

Life extension for subsea systems

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Foreword

The NORSOK standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for petroleum industry developments and operations. Furthermore, NORSOK standards are, as far as possible, intended to replace oil company specifications and serve as references in the authorities' regulations.

The NORSOK standards are normally based on recognised international standards, adding the provisions deemed necessary to fill the broad needs of the Norwegian petroleum industry. Where relevant, NORSOK standards will be used to provide the Norwegian industry input to the international standardisation process. Subject to development and publication of international standards, the relevant NORSOK standard will be withdrawn.

The NORSOK standards are developed according to the consensus principle generally applicable for most standards work and according to established procedures defined in NORSOK A-001.

The NORSOK standards are prepared and published with support by The Norwegian Oil Industry Association (OLF), The Federation of Norwegian Industry, Norwegian Shipowners' Association and The Petroleum Safety Authority Norway.

NORSOK standards are administered and published by Standards Norway.

Introduction

Facilities installed on the Norwegian Continental Shelf (NCS) have a lifetime and a number of assumptions that are the basis for the approval of the Plan for Development and Operation (PDO) for the field they are associated with. In the event that the facilities are planned to be used beyond the service life and/or assumptions in the PDO are changed, then the Operator is required to apply for a new consent document to use the facilities. This consent will cover use in a new period.

The subsea system in this context is understood to include all production facilities located subsea with exception of pipelines, flexible risers and wells. Subsea processing is also defined to be included in the subsea system. Formalities regarding application process towards authorities are prepared through OLF guideline no. 122.

For components included in a subsea processing system that are covered by one of the below mentioned OLF standards, the specific standard is applicable. All the others, such as compressors, pumps, separators etc shall follow the general process described in this NORSOK standard and Annex A.

Annex A gives system specific requirements for life extension, and is in this matter different from the other annexes. To ensure the integrity of the total system Annex A should be used in all life extension processes.

Pipelines, flexible risers and wells are directly involved in the containment of process fluids, and will be covered by NORSOK Y-002 "Life extension for transportation systems" (under preparation) and the "Wells lifetime extension checklist". Topsides hydraulic systems, power, DCS and chemical supply units will be addressed under the topside standards.

Battery limits for the subsea system are in general at contact point with the following systems:

- transportation systems – pipelines;
- topside systems - hydraulic, power, DCS, chemical supply;
- wells – subsea tree connectors;
- umbilical – termination on platform or turret.

OLF is developing standards and guidelines to provide requirements for the industry, and the following segments are defined:

- | | |
|--|----------------------|
| • load bearing structure | NORSOK N-006 |
| • transportation systems (pipelines, risers) | NORSOK Y-002 |
| • subsea systems | This NORSOK standard |

- | | |
|--|--|
| • drilling and well systems | Checklist developed by OLF's Drilling Managers Forum |
| • technical safety systems | Under development |
| • HSE (health, safety and working environment) | Under development |
| • topside | |
| • processing system | Under development |

It is the intention of the standards listed above, that they shall cover all underwater equipment.

NOTE The interfaces between the standards will in some cases not be clear-cut. The objective in these OLF life extension standards is to ensure coverage of all elements underwater. To avoid gaps, the ruling principle is to accept some degree of overlap to ensure that all underwater equipment/components are covered by the life extension standards.

Example:

Jumpers and anchor lines are included in subsea scope.

It can be argued that jumpers can also be covered under transportation systems. For most practical issue, the same considerations shall be made for pipelines and jumpers. Future revisions may place jumpers in transportation systems.

The same issue may be valid for anchor lines - currently in subsea, but could also be part of load bearing structures.

Technical integrity of the subsea equipment, i.e. ensuring containment of hydrocarbons and other harmful substances, is the primary concern of this NORSOK standard. Operational integrity will be taken into consideration where this is essential for the system. For more description on application of this NORSOK standard, see Clause 1 and 5.6.

Subsea systems consist of many and complex sub-systems and components. Each part has a range of characteristic properties which need to be assessed when quantifying the expected lifetime. The interaction between the different sub-systems and components must also be considered during the assessment.

Subsea systems are increasingly used on the Norwegian Continental Shelf and this NORSOK standard is prepared as a national standard and the identified requirements are based on available knowledge and experience provided by the systems in the national domain.

1 Scope

This NORSOK standard defines general principles for assessing an extension of service life beyond the original service life of subsea systems.

NOTE 1 This may require extension of the design life premised in the original design.

Sub-systems and components included within a subsea system are

- subsea trees (Annex B),
- manifolds (Annex C and Annex E),
- protection and support structures (Annex C),
- tethers and buoyancy aids (Annex H),
- valve stations (Annex D),
- subsea isolation valves (Annex D),
- interconnecting flowlines (Annex E),
- electrical, hydraulic, chemical and power umbilicals (Annex F),
- topsides control system modems/interface (Annex G),
- hydraulic/chemical lines (Annex E),
- subsea processing system.

The scope distribution is graphically shown in Figure 1.

NOTE 2 It should be noted that service life and design life are defined with some difference in identified standards.

Some examples are quoted here:

DNV-OS-F101:2007	Design life is the initially planned time period from initial installation or use until permanent decommissioning of the equipment or system. The original design life may be extended after a re-qualification.
ASME B31.8:2003	<i>(Does not define a design life, but uses design life and service life as dimensional limits for design with respect to cyclic loading and cathodic protection systems).</i>
ASME B31.4:2006	Design life is a period of time used in design calculations selected for the purpose of verifying that a replaceable or permanent component is suitable for the anticipated period of service. Design life does not pertain to the life of the pipeline system because a properly maintained and protected pipeline system can provide liquid transportation indefinitely.

The difference between service life and design life may be illustrated by the following example:

The design life of a system is 25 years. However, the system was intended to operate 15 years (limited by the reservoir predictions), and the operator applied for a 15 years permission – which becomes the original service life.

Later the operator wants to extend the service life by 5 years, for a total of 20 years. In this case the design supports the application for service life extension with respect to design life. The operator will still have to document acceptable system integrity to the end of the extended service life, and apply to the authorities.

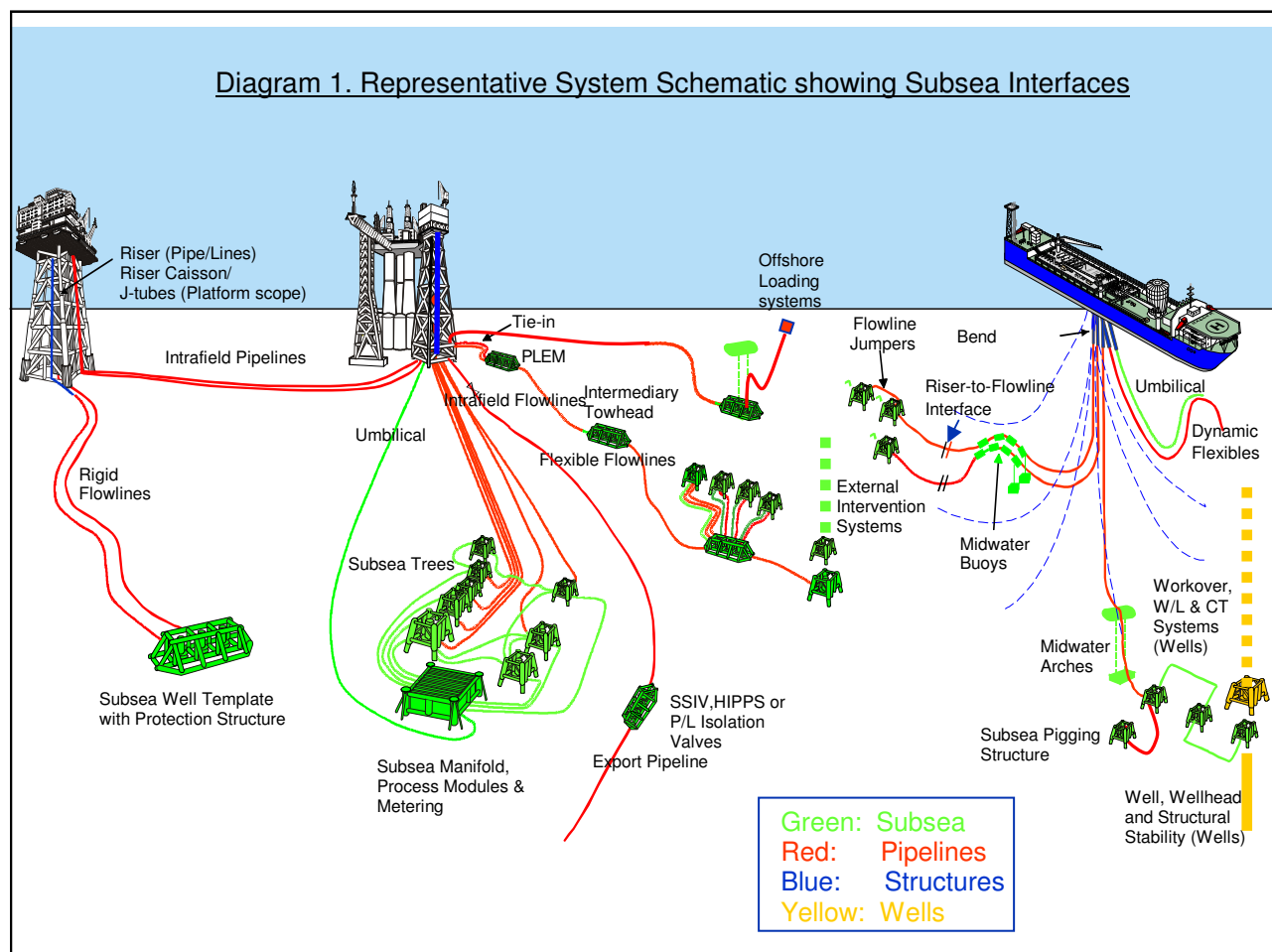


Figure 1 - Overview subsea systems applicable for this NORSOK standard

2 Normative and informative references

The following standards include provisions and guidelines which, through reference in this text, constitute provisions and guidelines of this NORSOK standard. Latest issue of the references shall be used unless otherwise agreed. Other recognized standards may be used provided it can be shown that they meet the requirements of the referenced standards.

2.1 Normative references

NORSOK N-006,	Assessment of structural integrity for existing offshore load bearing structures
OLF guideline no. 122,	Recommended guidelines for the assessment and documentation of service life extension of facilities

2.2 Informative references

ASME B31.3,	Process Piping
ASME B31.4,	Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids
ASME B31.8,	Gas Transmission and Distribution Piping Systems
ASME B16.34,	Valves – Flanged, Threaded and Weld Ends
IEC 61508,	Functional safety of electrical/electronic/programmable electronic safety-related systems -
ISO 10423,	Wellhead & XT equipment
ISO 14313,	Pipeline Valves
ISO 14723,	Subsea Pipeline Valves
ISO 13628-1,	Petroleum and natural gas industries – Design and operation of subsea production systems – Part 1: General requirements and recommendations
ISO 13628-4,	Petroleum and natural gas industries – Design and operation of subsea production systems – Part 4: Subsea wellhead and tree equipment

ISO 13628-5,	Petroleum and natural gas industries – Design and operation of subsea production systems – Part 5: Subsea umbilicals
ISO 13628-6,	Petroleum and natural gas industries – Design and operation of subsea production systems – Part 6: Subsea production control systems
ISO 13628-15,	(Under approval)
ISO 13703,	Design and installation of piping systems on offshore platforms
ISO 16708,	Petroleum and natural gas industries – Reliability based limit state methods
NORSOK D-010,	Well integrity in drilling and well operation
NORSOK Y-002,	Life extension for transportation systems
NORSOK U-001,	Subsea Production Systems
NORSOK N-001,	Integrity of offshore structures
NORSOK N-003,	Action and action effects
NORSOK N-004,	Design of steel structures
NORSOK N-006,	Life extension of load bearing structure
NORSOK L-001,	Piping and Valves
API-RP-2A/API-RP-2SK,	Recommended Practice for Planning, Design and Construction Fixed Offshore Platforms – WSD/Design and Analysis of Stationkeeping Systems for Floating Structures
API 598,	Valve inspection and testing
BS 6755-1,	Testing of valves. Specification for production pressure testing
DNV-OS-C101/DNV-OS-C201,	Design of Offshore Steel Structures – General (LFRD Method)/Structural Design of Offshore Units (WSD method)
DNV-OS-F101,	Submarine Pipeline Systems
DNV-OS-F201,	Dynamic Risers
DNV RP B-401,	Cathodic Protection Design

3 Terms, definitions and abbreviations

For the purposes of this NORSOK standard, the following terms, definitions and abbreviations apply.

3.1 Terms and definitions

3.1.1

acceptance level

maximum level of risk that is acceptable for the system at any time during its operation

NOTE A defined acceptance level is based on governmental regulations, design code or company requirements.

3.1.2

assessment

total set of activities performed in order to find out if the reliability of a system is acceptable or not

3.1.3

can

verbal form used for statements of possibility and capability, whether material, physical or casual

3.1.4

degradation

gradual breakdown of components or of a material, as a result of being exposed, i.e. to time and environment

NOTE Sections and components degrade as a function of time and exposure, and the rate of degradation will vary. The components in the system have been qualified as a minimum to the design life.

A system may also consist of components that are not intended to be in service for the design life. These components are planned to be replaced throughout the operational life based on specific intervals or condition based intervals. They are then a part of a maintenance plan.

3.1.5

degradation model

model which shall describe how the integrity level of the system evolves over time and exposure

NOTE The degradation model can also be called "risk evolution model". Typically the integrity will decrease, in other words the risk inherent in the system will increase.

The degradation model is typically centered on the structural integrity of the system. Important factors are corrosion, fatigue, stress levels, temperature, pressure, erosion, operational environment etc.

The degradation model is usually defined by the design standard, known technology and industry practice. This model can change over time, due to new technology and research, as well as changes in industry practice and updated design standards.

In cases where the risk to/integrity of the system is defined more broadly (i.e. not only structural integrity, but also operational integrity, economic performance etc), other factors may play an important role in the degradation model.

3.1.6

design life

specified period for which the integrity of the system is documented in the original design with anticipated maintenance, but without requiring substantial repair

3.1.7

feasibility

something that is feasible can be done, made, or achieved

3.1.8

integrity

the state of being complete/ in "perfect" condition

3.1.9

integrity assessment

documents the present system integrity level, and forms a basis for further life extension work

3.1.10

integrity life

period during which the system or component may be operated without infringing the integrity acceptance level

NOTE The integrity life is longer than the design life, and in most cases the integrity life can not be documented.

Conservatism in design and material data is the background for much of the difference between integrity life and design life. In the design process the focus is on documenting an acceptable integrity level for the specified design life. The design process is often conservative when choosing parameters for calculations and qualifications.

The integrity life is the upper theoretical limit for the design life.

3.1.11

integrity level

expression of the absence of risk inherent in the system

NOTE The risk can be of various natures; human, environmental, economic or political. Different systems have different failure modes or critical situations, and the risk associated with each of these can vary from system to system.

3.1.12

life extension

documented justification for operating a system beyond its original service life

3.1.13

may

verbal form used to indicate a course of action permissible within the limits of this NORSOK standard

3.1.14**modification**

changes, improvements or repairs of a system

3.1.15**re-qualification**

re-assessment of design due to modified design premises and/or sustained damage

NOTE Life extension is a design premise modification.

3.1.16**risk**

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

3.1.17**service life**

time length the system is intended to operate

NOTE The service life is a part of the application toward authorities.

EXAMPLE

The design life of a system is 25 years. However, the system was intended to operate 15 years (limited by the reservoir predictions), and the operator applied for a 15 years permission. Later the operator wants to extend the service life with 5 years, for a total of 20 years. In this case the design supports the application for service life extension with respect to design life. The operator will still have to document acceptable system integrity to the end of the extended service life, and apply to the authorities.

3.1.18**shall**

verbal form used to indicate requirements strictly to be followed in order to conform to this NORSOK standard and from which no deviation is permitted, unless accepted by all involved parties

3.1.19**should**

verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required

3.2 Abbreviations

ALS	accidental limit states
API	The American Petroleum Institute
ASME	American Society of Mechanical Engineers
BOP	blow out preventer
CP	cathodic protection
DNV	Det Norske Veritas
FMEA	failure mode and effect analysis
IMS	integrity management system
ISO	International Organization for Standardization
NPD	Norwegian Petroleum Directorate
OLF	Oljeindustriens Landsforening
OCIMF	Oil Companies International Marine Forum
PLEM	pipeline end manifold
PSA	Petroleum Safety Authority
RAM	reliability, availability and maintainability
ROV	remotely operated vehicle
SSIV	sub sea isolation valve
ULS	ultimate limit states
XT	X-mas tree

4 Assessment methodology

4.1 Objective

This clause describes the general methodology to be applied to a life extension process. The remaining sections of this NORSOK standard are built up according to this methodology.

4.2 Integrity management system (IMS)

The operators follow up the subsea systems through an IMS. The objective of the IMS is to ensure that the technical and operational integrity of the subsea system is continuously maintained at an acceptable level. The structure of an integrity management system is illustrated in Figure 2.

The activities and assessments carried out as a part of the integrity management system is not part of the life extension process. A continuous integrity assessment is an inherent part of the integrity management process, where data from inspection, monitoring and testing are evaluated against the need for mitigation, intervention or repair. The integrity management process is carried out within the constraints of the original design, and is not necessarily sufficient to document and justify a life extension. However, the data provided by the integrity management system is necessary in order to perform a life extension process.

INTEGRITY MANAGEMENT SYSTEM

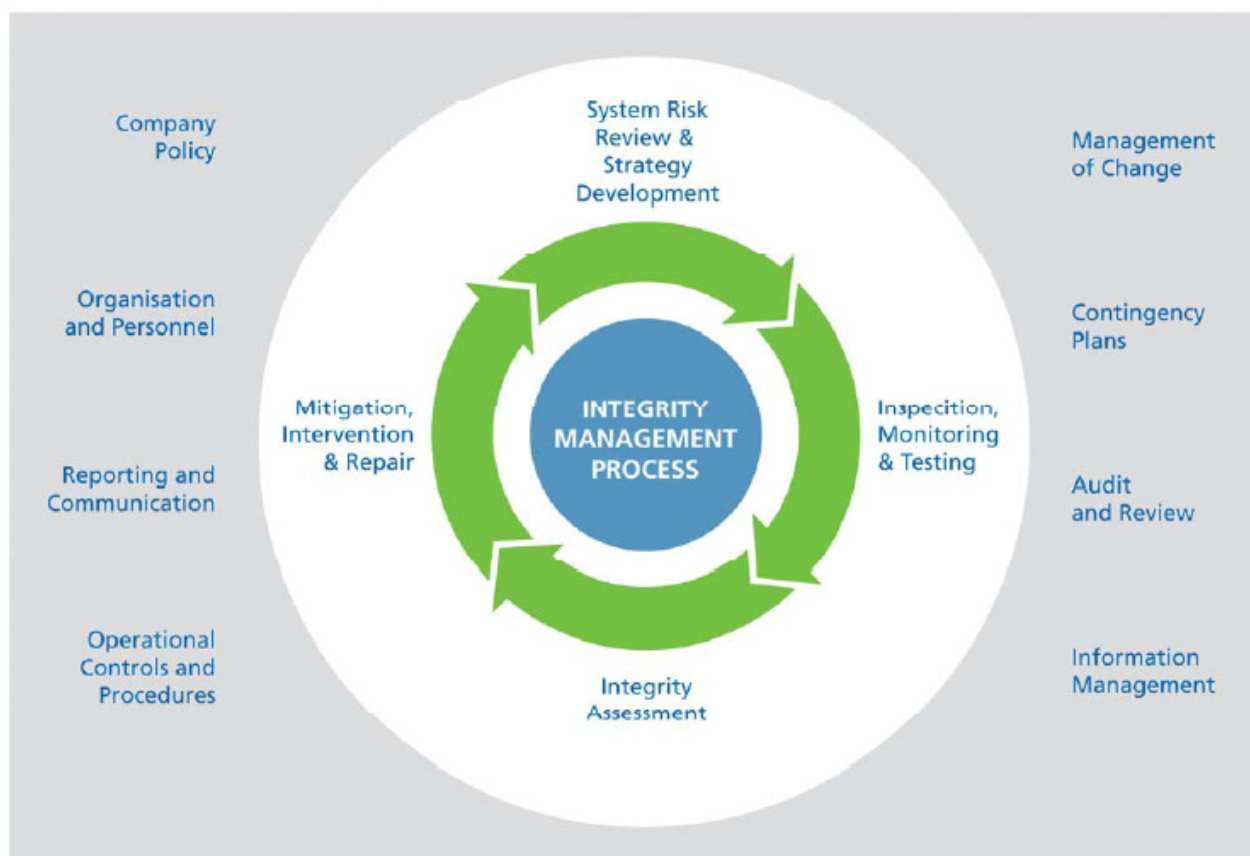


Figure 2 - The structure of an integrity management system and process

4.3 Life extension process

The life extension process can also be called a re-qualification, see Annex I. It is triggered by the desire to continue the operation of the system beyond the original service life. The process that may be followed in a life extension assessment is outlined in Figure 3.

The purpose of the life extension process is to document acceptable system integrity to the end of the extended service life.

The overall life extension methodology is as follows:

- define the premise for the extended operation, and identify new threats to the system, i.e. temperature, pressure, external loads, new rules and regulations and codes, human factors;
- assess the integrity of the system, i.e. as far as possible quantify the current condition;
- carry out a reassessment of the system based on the available information, current industry practice and available technology;
- the reassessment can conclude that the integrity of the system is acceptable up to the end of the extended service life, in which case the process moves on to documentation/application and implementation. If the integrity is not acceptable, modifications shall be considered, and possibly evaluate the feasibility of the entire life extension.

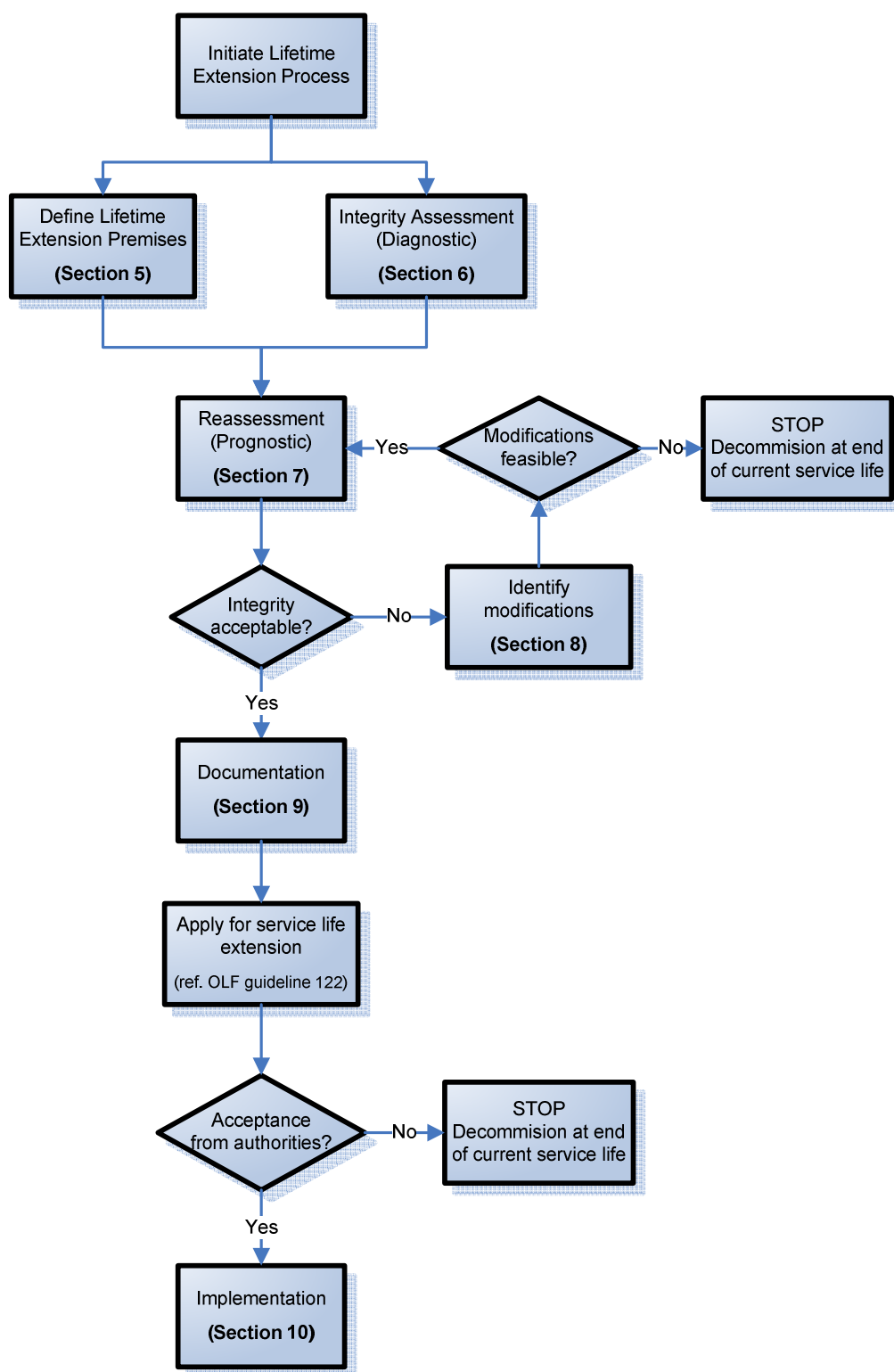


Figure 3 - Life extension work process

4.4 Degradation

The life extension process shall take into account the degradation that has taken place since the installation of the system.

Figure 4 is an example of degradation and integrity assessment, see also Annex I. A life extension evaluation should be initiated well ahead of the end of the original service life. The original service life is limited by the design life and the authorities permission. In the original design, a given degradation model was used, which does not provide sufficient design life for the desired extended service life.

At the time of the life extension evaluation, an integrity assessment is performed. In this example it was found that the degradation model was conservative, and the current condition of the system is actually better than anticipated. In the reassessment, a new degradation model is introduced based on new technology and/or industry practice. Based on this new degradation model, the new extended design life is established, which exceeds the desired extended service life. Subsequently a life extension application for the system can be submitted to the authorities, and service life for this system may be extended toward the extended design life without requirements to repair or modifications.

Note that in this example the first degradation model limited the original design life – without the integrity assessment and the new degradation model, the life extension would not have been possible, since the extended service life was beyond the original design life.

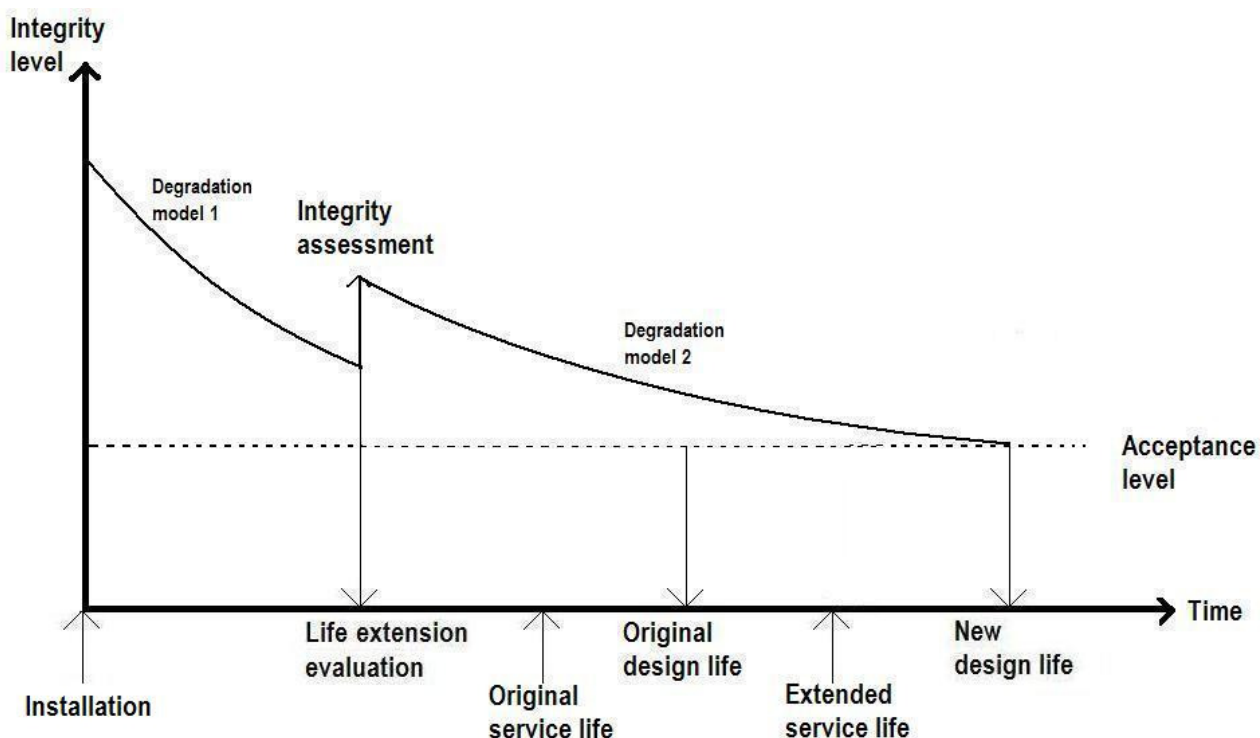


Figure 4 - A schematically sketch of the identified integrity level vs. time

5 Life extension premises

5.1 Objective

The original design premises shall be reviewed to assess whether they are still applicable for the extended life period. Revisions may be required, e.g. authority regulations. Changes or updates to the premises can lead to solutions that are more reliable and more cost-effective.

5.2 Authority regulations

The latest authority regulations apply to the subsea system. Implementation of a life extension for a subsea system requires consent from the authorities, which are represented by the PSA.

The consent application process is presented in OLF guideline no. 122.

5.3 Design standards

The subsea system is designed according to applicable standards that were selected at the time of design. The same design standards may be used throughout operation of the system (existing last revision shall be used), also when changes to this system are introduced. This includes life time extension.

When initiating a life extension process other standards may be commonly used for design of new subsea systems. Gaps between the original design standard (original revision shall then be used) and applicable other standards at time of life extension shall be identified. Such gaps can indicate changes in the integrity acceptance level, and the subsea system operator shall assess the risk associated with this gap.

5.4 Design premise

The design premise is the basis for the original design, and describes the operational and design limits for the system at time. The design premise also outlines the functional requirement/constraints to the system.

In the context of this NORSOK standard, the primary premise is the design life, and this will be changed in the life extension process. Other premises may also be changed or updated, or they have already been changed during the operation of the system.

The operator shall ensure that all premises relevant for the life extension are addressed.

Table 1 gives examples of parameters premised for design.

NOTE The table is not intended to be complete.

Table 1 - Examples of parameters premised for design

Category	Subject
Operational parameters	Flow
	Pressure
	Temperature
	Density
	Shut in characteristics
	Cyclic operations of the system with respect to above mentioned data
	Chemical composition
External parameters	Fisheries (trawling)
	Anchoring
	Metocean data
	Subsidence
	Earthquake
	Geotechnical
	Vessel motion characteristics
Methodologies for response and capacity calculations	Cyclic/fatigue capacity
	Design/operational load capacity

5.5 Threats to the subsea system

5.5.1 General

The subsea system shall be designed with an acceptable safety to failure. A subsea system is exposed to external as well as internal threats. The threats also have different characteristics:

- event based; e.g. dropped objects, dragged/dropped anchor, drill pipe etc.
- condition based; e.g. change in operational parameters
- time based; e.g. excavation/scouring, ineffective corrosion protection or corrosion control

The combined effect of threats shall also be considered. New threats based on new or changed design premises shall be identified.

