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BSI Standards Publication

Well integrity

Part 2: Well integrity for the operational phase

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National foreword

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The UK participation in its preparation was entrusted by Technical Committee PSE/17, Materials and equipment for petroleum, petrochemical and natural gas industries, to Panel 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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Published by BSI Standards Limited 2016

ISBN 978 0 580 81937 7
ICS 75.180.10

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This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 January 2016.

Amendments/corrigenda issued since publication

Date	Text affected

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TECHNICAL SPECIFICATION

SPÉCIFICATION TECHNIQUE

TECHNISCHE SPEZIFIKATION

CEN ISO/TS 16530-2

December 2015

ICS 75.180.10

English Version

Well integrity - Part 2: Well integrity for the operational phase (ISO/TS 16530-2:2014)

Intégrité du puits - Partie 2: Intégrité du puits pour la phase opérationnelle (ISO/TS 16530-2:2014)

Bohrungsintegrität - Teil 2: Bohrungsintegrität für die Betriebsphase (ISO/TS 16530-2:2014)

This Technical Specification (CEN/TS) was approved by CEN on 28 March 2015 for provisional application.

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European foreword

The text of ISO/TS 16530-2:2014 has been prepared by Technical Committee ISO/TC 67 "Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries" of the International Organization for Standardization (ISO) and has been taken over as CEN ISO/TS 16530-2:2015 by Technical Committee CEN/TC 12 "Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries" the secretariat of which is held by AFNOR.

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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).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 4, *Drilling and production equipment.*

ISO/TS 16530 consists of the following parts, under the general title *Well integrity*:

— *Part 2: Well integrity for the operational phase*

The following parts are under preparation:

— *Part 1: Life cycle governance manual*

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Introduction

This Technical Specification has been developed by producing operating companies for oil and gas, and is intended for use in the petroleum and natural gas industry worldwide. This Technical Specification is intended to give requirements and information to the Well Operator on managing well integrity for the operational phase. Furthermore, this Technical Specification addresses the minimum compliance requirements for the Well Operator, in order to claim conformity with this Technical Specification.

It is necessary that users of this Technical Specification are aware that requirements above those outlined in this Technical Specification can be needed for individual applications. This Technical Specification is not intended to inhibit or replace legal requirements; it is in addition to the legal requirements; where there is a conflict the legal requirement always takes precedence. This can be particularly applicable where there is innovative or developing technology, with changes in field or well design operating philosophy.

This Technical Specification addresses the process of managing well integrity by assuring compliance to the specified operating limits for identified well types, that are defined based on exposure of risk to people, environment, assets and reputation, supported by associated well maintenance/monitoring plans, technical reviews and management of change.

The following terminology is used in this Technical Specification.

a) The term “shall” or “must” denotes a minimum requirement in order to conform to this Technical Specification.

b) The term “should” denotes a recommendation or that which is advised but not required in order to conform to this Technical Specification.

c) The term “may” is used to indicate a course of action permissible within the limits of the document.

d) The term “consider” is used to indicate a suggestion or to advise.

e) The term “can” is used to express possibility or capability.

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Well integrity —

Part 2:
Well integrity for the operational phase

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1 Scope

This Technical Specification provides requirements and methods to the oil and gas industry to manage well integrity during the well operational phase.

The operational phase is considered to extend from handover of the well after construction, to handover prior to abandonment. This represents only the period during the life cycle of the well when it is being operated and is illustrated in Figure 1.

The scope of the Technical Specification includes:

— A description of the processes required to assess and manage risk within a defined framework. The risk assessment process also applies when deviating from this Technical Specification.

— The process of managing well integrity by operating wells in compliance with operating limits for all well types that are defined based on exposure of risk to people, environment, assets and reputation. The management of well integrity is supported by associated maintenance/monitoring plans, technical reviews and the management of change.

— The assessment of existing assets (wells / fields) in order to start the process of Well Integrity Management in accordance with this technical specification.

— The handover process required when changing from one activity to another during the operational phase.

The scope of the Technical Specification applies to all wells that are utilized by the oil and gas industry, regardless of their age, type or location.

The scope of the Technical Specification does NOT apply to:

— The periods during well intervention or work-over activities but it DOES include the result of the intervention and any impact that this can have to the well envelope and the associated well barriers.

— The equipment that is required or used outside the well envelope for a well intervention such as wire-line or coiled tubing or a pumping package.

