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Requirements for Life Extension of Ageing Offshore Production Installations

For: Petroleum Safety Authority Norway

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TWI Report 17554/1/08
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Background

Many fixed offshore installations in the Norwegian and UK sectors of the North Sea are now over 25 years old. Over time the structure and process plant, the safety systems and other facilities are subject to ageing mechanisms leading to deterioration of their condition, with potential impact on fitness-for-service, functionality and safety. In the UK, the Health and Safety Executive (HSE) is addressing asset integrity of ageing installations through Key Programme 3 of targeted inspections.

The concept of 'life extension' is that there is a time or an amount of duty when the installation would normally be considered for retirement, but where, with certain processes and criteria, life can be extended for a further period without a reduction in margins below safe operating limits. Recognising this, the Norwegian Information Duty Regulations require offshore operators to apply to the Petroleum Safety Authority Norway (PSA) for consent when planning to use an installation beyond the original design life or current life span. The project contributes to PSA's approach to evaluating applications.

Objective

The objective of the work is to determine the information, processes and criteria required in order for PSA and the operator to be able to decide whether an ageing offshore installation can continue its production in extended life or not.

Work Carried Out

The major offshore hazards against which protection is required, and the functional barriers designed to provide this protection, are described. Barrier systems of topside equipment, structure and components critical to maintaining safety are discussed, and a distinction is drawn between active and passive components and the need for prioritisation for life extension assessment. Factors influencing the performance of the barrier systems are highlighted including organisational and human aspects.

Indicators of integrity are considered, including the design and operating life, compliance with specification and standards, inspection and monitoring and data trend analysis, and fitness-for-service assessment. Factors that can enhance the risk, occurrence and rate of ageing are identified for typical process equipment. A scheme is proposed for classifying equipment on the basis of stage of ageing in terms of accumulated damage and other aspects, and it is suggested how the approach to the selection of indicators of ageing may change according the stage that ageing has reached. Current guidance on ageing management and life extension in the offshore industry is reviewed.

Obstacles to life extension and conditions necessary for it to proceed are discussed. The content of an application for consent to life extension and the processes that may be involved are presented in terms of a process flow diagram. The benefits of holding 'Life Extension Workshops' are highlighted. Finally the report considers how an application for consent to life extension may be evaluated and checked, and the need for increased vigilance from both duty holders and regulators during the life extension period.

Conclusions and Areas for Further Work

1 This report concludes that the life of fixed offshore installations may be extended providing the integrity of the topside equipment, structures and components is properly managed. The application for consent to life extension provides a point in time for taking stock of the extent and effects of ageing on performance, and for planning for the period of anticipated extended operating life. Leading and lagging integrity indicators and risk factors, combined with fitness-for-service assessment, performance monitoring and effective maintenance provide the basis on which the case for life extension should be made.

2 During the final stages of this project, HSE published the final report on its KP3 initiative associated with asset integrity. A brief review appears in Section 1.1.2. The KP3 report identified weak Leadership, Engineering and Learning as underlying causes leading to poor performance. An evaluation of the impact of KP3 on the Norwegian approach to life extension is recommended.

3 The definition and treatment of active and passive components need greater clarity for the purpose of prioritising and focusing the life extension assessment task. Key systems and tests that could be representative of the more general condition could be identified. Greater attention should be given to assessing the management and workforce readiness to accept the responsibility of extended life operation. Further examples of typical structures, equipment and components in different stages of ageing would be helpful to illustrate the different ageing stages.

4 The issue of demonstrating appropriate competencies to manage life extension is briefly referred to in Section 1.3.4 and the Appendix. However it is considered that this is an important area which deserves further consideration of suitable competencies along the lines of those recommended for structural integrity management in ISO 19902 and management of ageing pressure equipment in HSE report RR 509.

5 TWI and the authors of this report are currently involved in a project funded by the Energy Institute on developing indicators for ageing of offshore safety critical elements. It is expected that this work will develop useful guidance that would relate to the requirements for life extension in Norwegian waters.

1 Scope

1.1 Need for life extension requirements

1.1.1 Background and objectives

Many fixed offshore installations in the Norwegian and UK sectors of the North Sea are now over 25 years old. In the Norwegian sector there are around 20 installations older than 20 years. In the UK sector there are now around 90 fixed installations of this age. Although a few of these have been decommissioned, or are due to be decommissioned in the near future, there remain a substantial number of installations still in service where operators have indicated their intention to continue their service for the foreseeable future.