5.5.2 Containment and integrity

One of the main service/criterion for a subsea system is containment. Failures of the subsea system are identified by

- leak,
- rupture/burst,
- collapse.

To ensure that these events do not occur, acceptance criteria are prescribed by design standards. These criteria may be expressed through allowable stress design format or limit state design format.

5.5.3 Internal threats

The potential internal threats to subsea system may be dependent of the medium(s). Typical threats are

- corrosion,
- erosion,
- wear,
- chemical and physical ageing,
- overpressure,
- underpressure,
- changes in flow characteristics,
- clogging (hydrates etc.),
- slugging.

5.5.4 External threats

The potential external threats to a subsea system will be the same but independent of the medium. The various threats will vary along the subsea system. Typical threats are

- external corrosion,
- trawl pullover and hooking,
- well growth,
- structural collapse,
- design, fabrication and installation "shortcomings",
- installation damage (e.g. to electrical, hydraulic connectors),
- other third party damages (dropped objects etc.),
- seabed subsidence (compaction).

5.6 System overview

5.6.1 General

The subsea system for which a life extension process is carried out shall be described in such detail that battery limits are clearly defined. All sections and properties of the system associated with the life extension shall be described, as well as components along the system.

The system may consist of components that are subject to other standards with respect to life extension than this NORSOK standard. Reference to these components and their applicable standards shall be given. In Clause 1 interfaces are described that may be relevant for the system and reference to standards and guidelines are provided.

The entire system shall be considered in the life extension process, not only parts therein.

5.6.2 Configuration and support systems

Components that have no pressure containment are also important parts of the subsea system. These components shall be defined as integral parts of the subsea system since they are vital for the function of the subsea system. These include

- CP system,
- protection system,
- tethers and buoyancy aids,
- electrical and power umbilicals,
- control system.

5.6.3 Spare parts and repair system

Spare parts and repair systems that are system-specific and stored onshore shall also be included in the diagnostic phase of the life extension process. This is provided that they will be a part of the system into the life extension period. Their condition, stocking levels and storage facilities shall be evaluated, and the consequence of continued storing shall be assessed. In case any changes are made to the system (system parameters, improvements/reconstruction) the fitness-for-purpose of the parts shall be re-evaluated.

Spare parts are as follows:

- valves;
- electrical cables;
- hydraulic hoses;
- control modules;
- choke modules.

6 Integrity assessment

6.1 Integrity management system

The subsea system should have an established IMS. Different integrity management systems can have different scope. The IMS will be the primary source of information and will form the basis of a life extension process. The IMS is used to carry out

- data collection,
- condition assessment.

6.2 Data collection

A well developed integrity management system can produce and store a large quantity of data. For assets without an integrity management system, information may be difficult to access, i.e. operational parameters, other.

Information relevant for a life extension process captured in the integrity management system may be

- structural analyses,
- flow assurance,
- operational procedures,
- risk and hazard evaluations,
- inspection data,
- maintenance program,
- modifications/changes,
- environmental loads.

The quality of the inspection, monitoring and maintenance program is of vital importance for the ability to perform a condition assessment and assess the future life of a subsea system. The collected data should be thoroughly reviewed to ensure quality and relevance for use in a life extension process.

Any identified gaps should, if possible, be closed by remedial measures, such as additional inspections or improved monitoring.

6.3 Condition assessment

6.3.1 Condition control

The design premise defines the operational envelope for the system, i.e. the allowable limits on various parameters. In general, condition control is focused on identifying aspects of the operation or system that are outside the defined envelope. This means that the design assumptions are compared with the observations and data provided by monitoring and inspection activities.

A large part of the condition control activities are directed toward confirming that system operation is inside the operation envelope defined in the design process. Direct observation of the system condition may not be sufficiently detailed to allow a calibration of the degradation model used in design.

As long as the observations and data from the condition control are inside the operation envelope defined in the design process, it is likely that the integrity life exceeds the design life.

The challenge is to document that the integrity level is higher than assumed in the design process, so that there is a basis for further operation of the system.

Based on the quality or strategy of the integrity management system, the condition could be

- unknown; no integrity management system established,
- known by design; operational parameters monitored to be within design limits,
- known by operational experience; operational data available and structural integrity may be assessed,
- quantified through direct measurements; physical condition of structure measured.

Controlling condition by design requires that the degradation models are identified and correctly understood in the design.

The different types of condition control will have different impact on the ability to assess current condition, see Figure 5.

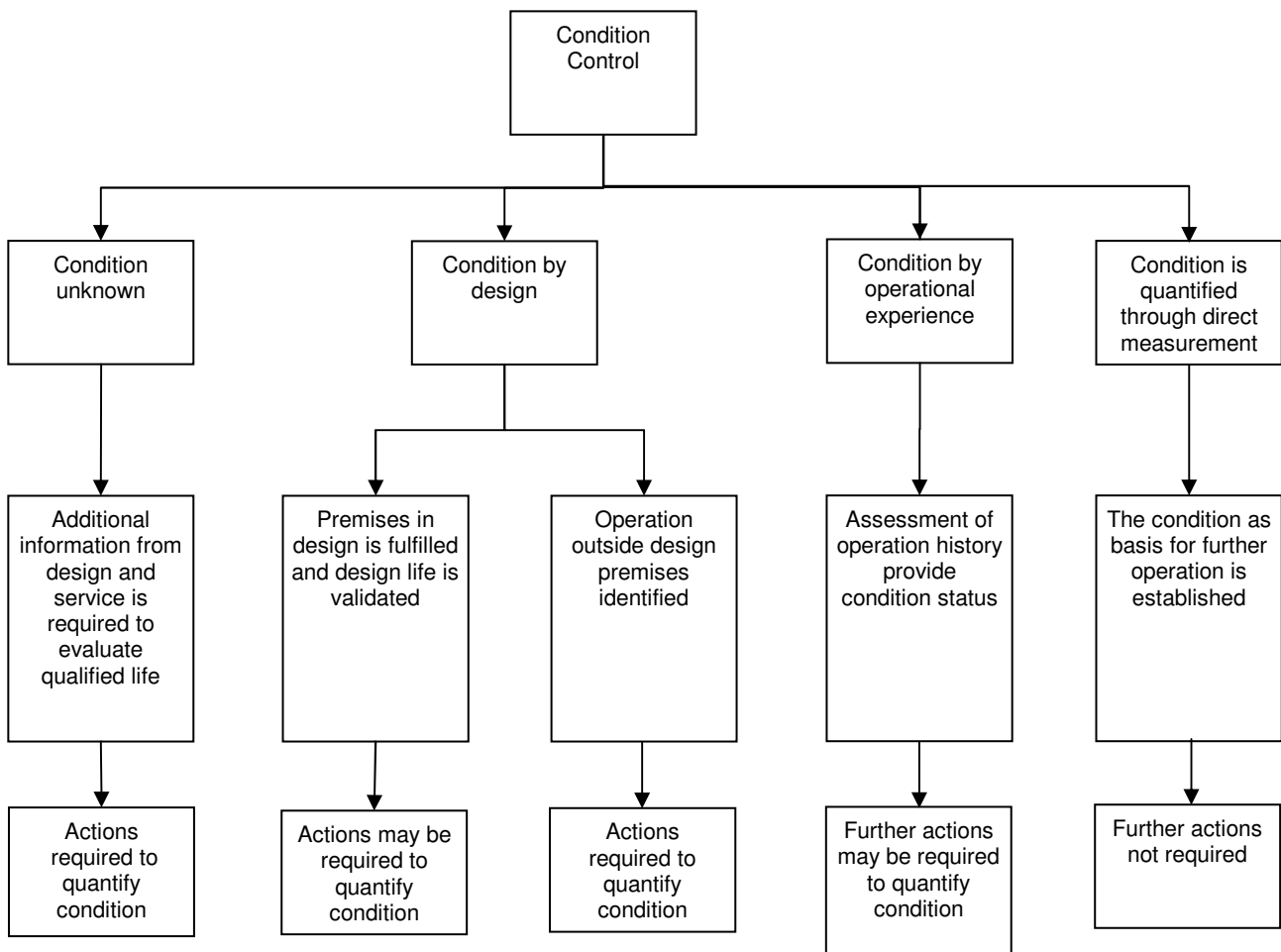


Figure 5 - Types of condition control

6.3.2 Requirement to condition

Threats to the subsea system lead to limitations in operation or other requirements. The condition identified for the system should be checked to be in compliance with these requirements. The requirements to current condition are given by the original design documentation and revisions documented in the integrity management system.

Examples are

- applicable design standards,
- required wall thickness,
- allowable degradation of material,
- corrosion allowance,
- erosion allowance,
- wear limit,
- scour criteria,
- etc.

6.3.3 Current condition

The collected data should be reviewed in order to map how the system has been operated and maintained. The current physical condition should be identified. This will form the basis for the life extension reassessment.

Depending on the possibility to quantify the condition, the integrity level may also be quantified. This may then be used as a baseline for the development of the degradation mechanism into further operation. Depending on the type of condition control used for the subsea system the level of condition is quantified, see Figure 5.

The assessment of the condition may provide information that improves the understanding of the degradation mechanisms and the rate of the degradation mechanisms (calibration of degradation model). This should be incorporated in the reassessment for life extension.

6.4 Remedial actions

If the condition of the system can not be quantified or the system has been operated or maintained outside the intended use, the gaps in information shall be given as input for reassessment. Recommendations to the reassessment activity about how to close these gaps shall be provided.

7 Reassessment

7.1 Objective

This clause describes the reassessment (prognostic) process in the life extension project. The reassessment is the activities related to analysis of the generated information (inspection and monitoring data, as well as life extension premises), and establish the integrity of the system through the full extended lifetime.

7.2 Process overview

The input to the reassessment process is provided by the condition assessment (diagnostic) and the determination of the life extension premises.

The output of the reassessment process provides the basis for the documentation of the system integrity over the extended lifetime.

The reassessment process is illustrated through Figure 6 and should be regarded as a part of the life extension process (prognostic) described in Figure 3. The dotted line indicates the reassessment part of the process.

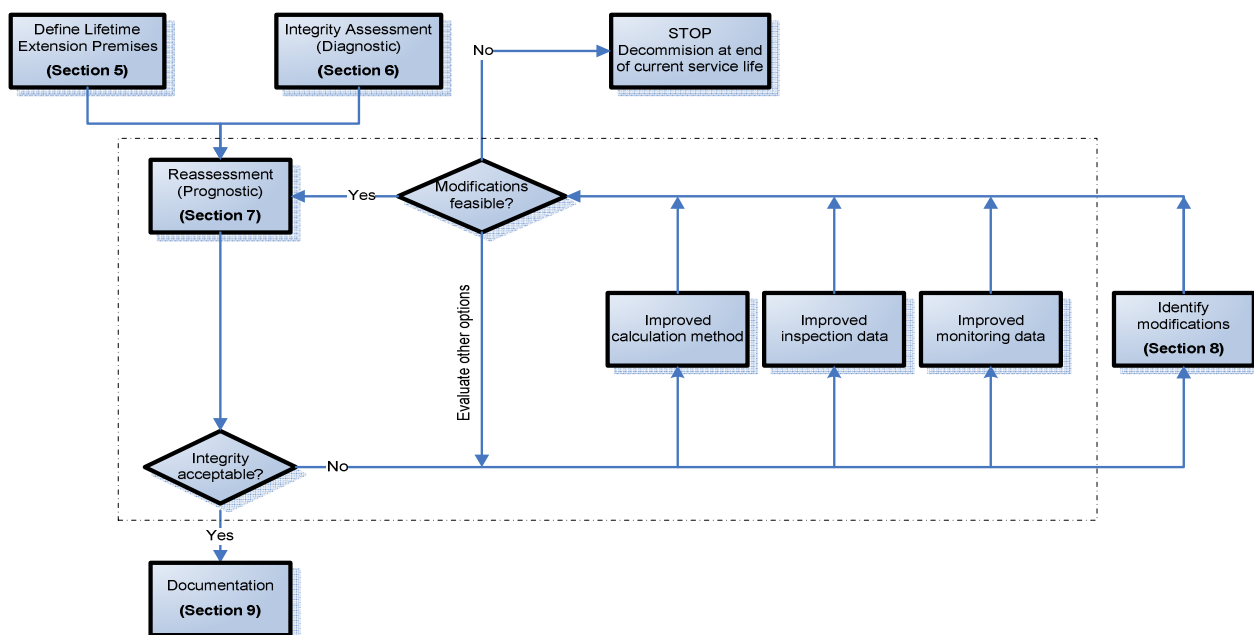


Figure 6 - Flowchart of the reassessment process

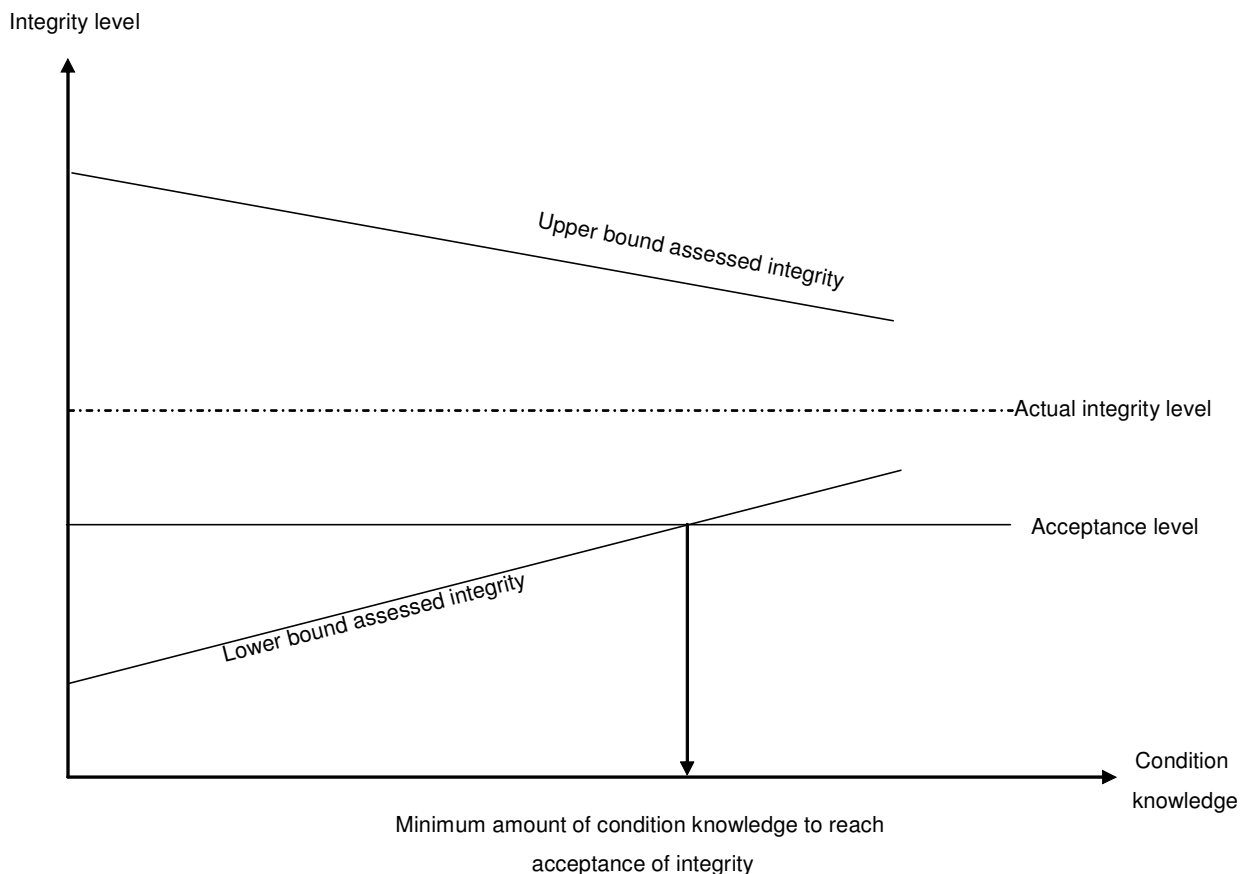


Figure 7 - Accuracy of the assessed integrity level relatively to the condition knowledge of the system

The actual integrity level of the subsea system can never be fully known. The condition assessment is based on inspection and monitoring data, as well as an understanding of materials and system models. These have all inherent uncertainties and inaccuracies.

The actual integrity of the system is not a variable, even though it is unknown. On the other hand, the assessed integrity (the result of condition analysis) is a variable, which depends on the accuracy and quality of the available information.

The assessed integrity, as illustrated in Figure 7, has a lower and an upper bound. In other words, based on the available information all possible condition assessments will most likely position themselves between the lower and upper bound. However, good engineering practice and proper conservative assumptions should result in a lower bound integrity assessment. Hence, the lower bound integrity level shall be compared with the acceptance level.

A practical example is the consideration of pipe wall thickness with reference to erosion.

There are the following two potential situations at the end of the reassessment:

- a) the assessed integrity level is equal to or exceeds the acceptance level. The reassessment is complete and the life extension project proceeds to documentation;
- b) the assessed integrity level does not meet the acceptance level. As illustrated in Figure 6, several options are available in order to increase the assessed integrity level:
 - 1) improved calculation method;
 - 2) improved inspection data;
 - 3) improved monitoring data.

The feasibility of the chosen options should be assessed. The feasibility is based on the need to reach a defined acceptance level. In special cases modifications to the system may be required. However, if no option is feasible, the result from the reassessment will be to not recommend life extension.

7.3 Acceptance level

The design standards chosen for the subsea system defines the acceptance level.

The acceptance level for a life extension evaluation shall be the same as for a new design with respect to acceptable risk for the system. This means that at the end of the extended service life, and at all times during the operational phase, the integrity of the system shall not be lower than what is required by the applicable design standard.

Common for all acceptance levels is ensuring a sufficiently low risk, in other words a sufficiently high safety level. The risk is expressed as a product of the probability of failure and the consequence of failure. E.g.: pressure drop over time reduces the risk by reduction of consequence, while aging of equipment increases the risk by increased probability of failure, i.e. the risk as a total may then be the same.

The probability may be stated explicitly, or it may be implicit (i.e. design standards based on “best engineering judgment” or “good industry practice”). In order to properly carry out a reassessment of the subsea system, it may be necessary to determine the probability requirement implicit in a design standard, and use this as the acceptance criteria for the life extension.

7.4 Design based reassessment

Design based reassessment makes use of industry best practice. This assumes no information about the current condition is available, which means that there is no updated baseline for the development of the degradation mechanism into further operation. The integrity level shall be assessed through the timeline from installation until the end of the life extension.

Industry best practise changes continuously, and improved knowledge about failure mechanisms and degradation models may be implemented in the life extension reassessment.

7.5 Condition based reassessment

Condition based reassessment makes use of operational experience data. The data provides condition knowledge of the system, and should be integrated in the reassessment models. In new design, uncertainties regarding operation are incorporated in the premises and assumptions. For the systems that have been in operation experience data provide additional information that may give enhanced understanding of the system response.

The methods used to assess the system capacity are constantly being developed. Data processing capacity is also increased with time. This gives possibilities to perform assessments with improved representation of the system.

Inclusion of information from operation providing a condition based assessment is illustrated in Figure 8. The design process starts with a number of premises and assumptions, as well as functional requirements. A model is developed and used to calculate the global and local behaviour of the system, which gives information about local conditions in individual sections. Based on these local conditions materials and components are specified and manufactured, and degradation estimates can be established. Both general technology development and condition based data can influence this process, as illustrated in Figure 8.

Monitoring and inspection data can refine the design premise and assumptions, and make them less conservative. Direct measurements of load conditions and local system response can calibrate the models, and also expose excessively conservative results. The models and calculations benefit from continuous improvements in computer technology and from research into models and general system understanding. It is important to note that the material and components can not be changed in a life extension, unless a modification/replacement is carried out. Still, the damage/degradation estimates can be updated based on the possible input illustrated in Figure 8.

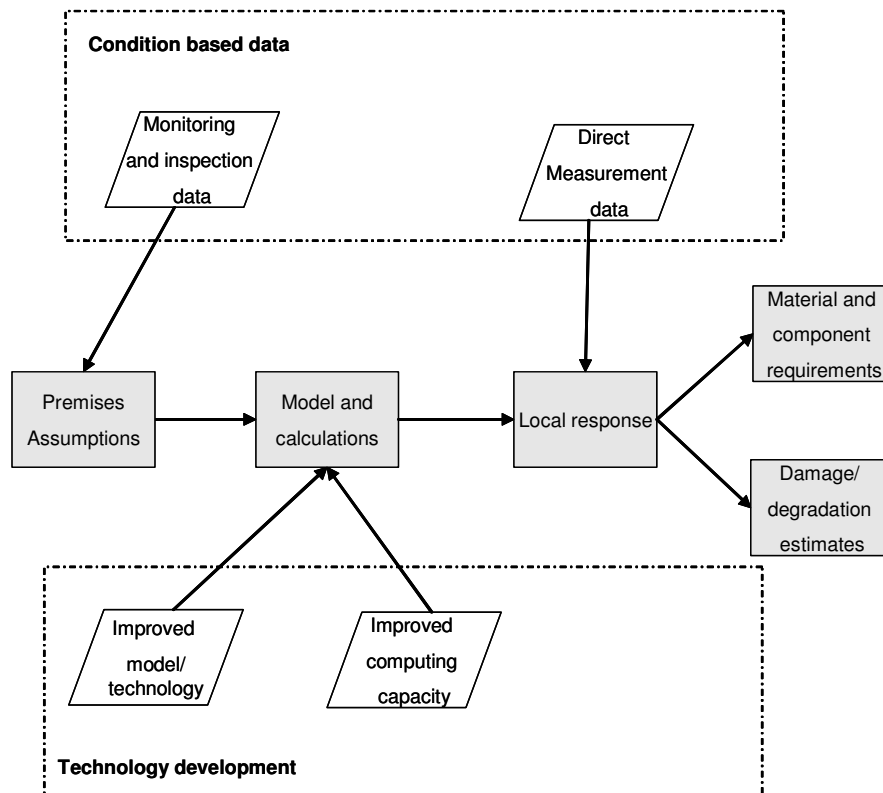


Figure 8 - Influence from condition data for the assessment of life extension

Condition-based assessment brings to use all the available information about the subsea system. In the design of a new system, the operational and environmental parameters are estimated, and these estimates are used in a model in order to calculate the system requirements. Condition-based assessments utilise information from operation of the system, which means that both the estimates and the models may be improved.

Monitoring and inspection data can improve or replace the original premises and assumptions, and a new calculation can be carried out. A more accurate estimate of the system condition will be obtained.

Direct measurements in the subsea system can give data that makes some of the calculation models less necessary or improved. The models convert external influences to effects internally in the system. If these internal effects are measured directly, the uncertainties and conservatism in the models are reduced.

For more information about condition based reassessment, see Annex K.

8 Modifications

8.1 Mitigation

Mitigation is a reduction in the severity of an operational parameter, i.e. pressure reduction, temperature reduction, other measures.

Chemical composition of the produced fluid may be influenced by change in use of inhibitors. The inhibitors shall be qualified for compatibility with the subsea system.

8.2 Intervention

Intervention is activities performed to the various parts of the subsea system, e.g. open/close connector, change of seals.

8.3 Repair

Repair solutions may be assessed through use of available recommended practice or similar.

8.4 Replacement

A modification is categorised as a replacement when a component or larger sections are replaced in the system. When designing a replacement the operator should use the latest available design standard for the new part of the system.

8.5 Change of operational procedure

Change of operational procedure may include increase of frequency of the operation (e.g. monitoring) or introduction of new operations, e.g. leak detection.

9 Documentation

Delivery from a life extension project shall be

- integrity documentation,
- plan for modification (if any),
- input to plans for monitoring and inspection.

The potential for extension of service life beyond the extended service life applied for should be provided. The robustness on margins should also be discussed.

The integrity of the subsea system shall be documented based on the current condition assessment (diagnosis), the reassessment (prognosis) and required modifications. This includes the premises for the life extension, the present condition of the system parts and components, as well as the condition at the end of the design life. Gaps in the risk level between the original design standard and current status shall be documented.

The life extension project will in most cases identify a number of requirements related to modifications, monitoring and inspection. These requirements will also form a necessary input for updating the various documents and activities in the integrity management system, e.g. inspection plan, monitoring plan, maintenance plan, modification plan.

The plans for modifications, monitoring and inspection shall be clearly documented as individual deliverables from the life extension project. The content of the plans shall state the actions to be taken and their respective time limits.

10 Implementation

The life extension project may conclude with requirements that shall be met by the organisation responsible for operation of the subsea system. These requirements shall be integrated with the controlling processes in the operator's organisation in order to ensure that implementation will be carried out.

In effect, this means that the requirements given by the life extension project are integrated into the IMS of the subsea system. Continued operation of the subsea system into and through the life extension period will then be within the acceptable safety level.

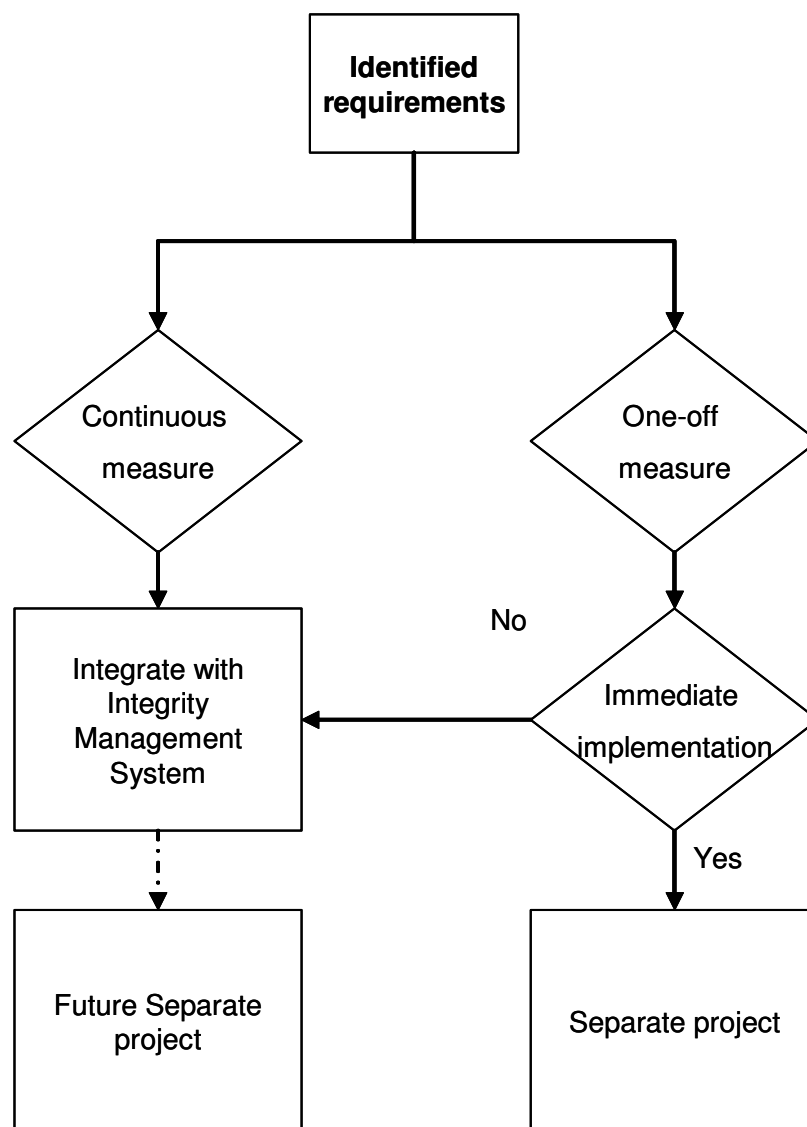


Figure 9 - Implementation strategy

Continuous measure: This may be changes and updates to inspection and monitoring strategies. Such measures are activities that shall be repeated at regular intervals, and will be an inherent part of the operation of the subsea system.

One-off measure: This may be unique modification activities, e.g. intervention, repair and replacement. These activities are either initiated immediately (possible as separate projects during the life extension projects), or responsibility for execution is handed over to the system operator. Such postponed modification activities may be initiated as a separate project even after the original design lifetime has expired (as determined by the life extension project).

NOTE Not all modification activities are required to be carried out immediately. Some repair and replacement of components in the subsea system may be required in order to extend the system lifetime. However, it may be that the activity itself can be executed at a later time.

EXAMPLE

The original design life was 20 years, and the operator seeks a 15 year life extension (total 35 years). A component has a maximum re-qualified design life of 25 years. Hence this component shall be replaced/repared 5 years into the extended lifetime. This activity is not carried out at the time of life extension, but has been identified as a requirement. Hence the requirement is entered into the IMS, and the activity shall be initiated at the appropriate time.

Annex A

(Normative)

Subsea system - Specific requirements for service life extension

Introduction

This annex contains the specifics for the overall subsea system including the sub-systems and components listed under Clause 1 and the interaction between them, see also Figure A.1.

The subsea system is a complex design consisting of pressure containing equipment, moving parts, electrical, electronic and hydraulic components. As a result, a thorough evaluation is needed to ensure a satisfactory level of confidence for service life extension.

This NORSOK standard defines the general requirements and introduces the overall working process. For ease of use, the basic layout of all the annexes in this NORSOK standard, with the exception of Annex A, is structured using the same format found in the main part of this NORSOK standard.

Each of the annexes relates to a particular sub-systems or type of equipment and contains particular requirements specifically relating to that sub-system or equipment. Where an annex contains no particular requirements (i.e. the section contains no information) the requirements in the main part of this NORSOK standard shall apply.

This annex gives system specific requirements for service life extension and consequently is laid out in a different format. Due to the unique aspect with the subsea control system (see Annex G) this annex is also laid out somewhat differently.

A.1 Scope

It is the intention that this annex will be used by the system engineers in their work to co-ordinate the life extension process across the disciplines making sure that a common process is followed and interfaces are handled properly. An important aspect of this work is to establish a common set of life extension premises and ensure that these are considered throughout the system.

The figure below shows the interfaces between the sub-systems and the components in a subsea system. The references to the relevant annexes have also been included.

