absence of a proper one, or by a failure

Note 1 to entry: All failures cause faults; not all faults are caused by failure.

Note 2 to entry: System elements can include, for example, an entire subsystem, an assembly, or a component.

3.24
flow-wetted
<surface> coming into direct contact with the dynamic movement of well fluids in the flow stream
[SOURCE: API Spec 11D1]

3.25
fluid
substance that has no fixed shape and yields easily to external pressure

Note 1 to entry: A fluid can be either a gas or a liquid.

3.26
formation integrity test
FIT
application of pressure by superimposing a surface pressure on a fluid column in order to determine ability of a subsurface zone to withstand a certain pressure

3.27
formation strength
pressure that the formation can withstand

3.28

functionality

operational requirements of the system/structure/equipment in order to establish and maintain integrity

3.29

hazard

source of potential harm or a situation with a potential to cause loss (any negative consequence)

3.30

hybrid well

well drilled with a subsea wellhead and completed with a surface casing head, a surface tubing head, a surface tubing hanger and a surface tree

Note 1 to entry: A hybrid well can have either one (single-bore production riser) casing string or two (dual-bore production riser) casing strings brought up from the subsea wellhead and tied back to the surface equipment. These wells are typically located on floating production platforms, e.g. tension-leg platforms (TLPs).

[SOURCE: API RP 90, modified]

3.31

impairment

state of diminished ability to perform a function, without having yet failed

3.32

imposed annulus pressure

annulus pressure that is imposed for purposes such as gas lift, water injection, thermal insulation, etc.

[SOURCE: API RP 90, modified]

3.33

inflow testing

leak test of well barrier element by creating a differential pressure and observing for pressure change on the low pressure side

Note 1 to entry: See also [5.9.3.3](#).

3.34

intervention

operation to enter the well which requires breaking containment of an existing well barrier

3.35

leak

unintended and undesired movement of fluids

3.36

leak off test

LOT

application of pressure by superimposing a surface pressure on a fluid column in order to determine the pressure at which the exposed formation accepts whole fluid

[SOURCE: API RP 59, modified]

3.37

major accident

incident such as an explosion, fire, loss of well control, release of oil, gas or dangerous substances causing, or with significant potential to cause, damage to facilities, serious personal injury or widespread persistent degradation of the environment

3.38
major accident hazard
MAH

hazard with a potential for causing a *major accident* ([3.37](#))

3.39
maximum allowable annulus surface pressure
MAASP

p_{MAASP}

greatest pressure that an annulus can contain, as measured at the wellhead, without compromising the integrity of any element of that annulus, including any exposed open-hole formations

3.40
monitoring

observation of the operating parameters of a well, via instrumentation, on a predefined frequency to ensure that they remain within their operating limits

Note 1 to entry: Examples of well operating parameters include pressures, temperatures, flow rates.

3.41
operated well

well for which the well operator has control and management of operations

3.42
operating limits

set of established criteria, or limits, beyond which a device or process should not be operated

3.43
outflow

fluids that flow out of one place to another, typically out of a well

3.44
performance standard

statement, which can be expressed in qualitative or quantitative terms, of the performance required of a system or item of equipment in order for it to satisfactorily fulfil its purpose

3.45
pressure test

application of pressure to a piece of equipment or a system to verify the pressure containment capability for the equipment or system

3.46
primary well barrier

first set of well barrier elements that prevent flow from a source of inflow

3.47
production casing

innermost string of casing in the well

[SOURCE: API RP 90, modified]

3.48
production riser

casing strings rising from the seafloor to the wellhead (fixed platforms) or casing strings attached to the subsea wellhead rising from seafloor to a surface wellhead (hybrid wells)

3.49

production string completion string

string consisting primarily of production tubing, but also including additional components such as the surface-controlled subsurface safety valve (SCSSV), gas-lift mandrels, chemical injection and instrument ports, landing nipples, and packer or packer seal assemblies

Note 1 to entry: The production string is run inside the production casing and is used to conduct production fluids to the surface.

[SOURCE: API RP 90, modified]

3.50

production tubing

tubing that is run inside the production casing and used to convey produced fluids from the hydrocarbon-bearing formation to the surface

Note 1 to entry: Tubing can also be used for injection. In some hybrid wells, for example, tubing is used as a conduit for gas for artificial lift below a mudline pack-off tubing hanger to isolate the gas-lift pressure from the production riser.

[SOURCE: API RP 90, modified]

3.51

reliability

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

3.52

residual risk

risk that remains after controls have been implemented

3.53

risk

combination of the consequences of an event and the associated likelihood of its occurrence

3.54

risk assessment

overall process of risk identification, risk analysis and risk evaluation

[SOURCE: ISO Guide 73:2009, 3.4.1]

3.55

risk register

tool to record, follow up and close out actions related to relevant assessed risks

Note 1 to entry: Each entry in the risk register typically includes a description of the risk, a description of the action(s), the responsible party, the due date, and status of the action.

3.56

safety-critical element

SCE

part of a facility, including computer programs, whose purpose is to prevent or limit the consequences of a major accident, or whose failure could cause or contribute substantially to a major accident

Note 1 to entry: Safety critical elements include measures for prevention, detection, control and mitigation (including personnel protection) of hazards.

[SOURCE: EU Directive 2013/30/EU, modified]

3.57

secondary well barrier

second set of well barrier elements that prevent flow from a source of inflow

[SOURCE: API RP 90, modified]

3.58

shut-in well

well with one or more valve(s) closed on the flow path

3.59

subsea well

well completed with a subsea wellhead and a subsea tree

[SOURCE: API RP 90, modified]

3.60

subsea wellhead

wellhead that is installed at or near the seabed

3.61

surface casing

casing that is run inside the conductor casing to protect shallow water zones and weaker formations

Note 1 to entry: Surface casing can be cemented within the conductor casing and is often cemented back to the mud-line or surface.

Note 2 to entry: The surface wellhead is normally installed on this casing for surface wells.

[SOURCE: API RP 90, modified]

3.62

surveillance

continual, checking, supervising, critically observing or determining the status in order to identify change from the performance level required or expected

Note 1 to entry: Examples of well physical characteristics include tubing wall thickness measurements, visual inspections, sampling.

3.63

suspended well

well that has been temporarily isolated from the producing reservoir

Note 1 to entry: Components above the isolation device are no longer considered flow-wetted.

3.64

sustained casing pressure

SCP

pressure in an annulus that

- a) rebuilds after having been bled down;
- b) is not caused solely by temperature fluctuations; and
- c) is not a pressure that has been imposed by the well operator

Note 1 to entry: Sustained casing pressure can be present on wells without annular access.

[SOURCE: API RP 90, modified]

3.65

thermally induced annulus pressure

pressure in an annulus generated by thermal expansion or contraction of trapped fluids

Note 1 to entry: On wells where there is no annulus access, sustained casing pressure can be present.