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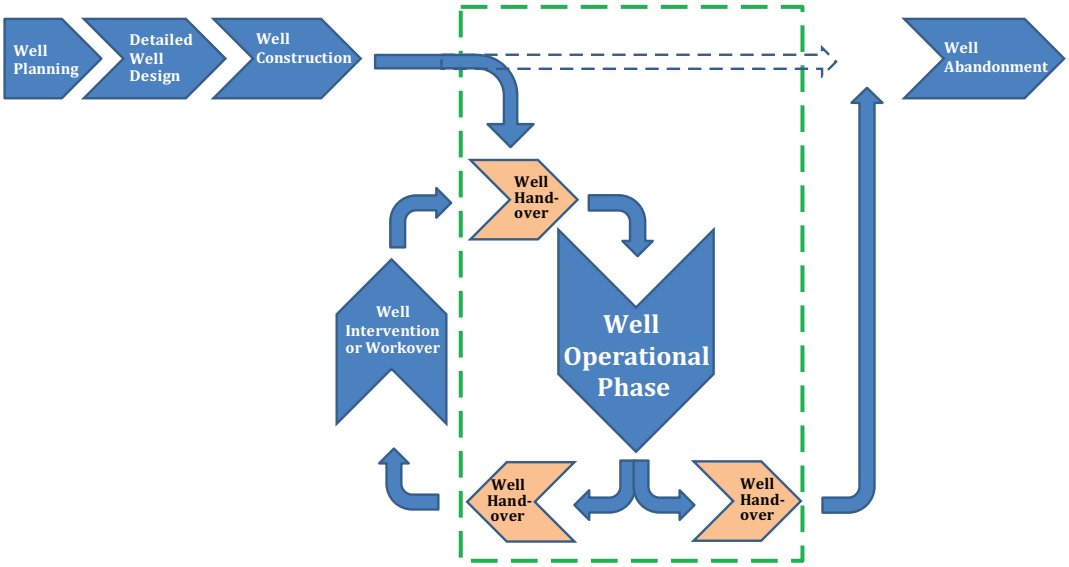

Figure 1 — Illustration of the scope of this Technical Specification

2 Normative references

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

ISO 10417:2004, *Petroleum and natural gas industries — Subsurface safety valve systems — Design, installation, operation and redress*

API RP 14H, *Recommended Practice for Installation, Maintenance and Repair of Surface Safety Valves and Underwater Safety Valves Offshore, Fifth Edition*

3 Terms, definitions and abbreviated terms

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

3.1
A-annulus
designation of annulus between the production tubing and production casing

[SOURCE: API RP 90, modified]

3.2
abandoned well
permanent subsurface isolation of the well

3.3
ambient pressure
pressure external to the wellhead

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

[SOURCE: API RP 90, modified]

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3.4
anomaly
condition that differs from what is expected or typical, or which differs from that predicted by a theoretical model

3.5
B-annulus
designation of annulus between the production casing and the next outer casing

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

[SOURCE: API RP 90, modified]

3.6
breaking of containment
breaking into the containment system of integrity or barrier envelope

3.7
competency
ability of an individual to perform a job properly through a combination of training, demonstrated skills and accumulated experience

3.8
component
mechanical part, including cement, used in the construction of a well

3.9
conductor casing
element that provides structural support for the well, wellhead and completion equipment, and often 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 may have a casing head; therefore, it can be capable of containing low annular pressures. For subsea and hybrid wells, the low pressure subsea wellhead is normally installed on this casing string.

[SOURCE: API RP 90, modified]

3.10
consequence
expected effect of an event that occurs

3.11
deep-set
below or close to the production packer, or at the cap rock of a reservoir to isolate the production tubing or casing from the producing reservoir

3.12
deviation
departure from a standard

3.13
double-block and bleed principle
operation with two valves or seals, in series, or a valve and a blind cap in all relevant, utilized flow paths into and out of the well that are not connected to a closed system

3.14
failure
loss of intended function

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3.15
failure mode
description of the method of failure

3.16
failure modes and effects analysis
FMEA
procedure used in design, development and operations management for the analysis of potential failure modes within a system for classification of the severity and likelihood of the failures

3.17
failure mode, effects, and criticality analysis
FMECA
extension of FMEA (3.16) that in addition includes an analysis of the criticalities to evaluate the seriousness of the consequences of a failure versus the probability of its occurrence

3.18
fault
abnormal, undesirable state of a system element (e.g. entire subsystem, assembly, component) 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.

3.19
flow-wetted
any surface that is exposed to fluids coming from a pressure source for that fluid

3.20
handover
act or process of transferring responsibility for operating a well from one competent party to another, including both custody to operate (certificate) and the requisite data and documents which describe the well construction

3.21
hazard
source of potential harm or a situation with a potential to cause loss (any negative consequence)

[SOURCE: API RP 90, modified]

3.22
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 Christmas 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, such as spars or TLPs.

[SOURCE: API RP 90, modified]

3.23
impairment
state of diminished ability to perform a function, but not yet failed

3.24
inflow testing
use of the tubing or casing pressure to perform leak testing

3.25
intervention
operation to enter the well through the Christmas tree

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3.26
leak
unintended and, therefore, undesired movement of fluids, either to or from, a container or a fluid containing system

3.27
casing/liner
casing string with its uppermost point inside and near the bottom end of a previous casing string using a liner hanger

3.28
major hazard
hazard (3.21) with a potential for causing major accidents, i.e. involving fatality due to fire or explosion, major pollution, multiple fatalities, or severe damage to the installation

3.29
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

3.30
the operational phase
is considered to extend from handover of the well after construction, to handover prior to abandonment, indicating the life cycle of the well while being operated

3.31
Well Operator-imposed annulus pressure
casing pressure that is Well Operator-imposed for purposes such as gas lift, water injection, thermal insulation, etc

[SOURCE: API RP 90, modified]

3.32
performance standard
statement, which can be expressed in qualitative or quantitative terms as appropriate, of the performance required of a safety-critical element in order to ensure the safety and integrity of the installation

3.33
pressure test
application of a pressure from an external source (non-reservoir pressure) to ascertain the mechanical and sealing integrity of a component

3.34
primary well barrier
first well barrier envelope that the produced and/or injected fluids contact and that is in-place and functional during well operations

3.35
production casing
innermost string of casing in the well

Note 1 to entry: Production fluids enter the casing below the production packer and continue to the surface through the production string. At a minimum, the production casing is rated for the maximum anticipated pressure that can be encountered from the production zone.