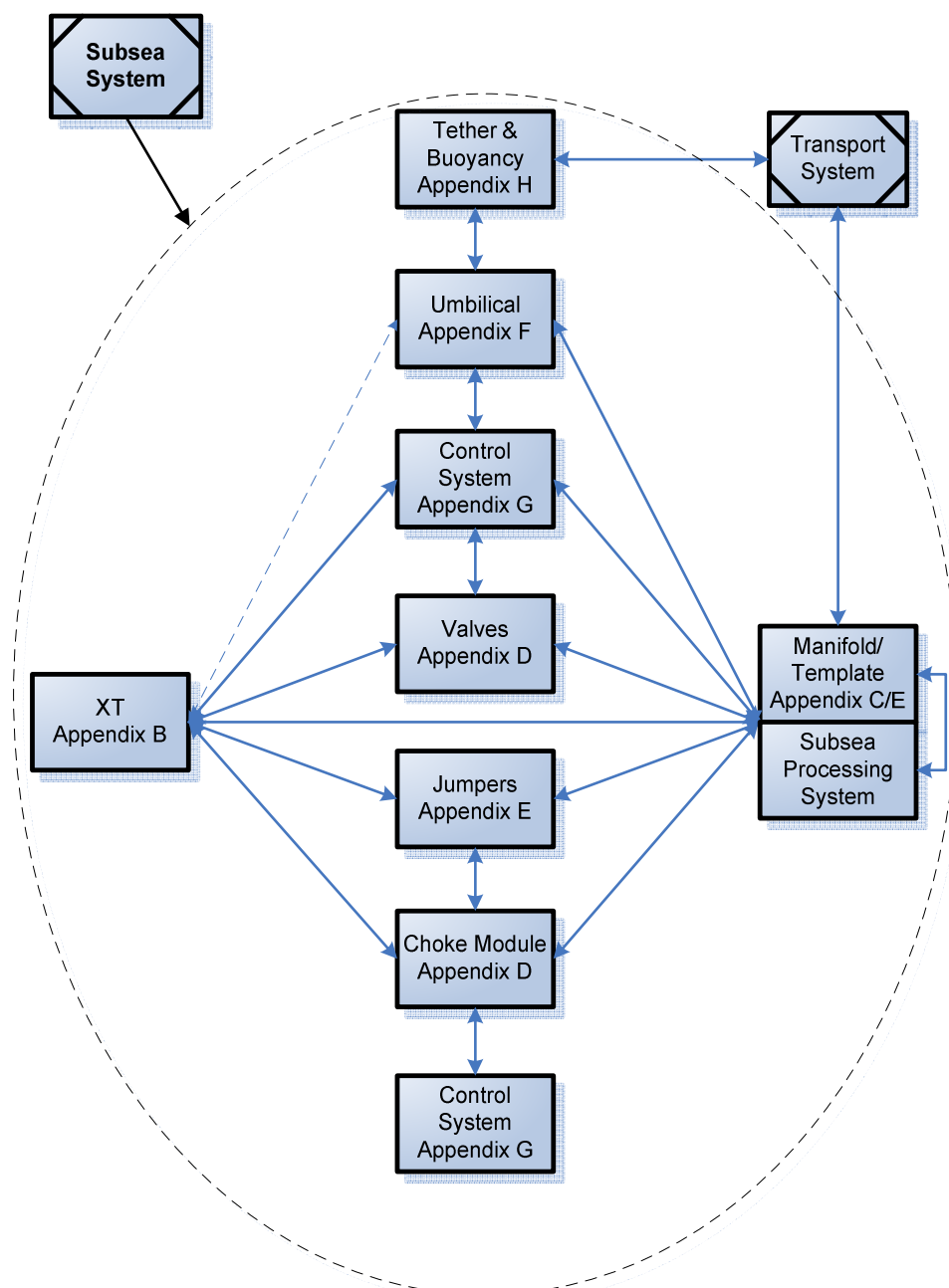


Figure A.1 - Interfaces between sub-systems and components in a subsea system

A.2 Work process

The role of the system engineer during the life extension process is important as the system engineer is responsible for ensuring that a consistent set of conditions are applied to all of the sub-systems and components within the subsea system. This should be done by facilitating and managing communications between the different disciplines.

Figure A.2 shows the life extension work process from “Initiation Phase” to “Documentation”. The highlighted sections show where the system engineer should have his/her focus during the life extension process. The system engineer should also be responsible for ensuring that the overall process is followed. The typical tasks that the system engineer should be responsible for during the life extension process are shown below. This list is supplied for guidance and is not intended to be complete.

Guidelines for managing the life extension of a system:

Initiate lifetime extension process

- Establish interface register (based on initial version)
 - Identify sub-systems and components in the subsea system
 - Identify other systems that are interfaced to the subsea system
 - Clearly define all interfaces
- Establish project team including responsible persons for all relevant disciplines
 - Ensure common understanding of the accomplishment
 - Ensure interaction between interfacing disciplines
 - Ensure quality in the accomplishment

Define lifetime extension premises

- Establish life extension premise basis
 - Identify overall design premises
 - Identify overall design standards
 - Identify current condition on a system level
- Evaluate the need to perform HAZID

Documentation

- Verification
 - All the individual studies should be verified against the interface register before application towards the authorities

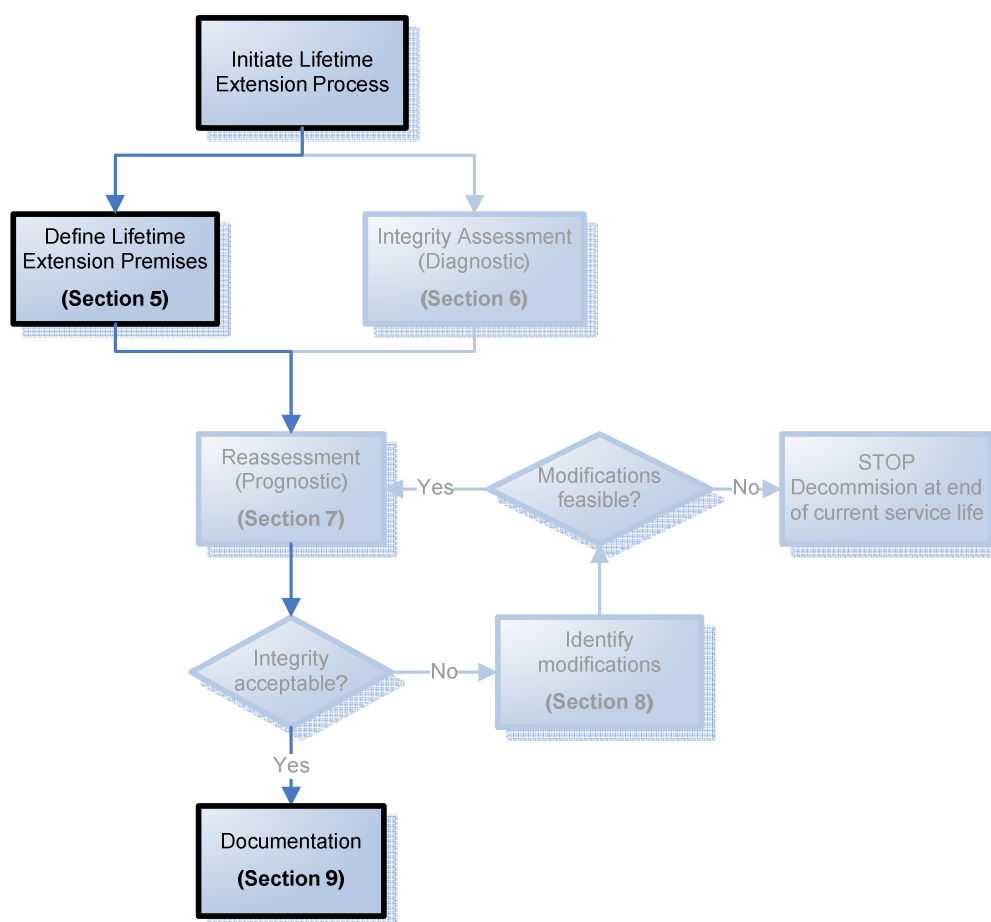


Figure A.2 - Life extension work process (system focus).

NOTE Section references relates to main clauses of this NORSOK standard.

A.3 System overview

The scope of the life extension (i.e. the subsea system) shall be defined so that the battery limits are clearly defined. All equipment that will be removed from the system shall be clearly defined, as shall all new equipment that will be added to the system. The scope should clearly indicate for instance whether or not the following equipment is to be included in the process:

- pipeline/flowline connectors/flanges;
- subsea well interface;
- topside control system.

A.4 Interface register

The interface document is an important document that should be used by the systems engineer to ensure parity between sub-systems and components during the life extension process. The format and contents of the interface register should be agreed between the interested parties. The interface register should cover aspects such as the functions flowing in both directions across the interface, including data, commands and power along with physical parameters such as fluids, heat, mechanical attachments and footprints, connectors, loads and important information relating to the life extension premise, such as design life, age and extension period. The system engineer should be responsible for verifying that the service life extension premises for the interfaced components are equivalent.

A.5 Design based reassessment

The design based reassessment methodology should make use of industry best practice. It can be applied when no information about current condition is available. This means that there is no updated baseline for the development of the degradation mechanism into further operation. In such situations the integrity level of the system shall be assessed along a timeline that starts at the point of at which the subsea system was installed and continues up until the end of the life extension period. Design based reassessment can make use of experience and knowledge developed since the equipment was originally designed, for example new and improved methods for calculating the anode consumption can be used to reassess the extent of the corrosion within the system. However, the application of codes and standards should be consistent and it should be stressed that 'mixing' of codes or code revisions shall be avoided.

A.6 Condition based reassessment

Condition based reassessment makes use of operational experience data. This data gathered from the system provides knowledge about the condition of the system and should be integrated in the reassessment models. Reference should be made to relevant PSA regulations.

A.7 Modifications

Spare parts/obsolescence

Obsolescence is defined as the non availability of products where there is no equal substitute without incremental cost being incurred. Subsea systems, especially electronic components, are at risk of becoming obsolete. In extreme cases, a control system may require a complete upgrade if certain items fail and are not available.

An obsolescence management system should be in place to ensure spare parts are available or an obsolescence philosophy exists. It is important that such systems are established in the early project phase and that key-suppliers are involved in the process.

Examples of systems can be found in other industries such as nuclear, defence and aerospace. The objectives of an obsolescence management system can be to

- implement a proactive obsolescence management system,
- avoid emergency obsolescence issue,
- mitigate the obsolescence risks,
- obtain a good compromise between the life cycle cost, the efficiency, the availability, the support and the security of subsea control products,
- ensure spares long-term availability for in-field products (xx years),
- cover every stages of the product lifecycles.

New equipment required as a result of the life extension project (e.g. the tie-in of new hydrocarbon reserves), should not be of obsolete design.

Annex B (Normative)

Subsea XT – Specific requirements for service life extension

Foreword

The subsea “Christmas tree or X-mas tree” (XT) which normally form part of a subsea system, are systems with pressure containing equipment and active components to safeguard the system. As a result, a thorough evaluation is needed to ensure a satisfactory level of confidence for service life extension.

Introduction

This annex contains the specifics for the equipment as listed under B.1.

All annexes are based on the main part of this NORSOK standard, where the main part defines general requirements and introduces the overall working process. Annex content is labelled and numbered according to the main part contents page. The main part contents page can therefore be used to navigate the annexes.

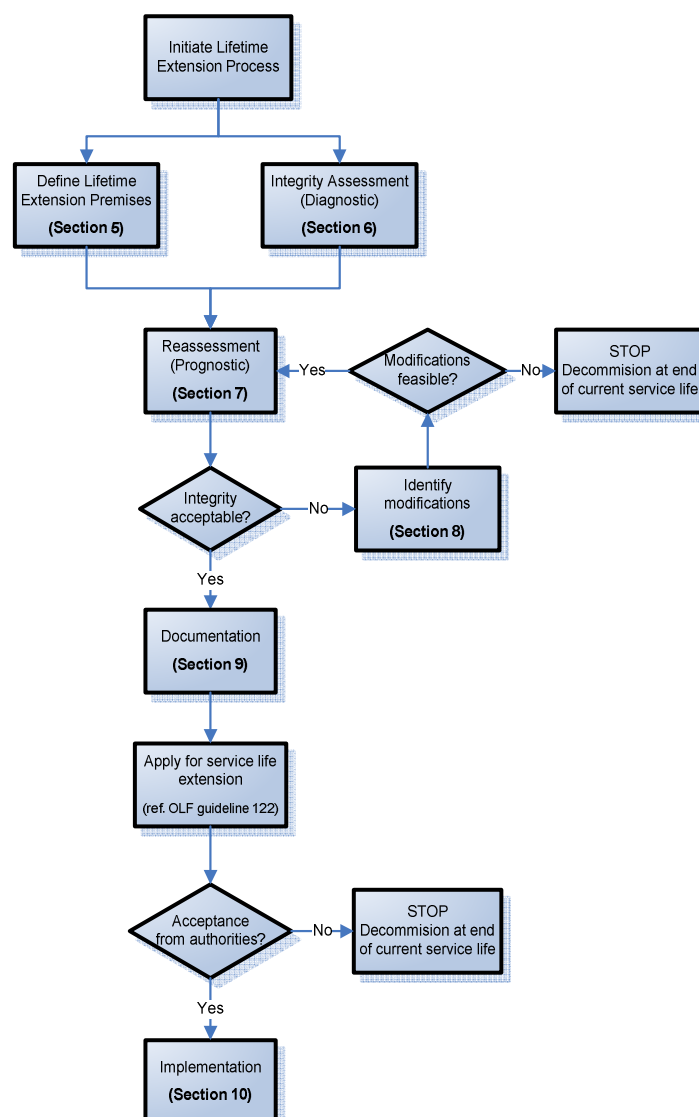


Figure B.1 - Life extension work process.

NOTE Section references relates to main clauses of this NORSOK standard.

B.1 Scope

This annex covers the subsea valve system/module, the “Christmas tree or X-mas tree”, (XT) forming the well barrier directly above the wellhead. Thereby the XT represent the primary and active barrier towards the hydrocarbon reservoir. The XT includes

- safety valves (master valves) for: the production tubing(s) (conduit conveying gas and/or oil or water) and the well annulus as well as the operational shut off valve (wing valve),
- it may include a choke valve to regulate the flow from the reservoir,
- it may include the following connections and conduits for service lines conveying e.g.:
 - hydraulic power lines,
 - MEG injection lines,
 - methanol injection lines,
 - wax inhibitor lines,
 - scale inhibitor lines,
 - corrosion inhibitor lines,
 - electrical signals to the well,
 - electrical power to components in the well.
- interface to the wellhead connector and the work-over lower riser package connector and a tree cap,
- interfaces to ROV operations or diver operations,
- protection system and guiding system used for mating to the wellhead,
- monitoring and control to valves and sensors.

The “XT” main valves include remotely operated actuation devices powered by hydraulic fluid or by electricity with a backup power from ROV or diver. The “XT” main valves have functions normally limited to closed/open. This function can be achieved by different valve designs, each with various possible failure mechanisms to be considered for a life extension. The most common types of the main valves are termed: gate valves. The choke, when included in the module, have function for flow control.

There are in principle two types of XT master valve configurations:

- vertical XT where the master valves have a vertical bore allowing access to the well through them with tools when they are in open position. The XT can be retrieved after installation of plugs in the wellhead to isolate the well, i.e. without retrieving the tubing;
- horizontal XT where the master valves are away from the main bore to the well and therefore will not be directly in contact with down-hole tools. Horizontal XTs normally are fitted with a tubing hanger allowing pulling of the tubing through the XT. Consequently a retrieval of the XT requires retrieval of the tubing prior to this. Replacement of the XT is therefore a major operation.

This causes different possible failure modes which will have an effect of the life extension extrapolation.

It is stressed that the focus should primarily be on the systems where a XT failure could cause a threat to the environment, the reservoir or to humans during an intervention. This includes the primary pressure retaining barrier and the function of the safety systems. The barrier is formed by mechanical sealing systems to the environment, the wellhead connector and the plug/tree cap. The function of the safety system is dependant on the control and monitoring system as well as the power system to the safety valves.

B.2 Normative and informative references

A list of references specific to all aspects of life extension is located within Clause 2. For discipline specific references with regards to system design, see 5.3.

B.3 Terms, definitions and abbreviations

For terms, definitions and abbreviations refer to Clause 3.

B.4 Assessment methodology

B.4.1 Objective

This section describes the methodology to be applied to the life extension process for the items listed under B.1.

B.4.2 Integrity management system

The operators follow the XTs etc. through an IMS. The objective of the IMS is to ensure that the technical integrity of the XT is continuously maintained at an acceptable level.

The activities and assessments carried out as a part of the IMS is not part of the life extension process. The integrity management process is carried out within the constraints of the original design and is not necessarily sufficient to document and justify a life extension. The data obtained will however, is required to perform the life extension process.

Specifically, the IMS for XTs etc. will typically include yearly inspection and pressure and temperature monitoring through manifold, piping and pipeline sensors subsea and topside. Further, in the cases where subsea leak detection sensors (SLD sensors) are installed, information on any leakages that have occurred, may also be available.

B.4.3 Life extension process

The purpose of the life extension is to document acceptable system integrity to the end of the defined extended service life.

The overall life extension model can be summarised into four steps:

- definition of the premise for the extended operation, including identifying new threats to the system;
- assessment of the current integrity of the system;
- reassessment of the system based on
 - the available information including replacement records and,
 - current industry practice and,
 - performance test historical trends,
 - new performance tests and available technology.
- evaluation of the results to decide whether the integrity of the system is acceptable up until the end of the extension period.

Safety critical functional elements

All elements of the XT that contribute to the functional safety of the system shall be identified. A system approach shall be used. When considering these elements, the whole system that supports the function shall be considered, i.e. not just the final element, but any component that enables that function and can fail in such away that it prevents the function from operating.

Such typical XT critical functional elements are

- the pressure retaining barrier formed by the housing, bonnet and seals,
- the internal closing mechanism with seals,
- the stem and power transfer mechanism to the XT closing mechanism (gate) with seals,
- the actuator with seals,
- the availability of power to the actuator,
- the monitoring and control system for the actuator and the XT itself,
- the interface to the wellhead connector,
- tree cap and mating for the work-over riser/BOP,
- coating and anodic corrosion protection system.

B.4.4 Degradation

The life extension process of the XT shall take into account the degradation as function of time and operation.

The following types of systems, sub-systems and components shall be assessed:

- systems, sub-systems and components whose failure would result in a release of hydrocarbons;
- systems, sub-systems and components that are a single mitigating barrier to the release of a significant hydrocarbon reserve.

See B.7 and the other annexes referred to for information on degradation mechanisms.

B.5 Life extension premises

B.5.1 Objective

The original design premises shall be reviewed to assess whether they are still applicable for the extended life period.

B.5.2 Authority regulations

Authority regulations shall be adhered to where required. For guidance, reference is made to 5.2.

B.5.3 Design standards

The XT was designed to applicable standards that were selected at the time of design. The same design standards may be used throughout operation of the system, also when changes to this system are introduced. This includes life extension.

Investigation is required to whether there are any changes/ revisions in the rules, regulations or design codes applied. Particular attention should be made to the following standard and codes:

- NORSOK U-001, Subsea Production Systems
- NORSOK D-010, Well integrity in drilling and well operation
- ISO 13628-4, Subsea wellhead and tree equipment
- ISO 10423, Drilling and production equipment – Wellhead and Christmas tree equipment

B.5.4 Design premise

The design premise is the basis for the original design, and describes the operational and design limits for the system at time. In the context of the NORSOK standard, the primary premise is the design life

Table B.1 gives examples of parameters premised for design. The table is not intended to be complete.

Table B.1 - Examples of parameters premised for design

Category	Subject	Comment
Operational Parameters	Fluid description and possible changes over time	Including possible deteriorating components such as H ₂ S, CO ₂ , Particles, chemical fractions that can cause clogging of XT cavities.
	Density	Initial and final
	Flow rates	Initial and final
	Pressure, internal	Initial and final
	Temperature, fluid	Initial and final
	Number of opening/closing operation	The differential pressure during opening or during operation should be included
	Power require to operate the XT	e.g. Required power for the XT actuation (pressure-stroke volume)
	Power available to operate the XT	e.g. Available power initially and in the future (pressure, reservoir volume)
	Power for DHSV	e.g. Pressure
	Power for instrumentation	Voltage and power-consumptions
	Replacements	Number of times the XT has been retrieved and degree of overhauling.
	Number of operations with BOP and Work over-riser	This should include duration for connection as well as related surface weather conditions. (for use of fatigue assessments)
External parameters	Descriptions of injected fluids	
	Water temperature	Max and mean
	Water depth	Tidal variations if of concern

Category	Subject	Comment
Functional requirements	Current profile	In relation to guiding systems
	Rate of marine growth	
	Fisheries/Trawling	In relation to XT protection
	Limiting loads from BOP and workover systems	
	XT valve response time	
Methodologies for response and capacity calculations, in particular for the wellhead connector	Performance test records (Torque/ Actuation force/stroke)	CV for choke and regulation XTs
	Tightness test records (Internal end external)	Accurate measurement of leak/ leak development over time
	Design/Operational load capacity related to loads from the pressure and conveyed from the BOP and workover system	It must be verified if the external and internal loads used in the initial design phase still are relevant, or if more accurate data are available

When doing a life extension specifically for XTs, the following needs to be established:

The premises for extended operation including

- original design pressure and comparison to the pressure regime for the extended life time,
- original design temperature and comparison to the temperature regime for the extended life time,
- original test pressure at manufacturer compared to possible reduced requirements,
- original test pressure after installation in the piping system compared to possible reduced requirements,
- external loads from drilling (and work-over riser to XT and from flowlines) are the design loads still valid or are more specific loads available? Loads at interface with flowlines/spool caused by well growth.

B.5.5 Threats to the subsea system

The XT shall have an acceptable safety margin to failure. A subsea system is exposed to external as well as internal threats with different characteristics as follows:

- condition based: e.g. change in operational parameters and consequences for the XT;
- time-based: e.g. ineffective corrosion protection or corrosion control;
- fatigue of the wellhead connector interface;
- impact damages to connectors/mating faces;
- damages to guiding/guideline systems and bumper structure;
- wear (abrasion), erosion and cavitations;
- deterioration of sealant materials;
- clogging.

The combined effect of threats shall also be considered.

B.5.6 System overview

The XTs for which a life extension process is carried out shall be described in such detail that the interfaces are clearly defined. Note in particular the following important items that need to be clearly defined to be/not to be part of the scope:

- the items listed in "scope of work, sec 1";
- connections/flanges to the piping system and wellhead connector;
- welds: pipes to XTs in the manifold system;
- support of the XT/connected piping;
- actuator connections to power;
- PI&D for the XT conduits, power, monitoring and control system.

B.6 Integrity assessment

B.6.1 Integrity management system

The subsea system should have an IMS. The IMS is used to carry out data collection and condition assessment. Thereby data from the XT performances should be available.

B.6.2 Data collection

For XTs etc. relevant data will be

- integrity inspection data (i.e. search for leakages) (external leak),
- leak test records,
- actuation forces and time,
- choke CV – flow coefficient (coefficient of volume flow),
- coating inspection,
- anode inspection,
- corrosion inspection (note particularly bolts, nuts and connections in general),
- historical/statistical data for equivalent and similar XTs for the same application,
- replacement records.

B.6.3 Condition assessment

The requirements to the current condition are given by the original design documentation and revisions documented in the IMS.

Examples are

- changes in operational performances,
- accessibility, whether any changes has taken place,
- applicable design standards,
- acceptance criteria.

The collected data should be reviewed in order to map how the system has been operated and maintained and the current physical condition should be identified. This will form the basis for the life extension reassessment.

B.6.4 Remedial actions

If the condition of the system can not be quantified or the system has been operated or maintained outside the intended use, the gaps in information shall be given as input for reassessment. Recommendations to the assessment activity about how to close these gaps shall be provided.

Examples of this can be higher internal pressure or temperature than catered for in the design process. Higher XT actuation forces than planned.

B.7 Reassessment

B.7.1 Objective

The reassessment is the activities related to analysis of the generated information including

- inspection data,
- monitoring data,
- statistical data,
- life extension premises.

Use this for establishing the integrity of the system through the full extended lifetime.

It is important to note that the actual integrity level of the XTs can never be fully known if the gathered data have uncertainties and inaccuracies.

There are two potential situations at the end of the reassessment:

- a) the assessed integrity level is equal or exceeds the acceptance level. The reassessment is complete and the life extension project proceeds to documentation;

- b) the assessed integrity level does not meet the acceptance level. In order to increase assessed integrity level several options are available:
- 1) **improved calculation method** – special attention should be given to the latest revision of the XT standards;
 - 2) **improved inspection data** - an example can be more thorough ROV inspection e.g. related to anodes in order to determine their consumption;
 - 3) **improved testing and monitoring data** – Example can be: operational performance changes, Leak rates and retrofit of subsea leak detection systems to better identify and monitor leakages of hydrocarbons.

B.7.2 Process overview

The reassessment process for systems, sub-systems and components shall be concurrent with the process overview presented in 7.2.

B.7.3 Acceptance level

Subsea system acceptance level criteria are defined in 7.3.

B.7.4 Design based reassessment

Guidance for design based re-assessment is contained within 7.4.

B.7.5 Condition based reassessment

Condition based reassessment makes use of operational experience data. The data provides condition knowledge of the system, and should be integrated in the reassessment models. For XTs safety valves there are required periodic testing. Historic files on this can show possible trends to be considered.

For XTs the following specific areas should be considered in order to determine the degree of possible concern and related degradation status and performing condition based assessment.

It is expected during the life of a subsea system that an XT may need to be retrieved. Changing reservoir conditions can result in the need for well maintenance. This is particularly relevant to “vertical” XTs. Access for maintenance of the XT has two alternatives. One is to undertake maintenance on site. The other is to undertake necessary actions on an XT in storage, giving greater access possibilities.

External leakage

Experience shows that external leakages from XTs occur at

- the stem seal,
- body seals,
- auxiliary connections,
- mechanical connections to the piping system,
- wellhead connector interface,
- XT valve body and bonnet (less likely).

Data like test records and video recordings from ROV inspections where possible leakages forms visible traces in the water can be the basis for determine leakage status.

Further can the use of subsea leak detection sensors provide data. Such systems may, however, be hampered by false indications caused by hydrocarbons seeping from the seafloor and by sensor failures.

The wellhead connector interface can have a limited fatigue life. The remaining life prediction should be based on the design documentation and operational history.

Renewed leak/pressure test can be used to assure a margin to leak. In most cases the connected piping test pressure limit will govern the maximum test pressure magnitude rather than the XT test pressure used at the XT manufacturer. Further is the test pressure less for the valve closure mechanism than for the body.

External corrosion

The corrosion resistance of XTs depends on the material selection, the coating system and externally the cathodic protection system. The primary external protection is the coating system and the cathodic protection system is a backup. The coating will break down over time and the associated protection will be reduced.

As many XT's material designs currently are made with Duplex or Super Duplex, Hydrogen induced stress cracking (HISC) is an effect that needs to be considered. Reference is made to DNV-RP-F112 for further description.

Internal material degradation

XT main pressure retaining barrier

Internal corrosion resistance is of concern to the XT main pressure retaining barrier. It depends on the material selection and the corrosive potential of the transported fluid. Some corrosion damage may occur, but if the system is properly designed and operated it should not be a concern during the design life. For a life extension project, it is important to note that corrosion damage can not be reversed. However, the internal corrosion can be slowed down (e.g. inhibitors, other measures). Early initiation of the life extension process is important for internal corrosion as the integrity life can be longer when measures are introduced early.

The use of corrosion allowance (CA) is often used in design for carbon steel (CS) piping. The degradation of the CA may be monitored by corrosion probes which can be integrated in the XT's design or by thickness tests at predetermined positions. The data from these instruments may be an important part of the operational experience data and input for the life extension assessment.

Internal leakage

XT internal parts

Internal part forming parts of the sealing system are sensitive to any corrosion. This may cause leak and increase requirement to the operating forces. Leak and performance testing will indicate possible changes for use in a prediction.

Sealing materials

Seal materials of polymer materials have limited life governed by their chemical composition, exposure to detrimental chemical fluids, temperature and temperature duration, mechanical stresses, decompression rate after gas exposure and light exposure.

The latter in subsea systems is only relevant for spare parts. The "Arrhenius equation" indicates correlation for material life considerations. It is used to predict the life based on the operational history of time/temperature and fluid type. This is provided relevant material test data or statistical data is available. Consequently Arrhenius equation is used to correlate the material life experienced or tested with that actual at deviating temperatures.

The types of detrimental chemicals would normally be specified by the seal supplier and can be compared with the internal fluid and possible injected fluids. Temperature and mechanical stresses (sealing of clearances) acceptance criteria are normally specified by the seal manufacturer.

Further is seal materials of metals (Tungsten carbide and Stellite in loaded dynamic seal areas, ring type gaskets of soft stainless steel in flanges, metal O-rings), carbon, ceramics and mixed compound materials (flat gaskets) used. These materials have different failure modes to be considered in assessment of their life. The type of possible failure modes can normally be studied in generally recognised gasket manufacturers handbooks.

Migration of molecules from the pressurised fluid takes place through the all types sealing system (except for static soft metal seals perfectly made up). Such migration is not termed as leak, but must be considered with respect to possible detrimental consequences.

Wear and abrasion

Each operation of the XT valves, connections/disconnections and connecting operations for BOP or work-over risers causes wear. High loads between moving parts are of particular concern. High loads are caused by differential pressure during opening and differential pressures over dynamic seals. Wear of connectors are affected by the actual forces/moment during disconnection and landing velocities. Further can particular design increase the wear resistance, e.g. by particular hard metallic materials (Stellite, White cast iron, Tungsten Carbide (WC) and even diamond) and by combination of hard and softer metallic materials.

The following items are of particular concern:

- stem seal and stem surface evenness;

- main seal and main seal counterpart;
- wellhead connector;
- XT top mating to BOP/work-over system.

Solid particles in the fluid tend to gather in the surface of softer materials such as main seals auxiliary plastic seals and can increase the wear of the gate.

Performances testing of the XT will indicate possible margins to limits and can therefore be used for life extension prediction.

Erosion

Piping systems with high fluid velocity and with particles are subject to possible erosion. Erosion causes material loss. Gas with particles is of particular concern! A choke on a XT represents a part of a fluid conveying system with high local fluid velocity. Chokes will often have a shorter life than the rest of the XTs due to erosion.

Performances testing of the choke-XT showing detrimental trend indicates possible life limits and should be used for prediction of the remaining life for this component.

Relevant sensors available in the piping system are important. Thereby it is feasible to monitor the choke performance and the choke characteristics (CV).

The damage may, however, occur in the high turbulence downstream the choke. Therefore analytical numeric calculations should be used to verify whether this may have any concern to the downstream piping. If so, then thickness measurements must be performed to support any life extension.

Cavitation

Cavitation is caused by imploding vapour bubbles in a liquid. The implosion transfers a damaging chock to the surrounding materials. This requires a local liquid pressure less than the boiling pressure for the liquid. Again a choke can cause such low pressures locally downstream causing material loss.

Life extension should be based on the same principle as described for erosion.

Clogging

XTs can be subject to deposits caused by scaling, wax and hydrates. Further may solid particles (sand, rust etc.) follow the conveyed fluid. These undesirable substances in produced hydrocarbons and water can fill cavities in the XT and prevent its operation. Deposits on the walls may be removed with some chemicals injected in the fluid.

Performances testing of the XT will indicate possible potentials for life extension.

Well maintenance

XT are designed to allow for down-hole maintenance. This may include wire-lining with tools, coiled tubing operations and even drilling operations which have potentials for impact damages and wear/abration to protective sleeves and even internal profiles and mating surfaces.

Further can passed replacement of XT and landing of BOP and Lower Work-over Riser package (LRP) cause impacts to mating surfaces.

ROV interfaces are subject to possible impacts damages from the ROV. This may prevent later emergency operations.

Operational history, Inspection and performances testing of the XT will indicate possible potentials for life extension limits.