[SOURCE: API RP 90, modified]

3.66

type testing

testing of a representative specimen (or prototype) of a product which qualifies the design and, therefore, validates the integrity of other products of the same design, materials and manufacture

3.67

verification

examination, testing, audit or review to confirm that an activity, product or service is in accordance with specified requirements

3.68

well abandonment

permanent subsurface isolation to prevent any undesired communication between any distinct zones and fluid movement out of a well using validated well barriers

3.69

well barrier

system of one or several well barrier elements that contain fluids within a well to prevent uncontrolled flow of fluids within or out of the well

3.70

well barrier element

WBE

one of several dependent components that are combined to form a well barrier

3.71

well barrier plan

well operator's specific programme for barrier placement and verification in a well to prevent unplanned flow during each stage of well construction, operation, abandonment or decommissioning

3.72

well handover

act or process that formalises the transfer of a well, and operating responsibility, from one competent party to another, including the requisite data and documents

3.73

well integrity

containment and prevention of the escape of fluids to subterranean formations or surface

3.74

well integrity management

application of technical, operational and organizational methods to prevent the uncontrolled flow of fluids at the surface or across subsurface formations throughout the life cycle of the well

3.75

well operator

company that has responsibility for the well

3.76

well operating limits

combination of parameters established by the well operator within which the well should be operated to ensure that all component specifications, including their applicable design or safety factors and performance standards, are not violated throughout the well life cycle

3.77

well status

well's current operational function

Note 1 to entry: Functions include undergoing construction, in operation (i.e. producing, injecting, shut-in), undergoing intervention, suspended, or abandoned.

3.78

well stock

portfolio of wells for which the well operator has operating or well integrity assurance responsibility

4 Abbreviated terms

ALARP	as low as reasonably practicable
API	American Petroleum Institute
ASV	annulus safety valve
BOP	blow-out preventer
BS&W	base sediment and water
ECD	equivalent circulating density
ESD	emergency shutdown
FIT	formation integrity test
FMEA	failure modes and effects analysis
FMECA	failure mode and effects and criticality analysis
FS	formation strength
HPHT	high pressure and high temperature
ID	internal diameter
KPI	key performance indicator
LOT	leak-off test
MAASP	maximum allowable annulus surface pressure
MAH	major accident hazard
MFL	magnetic flux leakage
MOC	management of change
NORM	naturally occurring radioactive material
NORSOK	Norsk Søkkel Konkurransesystem
OD	outer diameter
OEM	original equipment manufacturer
QA	quality assurance
QC	quality control

QRA	quantitative risk assessment
RACI	responsible, accountable, consulted, informed
ROV	remotely operated vehicle
SCE	safety-critical element
SCP	sustained casing pressure
SCSSV	surface controlled subsurface safety valve
SPM	side pocket mandrel
SIMOPS	simultaneous operations
SSCSV	subsurface controlled subsurface safety valve
SSSV	subsurface safety valve
SSV	surface safety valve
TOC	top of cement
TVD	true vertical depth
WBE	well barrier element
WIMS	well integrity management system
XLOT	extended leak-off test

5 Common elements of the well integrity life cycle

5.1 General

The phases of the life cycle of a well have common elements, methods and processes, which are integral to the management of well integrity. This clause identifies and discusses these elements, which are outlined in [Figure 1](#) in the Introduction.

Major accident hazards (MAH) and the risks they present to people, the environment and facilities in the oil and gas industry require stringent management. While this document describes requirements and recommendations for managing well integrity, it should be realized that well integrity is an integral part of asset integrity (see Reference [22]) and process safety (see Reference [23]).

This document covers the full well life cycle, including design. Another International Standard closely linked with design is ISO 17776, which establishes the requirements for the effective planning and execution of risk reduction through design hazard management of MAHs, and focuses on the process of conducting hazard management rather than providing detailed requirements as to how each individual activity should be conducted.

Safety-critical elements (SCEs) are the equipment and systems, which provide the basis to manage the risks associated with MAHs. The proper and reliable functioning of SCEs is hence critical to managing MAHs. The well operator should define SCEs in their well designs, taking into consideration applicable regulatory statutes.

5.2 Well integrity

Well integrity refers to maintaining full control of fluids within a well at all times by employing and maintaining one or more well barriers to prevent unintended fluid movement between formations with different pressure regimes or loss of containment to the environment.

5.3 Well integrity policy

The well operator shall have a policy that defines their commitments and obligations to safeguard health, safety, environment, asset and reputation with respect to well integrity. This policy will detail how well integrity is established and preserved through a documented management system that is applied to all wells under the well operator's responsibility.

5.4 Well integrity management system

The well operator should have a well integrity management system (WIMS) to ensure that well integrity is maintained throughout the well life cycle by the application of a combination of technical, operational and organizational processes.

The WIMS should address the following elements for the well operator's well stock:

- risk assessment;
- organizational structure (roles, responsibilities, accountabilities and competencies);
- well barriers;
- performance standards;
- well barrier verification;
- reporting and documentation;
- management of change process;
- continuous improvement process;
- auditing.

5.5 Risk assessment

5.5.1 General

The well operator shall identify the well integrity hazards over the life cycle of the well and identify the risk associated with these hazards. Risk is defined by the likelihood of event occurrence and the consequences should the event occur. The well operator should determine acceptance levels for likelihood and consequence.

Techniques that can be applied for risk assessment are listed in [Annex A](#). The assessment of a well integrity-related event can be depicted on a risk assessment matrix such that risk can be categorised or ranked based on the combined effects of consequence and likelihood of event occurrence. An example of a '5 × 5' risk assessment matrix is given in [Figure 2](#).

For risks exceeding the well operator's acceptance levels, control measures and mitigations should be put in place to reduce the risk to the well operator's defined risk tolerance level. ALARP principles can be used to determine whether additional controls or mitigations are required to further reduce the level of risk.