[SOURCE: API RP 90, modified]

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3.36
production riser
on fixed platforms, the casing strings rising from the seafloor to the wellhead or, on hybrid wells, the casing strings attached to the subsea wellhead rising from the seafloor to the surface wellhead

[SOURCE: API RP 90, modified]

3.37
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 used to conduct production fluids to the surface.

[SOURCE: API RP 90, modified]

3.38
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]

3.39
reliability
probability that equipment can perform a specified function under stated conditions for a given period of time

3.40
risk
combination of the consequences of an event and the associated likelihood of its occurrence

3.41
risk assessment
systematic analysis of the risks from activities and a rational evaluation of their significance by comparison against predetermined standards, target risk levels or other risk criteria

Note 1 to entry: Risk assessment is used to determine risk management priorities.

3.42
safety critical element
part of the installation or plant that is essential to maintain the safety and integrity of the installation

Note 1 to entry: This includes any item that is intended to prevent or limit the effect of a major hazard or which, upon failure, can cause or contribute substantially to a major hazard affecting the safety or integrity of the installation.

Note 2 to entry: Safety-critical elements include measures for prevention, detection, control and mitigation (including personnel protection) of hazards.

Note 3 to entry: Within the context of this Technical Specification, an installation is considered as a well.

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3.43
secondary well barrier
second set of barrier elements that prevent flow from a source

[SOURCE: API RP 90, modified]

3.44
shut-in well
well with one or more valve(s) closed in the direction of flow

3.45
subsea well
well completed with a subsea wellhead and a subsea tree

[SOURCE: API RP 90, modified]

3.46
subsea wellhead
wellhead that is installed at or near the seabed

3.47
surface casing
casing that is run inside the conductor casing to protect shallow water zones and weaker formations and may be cemented within the conductor string and is often cemented back to the mud-line or surface

Note 1 to entry: The surface wellhead is normally installed on this string for surface wells.

[SOURCE: API RP 90]

3.48
suspended well
well that has been isolated from the producing reservoir via a deep-set down-hole isolation device (mechanical or cement plug)

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

3.49
sustained annulus pressure (SAP)
pressure in an annulus that

a) rebuilds when bled down;

b) is not caused solely by temperature fluctuations; and

c) is not a pressure that has been imposed by the Well Operator

[SOURCE: API RP 90, modified]

3.50
thermally induced annulus pressure
pressure in an annulus generated by thermal expansion or contraction of trapped fluids

[SOURCE: API RP 90, modified]

3.51
verification
examination, testing, audit or review to confirm that an activity, product or service is in accordance with specified requirements

3.52
well barrier element
one or several dependent components that are combined to form a barrier envelope that, in combination, prevent uncontrolled flow of fluids within or from a well

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3.53
well barrier envelope
combination of one or several well barrier elements that together constitute a method of containment of fluids within a well that prevent uncontrolled flow of fluids within, or out of, a well

3.54
well integrity
containment and the prevention of the escape of fluids (i.e. liquids or gases) to subterranean formations or surface

3.55
well integrity management
See 5.1

3.56
well inventory
portfolio of wells that are not abandoned

3.57
Well Operator
company that has responsibility for operating the well

3.58
well operational phase
portion of the well's life cycle starting at the handover of the well after construction, until the well's permanent abandonment

Note 1 to entry: This includes production, injection, observation, closed-in and suspended well statuses.

Note 2 to entry: Well intervention activities, either rig based or rig-less, that involve breaking containment at the Christmas tree or wellhead are not part of the well operational phase.

3.59
well operating limits
combination of criteria that are established by the Well Operator to determine acceptable well integrity performance for the well's life

3.60
well status
well's current operational function i.e. flowing, closed in, suspended, undergoing construction or abandoned

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 & water
DASF	drilling adaptor spool flange
DHSV	Down-hole safety valve
ESD	emergency shut-down
EVP	emergency valve pilot

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FMEA	failure modes and effects analysis
FMECA	failure-mode and effects and criticality analysis
FS	formation strength
BOP	annulus safety valve
BS&W	blow out preventer
NORSOK	Norsk Sokkels Konkurranseposisjon
NPT	national pipe thread
OCP	observed casing pressure
OD	outer diameter
OEM	original equipment manufacturer
QRA	quantifiable risk assessment
RACI	responsible/accountable/consulted/informed
ID	internal diameter
KPI	key performance indicator
MAASP	maximum allowable annular surface pressure
MOC	management of change
ROV	remotely-operated vehicle
SCE	safety critical element
SAP	sustained annulus pressure
SF	safety factor
SCSSV	surface controlled subsurface safety valve
SSCSV	subsurface controlled subsurface safety valve
SSSV	sub surface safety valve
SSV	surface safety valve
TOC	top of cement
WBE	well barrier element
WIMS	well integrity management system
WOE	well operating limits
NOTE	NORSOK standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for petroleum industry developments and operations.