Replacements

XT are designed for replacements. Guiding structures and guidelines and bumper/protective structures are therefore subjects to possible damages from erroneous retrieval/installation operations causing impact damages. Possible damages may be detected by inspections or indicated from installations parameter recordings. Damages that will escalate are of concern for the life extension. The challenges in replacement will not increase by a life extension if an escalation is not expected!

Fatigue

Fatigue of XT is relevant for the wellhead connector interface and for interface with the BOP/LRP connector. This is a fact experienced after well operations of long duration when there is alternating bending moment transferred from the riser. Some wellheads have cracked and wellhead connectors have revealed failures. It has not been the tradition to design against fatigue. Therefore this issue must be assessed for life extension.

B.8 Modifications and testing

B.8.1 Mitigation

Mitigation is defined within 8.1.

Chemical composition of the transported fluid may be influenced by change in use of inhibitors. Also, well stream may change over time, i.e. higher water cut.

B.8.2 Intervention

Intervention is defined within 8.2.

B.8.3 Repair

Repair solutions may be assessed as an alternative to retrieve the XT.

B.8.4 Maintenance and planned replacement

Some XTs may have been ordered with a shorter lifetime than the rest of the system. This can also be the case for chokes. Therefore replacement may be needed. Performance testing may, however, justify life extension also for this.

Some surface XTs are designed to be lubricated by regular intervals or for retightening of stem seals. The consequences for using such XTs subsea must be evaluated.

B.8.5 Change of operational procedure

Reference is made to 8.5.

B.8.6 Pressure/leak test

Leak test

Measurement of possible leak rate for the XT in closed position:

The measurement accuracy depends on the test time, system response (e.g. time to detect pressure changes caused by leak based on: fluid volumes and possible temperature changes during the measurement) and instrumentation accuracy. The measurement accuracy must be established to check whether the method is applicable for the leak rate acceptance criteria. This criterion is twofold; one absolute related to the consequence acceptance criteria and one relative to check for trend. The latter depends on previous data from measurements. Guidance and requirements on this is specified by standards (NORSOK and ISO).

Measure the tightness towards the environment. This would normally be done by the XT in open position, i.e. during normal production. ROV inspection could reveal leaks provided the leak medium is visible (by colour/black light/ diffraction index/ turbulence). The use of "clouding" could also be considered (making turbulence more visible by adding slight colour tracing to the surrounding water). See "External leak" above.

Pressure test

Pressure test can be combined with the above "Measure the tightness towards the environment". The pressure test will load the seals more and is therefore an important issue to verify a safety margin to leak.

B.8.7 Performance testing

The result and value from the performance testing of XT depends on the degree of monitoring and recording. It is foreseen three alternatives of monitoring for remotely operated open/closed XTs. The following starts with the most valuable:

- a) for shut off XTs: record the opening sequence by degree of opening as a function of actuator force and possible differential pressure and time. This is the ideal case requiring monitoring exceeding most application.

- b) measurement of time for open/closing and power-consumption together with upstream and downstream pressure.
- c) derive time for open/close by flow/pressure monitoring of the line and derive actuator force from that available during the operation.

ROV operated valve emergency system should be included in the test.

Choke on XTs require checking of their CV (flow coefficient) for possible changes (the relation between area of the opening and actuation stroke). This can be done by measuring their flow characteristics for possible trends.

B.9 Documentation

Delivery from a life extension project shall be

- integrity documentation,
- plan for modifications (if any),
- input to plans for monitoring and inspection.

The potential for extension of service life beyond the extended service life should be provided.

Documents facilitating lifetime extension evaluations are

- PI&D for the XT applications,
- general arrangement drawing for the XT with part list identifying the materials,
- "Data book" for the XT contain material certificates, manufacturing record and test records,
- pressure and leak test records,
- performance test records,
- statistics for failures on equal and similar XTs for the same application.

B.10 Implementation

Conclusions derived from the life extension process shall be implemented in accordance with the requirements of Clause 10.

Annex C (Normative)

Subsea structures – Specific requirements for service life extension

Foreword

The subsea manifold and structural components that normally form part of a subsea system can be described as all structural components supporting and protecting the pressure containing equipment subsea. If the intended functionality is not maintained, a thorough evaluation is needed to ensure a satisfactory level of confidence for service life extension.

Where applicable, this annex is based on NORSOK N-006, rev.1, 2009.

Introduction

This annex contains the specifics for the equipment as listed under C.1.

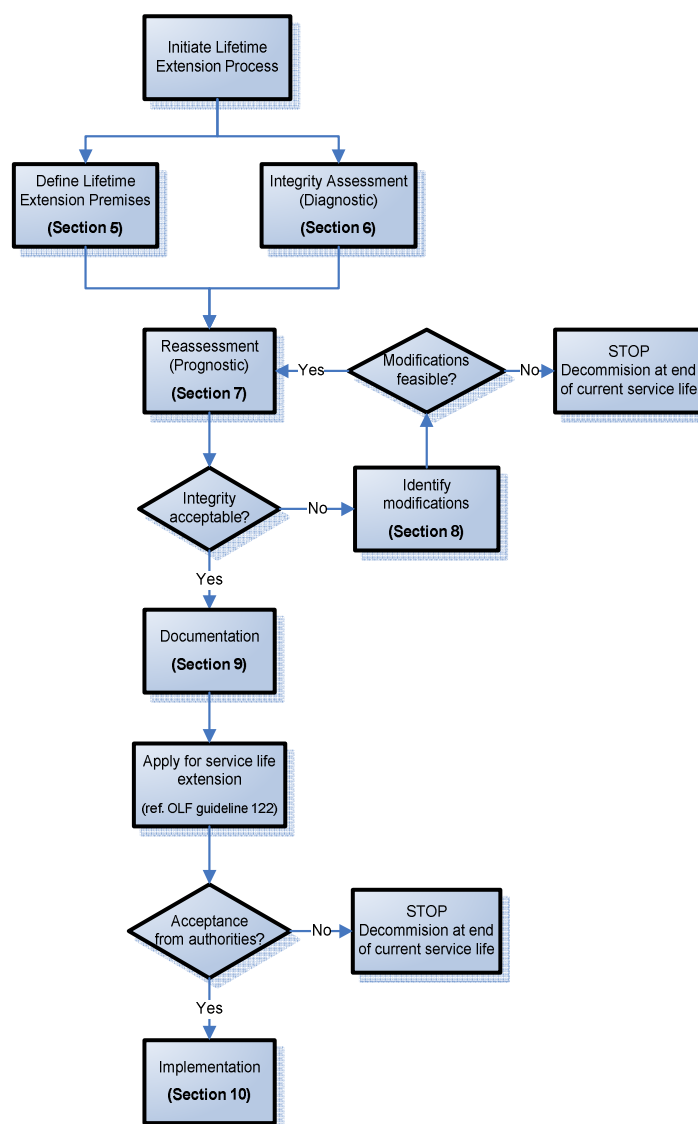


Figure C.1 - Life extension work process.

NOTE Section references relates to main clauses of this NORSOK standard.

All annexes are based on the main part of this NORSOK standard, where the main part defines general requirements and introduces the overall working process. Annex content is labelled and numbered according to the main part contents page. The main part contents page can therefore be used to navigate the annexes.

C.1 Scope

This annex includes

- manifold structures,
- X-tree templates,
- trawl and dropped objects protection structures,
- support and protection structures for PLETs and PLEMs,
- support and protection structures for riser bases.

NOTE For simplicity, the term 'Subsea structures' is used below when describing the items listed under 'Scope'.

It is stressed that the focus should primarily be on the systems supporting and protecting hydrocarbons and other environmentally harmful substances. The water injection systems will have less consequence to the environment if the integrity is compromised.

C.2 Normative and informative references

A list of references specific to all aspects of life extension is located within Clause 2.
For discipline specific references with regards to system design, see 5.3.

C.3 Terms, definitions and abbreviations

For terms, definitions and abbreviations refer to Clause 3.

C.4 Assessment methodology

C.4.1 Objective

This clause describes the methodology to be applied to the life extension process for the items listed under C.1.

C.4.2 Integrity management system

Most operators monitor the subsea structure etc. by using an IMS. The objective of the IMS is to ensure that the technical integrity of the structures is continuously maintained at an acceptable level.

The activities and assessments carried out as a part of the IMS is not a part of the life extension process. The integrity management process is carried out within the constraints of the original design and is not necessarily adequate documentation to justify a life extension. The data obtained will, however, be an important input in the process of performing a life extension.

Specifically, the IMS for structural components etc. will typically include yearly inspection inspecting for damage from trawl activities, dropped objects, and monitor the reduction/use of anodes on the structures.

C.4.3 Life extension process

The life extension process is triggered by the decision that the operation of the system will be continued beyond the original service life. The purpose of the life extension is to document acceptable system integrity to the end of the extended service life.

The assessment process shall include or be based on

- design, fabrication and installation resume and as-built drawings,
- documentation of as-is condition,
- planned changes and modifications of the facility,
- updated design basis and specifications,
- calibration of analysis models to measurements of behaviour if such measurements exists,
- the history of degradation and incidents,
- prediction of future degradations and incidents,

- the effect of degradation on future performance of the structure,
- a documentation of technical and operational integrity,
- planned mitigations,
- a plan or strategy for the maintenance and inspection.

The assessment for life extension shall conclude on a safe life extension period with respect to technical and operational integrity of the subsea structure. The assessment shall further identify the circumstances that will limit the life of the facility without major repairs or modifications, and specify criteria defining safe operation (e.g. permissible corrosion or remaining thickness, remaining anodes, degrading of paint protection, changed load conditions, deteriorated mechanical supports), including appropriate factors of safety.

C.4.4 Degradation

The life extension process of the subsea structures must take into account all degradation that has occurred in the time period after installation of the system. See also C.7 for additional description.

C.5 Life extension premises

C.5.1 Objective

The original design premises shall be reviewed to assess whether they are still applicable for the extended life period.

C.5.2 Authority regulations

Authority regulations shall be adhered to where required. For guidance, reference is made to 5.2.

C.5.3 Design standards

The subsea structure is designed according to applicable standards that were selected at the time of design. The same design standards may be used throughout operation of the system, also when changes to this system are introduced. This includes life extension.

Investigation is required to whether there are any changes/revisions in the rules, regulations or design codes applied. Particular attention should be made to the following standards and codes:

- ISO 13628-1;
- ISO 13628-15 (under approval);
- NORSOK N-001;
- NORSOK N-004;
- NORSOK N-006;
- NORSOK U-001;
- DNV RP B-401.

C.5.4 Design premise

The design premise is the basis for the original design, and describes the operational and design limits for the system at that time. In the context of this NORSOK standard, the primary design driver is the design life of the system.

Table C.1 gives examples of parameters premised for design. The table is not intended to be complete.

Table C.1 - Examples of parameters premised for design

Category	Subject	Comment
Operational parameters	Equipment weight	New equipment installed compared to original design
	Sealine and manifold piping forces	Still valid?
	Drilling loads	New technology giving changed load conditions? Fatigue assessment
External parameters	Fisheries/Trawling	Evaluate potential new loading
	Metocean data	Changed weather characteristics
	Earthquake	
	Geotechnical	It should be verified whether the

Category	Subject	Comment
		geotechnical settlements used in the initial design phase still are relevant, or if more accurate data are available.
Methodologies for response and capacity calculations	Design/Operational load capacity	It must be verified if the external loads used in the initial design phase still are relevant, or if more accurate data are available
	Retrieval loads	It must be verified that the design conditions used in the initial phase still are relevant or if the retrieval load case is changed.

When doing a life extension for subsea structures, the following needs to be established:

The premises for extended operation including

- original design specification with loads and safety margins and comparison to the loading for the extended life time,
- external load conditions to the structures – are the design loads still valid or are more specific loads available? An example can be if actual well growth is known and these deviates from the values to the loads used in the initial design phase. Also consider new loads from drilling/workover operations and trawl activity, if applicable.

C.5.5 Threats to the subsea system

The subsea structure shall be controlled with requirements for safety to failure according to NORSOK N-001.

- Condition based: e.g. change in operational parameters
- Time-based: e.g. ineffective corrosion protection or corrosion control

The combined effect of threats shall also be considered.

C.5.6 System overview

The subsea structure for which a life extension process is carried out shall be described in such detail that the battery limits are clearly defined.

The subsea structure typical consists of all load-bearing structure supporting and protecting subsea control components and the hydrocarbon transport components such as manifold piping, x-trees etc.

C.6 Integrity assessment

C.6.1 Integrity management system

The subsea system should have an IMS. The IMS is used to carry out data collection and condition assessment.

C.6.2 Data collection

For a subsea structure the relevant data will be

- as built drawings of the structure,
- updated information on environmental data,
- permanent actions and variable actions,
- previous and future planned functional requirements,
- design and fabrication specifications,
- original corrosion management philosophy,
- original design assumptions,
- design, fabrication, transportation and installation reports which should include information about material properties (e.g. material strength, elongation properties and material toughness test values, weld procedure specifications and qualifications, non-destructive testing (extent and criteria used),

- in-service inspection history including information on corrosion, dents and deflections, scour, damages due to trawl impact, dents, erosion/abrasion, chloride intrusion, sulphate attacks,
- if relevant, information and forecast for seabed subsidence,
- information on modifications, repair and strengthening to the structure during service,
- soil conditions, pore pressures and consolidation.

C.6.3 Condition assessment

The requirements to the current condition are given by the original design documentation and revisions documented in the IMS. Examples are applicable design standards and required wall thickness.

The collected data should be reviewed in order to map how the system has been operated and maintained and the current physical condition should be identified. This will form the basis for the life extension reassessment.

C.6.4 Remedial actions

If the condition of the system can not be quantified or the system has been operated or maintained outside the intended use, information on gaps shall be given as input for the reassessment. Recommendations to the assessment activity about how to close these gaps shall be provided.

Examples of this can be higher external drilling loads acting on the subsea structure than catered for in the design process.

C.7 Reassessment

C.7.1 Objective

The reassessment is the activities related to analysis of the generated information including

- inspection data,
- monitoring data,
- life extension premises.

By evaluating these factors, establish the integrity of the system through the full extended lifetime. It is important to note that the actual integrity level of the subsea structure can never be fully known as the gathered data have uncertainties and inaccuracies.

There are two potential situations at the end of the reassessment:

- a) the assessed integrity level is equal to or exceeds the acceptance level. The reassessment is complete and the life extension project proceeds to documentation;
- b) the assessed integrity level does not meet the acceptance level. In order to increase assessed integrity level several options are available:
 - 1) **improved calculation method** – special attention should be given to ISO 13628-1, NORSOK N-001, NORSOK N-004 and the latest revision of these;
 - 2) **improved inspection data** - an example can be more thorough and more frequent ROV inspection e.g. related to anodes in order to determine the consumption and condition.

C.7.2 Process overview

The reassessment process for systems, sub-systems and components shall be concurrent with the process overview presented in 7.2.

C.7.3 Acceptance level

Subsea system acceptance level criteria are defined in 7.3.

C.7.4 Design based reassessment

Guidance for design based re-assessment is contained within 7.4.

Design based reassessment makes use of industry best practice. No information about current condition is available, which means that there is no updated baseline for the development of the degradation mechanism into further operation. The integrity level shall be assessed through the timeline from installation until the end of the life extension. An example can be a new and improved method for calculation of anode consumption.

C.7.5 Condition based reassessment

Condition based reassessment makes use of operational experience data. The data provides condition knowledge of the system, and should be integrated in the reassessment models.

For a subsea structure, the following specific areas should be examined in order to determine the degradation status and performing condition based assessment.

External corrosion

The corrosion resistance of the subsea structure depends on the material selection and the cathode protection system.

It should be ensured that the condition of the considered corroded structural element is sufficiently surveyed in order that the various failure modes can be properly addressed.

Structures that are not sufficiently protected against corrosion need to be assessed with their net thicknesses at the end of the assumed total design service life. The corrosion rate should be based on relevant experience and appropriate inspection plans need to be implemented.

Accidents – damages from trawl activity etc.

Structural parts that can be subjected to abrasion from normal use or by accidents need to be inspected to determine the extent of the abrasion. Structural assessments should be made on the basis of forecasted values for the net sections of the structural parts.

C.8 Modifications

C.8.1 Mitigation

One or more of the following mitigations may be selected in case the assessment of ULS or ALS has failed:

- installation of additional braces;
- reinforcement of steel structures by stiffeners, brackets etc.;
- instrumentation of the structure to better calibrate the actions, responses, etc.;
- use of material certificate or material testing in order to better estimate the structural resistance.

C.8.2 Intervention

Intervention is defined within 8.2.

C.8.3 Repair

Repair could require a retrieval of the Subsea Structure, which should be carefully assessed before put into action.

C.8.4 Replacement

A modification is categorised as a replacement when e.g. PLET or a large section of such are replaced. When designing a replacement the operator shall use the latest available design standard for the new part of the system.

C.8.5 Change of operational procedure

Reference is made to 8.5.

C.9 Documentation

Delivery from a life extension project shall be

- integrity documentation,
- plan for modifications (if any),
- input to plans for monitoring and inspection.

The potential for extension of service life beyond the extended service life should be provided.

The general requirements to documentation as given in NORSOK N-001 also applies for assessment of existing subsea structures. In addition the following aspects should be documented, if relevant:

- reason for the assessment (assessment initiator);
- basis for the condition assessment;
- performance history;
- as-is condition;
- expected future development based on experience;
- reference documents for the assessment including how the integrity of maritime systems and structures relates to regulations and standards;
- assessment analyses and results;
- maintenance plans for ensuring sufficient integrity including how to monitor and identify degradation and ageing, and the necessary future mitigations as a result of such degradation;
- description of necessary mitigations, including plan for replacement and need for future repairs of structures and maritime systems.

C.10 Implementation

Conclusions derived from the life extension process shall be implemented in accordance with the requirements of Clause 10.

Annex D (Normative)

Subsea valves – Specific requirements for service life extension

Foreword

The subsea valves which normally form part of a subsea system are systems with pressure containing equipment and moving parts. As a result, a thorough evaluation is needed to ensure a satisfactory level of confidence for service life extension.

Introduction

This annex contains the specifics for the equipment as listed under D.1.

All annexes are based on the main part of this NORSOK standard, where the main part defines general requirements and introduces the overall working process. Annex content is labelled and numbered according to the main part contents page. The main part contents page can therefore be used to navigate the annexes.

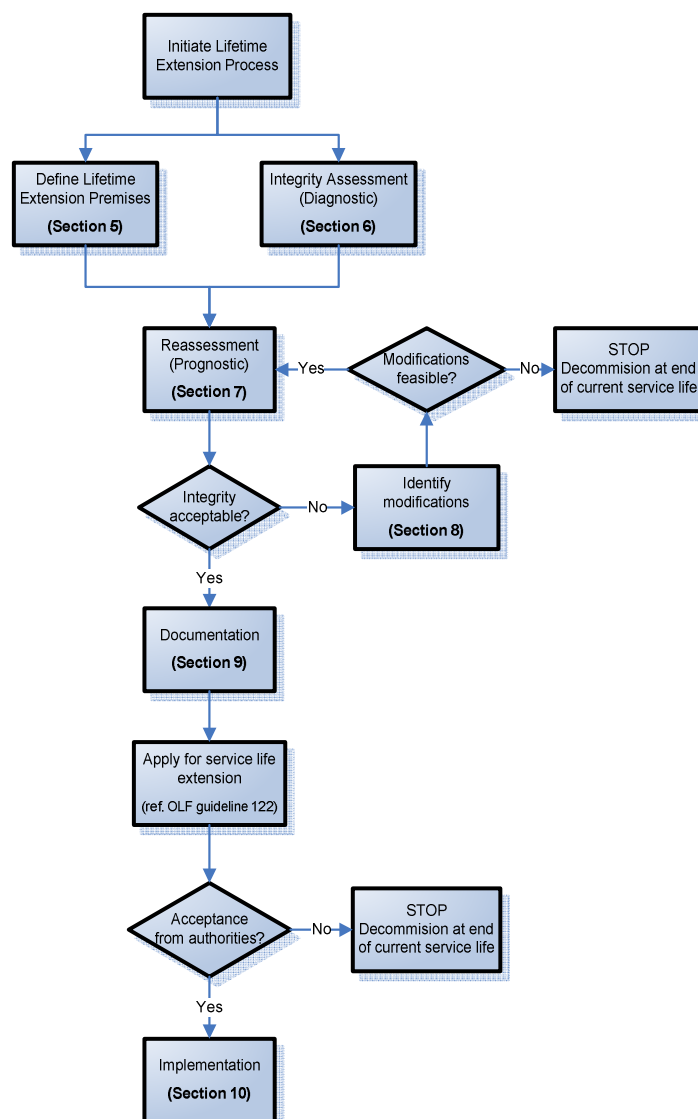


Figure D.1 - Life extension work process

NOTE Section references relates to main clauses of this NORSOK standard.

D.1 Scope

This annex includes

- valves in manifolds and piping/pipeline systems conveying: gas and/or oil or water
- valves in service lines conveying e.g.:
 - hydraulic power lines,
 - MEG injection lines,
 - methanol injection lines,
 - wax inhibitor lines,
 - scale inhibitor lines,
 - corrosion inhibitor lines.
- valves used to isolate water related to buoyant systems, such as for used during installation and removal and for flotation devices.

The “Valves” includes actuation devices being: manual, ROV, automatic or remotely operated. Further “Valves” includes functions with only on/off function (e.g. safety valves) or control of flow. The valve function can be achieved by a range of different designs, each with various possible failure mechanisms to be considered for a life extension. The most common types of valves are termed: ball valves, gate valves, globe and needle valves, plug valves, butterfly valves, diaphragm valves. Further are valves termed according to their function such as: open/shut (on/off) valves, choke valves, control valves, check valves.

Valves could in open condition provide a full bore or a reduced flow-cross-section which is not “pig-able”. Their actuation could be: manual by a simple wheel/mechanism operated by a diver or ROV, by a permanently fitted actuator powered by hydraulic fluid or by electricity. It could also be powered by the pipe fluid. Further can the actuation mechanism include reduction gears or mechanisms used to amplify the forces between the actuator and the valve.

It is stressed that the focus should primarily be on the systems where a valve failure could cause a threat to the environment or to humans during an intervention. This includes the primary pressure retaining barrier for all valves, in particular their mechanical sealing systems to the environment. The seal of most concern is the dynamic seal of the stem. Further focus should be on safety valves. Their correct function governs the safety of a system.

But the described principles for life extension apply to all valve types and to all valve applications.

D.2 Normative and informative references

A list of references specific to all aspects of life extension is located within Clause 2. For discipline specific references with regards to system design, see 5.3.

D.3 Terms, definitions and abbreviations

For terms, definitions and abbreviations refer to Clause 3.

D.4 Assessment methodology

D.4.1 Objective

This section describes the methodology to be applied to the life extension process for the items listed under D.1.

D.4.2 Integrity management system

The operators follow the Valves etc. through an IMS. The objective of the IMS is to ensure that the technical integrity of the valve is continuously maintained at an acceptable level.

The activities and assessments carried out as a part of the IMS is not part of the life extension process. The integrity management process is carried out within the constraints of the original design and is not necessarily sufficient to document and justify a life extension. The data obtained will, however, be required to perform the life extension process.

Specifically, the IMS for valves etc. will typically include yearly inspection and pressure and temperature monitoring through manifold, piping and pipeline sensors subsea and topside. Further, in the cases where

subsea leak detection sensors (SLD sensors) are installed, information on any leakages that have occurred may also be available.

D.4.3 Life extension process

The purpose of the life extension is to document acceptable system integrity to the end of the defined extended service life.

The overall life extension model can be summarised into four steps:

1. Definition of the premise for the extended operation, including identifying new threats to the system.
2. Assessment of the current integrity of the system.
3. Reassessment of the system based on
 - a. the available information,
 - b. current industry practice,
 - c. performance test historical trends,
 - d. new performance tests and available technology.
4. Evaluation of the results to decide whether the integrity of the system is acceptable up until the end of the extension period.

Safety critical functional elements

All elements of the valve that contribute to the functional safety of the system shall be identified. A system approach shall be used. When considering these elements, the whole system that supports the function shall be considered, i.e. not just the final element, but any component that enables that function and can fail in such away that it prevents the function from operating.

Such typical valve critical functional elements are

- the pressure retaining barrier formed by the housing, bonnet and seals,
- the internal closing/regulating mechanism with seals,
- the stem and power transfer mechanism to the valve with seals,
- the actuator with seals,
- the availability of power to the actuator,
- the monitoring and control system for the actuator and the valve itself,
- valve support,
- valve connections,
- valve coating and anodic corrosion protection system.

D.4.4 Degradation

The life extension process of the valve must take into account the degradation as function of time and operation.

The following types of systems, subsystems and components shall be assessed:

- systems, subsystems and components whose failure would result in a release of hydrocarbons;
- systems, subsystems and components that are single mitigating barriers to the release of a significant hydrocarbon reserve, for example an SSIV.

See D.7 for information on degradation mechanisms.

D.5 Life extension premises

D.5.1 Objective

The original design premises shall be reviewed to assess whether they are still applicable for the extended life period.

D.5.2 Authority regulations

Authority regulations shall be adhered to where required. For guidance, reference is made to 5.2.

D.5.3 Design standards

The valves etc. is designed to applicable standards that were selected at the time of design. The same design standards may be used throughout operation of the system, also when changes to this system are introduced. This includes life extension.

Investigation is required to whether there are any changes/ revisions in the rules, regulations or design codes applied. Particular attention should be made to the following standard and codes:

- NORSOK U-001, Subsea Production Systems
- NORSOK L001, Piping and Valves
- ISO 14313, Pipeline Valves
- ISO 14723, Subsea Pipeline Valves
- ISO 10423, Wellhead and X mas tree equipment (including valves)
- ISO 13703, Design and installation of piping systems on offshore platforms
- ASME B16.34, Valves – Flanged, Threaded and Weld ends
- API 598, Valve inspection and testing
- BS 6755-1, Testing of valves. Specification for production pressure testing
- DNV-OS-F101, Submarine Pipeline Systems
- ASME B31.3, Process Piping
- ASME B31.8, Gas Transmission and Distribution Piping Systems

D.5.4 Design premise

The design premise is the basis for the original design, and describes the operational and design limits for the system at time. In the context of this NORSOK standard, the primary premise is the design life.

Table D.1 gives examples of parameters premised for design. The table is not intended to be complete.

Table D.2 - Examples of parameters premised for design

Category	Subject	Comment
Operational Parameters	Fluid description and possible changes over time	Including possible deteriorating components such as H ₂ S, CO ₂ , Particles, chemical fractions that can cause clogging of valve cavities.
	Density	Initial and final
	Flow rates	Initial and final
	Pressure, internal	Initial and final
	Temperature, fluid	Initial and final
	Number of opening/closing operation	The differential pressure during opening or during operation should be included
	Power require to operate the valve	Required power for the valve actuation
	Power available to operate the valve	Available power initially and in the future
External Parameters	Water temperature	Max and mean
	Water depth	Tidal variations if of concern
	Rate of marine growth	
	Fisheries/Trawling	In relation to valve protection
Functional requirements	Valve response time	
	Performance test records (Torque/Actuation force/stroke)	CV for choke and regulation valves
	Tightness test records (internal end external)	Accurate measurement of leak/ leak development over time
Methodologies for response and capacity calculations	Design/operational load capacity related to loads from the pressure and conveyed from the piping system	It must be verified if the external and internal loads used in the initial design phase still are relevant, or if more accurate data are available

When doing a life extension specifically for Valves, the following needs to be established:

The premises for extended operation including

- original design pressure and comparison to the pressure regime for the extended life time,
- original design temperature and comparison to the temperature regime for the extended life time,
- original test pressure at manufacturer compared to possible reduced requirements,
- original test pressure after installation in the piping system compared to possible reduced requirements,
- external loads to the piping – are the design loads still valid or are more specific loads available? An example can be if actual well growth is known and this is larger than used in the initial design phase. Also consider loads from pipelines and flow lines,
- are there new loads transferred from the piping system e.g. connections to XT, flow lines, template structure. One example can be structure deflections more than anticipated.

D.5.5 Threats to the subsea system

The valves etc. shall be designed with an acceptable safety margin to failure. A subsea system is exposed to external as well as internal threats with different characteristics as follows:

- condition based: e.g. change in operational parameters;
- time-based: e.g. ineffective corrosion protection or corrosion control;
- wear (abrasion), erosion and cavitation;
- deterioration of sealant materials;
- clogging.

The combined effect of threats shall also be considered.

D.5.6 System overview

The valves for which a life extension process is carried out shall be described in such detail that the interfaces are clearly defined. Note in particular the following important items that need to be clearly defined to be/not to be part of the scope:

- connections/flanges to the piping system;
- welds: pipes to valves in the manifold system;
- support of the valve/connected piping;
- actuator connections to power
- PI&D for the valves, actuators and applicable monitoring and control system.

D.6 Integrity assessment

D.6.1 Integrity management system

The subsea system should have an IMS. The IMS is used to carry out data collection and condition assessment. Thereby data from the valve performances should be available.

D.6.2 Data collection

For valves etc. relevant data will be

- integrity inspection data (i.e. search for leakages) (external leak),
- leak test records,
- actuation forces and time,
- choke CV – flow coefficient (coefficient of volume flow),
- coating inspection,
- anode inspection,
- corrosion inspection (note particularly bolts, nuts and connections in general),
- historical/statistical data for equivalent and similar valves for the same application.

D.6.3 Condition assessment

The requirements to the current condition are given by the original design documentation and revisions documented in the IMS. Examples are

- changes in operational performances,

- accessibility, whether any changes has taken place,
- applicable design standards and required wall-thickness,
- comparison of valve housing wall thickness with piping wall-thickness.

The collected data should be reviewed in order to map how the system has been operated and maintained and the current physical condition should be identified. This will form the basis for the life extension reassessment.

D.6.4 Remedial actions

If the condition of the system can not be quantified or the system has been operated or maintained outside the intended use, the gaps in information shall be given as input for reassessment. Recommendations to the assessment activity about how to close these gaps shall be provided.

Examples of this can be higher internal pressure or temperature than catered for in the design process. Higher valve actuation forces than planned.

D.7 Reassessment

D.7.1 Objective

The reassessment is the activities related to analysis of the generated information including

- inspection data,
- monitoring data,
- statistical data,
- life extension premises.

Use this for establishing the integrity of the system through the full extended lifetime.

It is important to note that the actual integrity level of the Valves etc. can never be fully known if the gathered data have uncertainties and inaccuracies.

There are two potential situations at the end of the reassessment:

- a) the assessed integrity level is equal or exceeds the acceptance level. The reassessment is complete and the life extension project proceeds to documentation;
- b) the assessed integrity level does not meet the acceptance level. In order to increase assessed integrity level several options are available:
 - 1) **improved calculation method** – special attention should be given to the latest revision of the valve standards and the wall thickness requirement normally governed by a referenced pressure vessel standard;
 - 2) **improved inspection data** – an example can be more thorough ROV inspection e.g. related to anodes in order to determine their consumption and wall thickness measurement at predetermined positions;
 - 3) **improved testing and monitoring data** – example can be: operational performance changes, leak rates and retrofit of subsea leak detection systems to better identify and monitor leakages of hydrocarbons

D.7.2 Process overview

The reassessment process for systems, sub-systems and components shall be concurrent with the process overview presented in 7.2.

D.7.3 Acceptance level

Subsea system acceptance level criteria are defined in 7.3.