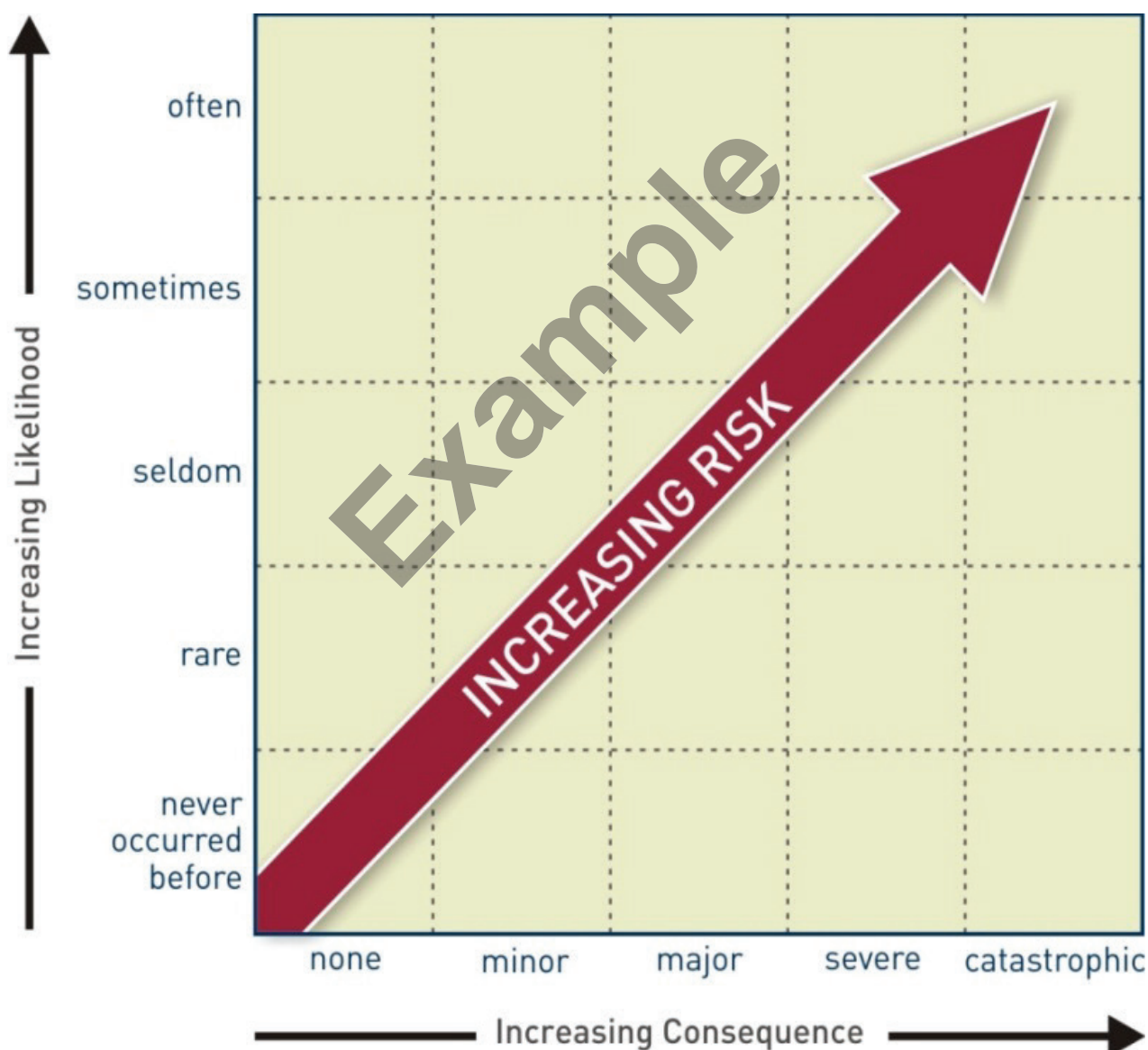


Figure 2 — Example of a risk assessment matrix

5.5.2 Risk register

The well operator should establish a risk register for all the identified hazards and risks, which is to be maintained and communicated to all relevant personnel throughout the well life cycle.

The risk register should contain, but is not limited to, the following:

- identified hazards;
- existing safeguards, mitigations and control measures;
- initial risk description(likelihood and consequences);
- plan for implementation of control measures;
- description of risk after control measures.

An example of a risk register can be found in [Annex B](#).

5.5.3 Well type risk profile

The risks defined in the risk register of the well(s) determine the elements of the well type risk profile for that given asset.

The well operator may have several different types of wells that are covered by their WIMS; well types can include e.g. water injectors, gas producers, disposal wells and oil producers. In such circumstances, especially when developing a field, it can be expedient to develop risk profiles for each well type. The use of such a risk profile allows consistent management of well barriers.

5.6 Organizational structure and tasks

The well operator should ensure that resources in its organization are available to manage well integrity throughout the entire life cycle of the well.

The well operator should define the roles and responsibilities for all professional, supervisory, operational and maintenance personnel required for well integrity management. Roles and responsibilities should be documented, for example in a RACI matrix (see [Annex C](#)).

Personnel competence requirements are analogous to performance standards for well barrier elements (WBEs). Different competencies are required for the various phases of the well life cycle. The well operator should ensure that personnel (employees and contractors) involved in WIMS activities are competent to perform the tasks assigned to them and that competencies are appropriate for each phase of the well life cycle. An example of a competence matrix is given in [Annex D](#). This matrix does not reflect the full range of competences required, but should be used by the well operator as a basis for developing a more rigorous and comprehensive matrix that represents the range of wells, their geographical locations, the operating regimes and the various skills required for all personnel working on well integrity related activities.

The well operator should define well integrity personnel competence requirements and the relevant training to ensure that tasks are carried out in a manner which is safe with regard to the protection of health, environment and assets. A competence performance record should be maintained that demonstrates conformance with the competency requirements.

NOTE 1 Competence can be gained through a combination of education, training programmes, mentoring, self-study and on-the-job training (transfer of experience/expertise).

NOTE 2 See ISO/TS 17969, which details the requirements of a competence management system and application to well operations personnel. The document includes example competence profiles which include competencies directly relevant to well integrity.

5.7 Barriers

5.7.1 General

Barriers are defined as a combination of components or practices that contribute to the well system reliability to prevent or stop uncontrolled fluid flow.

Barriers may be:

- hardware barriers (equipment which is designed, installed and verified);
- operational barriers (monitoring equipment, practices and procedures);
- human barriers (competencies, training);
- administrative controls (assignment of roles, resource provision, auditing, reviews).

For the purpose of this document, hardware barriers are addressed as well barriers; other barriers are addressed in the respective clauses of this document.

Assurance that barriers are in place and maintained throughout the well life cycle is the basis for managing well integrity.

5.7.2 Barrier philosophy

The well operator shall define and document a barrier philosophy that specifies the principles to maintain control of the well fluids. The philosophy should describe the barriers (well, operational and human) and administrative controls that will be employed.

A system of multiple barriers and redundancy in well barrier elements is used to achieve a high level of reliability. Well reliability is achieved through the combination of individual barriers as a system and is not the result of the infallibility of a single component.

5.7.3 Well barriers

5.7.3.1 General

A well barrier is a combination of one or several well barrier elements (WBEs) that contain fluids within a well to prevent uncontrolled flow of fluids within, or out of, a well.

The verification, maintenance, inspection and testing of well barriers are key aspects of the management of well integrity throughout the entire well life cycle.

The well operator should track the status of each well barrier and maintain all well barrier(s) according to the specified well operating limits.

5.7.3.2 Well barrier objectives

The objectives of a well barrier are to:

- withstand the maximum anticipated combined loads to which it can be subjected;
- function as intended in the environments (pressures, temperature, fluids, mechanical stresses) that can be encountered throughout its entire life cycle;
- prevent uncontrolled flow of wellbore liquids or gases to the external environment or within the wellbore;
- successfully undergo scheduled verification tests (may not apply to abandoned wells).

Examples of typical well barrier elements, their functions and failure characteristics are given in [Annex E](#).

5.7.3.3 Number of well barriers

At least two independently verified well barriers against uncontrolled outflow, along any potential flow or leak path, should be utilized where practicable.

Where it is not practicable to establish two independently verified barriers, a risk assessment should be performed to confirm that one well barrier provides an acceptable level of risk to maintain containment, including consideration of subsurface flow and the well's capability of flowing to surface.

The primary well barrier is typically the first set of well barrier elements exposed to the pressure source. The secondary well barrier is typically not exposed to the produced fluid or pressure but provides redundancy in the case of primary barrier failure. Examples of barrier diagrams per phase of operation are presented in [Annex F](#).

5.7.3.4 Primary well barrier

For a well, the primary well barrier is typically, but not exclusively, composed of one or more of the following WBEs subject to the applicable life cycle phase:

- cap rock;
- drilling fluids;
- casing cement;
- production casing;
- production packer;
- completion string;
- SSSV or tree master valve.