The increased world price and demand in oil and gas has made the economics of extracting from the North Sea fields more attractive to oil companies. Many production installations now have a continued requirement to produce oil or gas either from the original fields or to serve as a base for neighbouring subsea completions. The infrastructure is in place, and continued operation defers the costs of decommissioning.

Over time the structure and process plant, the safety systems and other facilities comprising the installation are subject to ageing mechanisms leading to deterioration of their condition, with potential impact on safety, functionality and fitness-for-service in the longer term. Many structures and process plants are designed for a nominal life of about 20 to 25 years, both for investment appraisal purposes, but also because this forms the approximate limit of current industry experience. On the other hand, where the effects of ageing are sufficiently slow, or can be mitigated and managed through timely inspection, maintenance, and replacement and upgrading, there is clearly potential further useful service to be obtained.

The concept of ‘life extension’ is that there is a time or an amount of duty when the installation would normally be considered for retirement, but where, with certain processes and criteria, life can be extended for a further period without a reduction in margins below safe operating limits. Recognising this, the Norwegian Information Duty Regulations require offshore operators to apply to the Petroleum Safety Authority Norway (PSA) for consent when planning to use an installation beyond the original design life or current agreed life span. The application should state the basis and assumptions upon which the plans for life extension are based, and if these are sufficiently different from the current basis, a new consent to operate is required before activities are continued.

In order to assess such plans, PSA invited TWI to apply its expertise to propose requirements for life extension of ageing offshore production installations. At present there is a lack of relevant guidelines and standards on the processes and criteria required for consent to life extension. The objective of the work is to determine the processes, information and criteria required in order for PSA and the operator to be able to decide whether an ageing offshore installation can continue its production in extended life or not.

For the purposes of this work, the areas of interest are limited to the main hydrocarbon and other process equipment, technical safety equipment (active and passive fire protection systems, fire and gas detection) and the structure in the area of the topside. This therefore excludes consideration of the sub-structure and foundations, concrete sub-structures, module support frame, the flare tower structure, the heli-deck structure and the drill tower structure, as well as emergency, evacuation and rescue equipment. In addition to equipment, the work also addresses the management systems and procedures and aspects of human performance, and considers how these may be affected by the ageing of the installation and the workforce.

The project contributes to PSA’s approach for evaluating applications for consent to life extension.

1.1.2 UK experience with managing integrity of ageing assets

Between 2000 and 2004, the UK HSE's Offshore Division (OSD) ran a major programme (KP1) aimed at reducing hydrocarbon releases focusing on the integrity of process plant. This resulted in a considerable reduction in the number of major and significant hydrocarbon releases. During this time, however, the Offshore Safety Division became increasingly concerned about an apparent general decline in the condition of the fabric and plant on installations and responded with Key Programme 3 (KP3) directed at evaluating asset integrity (Cutts, 2005). It was scheduled to run between 2004 and 2007.

KP3 involved targeted inspections of nearly 100 offshore installations representing about 40 per cent of the total. These included all types including fixed, manned and normally unattended installations, floating production (FP), floating production storage and offloading (FPSO) vessels and mobile drilling rigs. KP3 focused primarily on the maintenance management of SCEs (safety critical elements), the management systems and processes which should ensure that SCEs are available when required.

The inspection programme used a template containing 17 elements covering all aspects of maintenance management, in addition to a number of SCE systems tests. The performance of each template element was scored using a traffic light system which enabled the overall installation performance to be recorded in a matrix. This enabled an overview of company and industry performance to be obtained and examples of good and bad practice identified. Examples of good and best practice were shared with the industry and have also been included in the final report (HSE, 2007a).

The findings from the KP3 programme indicated that the performance of management systems showed wide variations between companies across the industry, and surprisingly there were often considerable variations in performance between assets in the same company. It was found that the state of the plant was often not properly recognised because of the complexity of categorising and recording equipment which was overdue for maintenance or found to be defective. OSD considered that significant improvement in maintenance systems could be achieved without major capital expenditure by better planning, improved training and clear statement of performance standards in testing and maintenance routines.

OSD also concluded that there is a poor understanding across the industry of the potential impact of degraded, non-safety-critical plant and utility systems on safety-critical elements in the event of a major accident, and the role of asset integrity and concept of barriers in major hazard risk control. OSD noted that the industry was not effectively sharing good and best practice. This even extended to companies not learning the well-publicised lessons gained during the life of KP3. Improvement was needed in cross-organisational learning processes and mechanisms to secure corporate memory.

The final report also highlighted that companies needed better key indicators of performance available at the most senior management levels to inform decision making and to focus resources. Many management monitoring systems tended to be overly biased to occupational risk data at the expense of precursors of major hazards. Many senior managers were not making adequate use of integrity management data and were not giving on-going maintenance sufficient priority.