D.7.4 Design based reassessment

Design based reassessment makes use of industry best practice. No information about current condition is available, which means that there is no updated baseline for the development of the degradation mechanism into further operation. The integrity level shall be assessed through the timeline from installation until the end of the life extension. An example can be a new and improved method for calculation of anode consumption and methods for internal material loss calculations.

D.7.5 Condition based reassessment

Condition based reassessment makes use of operational experience data. The data provides condition knowledge of the system, and should be integrated in the reassessment models.

For valves the following specific areas should be examined in order to determine the degradation status and performing condition based assessment. An example may be for valves that requires periodic testing, historic files on this can show possible trends to be considered.

External leakage

Experience shows that external leakages from valves occur at

- the stem seal,
- body seals,
- auxiliary connections,
- mechanical connections to the piping system,
- the valve body and bonnet (less likely).

Data like test records and video recordings from ROV inspections where possible leakages forms visible traces in the water can be the basis for determine leakage status.

Further can the use of subsea leak detection sensors provide data. Such systems may be hampered by false indications caused by hydrocarbons seeping from the seafloor and by sensor failures.

Renewed leak/pressure test can be used to assure a margin to leak. Further, if possible, seal tests by special designed arrangements on the piping connection could be used (interseal tests).

In most cases the connected piping test pressure limit will govern the maximum test pressure magnitude rather than the valve test pressure used at the valve manufacturer. Further is the test pressure less over the closure mechanism than for the body.

External corrosion

The corrosion resistance of valves depends on the material selection, the coating system and externally the cathodic protection system. The primary external protection is the coating system and the cathodic protection system is a backup. The coating will break down over time and the associated protection will be reduced.

As many valves designs currently are made with Duplex or Super Duplex, hydrogen induced stress cracking (HISC) is an effect that needs to be considered, in particular for the main bolts. Reference is made to DNV-RP-F112 for further description.

Internal material degradation

Valve main pressure retaining barrier

Internal corrosion resistance is of concern both to the valve main pressure retaining barrier. It depends on the material selection and the corrosive potential of the transported fluid. Some corrosion damage may occur, but if the system is properly designed and operated it should not be a concern during the design life. For a life extension project, it is important to note that corrosion damage can not be reversed. However, the internal corrosion can be slowed down, e.g. inhibitors, other measures. Early initiation of the life extension process is important for internal corrosion as the integrity life can be longer when measures are introduced early.

The use of corrosion allowance (CA) is often used in design for carbon steel (CS) piping. The degradation of the CA may be monitored by corrosion probes which can be integrated in the valves design or by thickness tests at predetermined positions. The data from these instruments may be an important part of the operational experience data and input for the life extension assessment.

Internal leakage

Valve internal parts

Internal part forming parts of the sealing system are sensitive to any corrosion. This may cause leak and increase requirement to the operating forces. Leak and performance testing will indicate possible changes for use in a prediction.

Sealing materials

Seal materials of polymer materials have limited life governed by their chemical composition, exposure to detrimental fluid chemicals, temperature and temperature duration, mechanical stresses, decompression rate after gas exposure and light exposure.

The latter in subsea systems is only relevant for spare parts. The "Arrhenius equation" indicates correlation for material life considerations. It is used to predict the life based on the operational history of time/temperature and fluid type. This is provided relevant material test data or statistical data is available. Consequently "Arrhenius equation" is used to correlate the material life experienced or tested with that actual at deviating temperatures.

The types of detrimental chemicals would normally be specified by the seal supplier and can be compared with the internal fluid and possible injected fluids.

Temperature and mechanical stresses (sealing of clearances) acceptance criteria are normally specified by the seal manufacturer.

Further is seal materials of metals (tungsten carbide and Stellite in loaded dynamic seal areas, ring type gaskets of soft stainless steel in flanges, metal O-rings), carbon, ceramics and mixed compound materials (flat gaskets) used. These materials have different failure modes to be considered in assessment of their life. The type of possible failure modes can normally be studied in generally recognised gasket manufacturers handbooks.

Migration of molecules from the pressurised fluid takes place through the all types sealing system. (except for soft metal seals perfectly made up). Such migration is not termed as leak, but must be considered with respect to possible detrimental consequences.

Wear and abrasion

Each operation of the valve causes wear. High loads between moving parts are of particular concern. High loads are caused by differential pressure during opening and differential pressures over dynamic seals. The various valve types are differently sensitive (globe valve is less sensitive). Further can particular design increase the wear resistance, e.g. by particular hard metallic materials (Stellite, white cast iron, tungsten carbide (TC) and even diamond) and by combination of hard and softer metallic materials.

Therefore the following items are of particular concern:

- stem seal and stem surface evenness;
- main seal and main seal counterpart;
- bearings (e.g. trunion bearings in ball valves).

Solid particles in the fluid tend to gather in the surface of softer materials such as main seals and can increase the wear of ball and gate valves.

Performances testing of the valve will indicate possible margins to limits and can therefore be used for life extension prediction.

Erosion

Piping systems with high fluid velocity and with particles are subject to possible erosion. Erosion causes material loss. Gas with particles is of particular concern. Choke valves represents a part of a piping system with high local fluid velocity. Chokes will often have a shorter life than the rest of the valves due to erosion.

Performances testing of the choke-valve showing detrimental trend indicates possible life limits and should be used for prediction of the remaining life for this component.

Relevant sensors available in the piping system are important. Thereby it is feasible to monitor the choke performance and the choke characteristics (CV).

The damage may, however, occur in the high turbulence downstream the choke. Therefore analytical numeric calculations should be used to verify whether this may have any concern to the downstream piping. If so, then thickness measurements must be performed to support any life extension.

Cavitation

Cavitation is caused by imploding vapour bubbles in a liquid. The implosion transfers a damaging shock to the surrounding materials. This requires a local liquid pressure less than the boiling pressure for the liquid. Again a choke can cause such low pressures locally downstream causing material loss.

Life extension should be based on the same principle as described for erosion.

Clogging

Valves can be subject to deposits caused by scaling, wax and hydrates. Further may solid particles (sand, rust etc.) follow the conveyed fluid. These undesirable substances in produced hydrocarbons and water can fill cavities in the valve and prevent its operation. Deposits on the walls may be removed with some chemicals injected in the fluid.

Performances testing of the valve will indicate possible potentials for life extension.

Foreign materials

Maintenance crew's tools has sometimes passed into the piping system, stopped in the valve or damaged the valve's closure mechanism.

Performances testing of the valve will indicate possible potentials for life extension limits.

Fatigue

Fatigue of valve parts would only be relevant for valves with a high number of operations. This might be applicable to a reduction gear's tooth of a pinion making the valve stem to actuate.

An analysis of the tooth fatigue resistance could be used for life extension predictions.

D.8 Modifications and testing

D.8.1 Mitigation

Mitigation is defined within 8.1.

Chemical composition of the transported fluid may be influenced by change in use of inhibitors. Also, well stream may change over time, i.e. higher water cut.

D.8.2 Intervention

Intervention is defined within 8.2.

D.8.3 Repair

Repair solutions may be assessed through use of available recommended practices. Smaller valves attached with mechanical connections may be replaced. Large valves welded to the pipes may be possible to open subsea and for internals replacements. Even machining of sealing surfaces is possible subsea.

D.8.4 Maintenance and planned replacement

Some valves may have been ordered with a shorter lifetime than the rest of the system. This can be the case for chokes. Therefore replacement may be needed. Performance testing may, however, justify life extension also for this.

Some surface valves are designed to be lubricated by regular intervals or for retightening of stem seals. The consequences for using such valves subsea must be evaluated.

D.8.5 Change of operational procedure

Reference is made to 8.5.

D.8.6 Pressure/leak test

Leak test

Measurement of possible leak rate for the valve in closed position:

The measurement accuracy depends on the test time, system response (e.g. time to detect pressure changes caused by leak based on: fluid volumes and possible temperature changes during the measurement) and instrumentation accuracy. The measurement accuracy must be established to check whether the method is applicable for the leak rate acceptance criteria. This criterion is twofold; one absolute related to the consequence acceptance criteria and one relative to check for trend. The latter depends on previous data from measurements.

Measure the tightness towards the environment. This would normally be done by the valve in open position. A requirement to the measurement accuracy is described above. ROV inspection during the test could reveal leaks provided the leak medium is visible (by colour/black light/ diffraction index/turbulence). The use of "clouding" could also be considered (making turbulence more visible by adding slight colour tracing to the surrounding water). See "External leak" above.

Pressure test

Pressure test can be combined with the above "Measure the tightness towards the environment". The pressure test will load the seals more and is therefore an important issue to verify a safety margin to leak.

D.8.7 Performance testing

The result and value from the performance testing of valves depends on the degree of monitoring and recording. It is foreseen three alternatives of monitoring for remotely operated open/closed valves. The following starts with the most valuable:

- for shut off valves: record the opening sequence by degree of opening as a function of actuator force and possible differential pressure and time. This is the ideal case requiring monitoring exceeding most application;
- measurement of time for open/closing and power-consumption together with upstream and downstream pressure;
- derive time for open/close by flow/pressure monitoring of the line and derive actuator force from that available during the operation.

ROV operated valves depends on the ROV monitoring systems.

Manual operated valves and valves operated by an actuator to be fitted require detailed planning for the performance testing.

Regulating valves and choke valves require checking of their CV (flow coefficient) for possible changes (the relation between area of the opening and actuation stroke). This can be done by measuring their flow characteristics for possible trends.

D.9 Documentation

Delivery from a life extension project shall be

- integrity documentation,
- plan for modifications (if any),
- input to plans for monitoring and inspection.

The potential for extension of service life beyond the extended service life should be provided.

Document facilitating lifetime extension evaluations are

- PI&D for the valve applications,
- general arrangement drawing for the valve with part list identifying the materials,
- "Data book" for the valve contain material certificates, manufacturing record and test records,
- pressure and leak test records,
- performance test records,
- statistics for failures on equal and similar valves for the same application.

D.10 Implementation

Conclusions derived from the life extension process shall be implemented in accordance with the requirements of Clause 10.

Annex E (Normative)

Subsea manifold piping systems and interconnecting pipeline – Specific requirements for service life extension

Foreword

The subsea manifolds which normally form part of a subsea system are complex designs with pressure containing equipment and moving parts. As a result, a thorough evaluation is needed to ensure a satisfactory level of confidence for service life extension.

Introduction

This annex contains the specifics for the equipment as listed under E.1.

All annexes are based on the main part of this NORSOK standard, where the main part defines general requirements and introduces the overall working process. Annex content is labelled and numbered according to the main part contents page. The main part contents page can therefore be used to navigate the annexes.

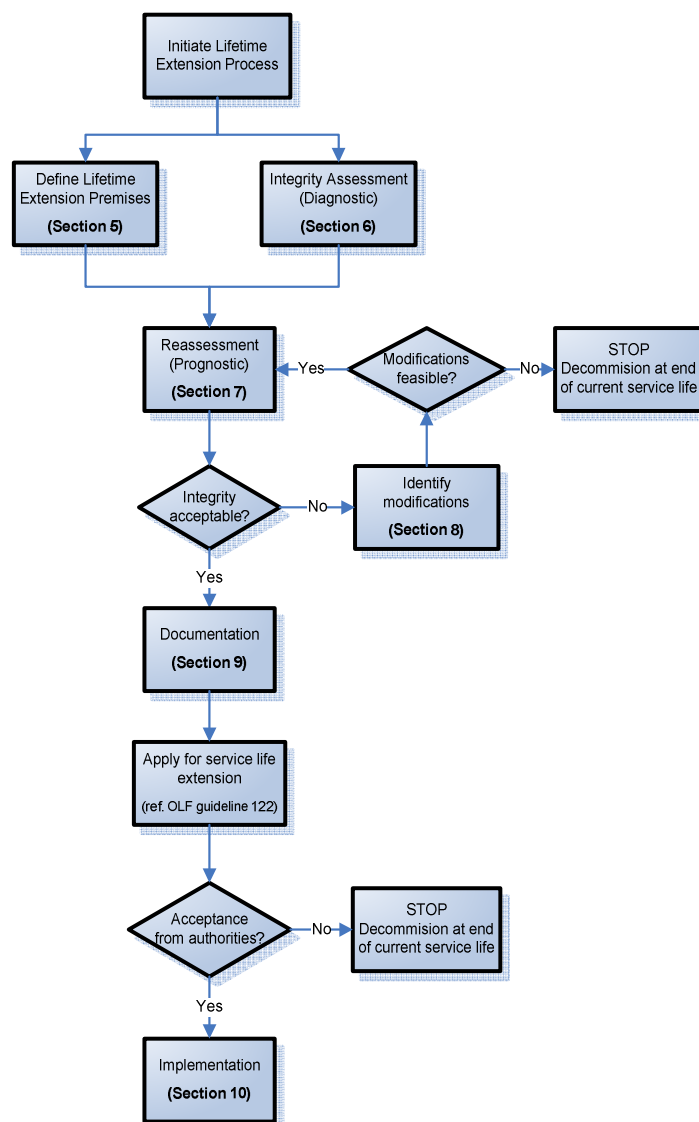


Figure E.1 - Life extension work process

NOTE Section references relates to main clauses of this NORSOK standard.

E.1 Scope

This annex includes

- manifold production piping (for gas and/or oil),
- manifold water injection piping,
- manifold gas injection piping,
- manifold lift gas piping,
- manifold service lines, both hardpipes and hoses - which include (not limited to)
 - HP/LP hydraulic lines,
 - MEG injection lines,
 - methanol injection lines,
 - wax inhibitor lines,
 - scale inhibitor lines,
 - corrosion inhibitor lines.
- interconnection production flowlines/jumpers,
- interconnecting water injection flowlines/jumpers,
- interconnecting gas injection flowlines/jumpers.

For simplicity, the term 'manifold piping' is used in this NORSOK standard when describing the items listed under E.1.

It is stressed that the focus should primarily be on the systems containing hydrocarbons and other environmentally harmful substances. The water injection systems will have less consequence to the environment if the integrity is compromised. However, produced water can be harmful to the environment and should be considered carefully.

E.2 Normative and informative references

A list of references specific to all aspects of life extension is located within Clause 2. For discipline specific references with regards to system design, see 5.3.

E.3 Terms, definitions and abbreviations

For terms, definitions and abbreviations refer to Clause 3.

E.4 Assessment methodology

E.4.1 Objective

This section describes the methodology to be applied to the life extension process for the items listed under E.1.

E.4.2 Integrity management system

Specifically, the IMS for manifold piping will typically include yearly inspection, pressure, temperature and sand production monitoring through manifold mounted sensors. Further, in the cases where subsea leak detection sensors (SLD sensors) are installed, information on any leakages that have occurred may also be available.

E.4.3 Life extension process

Reference is made to 4.3.

E.4.4 Degradation

As stated in the main part of this NORSOK standard the lifetime extension process shall take into account the degradation that has taken place since the installation of the process.

The following types of systems, subsystems and components should be assessed:

- systems, subsystems and components whose failure would result in a release of hydrocarbons;
- systems, subsystems and components that are a single mitigating barrier to the release of a significant hydrocarbon reserve.

See E.7 for information on degradation mechanisms.

E.5 Life extension premises

E.5.1 Objective

The original design premises shall be reviewed to assess whether they are still applicable for the extended life period.

E.5.2 Authority regulations

Authority regulations shall be adhered to where required. For guidance, reference is made to 5.2.

E.5.3 Design standards

The manifold piping is designed to applicable standards that were selected at the time of design. The same design standards may be used throughout operation of the system, also when changes to this system are introduced. This includes life extension.

Investigation is required to whether there are any changes/ revisions in the rules, regulations or design codes applied. Particular attention should be made to the following standard and codes:

- ISO 13628-1
- ISO 13628-4
- ISO 13628-15 (under approval)
- ASME B31.3
- ASME B31.4
- ASME B31.8
- DNV-OS-F101

E.5.4 Design premise

Table E.1 gives examples of parameters premised for design. The table is not intended to be complete.

Table E.1 - Examples of parameters premised for design

Category	Subject	Comment
Operational Parameters	Flow	The composition of the flow may change over time
	Pressure	
	Temperature	Is must be verified that insulation requirements are the same.
	Density	
	Slug characteristics	If the slug loads have been relevant from start of design life, it must be verified that these loads still are relevant
External Parameters	Fisheries/trawling	
	Metoccean data	
	Earthquake	
	Geotechnical	It must be verified if the geo settlements used in the initial design phase still are relevant, or if more accurate data are available.
Methodologies for response and capacity calculations	Design/operational load capacity	It must be verified if the external loads used in the initial design phase still are relevant, or if more accurate data are available
	Retrieval loads	It must be verified that the design conditions used in the initial phase still are relevant or if the retrieval load case is changed.

When doing a life extension project specifically for manifold piping, comparison between original design and life extension premises, needs to be performed. The following needs specifically to be established:

- a) original design pressure and comparison to the pressure regime for the extended life time;
- b) original design temperature and comparison to the temperature regime for the extended life time. Also insulation requirements need to be verified;
- c) external loads to the piping – are the design loads still valid or are more specific loads available? An example can be if actual well growth is known and these vary to the values to the loads used in the initial design phase. Also consider loads from pipelines and flowlines;
- d) are there any new loads which are applicable from e.g. connections to XT, flowlines, template structure? One example can be structure deflections higher than anticipated.

E.5.5 Threats to the subsea system

Reference is made to 5.5.

E.5.6 System overview

The e.g. manifold piping for which a life extension process is carried out shall be described in such detail that battery limits are clearly defined. Note in particular the following important items that need to be clearly defined to be/not to be part of the scope:

- pipeline and flowline connectors/flanges;
- branch connectors/flanges;
- welds vs valves in the manifold system;
- piping vs pipe supports and anchor points;
- piping vs sensors.

E.6 Integrity assessment

E.6.1 Integrity management system

The subsea system should have an IMS. The IMS is used to carry out data collection and condition assessment.

E.6.2 Data collection

For manifold piping relevant data will be

- integrity inspection data (i.e. search of leakages);
- coating inspection;
- anode inspection;
- corrosion inspection (note particularly bolts, nuts and connections in general);
- thermal insulation inspection;
- wall thickness inspection via intelligent pigging.

E.6.3 Condition assessment

Guidance for condition assessment is contained within 6.3.

E.6.4 Remedial actions

Remedial actions are described within 6.4.

E.7 Reassessment

E.7.1 Objective

The reassessment is the activities related to analysis of the generated information including

- inspection data,
- monitoring data,
- life extension premises.

By this, establish the integrity of the system through the full extended lifetime. Particular focus should be on historical data for operations as e.g. amount of sand production.

It is important to note that the actual integrity level of the manifold piping can never be fully known as the gathered data have uncertainties and inaccuracies.

There are two potential situations at the end of the reassessment:

- a) the assessed integrity level is equal or exceeds the acceptance level. The reassessment is complete and the life extension project proceeds to documentation;
- b) the assessed integrity level does not meet the acceptance level. In order to increase assessed integrity level several options are available:
 - 1) **improved calculation method** – special attention should be given to ISO 13628-1, ASME B31.3, ASME B31.8 and DNV OS-F101 and the analysis requirements herein;
 - 2) **improved inspection data** - an example can be more thorough ROV inspection e.g. related to anodes in order to determine the consumption and condition;
 - 3) **improved monitoring data** – An example can be retrofit of subsea leak detection systems to better identify and monitor leakages of hydrocarbons.

E.7.2 Process overview

The reassessment process for systems, sub-systems and components shall be concurrent with the process overview presented in 7.2.

E.7.3 Acceptance level

Subsea system acceptance level criteria are defined in 7.3.

E.7.4 Design based reassessment

Guidance for design based re-assessment is contained within 7.4.

E.7.5 Condition based reassessment

Condition based reassessment makes use of operational experience data. The data provides condition knowledge of the system, and should be integrated in the reassessment models. Reference is also made to PSA regulations.

For manifold piping the following specific areas should be examined in order to determine the degradation status and performing condition based assessment.

External corrosion

The corrosion resistance of manifold piping depends on the material selection, the coating system and the cathodic protection system. The primary protection is the coating system and the cathodic protection system is a backup. The coating will break down over time and the associated protection will be reduced.

As many manifold piping designs currently are made with Duplex or Super Duplex, hydrogen induced stress cracking (HISC) is an effect that needs to be considered. However, it should be noted that most reported HISC failures have occurred early in the operational life. Reference is made to DNV-RP-F112 for further description.

Reference is made to ASME B31.8 section A860 and A862 for typical relevant piping design code requirements.

Internal corrosion

Internal corrosion resistance depends on the material selection and the corrosive potential of the transported fluid. Some internal corrosion damage will occur, but if the system is properly designed and operated it should not be a concern during the design life. For a life extension project, it is important to note that corrosion damage can not be reversed. However, the internal corrosion can be slowed down, e.g. inhibitors, other measures. Early initiation of the life extension process is important for internal corrosion as the integrity life can be longer when measures are introduced early.

The use of corrosion allowance (CA) is often used in design for carbon steel (CS) piping. The degradation of the CA may be monitored by corrosion probes which are often integrated in the manifold piping design or intelligent pigging. The data from these instruments may be an important part of the operational experience data and input for the life extension assessment.

Reference is made to ASME B31.8 section A860 and A863 for typical relevant piping design code requirements.

Flange and connection leakages

Experience shows that leakages in subsea systems mostly occur at connection points as flanges or clamp connectors. Data like video recordings from ROV inspections can be the basis to determine the leakage status, but the use of subsea leak detection sensors may provide data with higher confidence level.

Fatigue

Fatigue calculations may or may not be relevant for subsea manifold piping. In the case of fatigue being a relevant load case, the piping subject to life extension shall meet the same code requirements as when initially designed, with the exception that load/cycle data may be different.

If possible, recorded data as start-stop of production should form the basis for the fatigue assessment. Other issues to examine are vortex shedding, slug induced vibrations, water hammer, valve shut-in and harmonic vibrations.

Relevant design codes are e.g. ASME B31.8 section A842.25.

E.8 Modifications

E.8.1 Mitigation

Mitigation is defined within 8.1.

Chemical composition of the transported fluid may be influenced by change in use of inhibitors. Also, well stream may change over time, i.e. higher water cut.

E.8.2 Intervention

Intervention is activities performed indirectly to the containment part of manifold piping. This may be modifications to the external loads from e.g. flowlines. These modifications can be achieved through rock dumping, installation of supporting devices or similar.

E.8.3 Repair

Repair solutions may be assessed through use of available recommended practices. Components to be replaced shall be designed according to chosen design standards and premises applicable for the manifold piping. This is most relevant for parts in the connectors or flanges, but may also apply to piping elements

Repair will often require a retrieval of the manifold, which should be carefully assessed before put into action.

E.8.4 Replacement

A modification is categorised as a replacement when e.g. a manifold, pig loop or a large section of such are replaced. When designing a replacement the operator shall use the latest available design standard for the new part of the system.

E.8.5 Change of operational procedure

Reference is made to 8.5.

E.8.6 Integrity indicators

Seal test (e.g. back seal tests on clamp connectors) can be a good way of establishing the integrity of a connection system. This can be combined with subsea leak indicators that are part of the original installation, or retrofitted. The seal test must be within the allowable limits set by the applicable design code for the connection and/or piping.

E.9 Documentation

Document requirements are detailed within Clause 9.

E.10 Implementation

Conclusions derived from the life extension process shall be implemented in accordance with the requirements of Clause 10.

Annex F (Normative)

Subsea umbilicals – Specific requirements for service life extension

Foreword

Subsea umbilicals are complex structures composed of multiple functional lines such as steel tubes, electrical conductors, fibre optics, tensile armours and protective sheets. Umbilicals are exposed to complex loading due to normal functional use as well as external environmental loading. External loads on dynamic umbilicals are governed by waves, floater motions and current. Global load effect analyses of dynamic umbilicals are challenging due to the nonlinearities present in such systems. Furthermore, special purpose software is required to establish the stress/strain in the individual components for a given tension/curvature of the umbilical.

Special design challenges are related to fatigue damage and extreme load at interfaces to rigid structures. A bellmouth or bend stiffener is applied at the floater interface to meet the design requirements. Integrity of these bend limiting devices is essential for the integrity of the umbilical.

Umbilicals are normally not considered as safety critical elements. This should, however, be evaluated on a case by case basis. Operational aspects are therefore the main concern for lifetime extension of umbilicals and consequently also the main focus of this NORSOK standard. As a result, a thorough evaluation is needed to ensure a satisfactory level of operational confidence for service life extension. Essential aspects are assessment of residual fatigue life and material degradation of the individual components.

Introduction

This annex contains the specifics for the equipment as listed under F.1.

All annexes are based on the main part of this NORSOK standard, where the main part defines general requirements and introduces the overall working process. Annex content is labelled and numbered according to the main part contents page. The main part contents page can therefore be used to navigate the annexes.

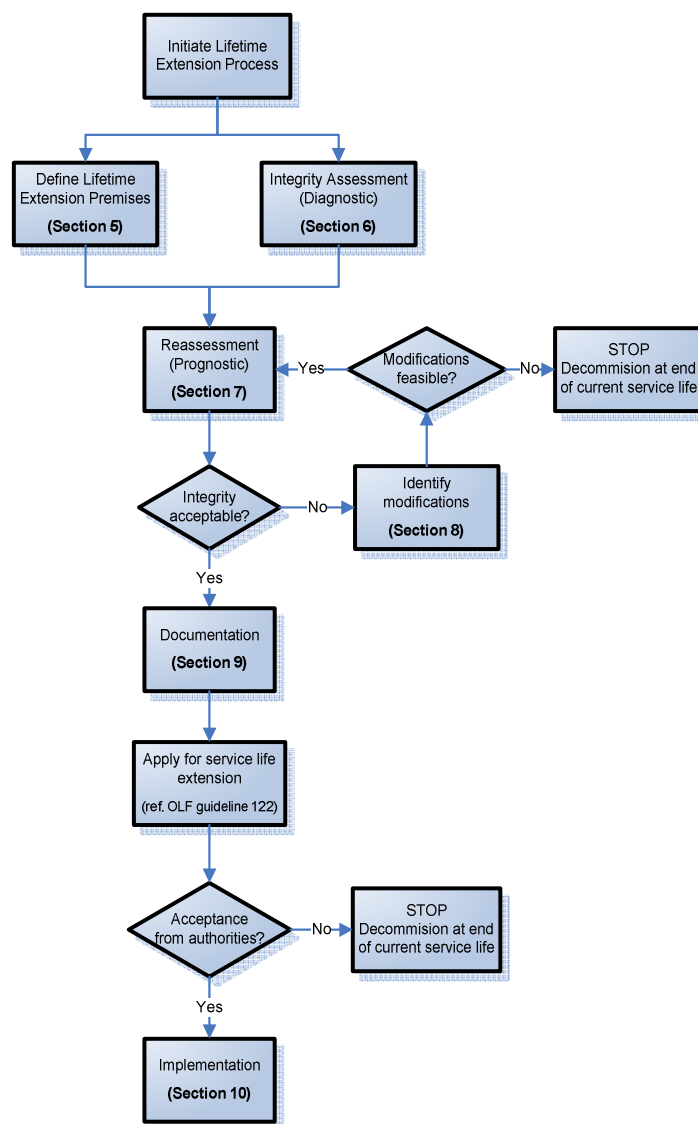


Figure F.1 - Life extension work process

NOTE Section references relates to main clauses of this NORSOK standard.

F.1 Scope

The focus of this annex is lifetime extension of the umbilical with end fittings.

Lifetime extension aspects of ancillary components of an umbilical system are not addressed in this annex. References to relevant documents/sections for ancillary components are given in Table F.1.

Table F.1 - References to relevant documents/sections

Component	Reference
Bend stiffener	LE standard for transportation system
Bellmouth	LE standard for load bearing structures
Buoyancy elements	Annex H
Subsea arch	Annex H
Tethers	Annex H
Anchors	Annex H
Clamps	Annex H
Bend restrictor	LE standard for transportation system
Mid-water arch	Annex H

F.2 Normative and informative references

A list of references specific to all aspects of life extension is located within Clause 2. For discipline specific references with regards to system design, see 5.3.

F.3 Terms, definitions and abbreviations

For terms, definitions and abbreviations refer to Clause 3.

F.4 Assessment methodology

F.4.1 Objective

The following sections describe the methodology to be applied to the life extension process for the items listed under F.1.

F.4.2 Integrity management system

The objective of an IMS is to ensure that the technical integrity of the umbilical is continuously maintained at an acceptable level.

The activities and assessments carried out as a part of the IMS is not part of the life extension process. The integrity management process is carried out within the constraints of the original design and is not necessarily sufficient to document and justify a life extension. The data obtained is, however, required to perform the life extension process. Where an IMS is not implemented this data has to be obtained by other means. Alternatively realistic conservative assumptions should be made.

Specifically, the IMS for umbilical systems may include regular inspection, monitoring/recording of fluids transported through tubing and hoses, applied pressures, functional testing of signal and control cables, monitoring of power transmitted in power lines, inspection of bend stiffeners, buoyancy modules, midwater arches, anchors, clamps etc.

F.4.3 Life extension process

The life extension process is triggered by the decision that the operation of the system will be continued beyond the original service life. The purpose of the life extension is to document acceptable system integrity to the end of the extended service life.

F.4.4 Degradation

The life extension process of the umbilical and ancillary components must take into account the degradation that has taken place since the installation of the system. See F.7 for additional description.

F.5 Life extension premises

F.5.1 Objective

The original design premises shall be reviewed to assess whether they are still applicable for the extended life period.

F.5.2 Authority regulations

Authority regulations shall be adhered to where required. For guidance, see 5.2.

F.5.3 Design standards

The umbilical system was designed to standards that were specified at the time of design. The same design standards may be used throughout operation of the system, also when changes to this system are introduced. This includes life extension.

Investigation is required to whether there are any changes/ revisions in the rules, regulations or design codes applied. Particular attention should be given to the following standard and codes:

- ISO 13628-5, Subsea umbilicals;
- DNV-OS-F101, Submarine pipeline systems;
- DNV-OS-F201, Dynamic Risers;
- NORSOK N-003, Action and action effects.

Criticality of identified modification shall be assessed and implemented in the life extension evaluations.

F.5.4 Design premise

The original design premises shall be reviewed to assess whether they are still applicable for the extended life period. The design premise is the basis for the original design, and describes the operational and design limits for the system at that time.

A design premise for the extended service life shall be specified.

Table F.1 gives examples of parameters premised for design. The table is not intended to be complete.