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5 Well integrity management system

5.1 Well integrity management

The management of well integrity is a combination of technical, operational and organizational processes to ensure a well's integrity during the operating phase of the life cycle.

5.2 Well integrity management system

The Well Operator shall have an approved well integrity management system (WIMS) that is applied to all wells under their responsibility, i.e. the well inventory.

As a minimum, the following elements shall be addressed:

a) well integrity policy and strategy;

b) resources, roles, responsibilities and authority levels;

c) risk assessment aspects of well integrity management;

d) well barriers;

e) well component performance standards;

f) well operating limits;

g) well monitoring and surveillance;

h) annular pressure management;

i) well handover;

j) well maintenance;

k) well integrity failure management;

l) management of change;

m) well records and well integrity reporting;

n) performance monitoring of well integrity management systems;

o) compliance audit.

6 Well integrity policy and strategy

6.1 Well integrity policy

The Well Operator shall have a policy defining its commitments and obligations to safeguard health, environment, assets and reputation by establishing and preserving well integrity. This well integrity policy shall be endorsed at a senior level within the Well Operator organization.

The Well Operator well integrity management system (WIMS) shall clearly indicate how the policy is interpreted and applied to well integrity.

6.2 Well integrity strategy

The Well Operator shall define the high level strategic measures to which it is committing in order to achieve the requirements of the asset (well) integrity policy.

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Such strategic measures may include an outline of how the Well Operator establishes

— business plans and priorities,

— resourcing plans, and

— budgeting

in support of its well integrity management objectives.

This high-level strategy shall manifest itself in, and be consistent with, the body of the well integrity management system (WIMS).

7 Resources, roles, responsibilities and authority levels

7.1 Organizational structure

Each Well Operator shall ensure that sufficient resources in their organizations are available to manage well integrity effectively during the operational life cycle of the Well Operator entire well inventory.

Each Well Operator shall define the roles and responsibilities for all professional, supervisory, operational and maintenance personnel required to manage the well integrity system. Roles and responsibilities should be documented, for example in an RACI matrix (see Annex A).

The Well Operator shall_assign the role of a well integrity technical authority / subject matter expert positioned outside of operations line management, to provide an independent technical review and recommendations on well integrity issues.

7.2 Competency

Each Well Operator shall ensure that their personnel (employees and contractors) who participate in well integrity activities are competent to perform the tasks assigned to them.

Each Well Operator shall define well integrity personnel competency requirements to ensure that well integrity activities are carried out in a manner which is both safe and efficient as regards protection of health, the environment and assets. A competence performance record should be maintained that demonstrates compliance.

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

An example of a competency matrix is given in Annex B.

8 Risk assessment aspects of well integrity management

8.1 General

Clause 8 discusses how established and proven risk assessment techniques are applied and used as a tool to assist in the management of well integrity. It identifies factors that should be considered and introduces evaluation techniques that may be applied when using risk assessment as the basis for

— establishing monitoring, surveillance and maintenance regimes for well barrier elements that are aimed at minimizing the potential risks of any impairment to well barrier envelopes;

— determining which of the barrier elements are considered safety critical elements that require performance standards and assurance tasks that confirm compliance to the performance standard;

— determining an appropriate course of action to address any well anomalies that are encountered during these monitoring, surveillance and maintenance regimes;

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— establishing risk of loss of containment considering, well type, pressure, effluent, outflow potential, location, environment against barrier redundancy.

8.2 Risk assessment considerations for well integrity

In 8.2.1 to 8.2.5 are given the minimum considerations that should be accounted for when assessing risks associated with well integrity in the operational phase.

8.2.1 Location

8.2.1.1 The well location can have a bearing on the risks presented by a well in terms of

— geographical location, e.g. onshore or offshore, urban or remote,

— facility/well type, e.g. platform, subsea, manned or unmanned facility/location,

— well concentration, e.g. single well, multiple well cluster.

8.2.1.2 Consideration should be given to the following:

— proximity of the well to workers and the potential effects on worker health and safety of any impairment to a well barrier envelope posed by any anomaly;

— proximity of the well to the environment and the potential effects on the environment of any impairment to a well barrier envelope posed by any anomaly;

— proximity of the well to other wells and infrastructure and the potential effects on such wells and infrastructure of any impairment to a well barrier envelope posed by any anomaly;

— assessment of any compounded risk posed by adjacent wells or infrastructure also having some form of impairment of their own barrier envelopes;

— societal impacts of any impairment to the well barrier envelope posed by an anomaly; consideration of such impacts should capture not only health, safety and environmental considerations to society at large, but also any economic impacts to society at large;

— ability to access the well in order to

  — monitor its condition,

  — perform maintenance,

  — perform repairs;

— ability to access the area in the vicinity of the well in order to mitigate the effects of any potential loss of integrity;

— ability and time to drill a relief well, if required.