5.7.3.5 Secondary well barrier

The secondary well barrier is typically, but not exclusively, composed of one or more of the following WBEs subject to the applicable life cycle phase;

- impermeable formation;
- completion fluids;
- casing cement;
- blow-out preventers;
- casing with hanger and seal assembly;
- wellhead with valves;
- tubing hanger with seals;
- tree and tree connection;
- actuated tree wing valve or master valve.

5.7.3.6 Well barrier schematic

The well operator should document the well barriers employed using a well barrier schematic (WBS), which also identifies the WBEs of each well barrier and the verification tests performed during the construction phase. A WBS can be used for an individual well or a well type.

The WBS normally contains the following types of information:

- a) a drawing illustrating the primary and secondary well barriers;
- b) formation integrity, when the formation is part of a well barrier;
- c) reservoirs/potential sources of inflow;
- d) tabulated listing of WBEs with initial verification and monitoring requirements against performance standards;
- e) dimensions and depth labelling (TVD and MD) for all tubular goods and cement (including TOC) defined as WBEs;
- f) calculated MAASP value for each annulus;

- g) maximum allowable tubing head pressure;
- h) well information including field/installation, well name, well type, well status, well/section design pressure, revision number and date, "Prepared by", "Verified/Approved by";
- i) clear labelling of actual well barrier status, planned or as-constructed;
- j) common WBEs across barriers;
- k) a note field for important well integrity information (anomalies, exemptions, etc.).

An example of a WBS is presented in [Annex F](#).

5.7.4 Operational barriers

Operational barriers are designed to prevent deviations from safe working practices, and to place worksite controls into operation on equipment and work methods in order to avoid human-related errors causing accidents or contributing to a hazard.

Examples of operational barriers are:

- detection and monitoring equipment;
- processes and work instructions;
- safety isolations and interlocks;
- permit-to-work system.

5.7.5 Human barriers

Human barriers are the skills and knowledge given to individuals to recognize hazards or deviations, and to take appropriate mitigating actions (response).

Examples of human barriers are:

- training;
- recognition and response;
- skills and competencies for response to risk;
- experience;
- supervisory skills.

The design and layout of equipment and their interfaces with personnel should be considered, in order to limit human error.

5.7.6 Administrative controls

An organization provides the structure and culture in which well integrity and its management are performed. As a part of this structure, administrative controls provide information on, support of and control of activities which are directly or indirectly related to well integrity.

Examples of administrative controls are:

- design standards;
- materials handling standards;
- procedures and policy manuals;

- change processes/escalation of decisions;
- quality assurance programme.

5.7.7 Impact barriers

Impact barriers are usually employed to prevent damage to primary and secondary well barriers as a result of some external impact. Such barriers can typically be conductors, crash frames, trawl net deflectors, concrete barricades and fencing.

5.8 Performance standards for equipment

5.8.1 General

In well integrity management there are several kinds of performance standards. These performance standards typically specify requirements in the following areas:

- people: standards for competence assessment;
- equipment (WBE): equipment performance standards and specifications;
- management system: standards defining key performance indicators and audits.

This subclause focuses on the performance standards for equipment. Other standards and requirements are covered in other subclauses.

The well operator should define performance standards for WBEs for each well type. Performance standards, supported by the risk assessment, are the basis for their design and selection, as well as for the development of maintenance and monitoring requirements.

The criteria to be determined for an equipment performance standard are the following:

- functionality — what the equipment is required to do in order to establish and maintain integrity;
- 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 on average over a given time;
- reliability — the probability that the equipment will operate on demand when required to maintain integrity;
- survivability — the ability of a component, a piece of equipment or a system to remain functional for a specified period when under attack from identified external loading events associated with a major accident;
- interactions and dependencies with other equipment that is critical for functionality.

Equipment performance standards should be developed over time, as the well-type definition evolves and as risk and hazard studies are conducted to demonstrate the level of performance necessary for each WBE to perform its role in controlling risk. The well barriers, WBEs and equipment performance standards should be fully established by the end of the well design stage. The performance standards should specify the periodic inspection, maintenance and testing requirements.

An example of a performance standard is given in [Annex G](#).

5.8.2 Well operating limits

Well operating limits are a combination of the criteria established by the well operator to ensure that the well remains within its design limits and its performance standard in order to maintain well integrity throughout the well life cycle.

The well operator should establish well operating limits for each well type as a part of the WIMS. Any changes in well configuration, condition, life cycle phase or status require the well operating limits to be checked and potentially updated.

The well operator should clearly define the following:

- responsibilities for establishing, maintaining, reviewing and approving the well operating limits;
- how each of the well operating-limit parameters should be monitored and recorded during periods when the well is constructed, operational, shut-in or suspended;
- requirements for any threshold settings for the well operating limits;
- actions that should be taken in the event a well parameter is approaching its defined threshold;
- actions, notifications and investigations required if well operating limit thresholds are exceeded;
- safety systems that are necessary to protect against exceeding the well operating limits.

5.9 Well barrier verification

5.9.1 General

A verification test is a check whether or not a WBE meets its acceptance criteria. It includes (but is not limited to) function testing, leak testing, axial load testing (tension and/or compression) and well load case modelling verification.

5.9.2 Function testing

5.9.2.1 General

Function testing is a check as to whether or not a well barrier or system is operating as intended. It should be realistic, objective, and the results should be recorded.

In cases where it is neither practical nor possible to perform a leak test, function testing may be accepted on its own as verification testing.

5.9.2.2 Function testing of valves

On manual valves, the function test indicates that the valve cycles (opens and closes) correctly by counting the turns of the handle and verifying that the valves cycle smoothly. On actuated valves, the test measures the opening and closing times and also confirms that the stem travels the full distance. The function test does not provide information about possible leakage of the valve.

Function testing of ESD/SSV valves may be carried out as defined in API/Std 6AV2. This method may also be applied to onshore wellhead and tree ESDs.

For some valves, where it is not possible to observe movement of the valve's stem, it may be possible to verify its correct functioning by observing the hydraulic signature (the control line pressure data and hydraulic fluid actuation volumes). Examples of the hydraulic signature of a surface-controlled subsurface safety valve (SCSSV) and a valve of a subsea tree are shown in [Annex H](#).

5.9.3 Barrier verification testing

5.9.3.1 General

Barrier verification testing is the application of a differential pressure to ascertain the integrity of the sealing system of the component that is part of a barrier system. Differential pressure can be obtained

by either pressure testing or inflow testing. An example of leak rate determination is provided in [Annex I](#).

The well operator should define the assessment methods of testing, for example:

- a) observation of flow against defined acceptance criteria; or
- b) monitoring of pressure changes against defined acceptance criteria.

5.9.3.2 Pressure testing

Pressure testing is the application of a pressure from a known source to ascertain the mechanical and sealing integrity of the component.

Fluids introduced into the well, annuli and voids during testing should be assessed to ensure they do not affect well integrity, for example the possible introduction of sulfate-reducing bacteria or the ability to freeze in low temperature environments.