Table F.2 - Examples of parameters premised for design

Category	Subject	Comment
Operational Parameters	Power cables	Operational parameters may have changed compared to the original design premise
	Signal cables	Operational parameters may have changed compared to the original design premise
	Piping/hoses	Operational parameters may have changed compared to the original design premise
	Redundancy	The required built-in redundancy by including additional functional lines in the umbilical may differ from the original design premise
External parameters	Geotechnical data	Updated soil data may affect the umbilical response in the touch-down area
	Marine growth	The marine growth on the umbilical should be inspected. Density and thickness of marine growth as function of depth should be derived from inspections and included in the updated design premise.
	Metocean data	Metocean data for the Norwegian section are updated on a regular basis, e.g. wave and current data. Enhanced metocean data may also allow for more refined load-effect analysis (e.g. directional wave data which may allow more detailed fatigue analyses)
	Floater	Floaters may be subjected to modifications that affect the motion characteristics over its lifetime. This may affect fatigue as well as extreme loading conditions.
	Station-keeping system	Changes in the station-keeping system may affect the floater platform motions in terms of mean offsets and low-frequency motions. This may affect fatigue as well as extreme loading conditions.
	Adjacent structures	Additional/modified adjacent structures such as risers, mooring lines and other umbilicals might lead to increased probability of interference.
Methodologies for response and capacity calculations	Enhanced load effect analysis capabilities	Enhanced methods for assessment of the load effect may allow for more accurate design life predictions. In particular this applies to fatigue analysis considering stick/slip behaviour of helix elements. Increased computer resources might also allow for more extensive load effect analyses
	Revised capacity data	Upgraded capacity data based on more available test data might be available for several components. This is of particular importance for SN-curves required for fatigue capacity evaluations. The rate of degradation of polymeric materials as a function of operational parameters may be better known compared with the design stage. The response of steel materials wrt the corrosive

Category	Subject	Comment
		environment inside the umbilical may be better known compared with the design stage.

Possible changes compared to the original design premises shall be implemented in the life extension design premises. The criticality of possible more severe design conditions shall be identified and given special attention in the life extension evaluation. This may require reanalysis of parts of or of the entire system.

F.5.5 Threats to the subsea system

The umbilicals shall be designed with an acceptable safety to failure. A subsea system is exposed to external as well as internal threats with different characteristics as follows:

- condition based: e.g. change in operational parameters;
- time-based: e.g. ineffective corrosion protection or corrosion control;
- external events: impact from dropped object, impact/snatching from trawling, anchors, bottom slides, earthquakes.

The combined effect of threats shall also be considered.

F.5.6 System overview

The umbilical shall be described in detail and battery limits shall be clearly defined. Battery limits shall be defined for each component in the umbilical, i.e. the battery limits of the armouring, tubing, hoses and cables shall be specified for each individual component. Battery limits for tubing may be different for the tube when acting as a pressure conduit and when acting as part of the umbilical armouring.

The ancillary equipment in the system shall be specified for information, see F.1, but life time extension of such equipment is outside the scope of this NORSOK standard.

F.6 Integrity assessment

F.6.1 Integrity management system

The subsea system should have an IMS. The IMS is used to carry out data collection and condition assessment.

F.6.2 Data collection

For umbilical systems relevant data to be collected are

- past, present and future operational data,
- integrity inspection data of the umbilical structure (i.e. search of leakages, external damages),
- position of sag/hog/touch-down of dynamic umbilical configuration,
- outer sheath inspection, focus on damages that can be associated with collision with adjacent structures,
- inspection/quantification of marine growth. Density and thickness as function of depth should be provided. Special attention should be given to possible scratches that can indicate contact with adjacent structures,
- anode inspection,
- corrosion inspection (note particularly bolts, nuts and connections in general),
- whether the system has been operated or maintained outside the intended use. In particular, accidental events involving partial loss of station-keeping capacity of structures to which the umbilical is attached,
- functional status of all components,
- operational track record of functional components,
- inspection of ancillary components. In particular bend limiting devices and buoyancy modules for dynamic umbilicals.

F.6.3 Condition assessment

The requirements to the current condition are given by the original design documentation with revisions. If an IMS is implemented this is normally documented in the IMS.

The collected data should be reviewed in order to map how the system has been operated and maintained and the current physical condition should be identified. This will form the basis for the life extension reassessment.

The following should be considered for conditional assessment of a global dynamic configuration:

- position of distributed buoyancy modules. Possible missing/dislocated/defect buoyancy elements should be identified;
- location of sag/hog/touch-down position should be evaluated against as-built documentation. Cause of possible deviation from as-built data should be evaluated (e.g. excessive loss of buoyancy);
- observed marine growth should be evaluated against data specified in the design premises.

The effects of the possible deviation from data specified in design premises for the original design of the umbilical should be quantified by revised load effect analyses.

The condition of bend-limiting devices should be given special attention. Possible full/partial failure of bend limiting devices may lead to severe damage to the umbilical over a short exposure time.

The redundancy of the umbilical should be assessed with basis in functional status of all components.

Influence of reported/documented loads exceeding the loads defined in the design premise (functional, environmental or accidental loads) on the system should be assessed. This may also cover revised metocean specification for the actual location.

The evaluation of the degradation of all components of the umbilical (excluding ancillary equipment) should be performed considering at least the following:

- experienced operational condition of each component (e.g. temperature, chemical environment);
- revised material data such as SN-curves;
- fatigue damage due to documented exposed cyclic loading (e.g. recorded environmental loading);
- creep;
- aging;
- corrosion;
- optical damping in fiberoptic components;
- degradation of electrical insulation;
- degradation of connectors, mechanical and electrical/signal;
- other relevant degradation mechanisms.

Holding force of frictional clamps (e.g. applied for buoyancy elements) should be assessed with basis in the long-term radial creep of the umbilical.

In order to obtain the necessary data it may be required that an evaluation of life time extension of ancillary equipment has been or is carried out in addition, see Annex H.

F.6.4 Remedial actions

If the condition of the one or more items in the umbilical can not be quantified the gaps in information shall be given as input for reassessment. Recommendations to the assessment activity about how to close these gaps shall be provided.

F.7 Reassessment

F.7.1 Objective

The reassessment is the activities related to analysis of the generated information including

- inspection data,
- monitoring data,
- life extension premises.

This information forms the basis for establishing the integrity of the system through the full extended lifetime. It is important to note that the actual integrity level of the umbilical system can never be fully known as the internal components of the umbilical can not be inspected and that the gathered data have uncertainties and inaccuracies.

There are two potential situations at the end of the reassessment:

- a) the assessed integrity level is equal or exceeds the acceptance level. The reassessment is complete and the life extension project proceeds to documentation;
- b) the assessed integrity level does not meet the acceptance level. In order to increase assessed integrity level several options are available:
 - 1) **improved calculation method** – Enhanced load effect analysis utilizing advanced computer tools, revised metocean data, refined modelling of environmental loading, updated capacity data, etc.;
 - 2) **improved inspection data** - an example can be more thorough ROV inspection e.g. related to condition of buoyancy modules and bend limiting devices;
 - 3) **mitigation or repair**, see F.8.1 or F.8.3.

F.7.2 Process overview

The reassessment process for systems, sub-systems and components shall be concurrent with the process overview presented in 7.2.

F.7.3 Acceptance level

Subsea system acceptance level criteria are defined in 7.3.

F.7.4 Design based reassessment

Design based reassessment shall be based on the design standards given in F.5.3. No information about current condition is available, which means that there is no updated baseline for the development of the degradation mechanism into further operation. The integrity level shall be assessed through the timeline from installation until the end of the life extension. An example can be a enhanced fatigue life calculation considering refined environmental load modelling as well as updated fatigue capacity data.

F.7.5 Condition based reassessment

Condition based reassessment makes use of operational experience data. The data provides condition knowledge of the system, and should be integrated in the reassessment models.

F.8 Modification

F.8.1 Mitigation

Mitigation is defined within 8.1.

A reduction of the severity of the load effects could be achieved by e.g. installing redesigned bend limiting devices reducing the fatigue loading on the system. Replacement of a bend stiffener is however a complicated operation requiring re-termination of the umbilical. Other actions to reduce fatigue damage accumulation could be to pull the umbilical a short distance and re-terminate to reduce the fatigue loading at the most exposed area. This strategy is only possible if the most severe fatigue loading is consternated to a limited area.

F.8.2 Intervention

Intervention is defined within 8.2.

F.8.3 Repair

Ancillary components may be possible to repair or replaced such as buoyancy elements, bend stiffeners, anchors, anchor/tether clamps. Repairs/replacements shall be carried out in accordance with the standards specified in 5.3.

F.8.4 Replacement

Replacement is defined within 8.4.

F.8.5 Change of operational procedure

Reference is made to 8.5.

F.9 Documentation

The delivery from a life extension project shall be

- integrity documentation,
- plan for modifications (if any),
- plans for repairs and replacements (if any),

- input to plans for monitoring and inspection.

The potential for extension of service life beyond the extended service life should be provided.

F.10 Implementation

Conclusions derived from the life extension process shall be implemented in accordance with the requirements of Clause 10.

Annex G (Normative)

Subsea control systems – Specific requirements for service life extension

Foreword

This annex applies to the systems and sub-systems that are responsible for the control and monitoring of a subsea system.

Introduction

This annex is intended to give application specific guidance that shall be considered in addition to the requirements laid down in the main part of this NORSOK standard.

Annex content is labelled and numbered according to the main part contents page. The main part contents page can therefore be used to navigate the annexes.

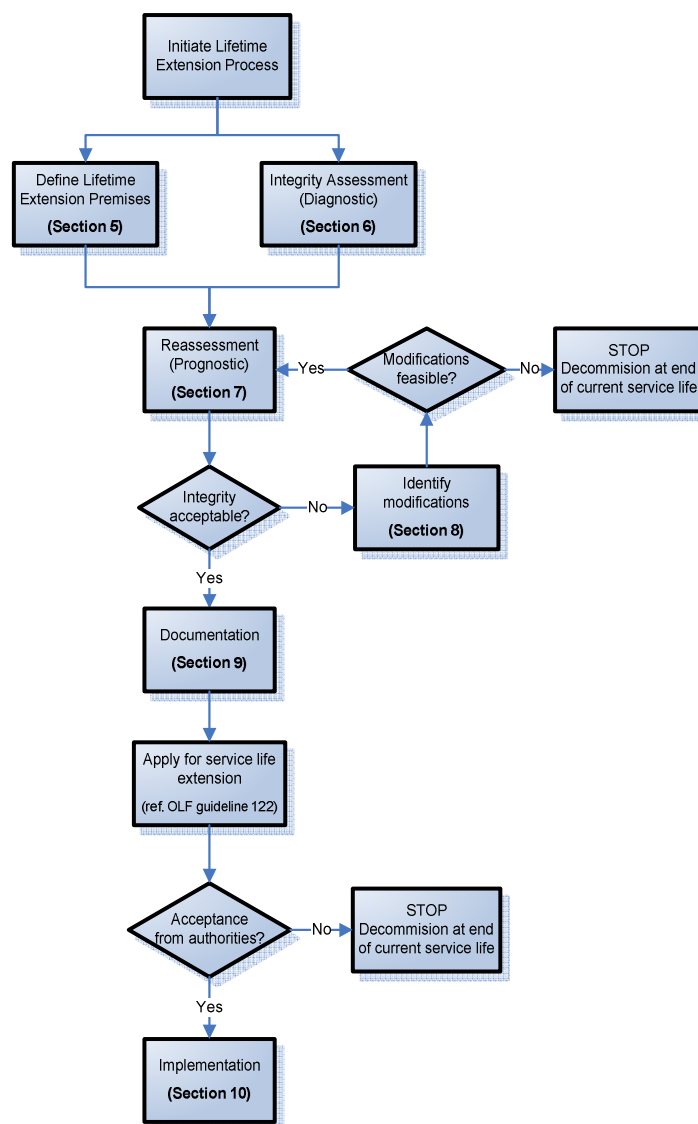


Figure G.1 - Life extension work process

NOTE Section references relates to main clauses of this NORSOK standard.

G.1 Scope

The scope of this annex is aligned to the requirements of ISO-13628-6.

The primary requirement of life extension assessment activities should be to ensure the continued safe containment of hydrocarbons and other environmentally harmful substances. This requirement may implicitly focus life extension activities only on equipment that is involved with the hydrocarbon containment and the technical safety of the installation. However, as the viability of the extending the life of an installation is governed by the continued production of hydrocarbons, the continued availability and reliability of the subsea control system should also be considered.

This annex covers all topside and subsea systems, sub-systems and components that collectively constitute the subsea control system.

For further equipment details, refer to G.5.6 and ISO-13628-6.

The scope of the life extension shall be defined such that battery limits are clearly identified. Any equipment to be removed from the system shall be clearly identified, as shall all new equipment that will be added. The scope should typically include subsea and topside elements and those systems or subsystems interfaced to the control system whose failure may result in a loss of containment or a loss in the availability of the subsea control system.

G.2 Normative and informative references

A list of references specific to all aspects of life extension is located within Clause 2. For discipline specific references with regards to system design, see 5.3.

G.3 Terms, definitions and abbreviations

For terms, definitions and abbreviations refer to Clause 3.

G.4 Assessment methodology

G.4.1 Objective

This subclause describes the methodology, requirements and recommendations for specific application to the subsea control system for life extension. The governing principles for the assessment are given in the main part of this NORSOK standard.

The subsea control system in the most part represents a low risk as when considering technical safety, the subsea control system mostly acts to prevent the escalation of a primary failure.

NOTE For example a catastrophic failure of a production jumper from a wellhead to a manifold would only escalate to a situation where there was an uncontrolled venting of a hydrocarbon resource if there was a simultaneous dangerous failure or previously undetected dangerous failure of the production master valve, the production wing valve, the production isolation valve and the downhole safety valves.

There are several exceptions to this, for example pressure protection systems and devices that act as a single mitigating device to the release of significant hydrocarbon resources, such as subsea surface controlled isolation valves and downhole safety valves.

As the decision to extend the life of an installation is based on the requirement that the installation continues to be commercially viable, then the availability of the subsea control system shall also be assessed. For marginal developments where the availability of the production facility is critical then this should be expressed in the life extension premise.

G.4.2 Integrity management system

Integrity management is defined and explained in 4.2. See also integrity assessment both in Clause 6, and in this annex.

G.4.3 Life extension process

As stated in the main part of this NORSOK standard, the purpose of the life extension process is to confirm acceptable system integrity to the end of the extended service life.

Mechanical system

When considering the mechanical and material aspects of the subsea control systems that are responsible for the hydrocarbon containment, for example the process interface (flange) for a pressure sensor, then the methodology common to all mechanical systems shall apply. Guidance for mechanical systems is not held specifically within this annex, reference should be made to this NORSOK standard as a whole.

Safety critical functional elements

All elements of the subsea control system that contribute to the functional safety of the system shall be identified. A system approach shall be used. When considering these elements, the whole system that supports the function shall be considered, i.e. not just the final element, but any component that enables that function and can fail in such away that it prevents the function from operating.

G.4.4 Degradation

The life extension process should consider degradation since installation.

The following types of systems, subsystems and components should be assessed:

- systems, subsystems and components whose failure would result in a release of hydrocarbons;
- systems, subsystems and components that are a single mitigating barrier to the release of a significant hydrocarbon reserve;
- systems, subsystems or components whose failure would result in a loss of the availability of the subsea control system. This includes subsea and topside elements and should also include any systems or subsystems interfaced to the control system whose non function would result in a loss of availability of the subsea control system.

As part of the assessment methodology a functional block diagram should be constructed and the integrity of each of the enabling components should be assessed based on an estimate of its degradation. The functional block diagram should clearly show the components required for the operation of each of the functions of the control system.

For sealing systems such as those for instrumentation, if both the primary seal and secondary seal are of similar mechanical properties, then they shall be considered to have the same state of degradation.

Subclause 4.4 gives an example of a degradation model that may assist in estimating whether the subsea control system components' integrity level has degraded below an acceptable level. This model holds true when considering the mechanical aspects of a subsea control system. However, for a number of electrical, electronic and electronic programmable components, which are for the most part solid state and not subject to wear, this degradation model is not representative. When assessing this type of component, a model should be agreed with the component supplier or a qualified technical body.

Graceful degradation

For situations where the end of the field life is uncertain and production is planned for only as long as the facilities remain viable. A graceful degradation of the subsea control system through the progressive failure of components shall be allowed, provided the risk to personnel and of hydrocarbon release does not exceed the installations risk acceptance criteria.

G.5 Life extension premises

G.5.1 Objective

This subclause gives requirements and recommendations on the specific application to the subsea control system.

The original system premises should be reviewed and assessed in order to identify whether they remain applicable for the life extension period. In certain cases, modifications to the premise may result in the subsea control system being replaced or substantially upgraded.

G.5.2 Authority regulations

Authority regulations shall be adhered to where required. For guidance, reference is made to 5.2.

G.5.3 Design standards

The primary standards for the subsea control system shall be ISO 13628-1 and ISO 13628-6.

For systems that were installed prior to ISO 13628-1 and ISO 13628-6 a gap analysis shall be performed to identify non-compliances that may have an effect on the technical safety and reliability/availability of the installation.

The governing standards for subsea systems with safety instrumented systems should be IEC 61508. For systems that were installed prior to IEC 61508 a gap analysis should be performed to identify non-compliances with IEC 61508.

ISO 13628-1, ISO 13628-6 and IEC 61508 shall be used in addition to shelf state authority requirements and contractual obligations.

Any gap analyses performed should also clearly record how identified gaps will be managed in order to ensure that the subsea control system has an equivalent level of technical safety, reliability and /or availability.

For any installation that has been modified or extended over time, a range of standards may apply depending on when the equipment was supplied. An audit should be performed to clearly identify the standards that were used when a piece of equipment was designed. The results of this audit will be used as an input to the regulations gap analysis plus be included in the interface register, see G.1.

G.5.4 Design premise

The original design premise shall be reviewed and if necessary updated to ensure that it is complete and relevant to the subsea installation.

The operator is responsible for ensuring that all premises relevant to the life extension are addressed.

Table 1 gives examples of parameters premised for design. This is not finite and reference may be made to ISO13628-6 for further information.

Table G.1 - Examples of parameters premised for design

Category	Subject
Operational parameters	Flow
	Temperature
	Pressure
	Reservoir characteristics
	Well fluid
External parameters	Water depth
	Step out
	No. of wells
Functional requirements	Valve response times
	Field start up and shutdown times
	Emergency shutdown requirements
	Communication bandwidth
Methodologies for response and capacity calculations	Power system analysis
	Hydraulic analysis
	RAMS analysis
	Quantitative risk analysis
	SIL studies

G.5.5 Threats to the subsea system

Mechanical systems

The threats to mechanical system components in the subsea control system are common to the mechanical components in the other elements that make up a subsea system. Details of these threats and guidance can be found throughout this NORSOK standard.

Threats related to the subsea control system may include

- blockage,
- breakdown of electrical insulation with loss of power and/or communication,
- damage to cables or connectors,
- electronic hardware failure,

- control and process valve failure,
- transmitter failure (pressure, flow, temperature),
- software errors and malfunction,
- mechanical connection leaks,
- well fluid compatibility,
- operational homogeneity,
- obsolescence (components, software, skills).

G.5.6 System overview

Equipment to be considered when undertaking a life extension study may include:

- topside components;
- instrumentation and monitoring systems;
- subsea processing systems;
- configuration and support systems:
 - IT infrastructure;
 - subsea control system software;
 - intervention equipment;
 - tools;
 - spares;
 - control fluids.
- electrical system;
- hydraulic system;
- connection systems.

This is not a finite list. For a defined scope of subsea equipment, see ISO-13628-6.

Interface register

If the subsea control system interfaces with a number of other systems, then an interface register shall be maintained.

The format and contents of the interface register should be agreed between the interested parties. The interface register should cover aspects such as, the functions flowing in both directions across the interface. These may include data, commands and power plus physical parameters such as fluids, heat etc.

A nominated party should be responsible for verifying that the life extension premises for the interfaced components are equivalent.

G.6 Integrity assessment

G.6.1 Integrity management system

The subsea system should have an IMS. The IMS is used to carry out data collection and condition assessment.

G.6.2 Data collection

Integrity management system

The integrity management system should be a source of information related to the current integrity of the subsea control system.

Inspections

Inspection of components can be the best measure of the current integrity of a subsea control system. Inspections allow for the direct assessment of wear and also the opportunity to identify tell tales for critical faults that can be an indication of the remaining life of the component.

Design, manufacturing and qualification records

Design, manufacturing and qualification records should give the original design premise for the equipment including usage and design life. Any records of testing, either qualification or manufacturing may give useful information, especially if it allows for an estimate of margin to failure of the equipment.

Operational and environmental records

The operational history of the equipment can be used in the assessment process. These records may give an indication of the normal operating region for the equipment along with details of occasions and durations when the equipment has been operated outside its normal operating region. For equipment subject to wear and fatigue only when in operation, (e.g. valves and motors /pumps), parameters such as hours run and number of operational cycles are important.

Environmental records, i.e. details of the conditions under which the equipment operates may be important when assessing the condition of certain types of equipment. For example, when assessing the condition of electrical and electronic components the ambient temperature will be one factor that dictates their remaining life.

RAM analyse

The RAM analyse performed previously on the subsea control system can provide insight in to the expected condition of the components. This can give valuable information in to any obsolescence management plans and availability assessments.

Risk studies

Risk studies provide useful input on many levels. The results of the original risk studies will provide data on how the original designers perceived that the subsea control system and its components would fail. This information can be used to design inspection and measurement plans along with data that can be used when predicting the current condition through estimation, modelling and simulation.

Operator input

Input from operations and maintenance staff may be considered, however care shall be taken as the results may not be quantifiable.

Reliability databases

When using either privately or publically available reliability databases, such as OREDA, care must be taken when interpreting data.

Ensure that the data was derived from components operating in a similar environment or that de-rating factors are properly applied. Database failure rates generally assume a constant rate over the lifetime of the component. This assumption is not true when considering components that may be at the end of their life. Therefore failure rates should be adjusted to reflect the actual characteristics of the component to which they apply.

G.6.3 Condition assessment

The following headings make reference to subsea control system elements which should be considered for condition assessment when undertaking a life extension study.

Inspection and measurement

Inspection and measurement activities correctly undertaken represent the most reliable form of condition assessment and can be capable of yielding data with the lowest uncertainty.

The measurement and inspection regime should be designed with input from the FMEA.

Where possible tell tales that represent the beginning of a critical failure identified during the FMEA should be included in the measurement and inspection regime. Tell tales are early indications of a failure developing, e.g. increasing temperature in an SEM, increase in current drawn to perform a function or the increase in hydraulic pressure required to perform a function. For some types of failure the development of the fault can be predicted and through measurement of the tell tale and information relating to the usage of the component, a time to failure can be predicted.

Operational review

Input from operations and maintenance staff may be considered for use in order to supplement a degradation model of the subsea control system that can be used to predict its current and future condition.

Estimation, modelling and simulation

Models used during the assessment process shall be validated. Gaps and assumptions shall be identified and the un-certainty associated with the models shall be quantified.

Failure rate models

Reliability models used in the assessment of safety critical functions shall be constructed using failure data that reflects the age of the components. Failure data, such as that contained in OREDA assumes a constant failure rate. The correct shape of the failure rate curve of the component is dependant on the component's attributes. For condition assessment it shall be assumed that the failure rate is not constant over time, but increasing under the influence of age related failure mechanism.

An FMEA shall be performed to identify age related failure mechanisms. These failure mechanisms shall be classified as either linear or non-linear. The effect of a linear failure mechanism will be represented in the failure rate from the component from the moment it is put in to use, whereas a non-linear failure mechanism will be represented only after some discrete time interval and where the change in failure rate does not have a linear relationship in the age of the component.

Testing

Testing is effectively re-qualification testing and involves designing a test or set of tests that will mimic the in service conditions and accelerate the aging process. Ideally the testing should be to the failure of the component. The sample size tested should be large enough such that a representative statistical model of the probability of failure of the components can be constructed.

Well fluid compatibility

As the reservoir matures, or as new hydrocarbon resources are routed through established facilities, careful consideration shall be paid to the compatibility of the equipment with the well fluid. A gap analysis shall be performed to identify variation in well fluid characteristics. Factors to be addressed should include, but not be limited to; increased wear due to an increase in sand, increased corrosion due to higher water content. Attention should be paid to whether a change in fluid characteristics may increase the risk of a valve not sealing correctly.

Operational homogeneity

The working methodology and operating instructions of the operator shall be reviewed to ensure that a common approach exists towards the safe operation of the system. A system that is constructed from a mixture of legacy and new components may require a different operating methodology from the operator and may increase the workload of the operator. In a stressful situation this may increase the risk of operator error leading to a hazardous event.

The working methodology and operating instructions of the operator should be reviewed to ensure that a common approach exists for safe operation of the system. In particular the procedures and command sequences associated with emergency or mitigating operations should be reviewed and modified where necessary to ensure that similar logical sequences are used.

Obsolescence assessment

An assessment shall be performed to establish the obsolescence status of system components. This assessment should consider the availability of spares, consumables, tools and skills.

The assessment should also cover subsea control system software. The control system software should include; operating systems, application code and all software tools (compilers, etc) and hardware supporting the subsea control system.

The assessment should consider the current state of the equipment and the equipment's state throughout the life extension period.

Availability and reliability assessment

An assessment of the availability and reliability of the subsea control system should be made. The availability assessment should take account of the increased failure rates of the system due to the age and extended downtimes that may result from spares depletion, increased lead times and obsolescence.

These assessments should be linked to the economic premise for extending the lifetime of the facilities.

Topside components

The assessment should include the topside systems, subsystems and components. An assessment should be made to confirm that the topside systems are suitable for use in the life extension period. This assessment should consider as a minimum the electrical and hydraulic supply and chemical injection requirements.

The assessment should consider the continuing need for equipment with a view to increasing or reducing the capacity as required.

The assessment should pay particular attention to the electrical safety of the topside equipment. Assessment of the hydraulic power unit should in addition consider the control fluids.

Activities relating to the topside should be coordinated with the wider topside life extension activities, this coordination should be through the interface register.

Instrumentation and monitoring systems

Instrumentation and monitoring systems should be assessed to ensure that they will be able to perform according to their specification throughout the life time extension process. This assessment should not be restricted to only the repeatability and accuracy of the instrumentation and monitoring system, but should also as a minimum include the process and electrical interfaces, the mechanical attributes and the sealing systems.

The assessment should also consider the future requirements that may arise from either the process or from the life extension activities to ensure that the instrumentation and monitoring systems will be acceptable throughout the period of the life extension.

For subsea control systems where complex monitoring or smart metering is used any software and external interfaces associated with the onsite or offsite maintenance should be included in the assessment process.

The assessment of instrumentation and monitoring systems required as part of the life extension process shall be controlled through the interface register.

Subsea processing systems

The control systems associated with subsea processing units should be included in the life assessment process. The assessment should include both topside and subsea elements of the subsea processing unit.

The assessment process should be co-ordinated with any topside life extension processes to ensure that there is parity between the life extension activities. This co-ordination should be controlled by the interface register.

Safety critical elements (SCE)

All safety critical elements shall be identified and assessed. This assessment shall include any associated hardware, software, tools, maintenance procedures, risk assessments, design premise and obsolescence management plan.

The requirement for critical safety systems shall be assessed based on the current situation. This assessment shall include the current operating conditions and account for the current degraded state of equipment.

The reliability and availability of critical safety systems shall be assessed; the assessment shall include component failure rates modified to account for their current age and condition.

Instrumented safety systems

For each safety instrumented function the current required level of risk reduction shall be assessed. This assessment should account for the current process conditions and recorded frequency of initiating events.

The level of risk reduction provided by each safety instrumented function shall be assessed. The assessment of the safety instrumented function should include consideration of the age the components, their useful life, the actual maintenance and test procedures and frequency of testing.

If a safety instrumented function no longer provides the required level of protection then remedial actions shall be taken, such as increased testing frequency, upgrade or replacement.

The useful life for all components in a safety instrumented function shall be established and recorded. If the useful life of a component in a safety instrumented function cannot be established then the component shall be assumed to be outside of its useful life.

The useful life of a component is defined as the operational time interval where the failure rate of a device is relatively constant.

Redundancy

The requirement for redundancy should be assessed, accounting for the current condition of the equipment, the operating procedures, business objectives and the required system availability. Additionally, the current level of redundancy available in the system should be assessed.

Electrical system analysis

The electrical system analysis shall be assessed.

Hydraulic system analysis

The hydraulic response shall be assessed. The assessment shall be carried out according to the requirements of ISO 13628-6. The assessment shall take into account the current condition of the subsea control system.

Connection systems

The condition of the connection system should be assessed and included in the obsolescence assessment. The assessment should include both the mechanical integrity of the connector and its functional integrity.

To establish an estimate of the likely wear, stress load and fatigue on the connection system an ROV inspection of the connection systems should be undertaken.

Configuration and support systems

Although the systems, components and devices included in this section are not directly responsible for the containment of hydrocarbons, safe and reliable operation of the subsea control system depends on their continued operation. Therefore, the below listed aspects shall be defined as integral parts of the subsea control system.

- IT infrastructure

The IT infrastructure should include network enabling devices (switches, routers, etc), protocol converters, modems, multiplexers, associated software tools required to support hardware devices and any such devices and tools required for transport of information between subsea control systems hardware for the purpose of control and monitoring.

- Subsea control system software

Subsea control system software should include both application specific software and generic software, such as operating systems, that are required for the operation of the subsea control system and its components.

An audit should be performed to systematically catalogue all software required by the subsea control system and its components. The software catalogue should contain enough information to uniquely identify the software and should as a minimum include, name, version number, build number if appropriate, media, storage location, owner, supplier, availability and a functional description of the software.

- Intervention equipment

The obsolescence status and availability of intervention equipment should be assessed and contingencies made so that intervention equipment is available for use throughout the life extension period.

- Tools

The obsolescence of all tools necessary for the safe maintenance and modification of the subsea control system should be assessed. The definition of tools includes both hardware and software tools required to maintain the subsea control system. Contingencies should be made so that these tools are available throughout the life extension period.

- Spares

Spare parts that will be part of the system into the life extension period should also be evaluated in the life extension process. Their condition and storage facilities will be evaluated and the consequence of

continued storage assessed. If the system is to be modified (system parameters, upgrades) then the fitness for purpose of the spare parts shall be re-evaluated.

- Control fluids

The control fluids shall be considered part of the subsea control system and as such, should be included and assessed as part of the life extension process.

G.6.4 Remedial action

If the condition of the subsea control system cannot be fully quantified or if the subsea control system or any of its subsystems or components have been maintained or operated outside their intended design parameters then these points shall be identified as gaps and shall be given as inputs to the re-assessment process. Recommendations shall be provided on how to close the gap.

G.7 Reassessment

G.7.1 Objectives and methods

As described in the main part of this NORSOK standard and the other annexes, the objective of re-assessment is to establish whether the integrity of the system will be adequate throughout the life extension period. However for the control system, discussed in G.1, the availability and reliability of the system should be considered as part of the acceptance criteria.

Acceptance is achieved by analysing the results obtained during the assessment process against the life extension premise.

This can be performed either through a design based re-assessment, where the current integrity of the system is unknown, or a condition based re-assessment where the current condition of the system has been established.

The output from the re-assessment process will either be a set of documentation confirming that the system integrity, availability and reliability will be adequate through the life extension period or that it will not.

If the re-assessment indicates that the system will not have the required integrity then further options are available as follows:

- the assessment methodology can be refined to try to identify and improve any conservative results;
- the maintenance regime and the life extension premise can be reviewed to ensure that the results are not over conservative;
- modifications or repairs can be made to the system.

G.7.2 Process overview

The reassessment process for systems, sub-systems and components shall be concurrent with the process overview presented in 7.2.

G.7.3 Acceptance level

Subsea system acceptance level criteria are defined in 7.3.

G.7.4 Design based reassessment

Guidance for design based re-assessment is contained within 7.4 and G.7.6.

G.7.5 Condition based reassessment

Guidance for condition based re-assessment is contained within 7.5 and G.7.6.

G.7.6 Particular requirements

Availability

Availability targets should be defined for the subsea control system and it should be demonstrated that these targets can be met. The calculation shall properly account for the current age and condition of the equipment.