In terms of the maintenance management system, the final report concluded that elements of good practice were: reporting to senior management, key company specific indicators of maintenance effectiveness, communications between onshore and offshore supervision (ie confirmation that maintenance tasks have been completed in accordance with the instructions on the work order, time spent on the plant by supervisors etc), and defined life repairs. Poor performance in maintenance management was associated with maintenance of SCEs, backlog management, deferrals, measuring compliance with performance standards and corrective maintenance.

Supporting the examples of poor performance the final report noted that for more than 50 per cent of installations inspected the “Physical State of the Plant” was considered to be poor. Companies often justified the situation with the claim that the plant, fabric and systems were non-safety-critical and a lower level of integrity was justified. It was noted that this illustrated a lack of understanding in many parts of the industry that degraded non-safety-critical plant and utility systems could reduce the performance of safety critical elements in the event of a major accident. Particular examples of SCE’s with poor performance were found to be associated with the Temporary Refuge and included the performance of the HVAC system and doors. The deluge system gave significant cause for concern.

The KP3 final report identified a number of weaknesses, which were underlying causes leading to poor performance. These were:

- Leadership: it was found that senior management set priorities between investment in field development, asset maintenance and profit on the basis of health, safety and financial risks. The findings indicated that the priority given to asset maintenance in the past has been too low. Only a limited picture on SCE status was being provided based on backlogs and deferrals. It was considered that senior managers must improve their understanding of the safety and business risks arising from continuing to operate with degraded SCEs and safety-related equipment.

- Engineering function: it was concluded that the influence of the engineering function has declined to a worrying level in many companies. It was suggested that a key element in balancing priorities is to ensure that the engineering function has sufficient authority to put forward the case for major hazard control and act as a backstop against degraded SCEs and safety related equipment and structure.

- Learning: KP3 has demonstrated that there is considerable variation in the performance of management systems and delivery of appropriate standards, across the UKCS and often in the same company. A significant factor in this is an underlying weakness in many companies’ audit arrangements to ensure compliance with procedures. These are not being used effectively to share learning arising from the audits and to promote best practise within the company and between companies. It was found that improved arrangements for auditing and monitoring performance are needed in most companies.

The UK experience from the KP3 inspections is of particular relevance to ageing installations in the Norwegian sector. Further work to examine the detail of the KP3 experience and to translate this into a form that would be useful to PSA, given the basis of this work, is recommended.

1.1.3 Case for life extension review

Maintaining an awareness of the progressive development and effects of ageing on equipment is a challenge for any industrial operator. By its nature, ageing of materials and systems often occurs relatively slowly over timescales of years, and for those in day-to-day contact with ageing equipment, while there may be an awareness of the rate at which the equipment is deteriorating, the change from the start of life condition becomes hard to recognise. For parts that are uninspectable using standard techniques, knowledge of their condition is, at best, based on extrapolation and assumptions.

As time passes, the operating conditions of plant and equipment may change from the original design intent. Where installations are taken over by new companies or workforces are replaced, there may be little knowledge of what the original design condition was or how fast change is occurring. There can be blindness to ageing where operations unconsciously adapt to compensate for degraded, worn, faulty or unsatisfactory conditions.

The design life of equipment, typically set at 20 to 25 years, is a guide and a limit to what can be underwritten by the manufacturers' expertise and expertise. Once equipment enters service its life is progressively determined by service, duty, and the level of maintenance and refurbishment. There is therefore an argument that there comes a time when a thorough review of integrity and remnant life may be necessary, possibly with a more radical step change in integrity management, if the required assurance in the future availability and reliability of equipment is to be upheld. A review also provides an opportunity for any improvements in design or function that have taken place over the life of the installation to be assessed with regard to whether the existing equipment still provides adequate safety.

The alternative argument that the industry often puts forward is that a specific life extension review is not necessary, and that installations should be allowed to continue to be managed as planned in the original design life. If there are non-conformances due to ageing, these have to be dealt with separately as and when they appear. On this basis it is argued that design regulation is still the best way of regulating ageing installations.

The main case for a life extension review is that life extension may throw up new potential failure modes and mechanisms which would not be evident or considered during original design life. It is an occasion to take stock of ageing and reliability and to anticipate change in the longer term future in a way that may not occur on its own. In this way, management, regulator and the work force can be reassured of continued safety from the threat of possible ageing degradation. Entering a period of life extension is an opportunity to address maintenance and inspection backlogs and to re-set the clock. It is a way of countering the dangers of over-familiarity and stagnation brought on by the passage of time, and to identify new potential failure modes whose indication may just be appearing.