8.2.2 Outflow potential

The ability of the well fluids to flow to the surface or into an undesirable subsurface location within the wellbore, with or without the aid of artificial lift, potentially has a bearing on the magnitude of the consequences associated with a loss of well integrity.

Consideration should be given to the impacts of the following:

— potential sources and leak-paths for outflow (tubing, annulus, control lines, gas-lift valves);

— outflow medium (from reservoirs and also limited volumes, e.g. gas lift gas);

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— failure of other barrier elements;

— rates;

— volumes;

— pressures;

— temperatures;

— duration over which the well is able to sustain flow;

— effects from offset wells, e.g. the effect that an offset injection well has on sustaining reservoir pressure support to a producer to enhance its ability to flow.

8.2.3 Well effluent

The composition of the well stream has a bearing on the risks posed by any well, both in terms of the effects of well effluent on impairment of the well barrier envelopes and the health, safety, environmental and societal risks associated with potential discharge of these effluents in the event of a loss of well integrity.

The effects of following fluid components within the well stream composition should be considered in a risk assessment associated with any potential anomaly:

— sour components;

— corrosive components;

— poisonous components;

— carcinogenic components;

— flammable or explosive components;

— erosive components;

— asphyxiating components;

— compatibility between components;

— formation of emulsion, scale, wax and hydrate deposits.

8.2.4 External environment

8.2.4.1 External risk to consider

In addition to well integrity risks influenced by outflow potential and well effluents, there are potential well integrity risks posed by exposure of well barriers to external environments that can be unrelated to the production or injection intervals to which these wells are connected.

The following effects should be considered:

— external corrosion of structural components such as conductor casing, surface casing and wellhead exposed to the atmosphere (i.e. due exposure to weather);

— external corrosion of structural components such as conductor, surface casing and wellhead exposed to the marine environment;

— external corrosion of casing strings exposed to corrosive fluids in subsurface locations (e.g. aquifers containing corrosive fluids, incompatibility between annulus fluid and top up fluid, corrosive top up fluid);

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— fatigue of structural components due to cyclic loading (e.g. motion of wellheads, conductors, tie-back casing strings, etc. due to the action of waves and currents offshore, wellhead motion due to interactions between loads imposed by BOPs/risers and wellheads during any drilling or work-over activities);

— impact of cyclic and/or thermal loading of wells on soil strength and the ability of soils to provide structural support to the well;

— external loads on wells associated with earth movements (e.g. reservoir compaction, earthquakes, tectonic motion associated with faults and motion of ductile materials such as salt formations);

— mechanical impacts associated with dropped objects (from facilities, vessels, vehicles or other equipment in the proximity of the wells);

— mechanical impacts associated with collisions (e.g. by ships or vehicles).

8.2.4.2 External risk mitigations

Some examples of risk and mitigations due external risk:

— subsea wells:

  — risk identified: collision with fishing trawlers' anchor chains/nets,

  — mitigation: deflector installed on subsea wellhead;

— offshore wells:

  — risk identified: dropped objects, drilling BOP of cantilever rig,

  — mitigation: weather deck above wellheads provided with a drop load capability;

— onshore wells:

  — risk identified: collision impact with moving vehicle,

  — mitigation: impact barriers placed around wellhead.

8.2.5 Redundant systems

Redundant systems constitute the components within the well that provide additional safeguards to mitigate potential impairments to well barrier envelopes.

Consideration should be given to the following when assessing how a redundant system affects well integrity risks:

— extent to which the redundant systems can be operated independently of a system that could be impaired;

— response time of redundant systems;

— service conditions for which the redundant systems are designed, relative to those of the system that can be impaired;

— method of operation of the redundant systems, e.g. manual or automatic.

Examples of redundant systems include an outer annulus (if rated), additional inline valves and additional ESD systems.

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8.3 Risk assessment techniques

Risk assessment techniques are used to assess the magnitude of well integrity risks whether these are potential risks, based on an assessment of possible failure modes, or actual risks, based on an assessment of an anomaly that has been identified.

Different types of techniques may be applied as deemed appropriate by the Well Operator for the particular well integrity issue that it is necessary to assess. A risk assessment process typically involves

— identification of the types of well anomaly and failure-related events that are possible for the well(s) that are being assessed;

— determination of the potential consequences of each type of well failure-related event; the consequences can be to health, safety, environmental or societal or a combination of these factors;

— determination of the likelihood of occurrence of the event;

— determination of the magnitude of the risk of each type of well failure-related event based on the combined effect of consequence and likelihood.

The assessment of any well failure-related event is normally depicted on a risk assessment matrix (an example of a "5 by 5" matrix is given in Figure 2) such that risk can be categorized or ranked based on the combined effects of consequence and likelihood of occurrence.