Obsolescence

It should be demonstrated that the obsolescence status of the subsea control system has been assessed. This assessment should include all tools (software and hardware), fluids, consumables, documentation and skills required to operate, maintain, modify and decommission the system.

An obsolescence management plan should be implemented to manage the critical components such that it can be demonstrated that the obsolescence of critical components can be managed over the extended life period without impacting the availability targets. Critical components may include

- electrical, electronic and electronic programmable components,
- software,
- connection systems,
- bespoke mechanical devices.

Redundancy

The level of redundancy should be equivalent to the level required by ISO 13628-6. For older installations this requirement may not be achievable, therefore a lower level of redundancy may be accepted provided it can be demonstrated that the level of redundancy throughout the life extension period is compliant with the operating procedures, business objectives, the required system availability and the necessary integrity and safety levels.

NOTE This requirement allows a system to be 'run into the ground' as redundant systems fail provided the integrity of the system remains acceptable, i.e. the risk of a hydrocarbon release or injury, does not exceed the installation risk acceptance criteria.

Re-assessment of safety critical elements (SCE)

The re-assessment shall identify gaps in the requirements for the SCE, in some cases this may require the addition of SCE to mitigate hazards not originally identified, but also to ensure compliance to the applicable regulations and design standards.

The risk analyses shall be reviewed to re-assess the hazards and the risk reduction requirements. Such analyses shall properly account for the current age and condition of the equipment.

When considering the reliability and availability of safety functions the calculation shall properly account for the current age and condition of the equipment. Assumptions that the component failure rates are constant until the end of life to the component shall not be accepted without adequate documentation, for example, qualification procedures and test records. In the absence of such proof a representative distribution of the failure rate shall be used.

Where it can be demonstrated that a SCE is no longer required, to avoid un-necessary production losses, the SCE shall either be removed, locked off such that they are able to disrupt the production process or the SCE shall continue to be maintained in accordance to the SCE maintenance procedures.

Instrumented safety systems

All instrumented safety systems shall be compliant to IEC 61508.

The required risk reduction for each safety instrumented function over the life extension period shall be reassessed. The reassessment shall consider the current operating conditions and the expected condition of the process plant at the end of the life extension period. The reassessment shall make use of recorded operating data when calculating the frequency of initiating events. It shall be demonstrated that the safety instrumented function shall provide the required level of risk reduction over the life extension period.

An action plan should be established for safety instrumented functions that contain components that will reach the end of their useful life within the life extension period.

Maintenance and test procedures

The maintenance and functional test intervals shall be re-assessed to ensure that the reliability and availability of the SCE is maintained. The effects of increased failure rates due to aging will be included in this assessment. The goal shall be to maintain the probability of an unsafe, undetected failure at the same level as a new SCE.

Hydraulic analysis

The acceptance criteria shall be as defined by ISO 13628-6.

Electrical analysis

The acceptance criteria shall be as defined by ISO 13628-6.

Connection systems

The connection system should be re-assessed to ensure that their use conforms to the original design premise and an estimate should be made for their expected remaining life. Where the expected remaining life of a connector is less than the proposed life extension period then its replacement should be planned for and any system downtime resulting from an intervention should be included in the availability re-assessment.

The connector systems should be included in the obsolescence management system.

Control fluids

A compatible control fluid shall be available throughout the life extension period.

Instrumentation and monitoring systems

The instrumentation and monitoring system should be re-assessed to confirm that the accuracy and repeatability of the instrumentation will be sufficient throughout the life extension period. The definition of what is sufficient should be agreed based upon a level of accuracy and repeatability that will not represent a hazard to production, integrity or the safety of the system. This may be less than the original design requirements where it can be demonstrated that the level will not represent a hazard to production, integrity or the safety of the system.

Where instrumentation, or monitoring systems is required as part of the life extension process, then these requirements shall be the acceptance criteria.

The re-assessment of instrumentation and monitoring systems required as part of the life extension process shall be controlled through the interface register.

G.8 Modifications

G.8.1 Mitigation

Mitigation is defined within 8.1.

G.8.2 Intervention

Intervention is defined within 8.2.

G.8.3 Repair

Reference is made to 8.3.

G.8.4 Replacement and/or addition of new equipment or facilities

Where reasonably practical, replacement equipment shall not be of obsolete design. Where obsolete equipment is used then an obsolescence management plan shall be developed to support the equipment through the life extension period.

New equipment required as a result of the life extension project, for example for the tie-in of new hydrocarbon reserves, shall not be of obsolete design.

G.8.5 Change of operational procedure

Reference is made to 8.5.

G.9 Documentation

Document requirements are detailed within Clause 9.

G.10 Implementation

Conclusions derived from the life extension process shall be implemented in accordance with the requirements of Clause 10.

Annex H (Normative)

Tether and buoyancy – Specific requirements for service life extension

Foreword

The subsea components covered by this annex are used to support the subsea system. Subsea buoyancy systems are used to give the subsea system the correct configuration and are in this way maintaining the integrity of the system. Due to this, a thorough evaluation is needed to ensure a satisfactory level of confidence for service life extension.

Introduction

This annex contains the specifics for the equipment as listed under H.1.

All annexes are based on the main part of this NORSOK standard, where the main part defines general requirements and introduces the overall working process. Annex content is labelled and numbered according to the main part contents page. The main part contents page can therefore be used to navigate the annexes.

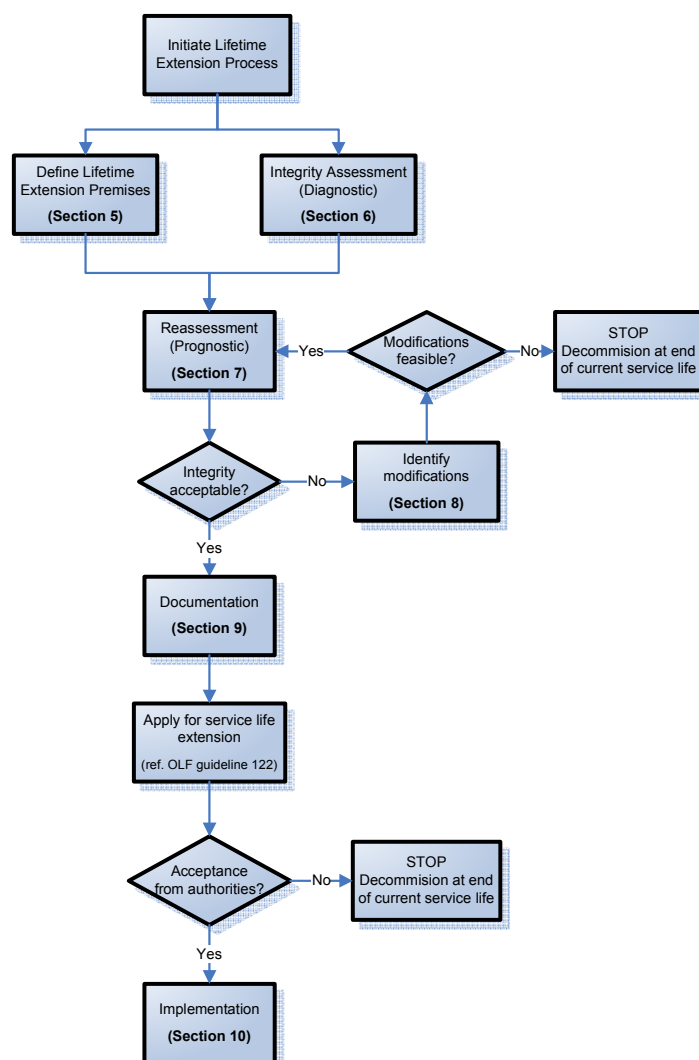


Figure H.1 - Life extension work process

NOTE Section references relates to main clauses of this NORSOK standard.

H.1 Scope

This annex includes

- mid water arch (MWA) system — which include (not limited to):
 - buoyancy tank,
 - tether system between buoyancy tank and anchor,
 - anchor.
- buoyancy system for offloading — which include (not limited to):
 - buoyancy tank,
 - clump weight,
 - mooring line and connection elements to clump weight, buoyancy element, vessel,
 - anchor.
- buoyancy elements on riser — which include (not limited to):
 - buoyancy elements (foam),
 - riser clamps,
 - tethers,
 - anchor for tether.
- riser towers;
 - buoyancy tanks;
 - structural elements;
 - ballast system.

For simplicity, the term 'subsea buoyancy system' is used below when describing the items listed under H.1.

H.2 Normative and informative references

A list of references specific to all aspects of life extension is located within Clause 2. For discipline specific references with regards to system design, see 5.3.

H.3 Terms, definitions and abbreviations

For terms, definitions and abbreviations refer to Clause 3.

H.4 Assessment methodology

H.4.1 Objective

This clause describes the methodology to be applied to the life extension process for the items listed under H.1.

For load bearing steel structures, moorings and foundations, reference is also given to NORSOK N-006 for specific assessment methodologies.

H.4.2 Integrity management system

The operators follow the systems through an IMS. The objective of the IMS is to ensure that the technical integrity of the systems is maintained at an acceptable level.

The activities and assessments carried out as a part of the IMS is not part of the life extension process. The integrity management process is carried out within the constraints of the original design and is not necessarily sufficient to document and justify a life extension. The data obtained can however contribute to the basis for the life extension reassessment.

For riser towers the IMS is consisting of continuous measurement of riser tension at seabed and in addition, periodical inspection of the riser tower. Records should show that the vessel is operating within given conditions. The tension measurement is a good measure of the condition of the riser tower. Indication of e.g. leakage or excessive marine growth will show by change in tension.

Subsea buoyancy systems will be inspected by ROV on a regular basis. The ROV inspection will typically look for damages, changes in configuration, wear of mechanical components and consumption of anodes.

MWA systems are normally designed for limited or no inspection during design lifetime. This is compensated by using high factors of safety in the design phase.

For offloading systems important data from operation is: deployment time (duration tanker is hooked up), type of positioning system the tanker is equipped with, records of repair, inspections etc. Part of the system may be designed for limited or no inspection during its lifetime.

H.4.3 Life extension process

The life extension process is triggered by the decision that the operation of the system will be continued beyond the original service life. The purpose of the life extension is to document acceptable system integrity to the end of the extended service life.

H.4.4 Degradation

The life extension process of the subsea buoyancy systems must take into account the degradation that has taken place since the installation of the system. Steel degradation effects are corrosion and fatigue.

Other materials than steel in the system are foam for buoyancy elements, polyester for fibre ropes may also experience degradation. Assessments shall be carried out to ensure that the buoyancy elements have sufficient buoyancy through out its lifetime and that the fibre ropes have sufficient strength through out the extended lifetime.

See H.7 for information on degradation mechanisms.

H.5 Life extension premises

H.5.1 Objective

The original design premises shall be reviewed to assess whether they are still applicable for the extended life period.

H.5.2 Authority regulations

Authority regulations shall be adhered to where required. For guidance, see 5.2.

H.5.3 Design standards

The subsea buoyancy systems are designed to applicable standards that were selected at the time of design. The same design standards may be used throughout operation of the system, also when changes to this system are introduced. This includes life extension.

Investigation is required to whether there are any changes/revisions in the rules, regulations or design codes applied. Particular attention should be made to the following standard and codes:

- API-RP-2A/API-RP-2SK;
- DNV-OS-C101/DNV-OS-C201;
- NORSOK N-001 (Integrity of offshore structures (Edition 5, August 2008));
- NORSOK N-004 (Design of steel structures (Rev. 2, October 2004));
- NORSOK N-006 (Life extension of load bearing structure).

H.5.4 Design premise

The design premise is the basis for the original design, and describes the operational and design limits for the system at time. In the context of this NORSOK standard, the primary premise is the design life. Any other changes in design premises shall also be included in the assessment.

Table H.1 gives examples of parameters premised for design. The table is not intended to be complete.

Table H.1 - Examples of parameters premised for design

Category	Subject	Comment
Operational Parameters	Riser tension	(applicable for riser tower, riser clamps)
	Weight of riser	
	Deployment time, type of vessel and vessel positioning system (passive mooring, thrusters), size of vessel etc.	(applicable for offloading systems)

Category	Subject	Comment
External parameters	Riser content and temperature of content	(applicable for buoyancy elements (foam) and riser clamps)
	Fisheries/Trawling /other offshore activities	(applicable for riser towers)
	Metoccean data	
	Earthquake	
	Geotechnical	It must be verified if the geo settlements used in the initial design phase still are relevant, or if more accurate data are available.
	Water temperature	
Methodologies for response and capacity calculations	Design/operational load capacity	It must be verified if the external loads used in the initial design phase still are relevant, or if more accurate data are available
	Retrieval loads	It must be verified that the design conditions used in the initial phase still are relevant or if the retrieval load case is changed. (only applicable for certain type of anchors)

When doing a life extension specifically for a MWA system the following needs to be established:

The premises for extended operation including

- a) original riser tension and comparison to the riser tension for the extended lifetime,
- b) original design temperature and comparison to the temperature for the extended life time,
- c) original external pressure on buoyancy tank and comparison to the external pressure for the extended lifetime,
- d) any changes in riser configuration,
- e) dynamic loads during operation, i.e. fatigue loads.

When doing a life extension specifically for riser buoyancy elements (foam), the following needs to be established:

The premises for extended operation including

- a) original riser tension and comparison to the riser tension for the extended lifetime,
- b) currently location of buoyancy elements above seabed (external pressure) and comparison to the design location above seabed (changes in location can be an index for the condition of the foam element, riser clamp integrity etc),
- c) riser content and temperature.

When doing a life extension specifically for offloading system, the following needs to be established:

The premises for extended operation including

- a) deployment time and number of deployments (connections and disconnections of tankers) of the system compared with the deployment time it was designed for and comparison to the expected deployment time in the extended lifetime,
- b) type of vessel being moored to system and for which duration,
- c) location of buoyancy tank shall be within initial design limitation (changes in location can be an index for amount of marine growth, leakage of buoyancy tanks etc.) Changes in operational depth shall be included in extended lifetime consideration.

When doing a life extension specifically for riser towers, the following needs to be established:

The premises for extended operation including

- a) original riser tension and comparison to the riser tension for the extended lifetime,
- b) operation history of ballast system,
- c) original fluid weight and comparison with future fluid weight,
- d) dynamic loads during operation, ie. fatigue loads.

H.5.5 Threats to the subsea system

The subsea buoyancy system etc. shall be designed with an acceptable safety to failure. Subsea buoyancy systems are exposed to external as well as internal threats with different characteristics as follows:

- condition based: e.g. change in operational parameters;
- time-based: e.g. ineffective corrosion protection or corrosion control, fatigue ageing of foam causing loss of buoyancy, loss of clamp pretension, wear of e.g. bearings;
- third party damage; falling objects, trawling.

The combined effect of threats shall also be considered.

Important/probable threat to riser tower is falling objects from offshore activity.

H.5.6 System overview

The subsea buoyancy system for which a life extension process is carried out shall be described in such detail that battery limits are clearly defined. Note in particular the following important items that are considered to be part of scope:

- riser clamps (interface between riser and MWA);
- riser clamps (interface between riser and buoyancy elements);
- tether including connection element between tether and anchor and buoyancy element;
- vertical and horizontal anchor;
- connection element between riser tower and riser.

H.6 Integrity assessment

H.6.1 Integrity management system

The subsea buoyancy system should have an IMS. The IMS is used to carry out data collection and condition assessment.

H.6.2 Data collection

For the systems relevant data can be

- tension measurement of riser during operation,
- integrity inspection data (i.e. search of leakages),
- anode inspections/measure current,
- coating inspection,
- corrosion inspection (note particularly bolts, nuts and connections in general),
- visual inspection of systems to check that
 - tanks are intact,
 - riser are in place,
 - riser clamps are mounted on risers (no slipping),
 - no damages to ropes and coating,
 - verify free articulation of swivels and other rotating elements (to avoid OPB).
- marine growth inspection,
- measure location of buoyancy tanks below sea level,
- check if location of vertical and horizontal anchors is as expected. If not this will change the design load situation,
- inspect if any cracks on critical areas (padeyes, connection points).

H.6.3 Condition assessment

The requirements to the current condition are given by the original design documentation and revisions documented in the IMS. Examples are applicable design standards and required buoyancy.

The collected data should be reviewed in order to map how the system has been operated and maintained and the current physical condition should be identified. This will form the basis for the life extension reassessment.

H.6.4 Remedial actions

If the condition of the system can not be quantified or the system has been operated or maintained outside the intended use, the gaps in information shall be given as input for reassessment. Recommendations to the assessment activity about how to close these gaps shall be provided.

Examples of this can be higher external loads (riser tension) on the subsea buoyancy system than catered for in the design process.

H.7 Reassessment

H.7.1 Objective

The reassessment is the activities related to analysis of the generated information including

- inspection data,
- monitoring data,
- life extension premises.

By this the integrity of the system through the full extended lifetime can be established.

It is important to note that the actual integrity level of the subsea buoyancy system etc. can never be fully known as the gathered data have uncertainties and inaccuracies.

There are two potential situations at the end of the reassessment:

- a) the assessed integrity level is equal or exceeds the acceptance level. The reassessment is complete and the life extension project proceeds to documentation;
- b) the assessed integrity level does not meet the acceptance level. In order to increase assessed integrity level several options are available:
 - 1) **improved calculation method** –refined calculations to get a less conservative result (FEA), use actual fatigue load data for the past operational life (Possible to reassess the fatigue calculations if cracks are more/less then expected);
 - 2) **improved inspection data** - an example can be more thorough ROV inspection e.g. related to anodes in order to determine the consumption and condition, to check for fatigue cracks in critical areas, measure corrosion on tethers etc.;
 - 3) **improved monitoring data** – e.g. improved tension monitoring.

H.7.2 Process overview

The reassessment process for systems, sub-systems and components shall be concurrent with the process overview presented in 7.2.

H.7.3 Acceptance level

Subsea system acceptance level criteria are defined in 7.3.

H.7.4 Design based reassessment

Design based reassessment makes use of industry best practice. No information about current condition is available, which means that there is no updated baseline for the development of the degradation mechanism into further operation. The integrity level shall be assessed through the timeline from installation until the end of the life extension. An example can be a new and improved method for calculation of anode consumption.

If there have been any changes in design condition from the initial design condition to the one for the life extension, this shall be included in the reassessment.

H.7.5 Condition based reassessment

Condition based reassessment makes use of operational experience data. The data provides condition knowledge of the system, and should be integrated in the reassessment models.

For subsea buoyancy system the following specific areas should be examined in order to determine the degradation status and performing condition based assessment.

External corrosion

Buoyancy tanks and tether chains are normally manufactured from carbon steel and can be protected by anodes throughout lifetime or designed with corrosion allowance. If designed by use of corrosion protection system, inspections will confirm if coating and anodes are intact. If designed by use of corrosion allowance inspection shall confirm that corrosion allowance is within the maximum limit. If amount of corrosion is less than expected this result may be a basis for a less conservative corrosion assessment for the extended life.

Fatigue

Fatigue calculations may be relevant for subsea buoyancy systems. The components subject to life extension shall meet the same code requirements as when initially designed, with the exception that load/cycle data may be different.

If possible, recorded data, as start-stop of operation, should form the basis for the fatigue assessment. Other issues to examine are vortex shedding (very relevant for riser towers) and slug induced vibrations.

Relevant design codes are e.g. DNV-RP-C203.

Fatigue is not so much a problem when designing buoyancy tanks as the dominating load is the external pressure, which is not varying significant during normal operation. Critical areas for fatigue cracking are padeyes and connections between tank and tethers, tethers and anchor, buoyancy tanks and mooring line/hose, riser tower and riser etc.

If the system is designed by use of bearings (e.g. in connections between tether chains, buoyancy elements and anchors) the correct function of the bearings shall be confirmed. In case of defect bearings, out of plane bending may give increased fatigue loads, which need to be taken into considerations when carrying out fatigue calculations.

Actual corrosion need to be taken into consideration when carrying out fatigue calculations.

Wear

Amount of wear on bearings shall be calculated as part of the reassessment. Nominal total wear in the extended lifetime shall not exceed the thickness of the bearing material.

For offloading system wear can be a likely reason to failure as the equipment is being handled (deployed, employed) several times a year.

How the fibre ropes are operated is vital for the degree of wear on the rope. Visual inspection shall prove that coating on fibre rope is still 100 % intact. If the rope has been in contact with the seabed it should be checked for ingress of sand.

H.8 Modifications

H.8.1 Mitigation

Mitigation is defined within 8.1.

H.8.2 Intervention

Intervention is an activity done to maintain the integrity of a system by a work over of a system. Intervention could be necessary to bring the configuration back to the original configuration and depth of the systems. This could be removal of marine growth or adjustment of ballast in a riser tower.

H.8.3 Repair

Repair solutions may be assessed through use of available recommended procedures. Components to be replaced shall be designed according to chosen design standards and premises applicable for the component.

Will be required if the reassessment result in components not having sufficient strength and could be improved.

Repair could be installation of new anodes, replacement of connection element etc.

H.8.4 Replacement

A modification is categorised as a replacement when e.g. a offloading buoy with tethers, Mid water arch or a large section of such are replaced. When designing a replacement the operator shall use the latest available design standard for the new part of the system.

H.8.5 Change of operational procedures

Reference is made to 8.5.

H.9 Documentation

Document requirements are detailed within Clause 9.

H.10 Implementation

The life extension project may conclude with requirements that shall be met by the organisation responsible for operation of the subsea system. This means that the IMS for the subsea system must be updated to reflect the life extension. This could be e.g. periodic survey to measure cathodic protection, verifying free articulation of bearings, controlling amount of marine growth etc. For offloading systems the implement could also include e.g Improvement of positioning systems or improved operational procedure with regard to handling of the mooring line.

Annex I (Informative)

Illustration of re-qualification schemes for life extension

The basic principle of life extension, integrity assessment and design life is illustrated through some schematic graphs. The intention is to put the definitions in this NORSOK standard into a context, and better explain their relationship.

The graphs are all in the same coordinate system; time along the horizontal axis, and the integrity level along the vertical axis. The timeline should start from the time of installation of the system. The integrity level is closely related to the risk in the system, i.e. it expresses the cumulative integrity of the system when taking into account all relevant failure modes and the condition of all components. The acceptance level is the minimum acceptable integrity level allowed by the authorities/design code. The acceptance level can be expressed as a minimum integrity level or maximum risk allowed.

The degradation model can be considered the mathematical “function” that exists in the coordinate system “time vs. integrity level”. This “function” governs the evolution (normally a decrease) of the integrity level over time. The degradation model can be changed, if this is substantiated by industry practice or new knowledge. A condition assessment can be carried out during operation of the system, and this may appear as a sudden change (a jump or a drop) in the integrity level.

In the various scenarios included below, the acceptance level does not change. It should be noted that implementation of a new design code, or new requirements from the authorities, can lead to changes in the integrity acceptance level.

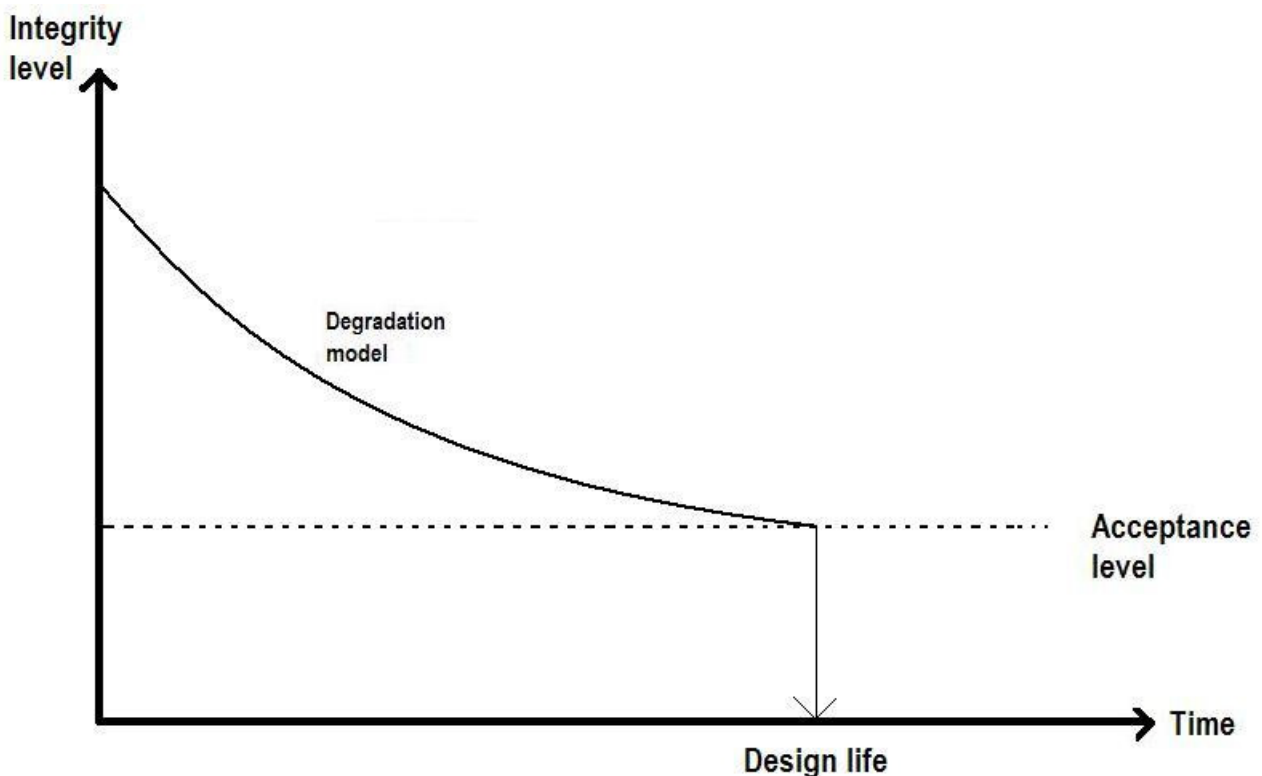


Figure I.1 - The design life is limited by the degradation model

A base case is shown in Figure I.1, where the design life is limited by the degradation model. This means that starting from the as-installed condition (at time zero), the degradation model chosen for the system does not allow a longer design life.

A different case is illustrated in Figure I.2, where another degradation model is used. From the as-installed condition the integrity level of the system only slowly decreases, and the design life is not limited by the system integrity. The design life of a system is often linked to the design life of the entire field development, which means that the design life of neighbouring systems can be limiting. In Figure I.2 a life extension is not

difficult to carry out, since the original documentation should be sufficient to show adequate integrity during the extended life. Still, it is advisable to carry out a condition assessment.

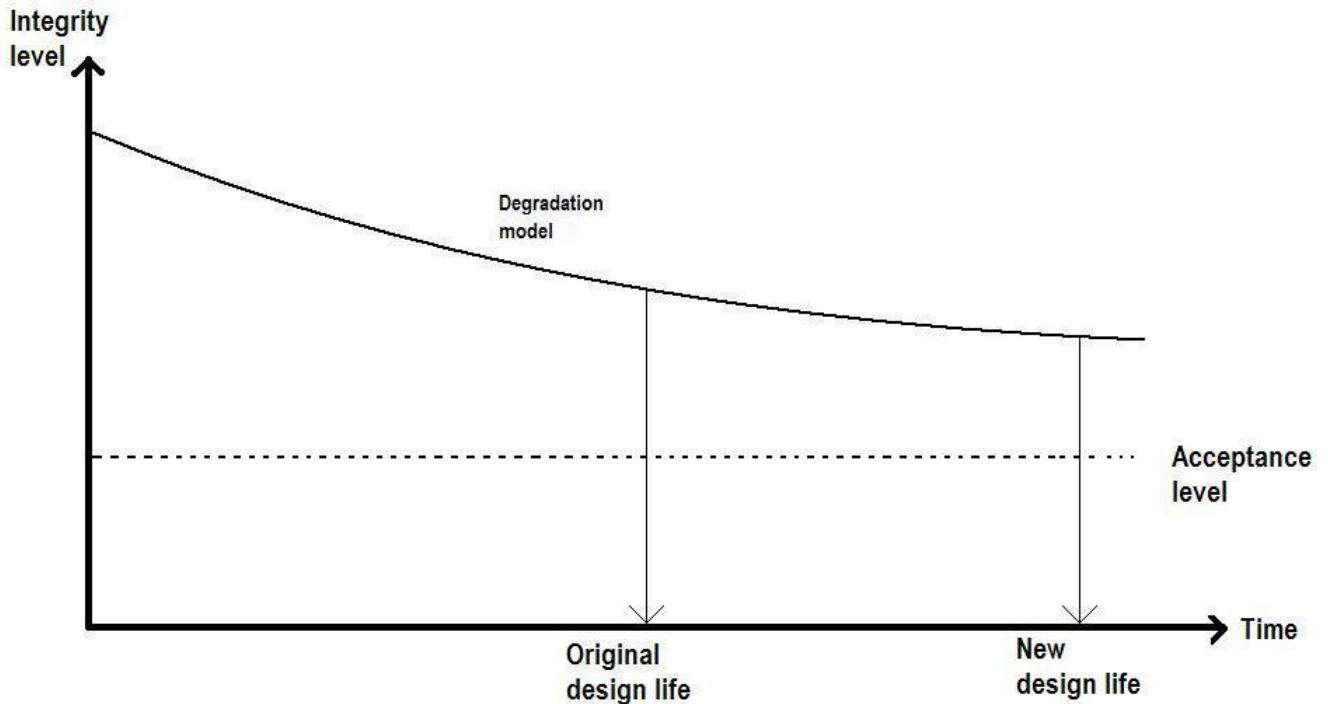


Figure I.2 - The degradation model does not limit the design life

Please note that both in Figure I.1 and Figure I.2 the integrity life of the system has not been addressed. The integrity life exceeds both the design life and the extended life of the system. For Figure I.1 the degradation model limits the design life, but this does not necessarily mean that the system is close to failure at that time – it only means that the integrity is not be documented further. Possibly a better (i.e. less conservative) degradation model would allow a longer design life.

A life extension project is shown schematically in Figure I.3. The degradation model, starting from the as-installed condition/integrity level, gave a design life during the original design process. However, this design life is not sufficient, and a life extension project is carried out. The same degradation model for the system is used both for the original design and for the life extension, but an integrity assessment (current condition) is carried out. With this assessment it is documented that the integrity level is actually higher than anticipated with the degradation model. In addition, knowing the current condition of the system, it is possible to “recalculate” (i.e. make a prognosis) the remaining life. As a conclusion it is documented that the system can be safely operated longer than originally planned.