Life extension is a process that should, at a defined and specific period of time, encourage Duty Holders to stand back from day-to-day operations, assess the current condition and state of knowledge and take a longer term view. For it to have meaning, the process should extend beyond what would be regarded as good routine management, and establish a new baseline against which decisions can be made. It should contain elements of independence from the installation operating team to mitigate any tendency to ageing blindness.

Planning for life extension is a good time to review integrity management systems and the human resource required to manage an ageing installation. Inspection and maintenance intervals, techniques and procedures, data management records, backlogs, corrosion and fatigue management programmes and trends can all be refreshed. While there are many advantages of an experienced workforce who understand the equipment they are dealing with, there is also benefit in involving other people and organisations, who can often bring different and wider expertise and experience, particularly with respect to ageing issues.

1.1.4 Environmental standards for emissions and wastes

Environmental standards for emissions and wastes from North Sea offshore installations have become progressively more stringent over the years of operation. Early equipment and operating procedures may no longer meet modern standards. Although the equipment may be operating as designed, the level of emissions and wastes may need to be addressed during the process of life extension.

1.1.5 Issues addressed in the report

In determining requirements for life extension there are a number of key issues to address.

- At what point during life does life extension occur and how is extended life defined?
- What are the key indicators and risk factors of performance, integrity and ageing?
- Can different stages of ageing be defined for the purposes of classifying equipment?

- How should the indicators and management measures change as equipment ages?
- Which aspects of ageing may reduce the safety of the installation?
- What conditions obstacles for life extension (life terminating show stoppers)?
- What extra conditions may have to be applied if life extension is to proceed?
- What is required in an application for life extension?
- What processes are expected in developing an application for life extension?
- How should applications for life extension be evaluated?
- What aspects of the application can be checked physically and in terms of audit of documentation and processes?
- What are the principles for the management of safety related systems during the life extension period?

These issues are considered in Sections 1 to 3 of this report.

Section 1 describes the major hazards of offshore production installations against which protection is required, and the functional barriers designed to provide this protection. The barrier systems of topside equipment, structure and components critical to maintaining safety are discussed, and a distinction is drawn between active and passive components and the need for prioritisation of the life extension assessment task. Factors influencing the performance of the barrier systems are highlighted including organisational and human aspects.

Section 2 considers indicators of integrity, including the design and operating life, compliance with specification and standards, inspection and monitoring and data trend analysis, and fitness-for-service assessment. Factors that can enhance the risk, occurrence and rate of ageing are identified for typical process equipment. A scheme is proposed for classifying equipment on the basis of the stage of ageing in terms of accumulated damage and other aspects, and it is suggested how the approach to the selection of indicators of ageing may change according the stage that ageing has reached. Current guidance on ageing management and life extension in the offshore industry is reviewed.

Section 3 deals with the contents of an application for consent to life extension and the processes that may be involved. Obstacles to consent to life extension and conditions necessary for life extension to proceed are discussed. The report discusses how an application may be evaluated and checked, and the need for increased vigilance from both Duty Holders and regulators during the life extension period.

Throughout this work, the emphasis has been on safety, although much will also be applicable to maintaining reliable and uninterrupted production.

1.2 Hazards and ageing

1.2.1 Major hazards on offshore installations

On a typical offshore production installation, there are several major hazards capable of producing a serious risk to personnel and equipment and affecting safety and production. These hazards are listed in Table 1 below together with their consequences that would be considered in a typical risk analysis. For each of these hazards, examples are given of the significance of ageing in enhancing the likelihood of the hazard occurring, and in reducing the effectiveness of the protection and mitigation systems.

Table 1 List of major offshore hazards

Major hazard	Consequences	Examples of the significance of ageing
Hydrocarbon (HC) leaks	Shut down, loss of production, fire and/or explosion, asphyxiation	Over 60% of leaks on HC systems are caused by ageing processes such as fatigue, corrosion, erosion, degradation (HSE statistics). Emergency shut-down and blow-down system valves and pipework may operate less efficiently due to wear, corrosion, fouling etc.
Fire and explosion (usually as a consequence of a HC leak)	Reduced safety of personnel, damage to equipment, loss of production, structural failure, collapse, escalation.	Reduced sensitivity of gas, smoke and fire detectors with age due to poisoning of sensor, mechanical damage, window deterioration (in infra-red detectors). Reduced pumping rates and leakage of active and passive fire systems. Degradation of PFP coatings reduces heat resistant properties and fixtures weaked due to corrosion. Reduced fixing and integrity of blast walls due to corrosion and damage.
Dropped objects	Rupture of vessels and pipework leading to HC leaks etc, endangering personnel. Damage to safety critical systems.	Fatigue and other ageing of lifting equipment components increases the likelihood of component failure (eg gears, bearings, brakes, shafts, cables, slings etc)
Structural collapse of topsides or topside equipment	Damage to safety critical systems, pipe rupture, HC leaks, loss of escape and rescue capability and routes.	Fatigue and corrosion of structural steelwork can reduce load carrying capacity
Failure of evacuation, escape and rescue (EER) systems	Risks to safety of personnel following an event	Corrosion and fatigue can cause reduced integrity/collapse of EER systems (walkways, moorings etc)
Human factors (eg in management, operations or maintenance)	Increased risk of other major hazards	Over familiarity with equipment and hazards can reduce awareness and responsiveness to ageing effects and lead to maintenance backlogs.