This may involve:

- using treated water (e.g. with low chloride and sulfur contents);
- increasing the pH of the test media;
- adding a biocide and oxygen scavenger to the test media;
- using non-freezing fluids such as brines or hydrocarbons;
- considering the use of an inert gas, such as nitrogen.

5.9.3.3 Inflow testing

Inflow testing, or negative testing, utilises pressure from an existing source such as reservoir or formation pressure. A WBE that is normally open is tested in the closed position (elements such as cement, casing and seals are considered closed).

The pressure downstream (i.e. on the side of the WBE opposite to the remote pressure source) of the WBE is reduced to create a pressure differential across it, and the volume downstream is monitored for a pressure increase that indicates a leak.

In the case of a successful valve inflow test, it can be assumed that the actuation system to close that valve is functioning to the extent that the valve closes. However, it does not necessarily confirm that the actuation system itself is functioning in accordance with its operating parameters, such as time-to-function, sufficient accumulator capacity, operating pressure, etc.

Subsurface safety valves can be verified only by an inflow test after closing the valve in accordance with the manufacturer's procedures. Inflow testing of subsurface controlled subsurface safety valves often requires that the well be lined up to a low-pressure test separator or a flare to simulate uncontrolled flow-to-surface conditions. If unable to perform inflow testing, the well operator should maintain such valves by establishing a replacement frequency (guidance can be found in ISO 10417).

5.9.4 Direction of flow

A component should preferably be tested in the direction of flow. If this is impossible or impractical, a test of the component in the opposite flow direction should be performed. The test in the opposite flow direction can be of limited value in establishing the component's ability to seal in the direction of flow. Any component tested in the opposite direction of flow should have this documented.

5.9.5 Effects of temperature

The effects of temperature changes should be taken into account, especially in subsea or arctic situations, since the wellbore, flow lines, manifolds, risers, etc., cool down quickly when remotely actuated valves are closed.

Temperature effects can influence leak test results and mask actual barrier performance, causing inaccurate leak test interpretation. The duration of the test might have to be reviewed.

In these cases, establishing a leak test might not be possible and it may be necessary for valve testing to rely on indirect indications, such as the temperature itself or interpretation of control-line pressure response characteristics.

5.9.6 Modelling verification

Certain WBEs might have to be verified by suitable modelling or type testing at the design stage, since operational testing might not be practical or achievable. Examples of such modelling and testing activities include:

- wave load impact on conductors;
- slam closure rates for SSSV's;
- establishing performance requirements of anticipated casing design, where it is undesirable to pressure test against a cemented shoe.

During the operational life cycle, periodic inspection of the physical condition of equipment may be performed to check for evidence of degradation. Modelling of the effects of the degradation may be considered.

5.10 Reporting and documentation

5.10.1 General

Data related to well design, construction, operation, maintenance and permanent abandonment should be maintained and accessible throughout the life cycle of the well.

The well operator should define:

- the information and records about a well which are necessary to be recorded and stored;
- personnel responsible for data collection and document management;
- the length of time that records are to be retained.

The well integrity record system should contain:

- a repository for data and provide access to data and documents for all approved users;
- a documented process and procedures for controlling and updating data and documents;
- data / document maintenance features to combat degradation and ensure software (where used) interchangeability.

5.10.2 Well integrity status reporting

The well operator should define the reporting requirements to monitor the status of well integrity. These may include, but are not limited to:

- routine reports issued on a predefined periodic basis (e.g. monthly, quarterly or annually) reflecting the well integrity activities and issues addressed;

- reporting on the identified key performance indicators (KPIs) (see [5.12.1](#));
- event-specific well integrity incidents and investigation reports;
- reporting to the government/regulator as required by local legislation.

The well operator should define the scope, recipients and requirements for acknowledgement of receipt of all such reports.

Topics covered in the reports may include, but are not limited to, the following:

- previous well reviews, or ad hoc well reviews;
- changes to the original boundary conditions;
- change in the well function;
- changes in the well fluid composition;
- change or possible degradation of well and well-related hardware;
- MOC notices;
- well deviations;
- well barriers;
- well integrity issues;
- scale or corrosion issues;
- wear and tear to hardware and equipment;
- accidental damage to hardware and equipment;
- equipment obsolescence;
- loss of barrier or containment;
- environmentally related changes;
- statutory or legislative changes;
- changes in local procedures and standards;
- advances in technology that may be implemented;
- changes to the design and/or design limits of equipment/material, e.g. latest manufacturer's bulletins or industry standards;
- repairs to, and replacements of, well components, from valve parts to complete work over;
- relevant equipment maintenance information in order to improve equipment technical specifications, reliability data and/or preventative maintenance intervals;
- changes to the well operating envelope, such as an MAASP review;
- risk register updates.

5.10.3 Well life cycle phase deliverables

At the end of each phase in the well life cycle, requirements for documentation, certification and verification shall be met to ensure that management of well integrity is maintained.

There are also instances, depending on the well operator's organization, of transfers of responsibility within a well life cycle phase. These instances have requirements regarding the stewardship of information and maintenance of the well integrity. The well operator should define these requirements within its WIMS.

5.10.4 Well handover process

The well operator should define the accountability and responsibility for the well during its life cycle and the well handover process requirements.

Well handover is the process that formalises the transfer of a well and/or well operating responsibility from one functional group to another and is endorsed by the use of related well handover documentation.

The process should define the relevant handover phases. The phases at which the well handover typically occur are at least at the following transitions:

- a) well construction phase to well operational phase;
- b) well operational phase to well intervention and workover phase, including maintenance or servicing, and back to well operational phase;
- c) well operational phase to abandonment phase.

The well operator should record the well operating limits and WBE status in the well handover documentation. As a part of the well handover documentation (see [Annex J](#)), the well operator should have a current WBS, or similar method of documenting well barriers (see [Annex F](#)).

Handover documentation should include only those items that are appropriate and capture any changes in the well's configuration, operating limits and known hazards (see [Annex J](#)).

The well operator should nominate competent personnel to be responsible for preparing, verifying and accepting the well handover documentation. These persons should sign and date the documentation accordingly.

5.11 Management of change

5.11.1 General

The well operator shall apply a management of change (MOC) process to address and record changes to well integrity requirements for an individual well or to the well integrity management system.

5.11.2 MOC process

The MOC process should include the following steps.

- a) Identify a requirement for change.
- b) Identify the impact of the change and the key stakeholders involved. This includes identifying what standards, procedures, work practices, process systems, drawings, etc. would be impacted by the change.
- c) Perform an appropriate level of risk assessment in accordance with the well operator risk assessment process (see [Annex A](#)). This includes:
 - identifying the change in risk level(s) via use of a risk assessment matrix or other means;
 - identifying additional preventive and mitigating measures that can be applied to reduce the risk level;
 - identifying the residual risk of implementing the change/deviation;

- reviewing the residual risk level against the well operator's risk tolerability/ALARP acceptance criteria;
 - updating the risk register accordingly.
- d) Submit the MOC proposal for review and approval in accordance with the well operator's MOC system.
- e) Communicate and record the approved MOC.
- f) Implement the approved MOC.

At the end of the approved MOC validity period, the MOC is withdrawn, or an extension is submitted for review and approval.

NOTE If the change is permanent, its implementation ends the MOC process.