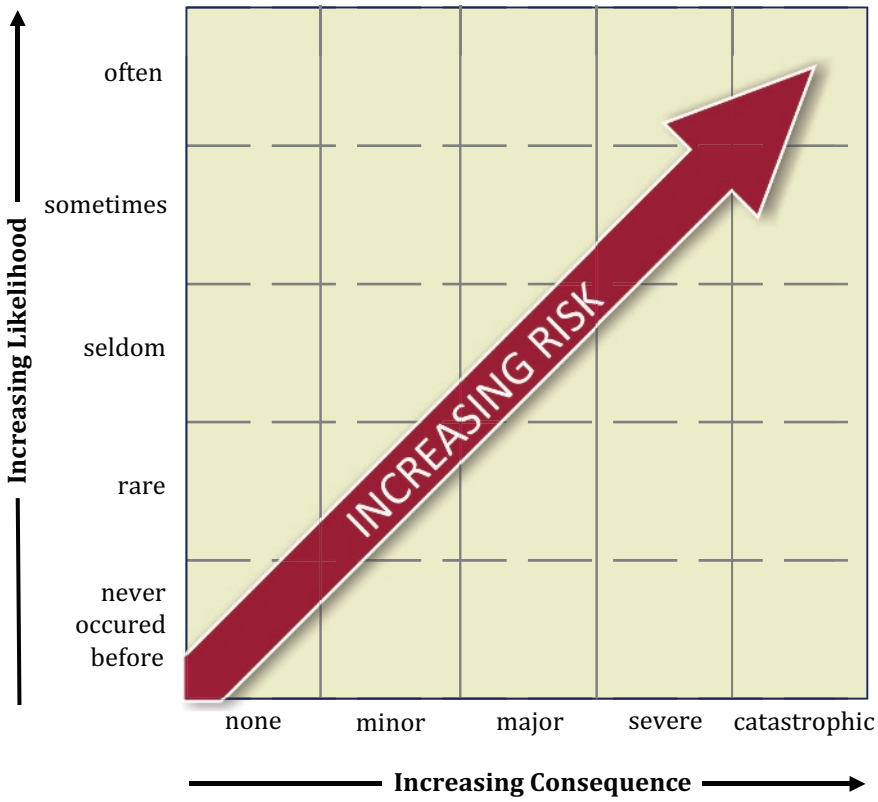

Figure 2 — Example of a Risk assessment matrix (RAM)

The Well Operator shall determine

— appropriate levels/definitions for consequence (severity) and likelihood of occurrence (probability) categories on the risk assessment matrix axes (simple examples of categories are shown in Figure 2); increasing levels of consequence and/or likelihood reflect increasing levels of risk (higher risk rankings);

— appropriate levels/definitions for the risk regions (boxes) within the risk assessment matrix.

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A qualitative risk assessment may be used where the determination of both consequence and likelihood of occurrence is largely based on the judgement of qualified and competent personnel based on their experience.

Quantifiable risk assessment (QRA) is another technique that may be applied to assess well integrity risks. This technique also assesses both consequence and probability but uses information from databases on well integrity failures to quantify the probability of a given event occurring.

Failure-mode and effects and criticality analysis (FMECA) can also be used to determine well integrity risks. FMECA is particularly useful in establishing the types of component failures that can occur, the effect on the well barrier envelope(s) and the likelihood of such failures occurring. This information can then be used to assist design improvements and in establishing the type and frequency of monitoring, surveillance and maintenance required to reduce the risk of the failures modes identified as part of the FMECA.

Detailed risk assessment methods and techniques can be found in ISO 17776, ISO 31000 and ISO/IEC 31010.

8.4 Application of risk assessment in establishing monitoring, surveillance and maintenance requirements

Monitoring, surveillance and maintenance techniques for wells are described in Clauses 14 and 15. The determination of appropriate techniques, including the required frequencies at which these techniques are applied, should ideally be supported by an assessment of the well integrity risks.

The risk assessment normally involves following the processes described in 8.3 to identify and rank the risks from potential well failure-related events.

The risk assessment is used to help establish

— types and frequency of monitoring;

— types and frequency of surveillance;

— types and frequency of maintenance;

— appropriate verification test acceptance criteria.

Once these parameters are established, they are used to reduce the risks of the identified potential well failure related events to acceptable levels.

There should, therefore, be a clear linkage between the overall risk profile of any given well type and its monitoring, surveillance, maintenance and acceptance regime. This normally means that wells with higher risks of well failure related events require more frequent maintenance in order to reduce risk (see Figure 3).

It is necessary for the Well Operator, when using a risk-based approach, to map for each well type, the components that may require monitoring, surveillance and maintenance in a risk based model. The risk based model (see API RP 580 for risk-based inspection examples) is used to identify the magnitude of the risk presented by the failure of a single component (initially assuming no monitoring, surveillance or maintenance) and maps this risk on a risk assessment matrix. Once the risks for all components are mapped on the matrix, isometric lines (i.e. lines plotted on the matrix that represent the same level of risk) can then be used to help define appropriate monitoring, surveillance and maintenance frequencies, together with an acceptance regime for such activities, to mitigate the identified risks. Figure 3 gives an example of a risk matrix used for this purpose.