1.2.2 Age related threats and damage mechanisms

There are a number of threats to integrity that increase with the age of an installation from physical degradation mechanisms that are time dependent. These are listed below.

a) **Corrosion**: loss of material due to electro-chemical reaction with the environment

- Internal: most of the internal corrosion problems are associated with the corrosive contents of the produced well fluids, such as dissolved gases eg CO_2 and H_2S. The constitution of the well fluids changes with life and older fields tend to be more sour, leading to an increasing rate of corrosion.

- External: this arises from the offshore environment, with seawater in the air. Corrosion under cladding or coatings (eg PFP, insulation) is a significant issue and difficult to detect. Corrosion of exposed steelwork is an increasing problem of ageing installations, particularly if maintenance (eg repainting) is poor.

- Can be linked with other mechanisms (eg fatigue, erosion-flow assisted), to produce even higher rates of damage.

b) **Erosion**: loss of wall thickness due to removal of material from fluid flow, particularly if the fluid contains solid particles, prior to separation.

c) **Wear**: loss of material due to friction between moving parts, particularly in lifting equipment, valves, compressors, pumps etc

d) **Environmentally assisted cracking**: cracking due to electrochemical reaction of the material with the environment. This includes stress corrosion cracking (SCC) and hydrogen embrittlement. The extent and rate of these processes are age related.

e) **Fatigue**: the development of cracks under cyclic loads (can be linked with corrosion)

- General: failure of welds and materials due to repeated application of cyclic stresses

- Vibration: high cycle low amplitude cyclic stresses due to poor fixing, resonance, such as in small bore piping attachments

f) **Physical damage**: damage such as dents and gouges due primarily to impact from dropped objects or as a result of maintenance. Damage can accumulate with age.

g) **Materials deterioration**: loss of material properties with age/exposure. This can include embrittlement of polymers, and loss of fire protective properties of coatings.

h) **Blockages, fouling and scaling:** blockage of pipework, valves, heat exchanger tubes, pressure relief systems etc. due to build-up of, for example, corrosion products, scale.

i) **Defective equipment** (seal and gas tightness, insulation breakdown)

1.3 Barriers and the effect of ageing

1.3.1 Barrier function

Barriers are often defined as any technical, operational or organisational measures whose function decreases the probability of hazardous events occurring or which limits the consequences of such events. Barriers are specifically mentioned in the PSA Management Regulations where it is stated that these can be either physical or non-physical or a combination of both. There is also a requirement in the Regulations for independence of barriers, which implies that several important barriers shall not be impaired or cease to function simultaneously, as a consequence of a single mechanism, failure or incident.

The functional performance of barriers can vary from optimum over time due to factors such as ageing processes and obsolescence of the original (i.e. performance influencing factors). Barriers can be divided into two main categories on this basis as follows:

- **Historic barriers**: these were put in place in the early stages of the platform life (eg safe design, redundancy, diversity, optimized layout). Due to improvements in knowledge and technology, or as a result of poor initial design, their functionality may no longer be optimised to the current state-of-the-art. Hence these barriers may require additional barriers to reduce risk to a level consistent with modern requirements.

- **Ageing barriers**; these are barriers whose function can be reduced by ageing processes, changing or degrading the equipment in some way. Examples are passive fire protection coatings affected by material degradation and emergency shut down systems whose speed of operation can decline as a result of fouling etc.