5.11.3 Dispensation from the WIMS

In the management of well integrity, dispensations are often employed, especially in the operational phase of the well life cycle, to manage deviations from the WIMS requirements.

The well operator should have a procedure that clearly specifies the process and approvals required for dispensations from the WIMS. Dispensations should be limited in time and, if extended, the well operator's dispensation process should manage the process and approval for such extensions.

In the event of barrier impairment, there can be instances when the risk of reinstating the original barrier arrangement is out of proportion to the risk of not implementing a repair. In such instances, and after re-evaluating the applicable performance standard using a risk assessment, continued use of the well may be undertaken using the revised performance standard.

Dispensations from the WIMS should be managed through the MOC process.

5.12 Continuous improvement

5.12.1 General

The well operator should include continuous improvement processes in the WIMS that would detail how the information and knowledge gained should be communicated to those responsible for the phase of the life cycle in which the improvement can be implemented.

The techniques and processes used to support the key elements of the WIMS described in [5.4](#) and any other elements defined by the well operator should be routinely monitored to ensure that they are effective.

Several methods may be employed to carry out such performance monitoring, including, but not limited to, the following:

- KPI monitoring;
- capture of lessons learned;
- a conformance audit programme.

These methods may be used to identify where aspects of the WIMS can be improved.

5.12.2 Key performance indicator monitoring

KPIs represent defined metrics associated with the elements of the WIMS described in [5.4](#), plus any other elements defined by the well operator.

Setting, tracking and regularly reviewing these metrics aids in:

- determining the effectiveness of the WIMS as currently implemented;
- identifying general trends regarding the reliability of the well stock;
- identifying general trends regarding the well integrity risk posed by the well stock.

The well operator should determine KPIs and a suitable review frequency that are appropriate to track the effectiveness of the WIMS. These should be based on metrics that are aligned to critical objectives of the WIMS. Examples are given in [Annex K](#). This allows monitoring of both the performance of well integrity activities and their effectiveness in maintaining and improving integrity.

5.12.3 Lessons learned

During the life cycle of the well, improvements that can be made to processes, procedures, designs and equipment will likely be identified.

The well operator should establish a formal process for capturing and documenting such lessons learned, in order to aid in the continuous improvement process.

5.13 Auditing

5.13.1 General

The well operator should establish an audit process to demonstrate conformance with the WIMS. The audit reports should provide an indication as to which parts of the WIMS are functioning adequately, and which parts need further action.

5.13.2 Audit process

Each element of the WIMS should be the subject of an audit. The frequency of audits should be established by the well operator, or as required by local regulation.

Each audit should have clearly defined terms of reference focused on testing conformance with the WIMS and the effectiveness of meeting the objectives of the WIMS.

The audit objectives, scope and criteria should be agreed in advance.

The audit team leader is responsible for performing the audit, and should be independent from the work process being audited.

The resultant audit report should identify any observed deficiencies and make recommendations to address such deficiencies.

The well operator management team responsible for well integrity should review the audit recommendations, and assign and track progress on action items as appropriate.

6 Basis of design phase

6.1 Basis of design phase objectives

The primary objective of the basis of design phase is to develop a basis of design that meets the functional requirements of the well, while also creating and sustaining well integrity through the entire life cycle. The elements of this phase are detailed in [Figure 3](#). This work should be performed by a competent team that understands and assesses the conditions that affect the planned well and the functional requirements of the well over its life cycle, in order to identify potential hazards and to define appropriate barriers that are capable of controlling or mitigating these hazards and associated risks.

The work should follow a structured process with specific requirements, such that well integrity is achieved through the whole well life cycle.

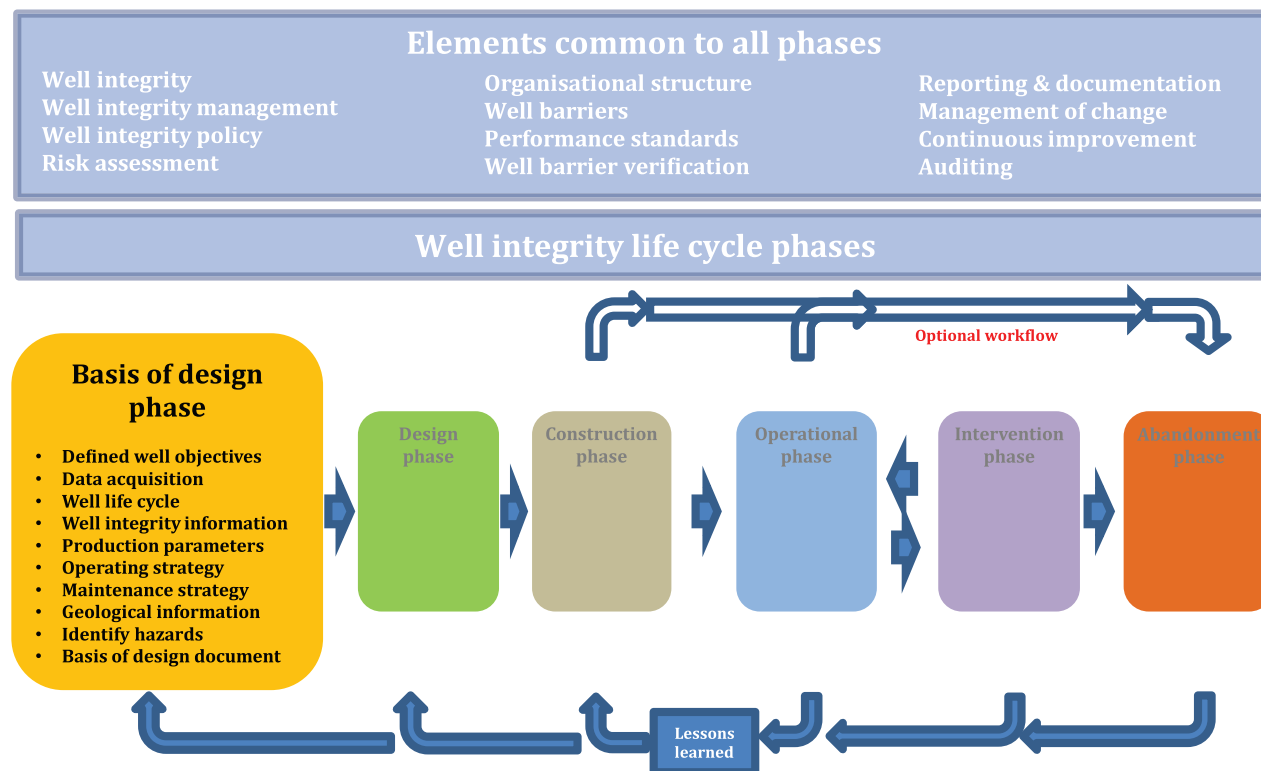


Figure 3 — Basis of design phase

6.2 Organizational structure and tasks

The resources and functional skills needed to carry out the basis of design phase should be defined to ensure sufficient time and competence levels for identifying the risks, hazards and appropriate mitigations considered over the life of the well. In most organizations, this task is addressed through collaboration among individuals with the relevant functional skills. The skill and experience levels required of the individuals depend on the particular challenges of the well.