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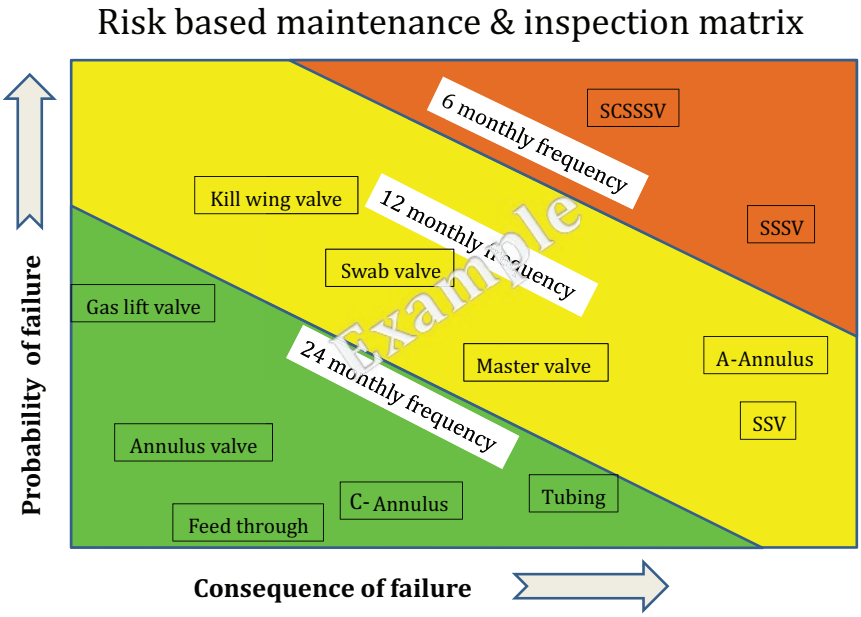

Figure 3 — Example of risk-based model as applied for well integrity assurance activities

8.5 Application of risk assessment in the assessment of well integrity anomalies

If an anomaly has the potential to affect the defined operating limits of the well, the risks posed by such an anomaly should be assessed and addressed. The Well Operator may already have established the activities that it is necessary to implement to address the anomaly based on existing practices or procedures.

The following steps describe the typical process that should be followed to establish the well integrity risk.

— Identify the well integrity anomaly.

— Assess whether the anomaly poses potential risks from well failure-related events or can lead to further anomalies that pose such risks.

— Assess the consequences and likelihood of each risk.

— Assess the magnitude of each risk (equal to the product of the consequence and the likelihood) associated with each event, preferably using a risk assessment matrix.

— Assess what actions or activities can be implemented that mitigate or reduce each risk.

— Assess the consequence, likelihood and magnitude of each risk after implementation of mitigating actions or activities, preferably using a risk assessment matrix.

— Assess whether each residual risk (i.e. the magnitude of the risk after any risk mitigation/reduction measures are implemented) is tolerable enough to permit the well to remain operational.

The magnitude of risk (prior to implementation of any risk reduction measures) should be used in determining the actions that are appropriate to address the anomaly. Generally, the higher the risk, the greater the priority and/or resources that are required, apply.

8.6 Failure rate trending

Trending of failure rates against time can also help to determine inspection frequencies for certain classes or models of equipment and can influence future replacement equipment selection.

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The failure rate can also change depending on the age of the component; this is depicted in the curve in Figure 4. This curve typifies the expected component failure rate across time and is divided into three distinct areas:

— early life (decreasing failure rate), when failure is due to component quality;

— useful life (constant failure rate), when failure is due to normal in-service stress;

— wear-out (increasing failure rate), when failure is due to component wear and tear.

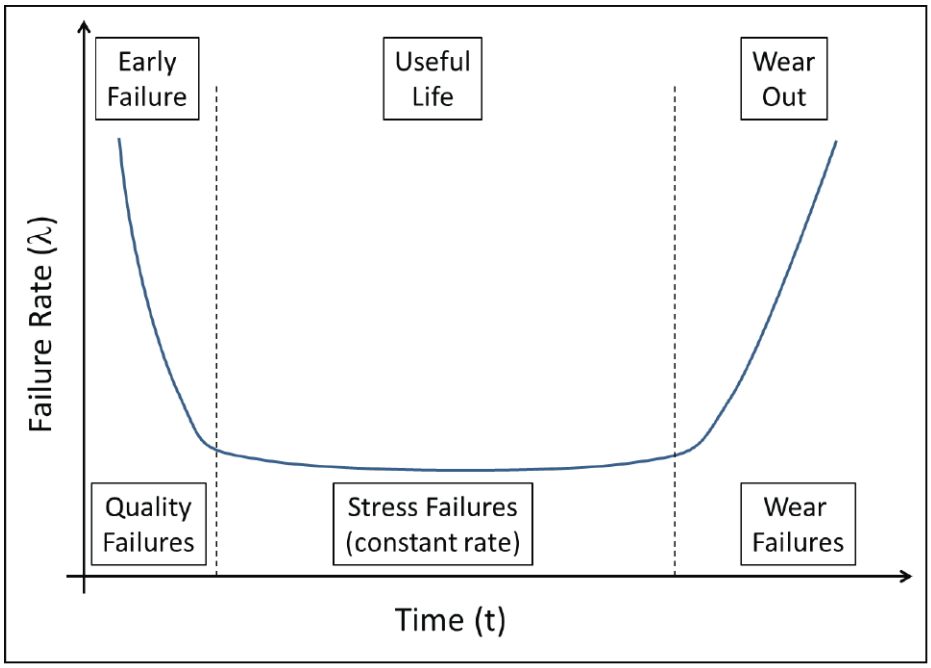

Figure 4 — Component failure rate as a function of time

Quality failures (or early failures) are typically associated with design or fabrication error (e.g. faulty material, bad assembly, etc.). Wear-out failures are typically associated with such failure mechanisms as metal loss, thermal fatigue, creep, etc.