Examples of three different hazard scenarios with barriers indicated are shown in Figures 1-3. A list of relevant ageing factors is also shown in each case, together with an indication of which types of barriers exist. More details of the barrier function and the effects of ageing are given in Table 2 below. The three hazard scenarios are as follows:

a) **Hydrocarbon leaks, fire and explosion**

The main ageing processes leading to hydrocarbon leaks are corrosion, erosion and fatigue/vibration, and seal/gasket wear and blockages of hydrocarbon containing vessels and piping systems. Barriers to HC leaks, shown in Figure 1, are the effective selection of corrosion resistant materials and coatings, good design of the corrosion protection system, improving the resistance to fatigue by good weld design and vibration control, and regular maintenance and inspection, including bolted joints. The first three of these may be 'historic barriers' depending on the original design. Additional barriers that should be in place to reduce the scale and consequences of fires and explosions resulting from HC leaks should ignition occur are gas, smoke and fire detection, emergency shut-down systems, and active and passive fire protection. All of these additional barriers should be considered as 'ageing barriers' due to the possibility of ageing processes reducing their efficiency.

b) **Structural collapse (topsides)**

The relevant ageing factors leading to topside collapse are corrosion, fatigue, damaged coatings, and accumulated damage of structural members from extreme weather or impact. The main barriers, shown in Figure 3, minimizing the risk of structural collapse are good design of the steelwork, selection of proper materials, and good weld design against fatigue failure, together with inspection, repair and maintenance and effective plant layout and weight management. The first three of these could be considered as 'historic barriers' depending on the original design requirements. The consequences of structural failure are not only risks to personnel but also damage to plant and equipment which could lead to HC leaks (case 1 above).

c) **Dropped objects**

In the case of dropped objects, the main impact of ageing is in the degradation of lifting equipment due to corrosion, wear and fatigue. Poor operating procedures could result from failure to update lifting routes on a modified facility. The main barriers, shown in Figure 2, are of the 'historic' type, as they depend on the original design and layout, together with inspection and maintenance. The latter is particularly important for risk reduction of cranes.

In all three cases listed above a barrier associated with inspection and maintenance is included. For ageing equipment and systems this is a very important risk reducing activity. The scope and level of inspection and maintenance might be expected to increase for ageing equipment. However risk based inspection planning tools are often used to optimise

the costs of inspection, and it is not always clear that proper account has been taken of the increasing risks from ageing systems.

Depending on the effectiveness of the 'historic barriers' an increased level of inspection and maintenance may be required to compensate for shortfalls in barriers introduced at the design stage. It is important that any reduction in the integrity of a design originated barrier is fully understood taking account of changes in knowledge and technology so that appropriate levels of inspection and maintenance can be introduced to compensate.

In some parts of an installation inspection may be difficult if not impossible. In this case other risk reduction issues may be required when 'historic barriers' are present. Lack of opportunity for inspection of critical equipment may be one factor that limits the ability to extend life.

Table 2 Explanation of historic and ageing type barriers and effects of ageing

Barrier described in diagram	Barrier function	Ageing processes
1 Materials choice for containment systems	Reducing the risk of HC leaks and enhancing the resistance to fire and explosion by proper selection of materials at the design stage	Degradation of materials. Materials selection at the design stage not meeting current standards
2 Design for corrosion protection	Reducing the risk of corrosion taking place during the life of the installation by good design of a corrosion protection system	Corrosion protection system with reduced performance due to ageing processes. Original design not meeting current standards.
3 Fatigue design	Resistance to fatigue and hence reducing the risk of HC leaks during the lifetime by good design of components	Fatigue processes accelerating due to ageing, leading to vibration and HC leakage. Original design not meeting current standards.
4 Inspection and maintenance	Reducing the risk of HC leaks occurring and to maintain the resistance to fire and explosion through regular in-service inspection and maintenance (IMR)	Lack of sufficient IMR to meet ageing requirements
5 Gas detection	Minimising HC leaks and reducing the risk of fire and explosion by detection of gas leaks to enable action to be taken	Degradation of gas detectors due to ageing eg window deterioration
6 Emergency shut-down systems	Minimising the risk of fire and explosion by a system to shut-down operations in the event of a HC leak,	Reduced capacity of the emergency shut-down system due to ageing processes eg corrosion of valves
7 Fire and smoke detection	Reduce the risk of escalation of fire by detection of fire and or smoke to enable action to be taken	Degradation of fire and smoke detectors due to ageing processes
8 Active fire protection	Reduce the risk of escalation of fire by protection of the installation against fire by an active protection system	Fire water systems degrading due to corrosion

Table 2 (continued) Explanation of historic and ageing type barriers and effects of ageing

Barrier described in diagram	Barrier function	Ageing processes
9 Passive fire protection	Reduce the risk of escalation of fire by protection of the installation against fire by a passive protection system, including the use of materials protecting critical members from temperature rise	Loss of performance of PFP coatings due to ageing
10 Blast walls	Limiting the extent of an explosion and protecting critical equipment and personnel by provision of blast walls	Supports for blast walls deteriorating due to corrosion
11. EER facilities	Enable the orderly evacuation from the installation if required by provision of emergency, escape and rescue facilities	Loss of performance of EER facilities (eg access ways) due to ageing processes (corrosion)