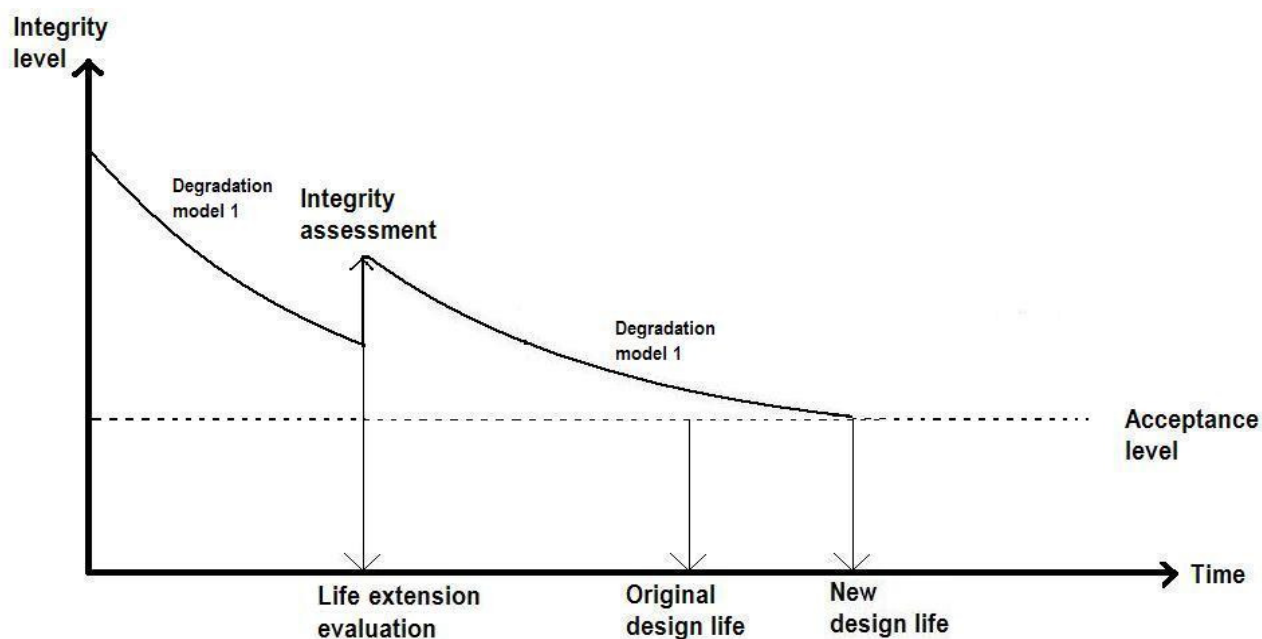


Figure I.3 - A life extension with integrity assessment

Note that the increase in integrity level in Figure I.3 can also be due to a modification or through e.g. repair of the system.

It is possible that an integrity assessment will result in a drop in the documented integrity level of the system, as illustrated in Figure I.4. This will typically be the case if the operational parameters (loads, temperature, pressure, chemical environment) are outside of the operation envelope from the design process. It is also possible that an incorrect degradation model was used, for instance if a critical failure mode was overlooked. In the case of Figure I.4 the system can not be operated for the full original design life without initiating modifications.

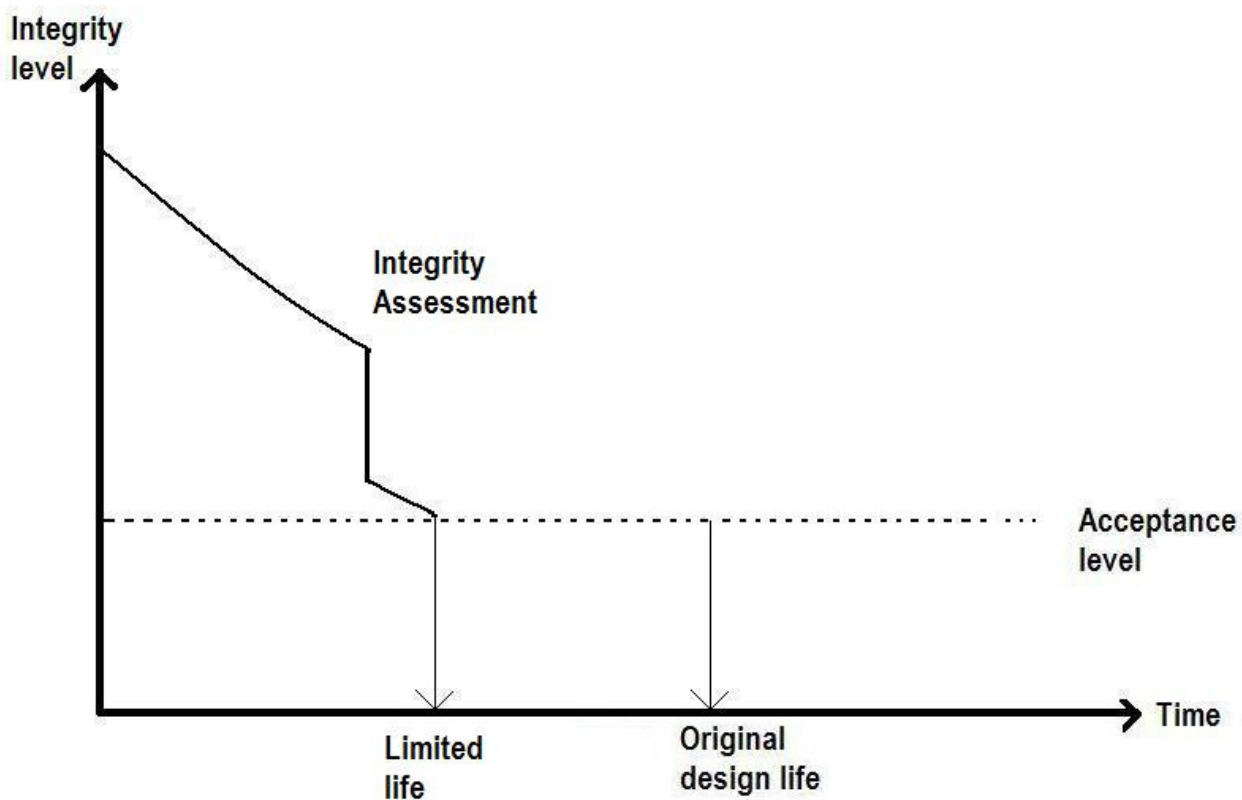


Figure I.4 - A drop in integrity level

A new degradation model can also be chosen, as illustrated in Figure I.5. The new degradation model can be based on new industry practice or updated research data. It is also possible that new operating conditions lead to a different degradation model. The operating conditions can be changes in temperature or pressure, or a new composition of transported fluids. It is also possible that the system has been moved to a different field, where the design premises can be different.

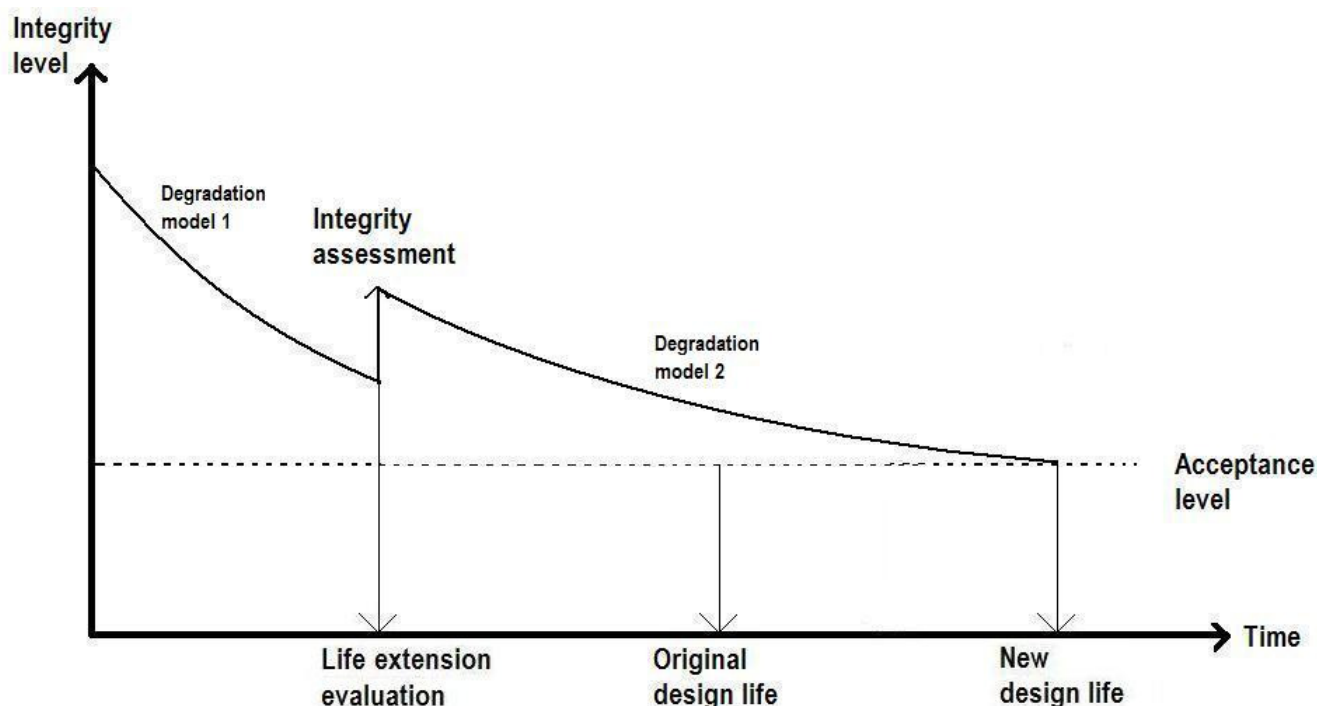


Figure I.5 - Life time extension with a new degradation model

Integrity assessment, based on qualified inspection intervals, is not only carried out in connection with life extension. It is possible that the degradation model may be quite conservative, and it is not possible to document acceptable integrity for the system for the required design life. One solution, illustrated in Figure I.6, is to carry out regular integrity assessments, and document through inspection and monitoring a higher integrity level than predicted with the degradation model. This means that it will require regular qualified inspections and integrity assessments, which must then be included in an appropriate integrity management system.

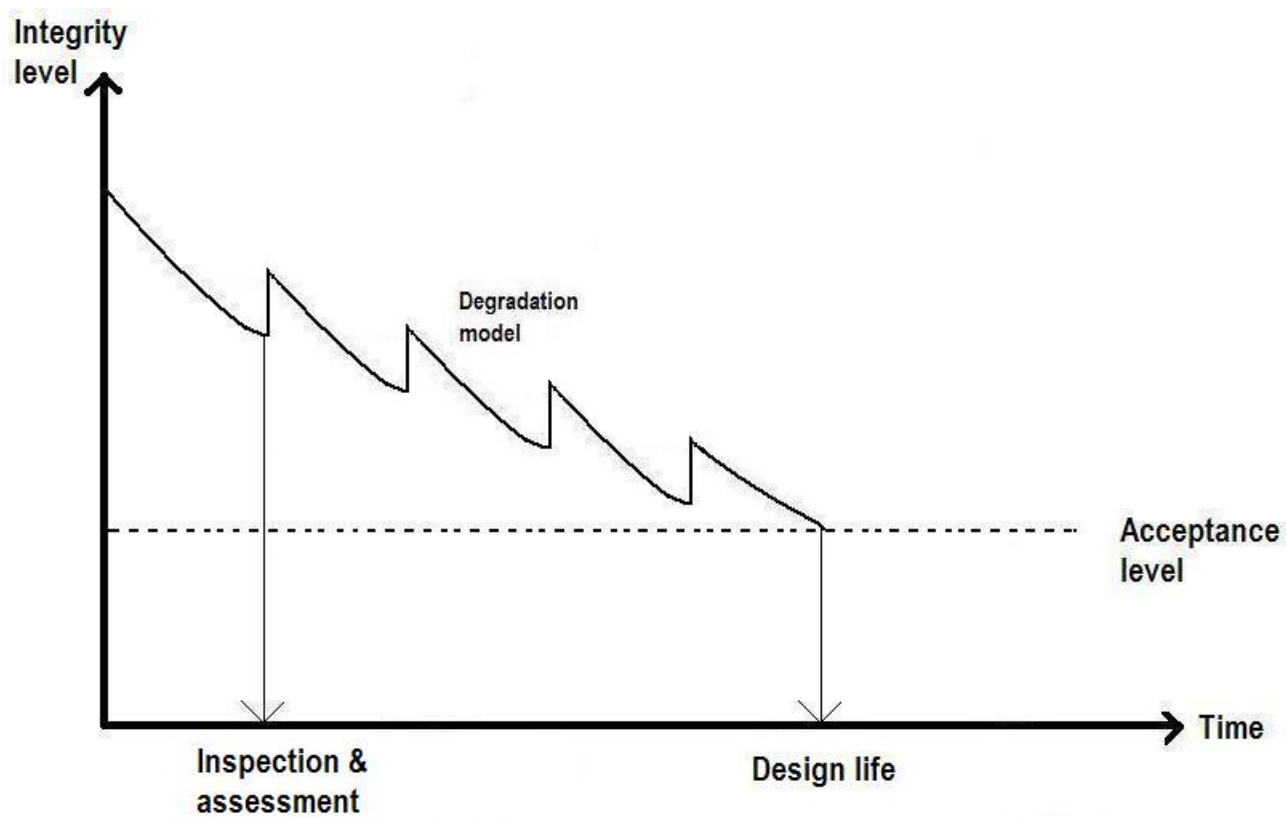


Figure I.6 - Regular inspection can be a condition in the design

Annex J

(Informative)

Work process paradigm

Life extension of a subsea system requires a reassessment to document that the system can be safely (and cost effectively) operated. The life extension process shall be a structured and planned process ensuring that all equipment and their potential integrity threats are evaluated and documented.

This annex presents how a system may be identified and how screening of the system in view of life extension may be performed.

J.1 Life extension premises

The premises for the life extension shall be established. This may include the following:

- life extension period;
- battery limits (what to be included/system description);
- regulatory requirements (e.g. according to this standard);
- reference to company specific procedures if relevant (e.g. procedure for handling of deviations from design codes);
- reference to applied design codes;
- technical/functional requirements (e.g., design pressure, design temperature, product composition).

J.2 System review and identification of equipment scope

The objective of this activity is to identify all equipment associated with system, and whose failure affects the integrity and imposes un-acceptable risk. Risk is the product of probability of failure times the consequence of failure. The consequences are commonly divided into safety, environmental and economical consequences.

For each identified equipment, the following information is collected:

- equipment ID;
- equipment type;
- purpose and barriers;
- design basis, hereunder design code(s);
- main design documentation, e.g. DFI;
- operational history (e.g. from an event log);
- inspection, maintenance and testing program and documentation from these activities;
- company or industry experience with this or equivalent equipment type (e.g. failure statistics);
- current design practice for this type of equipment (design code, recommended practices);
- future equipment loading, hereunder functional loads (e.g. dead load, pressure, temperature, flowrate), environmental loads (wave, wind, current, ice and internal fluid composition) or accidental loads.

The basis for and evaluation made to include or exclude an equipment/component from the life extension scope shall be documented. An example that could be used is shown in Table J.1.

Table J.1 - Equipment review form

Equipment ID	<Demo pipeline>	Type:	<Steel pipeline>
Section A Evaluation basis:			
A1	Purpose:	<Transport of content>	
A2	Barriers:	<Pipe wall>	
A3	Design code(s)	<Design code>	
A4	Design docs.	<Doc. No.1> <Doc. No.2>	
A5	History:	<Summary of important integrity events>	
A6	Inspection:	<Summary of inspection, maintenance and testing and evaluation of these>	
A7	Experience:	<Summary of company or industry experience with this type or comparable equipments>	
A8	Current design:	<Summary of current design practice compared to original design of this >	
A9	Future loading:	<Summary of equipment loading as compared to original design >	
Section B Questioner:			
		Yes	No
B1	Will the design life of the equipment be exceeded during the planned life extension period?		
B2	Have there been any events that could influence the planned life extension period?		
B3	Are there finding inspection, monitoring or testing that could influence the planned life extension period?		
B4	Is there company or industry experience with this equipment that should call for a re-qualification?		
B4	Have there been changes in the design practice resulting in reduction of the inherent safety level (former designs have been non-conservative) or has the code acceptance criteria been made more stringent?		
B5	Has the equipment loading increased?		
Section C Re-qualification is required?			
Evaluation:			
<.....>			

Annex K

(Informative)

Condition based assessment

The key issue in a condition-based assessment is thorough exploitation of all available data from the operation of the system.

The service data come in many forms, such as monitoring of production parameters and environmental conditions, as well as inspection of the system. In addition, more targeted monitoring and inspection methods can be implemented if deemed necessary.

Below are some generic case-studies, outlining how input data can be useful in a condition-based assessment. These case-studies are not meant to be comprehensive, but should give some guidance in the life extension process.

K.1 External corrosion

The corrosion resistance of a subsea system depends on the material selection, the coating system and the cathodic protection system. The primary protection is the coating system, and the cathodic protection system is a backup. The coating will break down over time, and the associated corrosion protection will be reduced.

Reassessment of the corrosion protection system should be based on inspection of the coating, as well as the anodes in the system. The important parameter is the coating breakdown factor, which can not be determined directly by inspection. However, based on the anode consumption it is possible to calculate “backwards” in time and estimate the coating breakdown already experienced during operation. This coating breakdown can then be extrapolated into future operation, and the future demand on the cathodic protection system may be quantified life extension.

The status of the cathodic protection system toward the end of the life extension period may then be quantified. The extrapolated coating breakdown should be evaluated to provide sufficient safety. In addition the CP system should cover the full transportation system in the extended lifetime.

Based on the evaluation of the coating and the CP system the estimated integrity level of the corrosion protection can be compared with the integrity acceptance level.

K.2 Fatigue

NORSOK N-006 is a relevant reference for fatigue.

Fatigue is a time-dependent failure mode. Extending the design life of an existing transportation system, or individual component, may be challenging. In fact, based on the calculations from design phase, the accumulated damage may exceed a critical level already at the end of the design life. This alone does not disqualify a subsea system from being used beyond its design life, since conservative assumptions made during the design phase can overestimate the damage. Results from a reassessment of the system may show that a life extension can be justified with the same acceptance level (as required by the applicable design standard).

Figure K.1 shows an example of how the probability of failure (PoF) for a system may evolve during its time in service, t_1 . The probability of failure will naturally increase with time due to the initiation and development of fatigue cracks. In order to maintain an acceptable integrity level, the PoF cannot exceed a maximum value (related to the acceptable risk level).

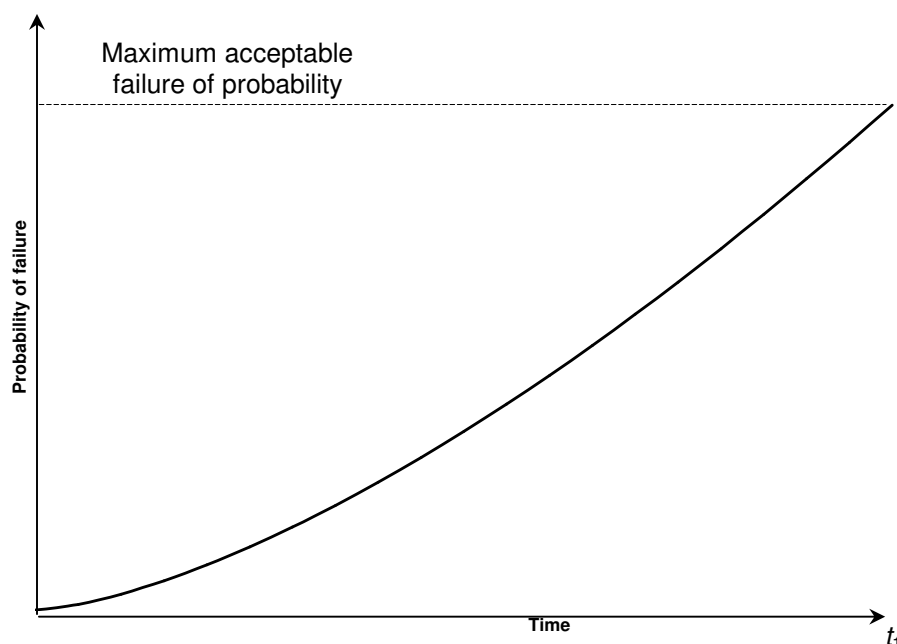


Figure K.1 - Illustration of the probability of failure (PoF) as a function of time

The PoF may reach the maximum acceptable failure level during the design life; hence extending the service life may pose a problem. Figure K.2 shows that the PoF related to the extended service life, t_2 , will exceed the PoF of the original design life, t_1 . If the increased risk is acceptable, the life extension is not a problem.

However, if the increased risk (i.e. lowered acceptance level) is not acceptable, alternative methods must be applied in order to justify an extended service life without increasing the risk.

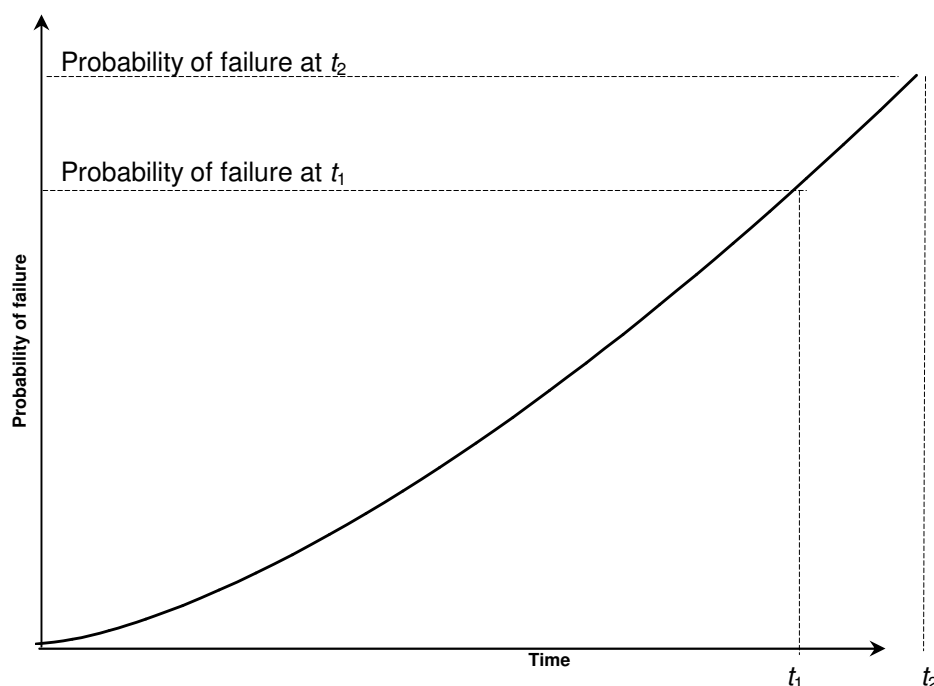


Figure K.2 - Increase in probability of failure (PoF) related to life extension

The probability of failure established in the original design must be reassessed. An alternative method could be to obtain a curve that falls below the original curve (i.e. the predicted rate of fatigue crack development is decreased). A new PoF curve may be obtained by

- carrying out a new fatigue analysis (e.g. more powerful and detailed calculation and modelling tools),
- inspection of the structure,

- incorporating environmental monitoring data in the analysis (e.g. using the real-life data, instead of depending on models and forecast with inherent uncertainty and conservatism),
- monitoring structural components (e.g. measuring the stress at critical locations, instead of depending on models to calculate the local stresses),
- a combination of the above.

The difference between the PoF curve established during design and an updated, more realistic curve will depend on conservative assumptions from the design phase. If such conservative assumptions are present, a re-analysis may result in a less conservative PoF curve.

Figure K.3 shows how an updated PoF curve (dotted line) based on a re-analysis can justify an extended service life without exceeding the maximum failure probability.

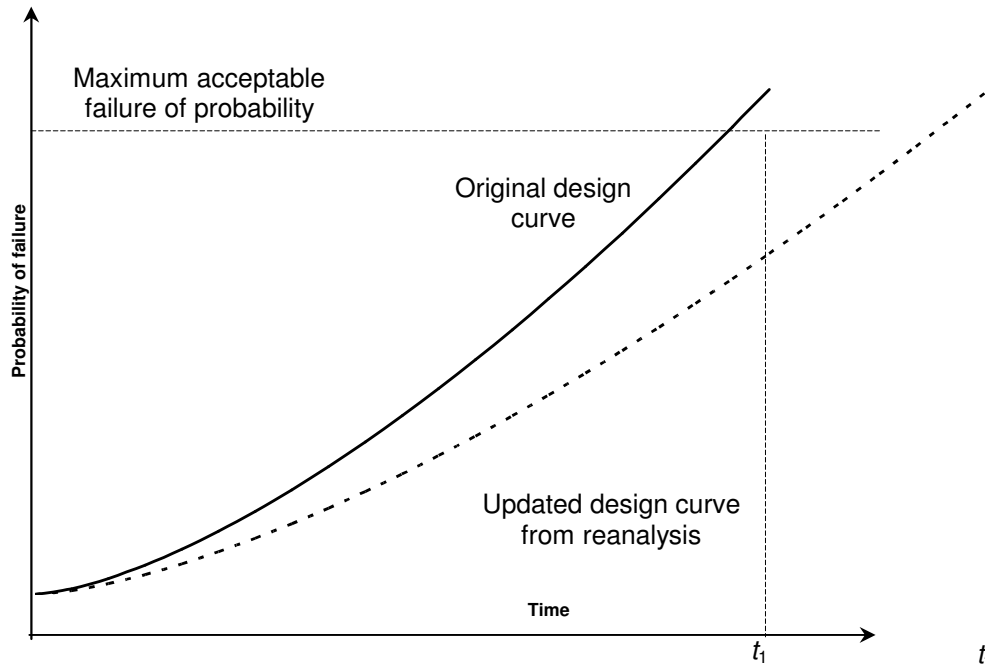


Figure K.3 - Probability of failure curves; original design and life extension re-assessment

Inspection of the system can also justify a life extension. The time-dependent defect distribution can be updated through inspection of locations and components that are assumed to be critical. Figure K.4 shows how the PoF curve can be updated based on results from the inspection. The defect distribution based on inspection at time t_i predicts smaller defects than assumed in the original design. In this case the result is a lower PoF curve. This is illustrated in Figure K.4 showing the assumed defect distribution (for original design) and the defect distribution based on inspection at time t_i .

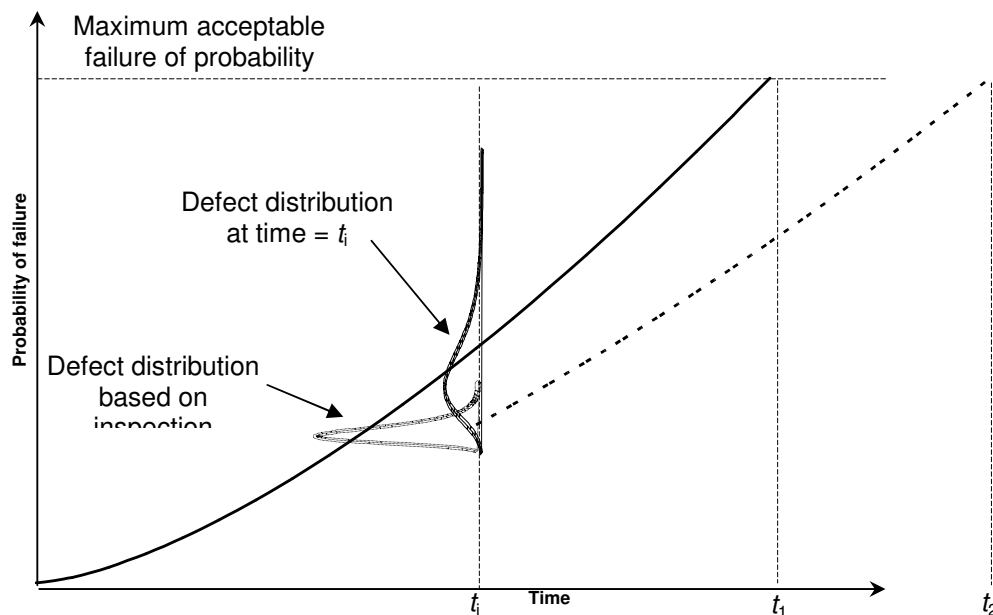


Figure K.4 - Illustration of how the probability of failure is updated based on inspection

K.3 Polymer material

Polymers are typically present in flexible pipes (both bonded and unbonded) and in seal/ gasket functions. A polymer material will during operation have deterioration of its properties, such as strength, ductility and chemical resistance. Temperature and fluid composition are important factors. However, research and new technology can give rise to new degradation models. Degradation of polymers is not reversible, and the components may have to be replaced.

Polymer materials are usually sensitive to operational parameters, such as temperature, pressure and chemical environment. Time dependent degradation leading to failure of polymers is often caused by operation conditions outside the assumptions used as basis for the qualification.

Design, as well as operational information, should be identified and assessed in a life extension project. Based on such data it may be possible to determine the capacity of the polymer toward an extended lifetime.

The following information should be obtained:

- a) related to the component:
 - 1) identify type of polymer (elastomers/thermoplasts, composition, properties) in the system, their location and function;
 - 2) determine the material specifications and functional requirements that were used as a basis for the selection of the elastomer/thermoplastic components;
 - 3) use inspection data and monitoring data about operation conditions to evaluate the condition of the components.
- b) related to the operating environment:
 - 1) identify the operation condition limits in the original design, or design envelope of operational parameters that were also used for qualification of the polymer);
 - 2) identify expected/possible changes in operating conditions (life extension premise);
 - 3) review data from the operation of the system. Identify any deviation of the operating parameters outside the design envelope (e.g. max/min temperature, maximum pressure/pressure cycling and changes in chemical environment).

The failure modes are often related to expected degradation of the polymers (elastomers/thermoplasts) in the operation/service environment. An evaluation of the effects of prolonged exposure to the operating environment will identify the most likely damage mechanism for the components.

If elastomers/thermoplasts have been exposed to operating parameters outside the design envelope (i.e. outside of the parameters for which the materials were qualified), the integrity of the elastomer/thermoplastic

components should be further evaluated. The probability of failure for the component increases if exposed to operation conditions close to or outside the design assumptions/envelope.

In a life extension project the premises shall be established, identifying failure modes based on any new/changed conditions or threats. Typical time dependent failure modes are listed below:

Time dependent failure mode	Parameters that may influence risk of failure
Chemical ageing (e.g. chain scissoring and cross linking of chains)	Temperature Chemical environment
Fatigue	Chemical environment Temperature Mechanical loads (cyclic/maximum values)
Rapid gas decompression (RGD)	Pressure cycling Temperature Maximum pressure
Gas permeation	Temperature Concentration gradients
Physical ageing	Temperature
Creep	Temperature Pressure
Problems related to additives	Temperature Concentration gradients Pressure gradients Chemical environment
Stress relaxation	Temperature

Elastomer/thermoplastic components can be replaced. The composition and production route of any replacement elastomer/thermoplastic component shall be comparable to the old component. If this can not be verified a qualification of the replacement elastomer/thermoplast must be performed, based on the life extension premises.

The integrity of spare parts must be evaluated before use, since polymers normally have a limited shelf life.

K.4 Internal corrosion

Internal corrosion resistance depends on the material selection and the corrosive potential of the transported fluid.

Some internal corrosion damage will occur, but if the system is properly designed and operated it should not be a concern during the design life. For a life extension project, it is important to note that corrosion damage can not be reversed. However, the internal corrosion can be slowed down (e.g. inhibitors, other measures). Depending on the margins in the system (i.e. wall thickness, corrosion allowance), it is important to start the life extension process early in the system life. Increased corrosion prevention measures can be introduced, which may extend the integrity life of the transportation system. If the remaining margins have become too small, such measures may not be sufficient to provide the required extension in integrity life.

Repair/intervention related to internal corrosion is normally not possible short of replacing large parts of the system, since the effect of corrosion is often evenly spread out in the transportation system. However, in some cases there can be severe local corrosion damage, and smaller sections/components can be replaced or repaired.