Typical areas where functional skills are needed include the following:

- geology, geophysics, geochemistry, geomechanics, petrophysics;
- reservoir and production engineering;
- drilling, well testing, completion, subsea engineering;
- facilities, production operations;
- intervention, workover and abandonment activities;
- well maintenance/inspection and well integrity technical reviews.

Each general function may require further consultation with more specific sub-specialities in some applications (e.g. HPHT, environmental, deep-water and sour conditions).

The well operator should define the competence requirements and assign the appropriate personnel to undertake the following tasks:

- a) define the well objectives, such as the subsurface target, and well type (producer, injector, gas or oil), life expectancy and productivity or injection capability with the anticipated effluent composition, and possible changes over the life cycle;
- b) identify the anticipated rock mechanical and subsurface hazards that can threaten well integrity over the anticipated life cycle of the well, e.g. faults, fractures, pore pressures, temperature, H₂S, CO₂, solids production, shallow gas, high pressure stringers, chinks, moving salts, permafrost, subsidence, earthquakes;
- c) provide any information pertaining to surface hazards and anticipated changes that can affect well integrity over the anticipated life cycle of the well, e.g. location, environment, urban planning, proximity to lakes, rivers, subsea, offshore, risk of ordnance, other operations or industrial activities, risk of subsidence, flooding;
- d) identify the hazards associated with existing wellbores, abandoned wells, condition of the offset wells, related environmental issues, directional well path, etc.;
- e) provide a combined hazard risk register from the identified and confirmed hazards for surface and subsurface conditions for the basis of design.

Typical sources of relevant input include:

- 1) offset wells, field operation history (downhole samples, formation pore pressures and strength, subsurface hazards);
- 2) local studies of surface and subsurface conditions (seismic, reservoir model, seafloor, topography, subsidence) that can affect well integrity during the life cycle;
- 3) lessons learned with respect to well integrity from other wells or projects in similar conditions;
- 4) anticipated life cycle changes or well operating limits that can affect well integrity.

The information should be used to outline the basis of design for the well to identify risks and associated hazards with respect to well integrity.

6.3 Well barriers

The well barrier assurance process in the basis of design phase consists of identifying potential hazards and defining appropriate barriers that are capable of controlling both subsurface and surface hazards over the well life cycle in accordance with the well operator's barrier philosophy and the requirements in this document.

A description of the system for well barrier monitoring, pressure management and the need for any chemical injection and inhibition should be included.

6.4 Hazard identification and assessment

A key objective of the basis of design phase is to identify the hazards related to well integrity. [Annex L](#) contains an example of a checklist to aid in the identification of potential hazards.

The level of detail should reflect this objective and, therefore, focus on identifying hazards that:

- represent a significant contribution to overall risk if the project is realized (i.e. potentially unacceptable risk);
- require control and mitigation through special attention and follow-up in the design phase to achieve an acceptable risk level.

The hazards identified should be captured and documented in a risk register.

6.5 Well integrity considerations for the basis of design

6.5.1 General information to be provided

The basis of design should contain the following information:

- project name;
- well location and target:
 - 1) latitude/longitude of all targets,
 - 2) target TVD depths;
 - 3) target formation information (name and type of formation);
- subsurface architecture (vertical/deviated/horizontal);
- well type (gas-lift, oil producer, water injector, gas producer, etc.);
- design pressures:
 - 1) maximum and minimum anticipated pore pressures over the well life cycle;
 - 2) formation fracture pressures or gradients;
 - 3) maximum expected wellhead pressures (flowing, shut-in or injection);
 - 4) maximum and minimum expected reservoir pressure over the well life cycle;
- production limits:
 - 1) maximum and minimum expected production rates (gas/oil/water);
 - 2) expected range of fluid type compositions to be produced or injected (e.g. sweet, sour, corrosive, solids content);
 - 3) strategy of stimulation/test/treatments and description of chemicals;
 - 4) expected surface and subsurface maximum and minimum temperatures;
- required well operating life, in years.

6.5.2 Well objectives and life cycle

Well objectives, and associated well integrity hazards over the well life cycle, should be defined by the drainage strategy, including any improved recovery methods. This includes a description of requirements for artificial lift, injectors for pressure support, any disposal wells and any anticipated changes or uncertainties during the well life cycle.

Activities needed to be performed in the well over its lifetime should be defined. This could be planned recompletion, conversion of producers to injectors, re-use of well by side-tracking, deepening to new targets, and changes in objectives, planned logging and intervention activities, etc.

6.5.3 Inflow requirements

Inflow aspects of the well that could influence well integrity should be included in this part of the basis of design, for example:

- Upper completion type: this should state if the well is a single or multi-string completion. A conceptual completion schematic/sketch may be included (as part of the supporting documentation).
- Lower completion type, e.g. cemented, mono-bore, open-hole.

- Sand control: sand failure assessment documentation should be included as part of the supporting documentation. If sand control is required, the methods of sand management should be included at this point. This may include screen selection, gravel selection, clean-up strategy, deployment strategy, etc.
- Perforation: if perforations are required, the target intervals should be provided at this point.
- Any zonal isolation requirements due to different reservoir parameters or pressure regimes.

6.5.4 Outflow requirements

Aspects of the well outflow that influence production should be included in this part of the basis of design, such as:

- flow requirements for production/injection;
- recompletion requirements over the lifetime of the well to accommodate changes in flow regime;
- requirements for chemical injection and/or artificial lift.

6.5.5 Well location and targets

The well location and targets should be described. This includes description of different locations and targets, with their associated identified hazards, as well as any expected changes during the life cycle. The well location should include the surface location, i.e. pad size, platform configuration, slot location and subsea topography.

6.5.6 Prognoses regarding geological formations, pore pressure, formation strength and temperature

A description of the expected formations and fluids, pore pressures, formation strength and temperatures to be encountered, including their uncertainty, should be provided. [Annex M](#) provides an example of a plot of pore pressure versus formation strength. The level of detail depends on well type and complexity.

The information should cover subsurface aquifers and hazards, faults and high pressure stringers, i.e. pore pressure prediction, freshwater zone protection, stratigraphic prognosis, well orientation and length of penetration through production zone.

6.5.7 Data acquisition requirements

The requirements for well integrity data acquisition during the construction and operation phases should be outlined in this part of the well basis of design. This should include:

- identifying data acquisition requirements during the construction of the well;

This should indicate what data are required during construction for each well section, and specify whether a cement evaluation log, an extended leak-off test, a saturation log, gamma ray logs, etc., are required.
- identifying data acquisition requirements during the operation of the well, related to monitoring of barrier performance.

This should indicate what data are required over the lifetime operation of the well, and should specify whether fibre optics, downhole pressure gauges, control sensors, etc. are required as part of the well design.