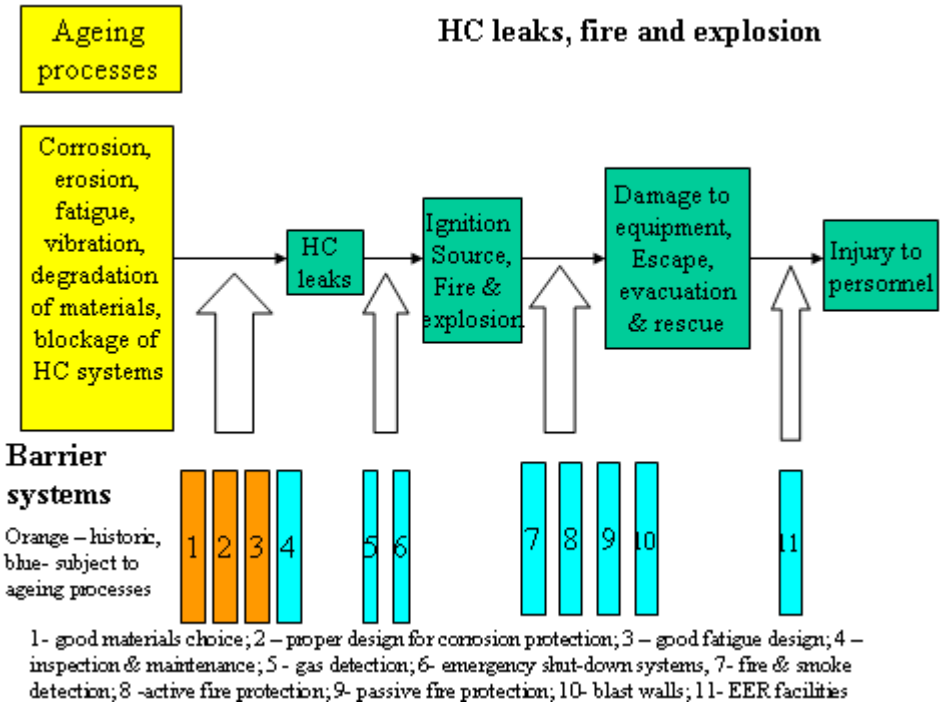

Figure 1 Barrier diagram for avoidance and mitigation of hydrocarbon leaks, fire, explosion.

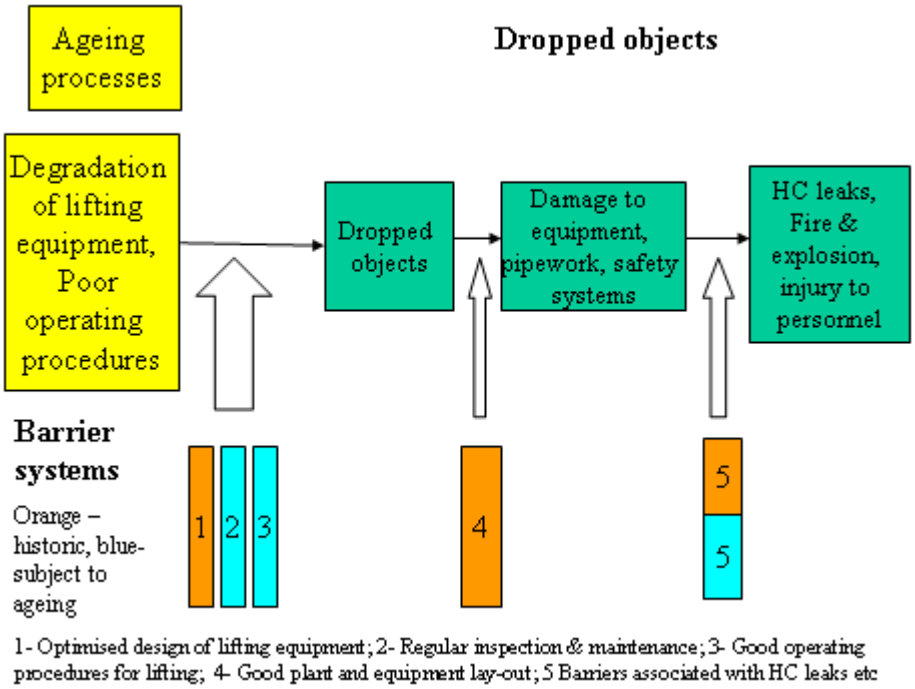

Figure 2 Barrier diagram for avoidance and mitigation of dropped loads.