The period where the failure rate is constant is the period of the component's useful life. During this period, a high confidence level can be applied to the component's probable time to failure and appropriate service and replacement intervals determined.

9 Well barriers

9.1 General

Well barriers are the corner stone of managing well integrity. Clause 9 discusses the well barriers, well barrier envelopes, well barrier elements, well barrier philosophy and how these are used by the Well Operator in their well integrity management system.

The primary purpose of well integrity management is to maintain full control of fluids at all times to prevent the loss of containment to the exterior of the wellbore, the environment and formations penetrated by the wellbore. This is achieved by employing and maintaining one or more well barrier envelopes.

9.2 Barrier philosophy

The Well Operator shall define a barrier philosophy for each of the well types within the WIMS.

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An example of a well barrier philosophy is given below.

— If a well is capable of sustained flow to the surface or to an external environment due to reservoir pressure (natural or maintained), at least two independently tested well barrier envelopes should be maintained.

— If a well is not capable of natural flow to the surface, one (1) mechanical well barrier envelope may be maintained. This is based on the principle that the hydrostatic column of the wellbore fluids provides the primary barrier envelope itself. In these cases, a risk analysis should be performed to confirm that one mechanical barrier envelope is adequate to maintain containment, including subsurface flow.

9.2.1 Barriers when breaking containment

— A minimum of two barriers that can be independently verified are required prior to breaking containment for repairs.

— The allowable leak rate through the sum of these two barriers should be zero or bubble-tight. If there is a small leakage rate through one of these barriers, a double block-and-bleed system should be in place so that the pressure is constantly maintained at zero.

9.3 Well barrier envelopes

The preservation, maintenance, inspection and testing of well barrier envelopes are key aspects of the management of well integrity throughout the operational phase of a well.

The Well Operator shall know the status of each well barrier envelope and shall maintain all well barrier envelope(s) according to the well's intended well operating limits.

In cases where a barrier envelope cannot be maintained according to the original design specification, the Well Operator shall perform a risk assessment to establish the required controls to mitigate the risk.

During the operating phase of a well, boundary conditions or well usage may change. This requires a re-evaluation of the barrier envelopes and the well operating limits.

A well barrier envelope shall

— withstand the maximum anticipated differential pressures to which it can be subjected;

— be leak- and function-tested, or verified by other methods;

— function as intended in the environment (pressures, temperature, fluids, mechanical stresses) that can be encountered throughout its entire life cycle.

Once a well has been constructed and handed over for operation, the number of barrier envelopes will have been determined during the well's design and shall be documented through a well handover process.

9.4 Well barrier element

9.4.1 A well barrier envelope may include mechanical well barrier elements.

For a well barrier element to be considered operational, it should be verified and maintained through regular testing and maintenance. The location and integrity status of each well barrier element should be known at all times (see Annex C).

9.4.2 For a well in operation, the primary well barrier envelope typically constitutes the following well barrier elements:

— cap rock,

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— casing cement,

— production casing,

— production packer,

— tubing

— SCSSV or Christmas tree master valve.

9.4.3 The secondary well barrier typically constitutes the following well barrier elements:

— formation,

— casing cement,

— casing with hanger and seal assembly,

— wellhead with valves,

— tubing hanger with seals,

— Christmas tree and Christmas tree connection.

— actuated wing valve or Christmas tree master valve

NOTE The SSSV is considered to be a part of the primary barrier envelope in some jurisdictions.

9.5 Documenting of well barrier envelopes and well barrier elements

The Well Operator shall be able to demonstrate the status of well barrier envelopes for each well and well type.

The Well Operator should consider recording the current barrier envelopes and their respective elements. It is suggested that a well barrier schematic be used to convey this information. Any failed or impaired well barrier elements should be clearly marked and stated on the well barrier record.

It shall be clear from the well handover documentation which components in the well are well barrier elements and comprise which barrier envelope, the primary or the secondary (where applicable).

A sample of a well barrier schematic is presented in Annex D.

10 Well component performance standard

10.1 General

A well component performance standard contains the functionality and acceptance criteria for each of the barrier safety critical elements. Acceptance criteria for well integrity describe such items as acceptable leak rates, time to closure, fail-safe specification; etc.

Clause 10 describes the required performance standards for the well barrier envelopes and associated barrier elements. Additionally, the section provides examples and guidance, including calculations, for verification of the performance standard as specified by the Well Operator.

The Well Operator shall define performance standards for each well type. Performance standards, supported by the risk assessment, are the basis for the development of maintenance and monitoring requirements.

Items to consider when defining a performance standard are

— functionality;

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