6.5.8 Other considerations for well integrity

Other information may be required to ensure that the well design provides the required isolation, systems for maintenance and condition monitoring of the well barriers, as well as the well barriers for future abandonment. This includes information pertinent to the casing and completion design. Special considerations that are taken into account should be captured here, for example:

- any requirements for maximum and minimum well operating limits;
- well integrity isolation requirements related to identified risks, e.g. minimum formation strength at packer setting depth to avoid risk of out-of-zone injection, ground water isolation requirements;
- any SCSSV requirements, such as setting depth, due to e.g. the risk of hydrate and solids deposition;
- reservoir compaction and stresses that can affect integrity, such as shifting clay or salts, moving permafrost, other tectonic movement or subsidence risk;
- cementing and casing requirements to protect against corrosive aquifer and external corrosion protection of surface casing;
- special considerations that can affect barrier design, e.g. artificial lift, single-barrier wells;
- cementing requirements, including minimum casing and plug cement heights and logging requirements, as well as the remedial cementing strategy;
- local regulations affecting well design;
- requirements and available systems for well barrier monitoring and monitoring of parameters affecting well integrity (sand production, H₂S content, pressure, temperature, scale, paraffin, etc.);
- intended operating and maintenance philosophy;
- cap rock thickness and depth relative to top of cement column;
- time to gain access to the well.

6.5.9 Production and injection characteristics affecting well integrity through the life cycle

All data should be listed that are pertinent to the operation of the well over its lifetime. A life cycle production forecast, production profile and/or injection rates/profiles should be included. Any production parameter information that could affect the well integrity should be included, for example:

- expected flow/injection rates for oil/gas/water and their expected ratios;
- deposits likely to occur in the well, such as scale, wax, asphaltene, hydrates, NORM, mercaptan, mercury, etc.;
- expected microbial-induced corrosion;
- anticipated produced fluid composition, e.g. H₂S, CO₂, solids;
- anticipated injection fluid composition, e.g. oxygen, sulfate, solids content.

6.6 Quality assurance and approval process

There should be a cross functional quality assurance process that approves the final basis of design with documented assumptions and defined data origins.

6.7 Deliverables

The deliverables of this part of the well life cycle are the basis of design with the supporting risk register.

The basis of design should contain the documentation required for detailed design as described in 6.5. The risk register should be attached and the main hazards highlighted. An example of a risk register template is found in Annex B.

Well design options should be clearly identified, described and evaluated. As part of these options, robust well design and well integrity management through the life cycle should be especially taken into consideration (see 7.3).

7 Well design phase

7.1 Well design phase objectives

At the well design phase, consideration should be given to well integrity over the well life cycle, including any future interventions and well abandonment. The well should be designed so that the well integrity can be managed for the life cycle of the well. Well integrity aspects of the design should be focused on managing the hardware and systems that make up the well barriers for the life cycle. The input to the well design phase is the “basis of design” document from the well basis of design phase, together with the supporting risk register. The risk register should be updated in the well design phase as the risks are addressed. The elements of this phase are detailed in Figure 4.

It is recommended that the well operator perform a review of the well design to ensure that all identified hazards, risks, controls and mitigations have been addressed.

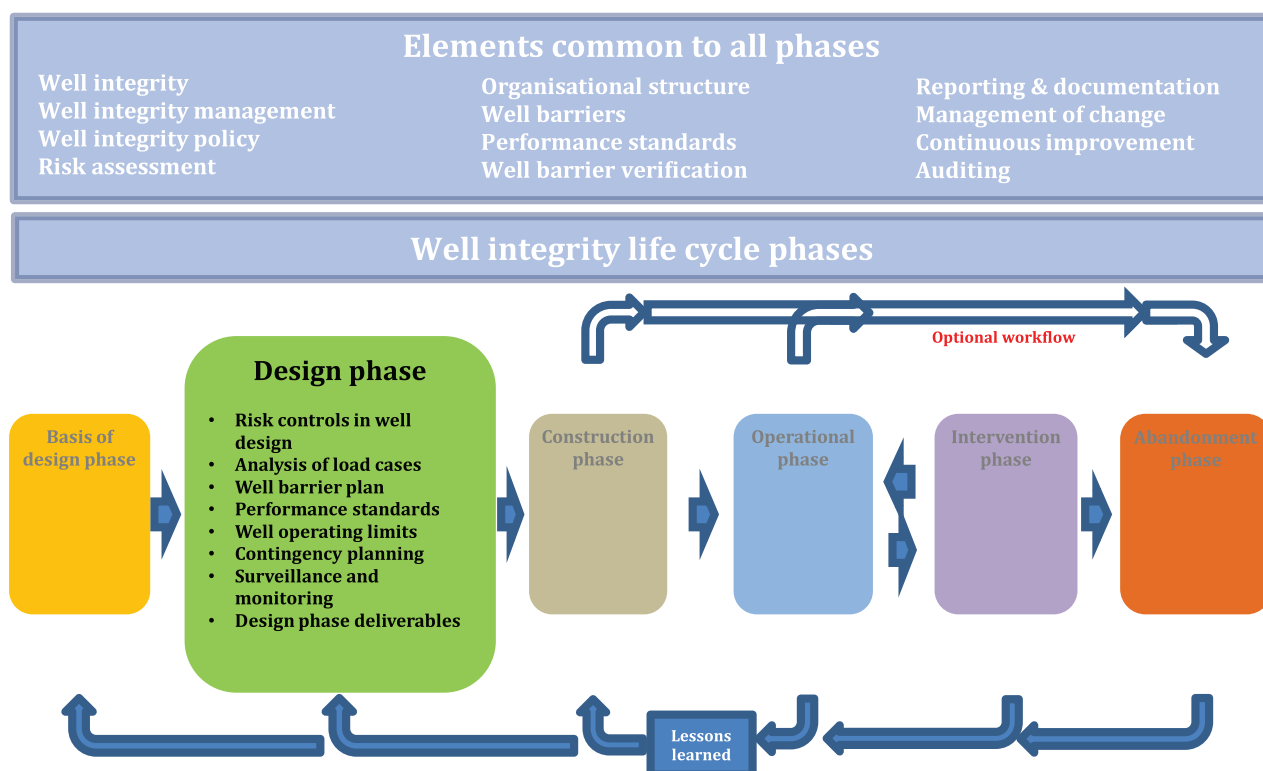


Figure 4 — Well design phase

7.2 Organizational structure and tasks

The well operator should define the minimum well integrity competence requirements and qualifications of personnel utilized to accomplish the requirements of the well design phase.

Typical examples of functional skills that are needed include the following:

- drilling engineering;
- well-testing engineering, completion engineering, subsea engineering;
- geology, geophysics, geochemistry, geomechanics, petrophysics;
- reservoir engineering;
- production engineering;
- risk assessment and management;
- well integrity engineering;
- fluids engineering (e.g. drilling, completion, packer, cementing fluids).

The well operator should define the competence requirements and assign appropriate personnel to fulfil the following tasks within the well design phase;

- casing design;
- completion design;
- analysis of pore pressures and rock mechanics;
- drilling and completion operations;
- well testing operations;
- well design risk management;
- material selection including corrosion and erosion analysis;
- load case analysis;
- specification of well and completion equipment;
- design and installation of well barriers;
- flow assurance;
- control and telemetry design;
- data acquisition design;
- well life cycle considerations;
- subsea design, including wellhead fatigue (if required);
- cementing design;
- abandonment (see [Clause 11](#)).

NOTE See ISO/TS 17969.

7.3 Risk controls in well design

7.3.1 Risk register

The risk register from the basis of design phase summarizes the hazards identified in the basis of design document. Additional hazards may be identified during the well design process. All these hazards, and