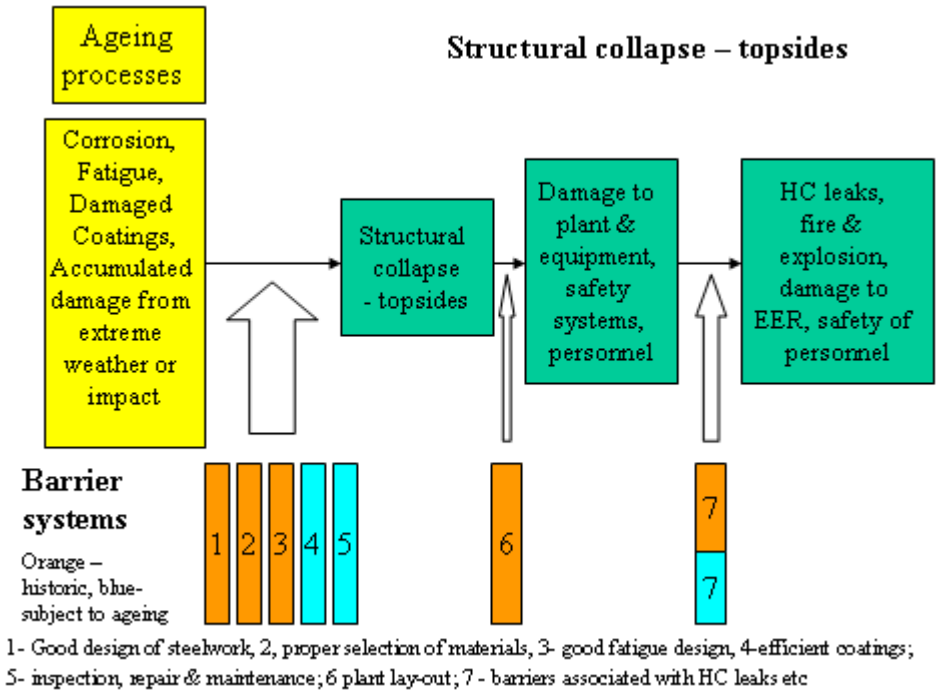

Figure 3 Barrier diagram for avoidance and mitigation of structural collapse.

1.3.2 Equipment for barrier systems

It is not the purpose of this report to provide a comprehensive list of every item of equipment and component to be found on a production installation that forms part of a barrier system to prevent a hazard occurring or mitigating escalation once a hazard has occurred. The Duty Holder is expected to undertake this task for each installation. It is helpful to provide a list of the broad categories of barriers systems against which a more detailed equipment list can be assessed.

At high level the following barrier systems are normally seen as critical to installation safety.

- Hydrocarbon, sour, produced water and steam containment systems
- Gas and fire detection and alarm systems
- Emergency shutdown, isolation and blowdown systems
- Fire and blast protection and fighting systems
- Temporary refuge, HVAC emergency power and control system
- Evacuation, escape and rescue systems
- Safety critical topside structures

At a more detailed level, examples of the types of equipment associated with these systems are shown in Table 3. It is important that Duty Holders understand the particular features of each item contributing to the barrier's functionality. For example, a simple vessel support lug can be a location for localised corrosion of the pressure boundary, a fatigue grown hydrogen crack, or gross corrosion, any of which could lead to a hydrocarbon leak through the pressure boundary or failure of the lug causing collapse of the vessel.

All items and features of equipment are subject to ageing mechanisms, and it is important for Duty Holders to have identified the relevant potential mechanisms associated with each item or feature. This should already be expected within the integrity management programme. For life extension, it becomes important for Duty Holders to consider the rate and effect of these mechanisms over the period of extended life that they are considering, bearing in mind the current condition and trends.

While corrosion and fatigue of metallic structures are well appreciated, deterioration in performance of non metallic features such as insulation, fire protective coatings, GRP pipe and tanks, seals and cabling, and electrical equipment are less well recognised yet equally important. There is a general lack of non-destructive techniques to diagnose the extent of ageing to these features. In practice, destructive testing on samples removed and replaced may be the only means to determine their condition and performance, and where there is concern or uncertainty, this may need to be done periodically throughout the extended life. Complete replacement of these features, where practicable, may be best option.

In summary, as part of the application for life extension, the Duty Holder is expected to:

- Identify the equipment and features forming the barriers that are critical to safety
- Identify all the potential ageing mechanisms for each item and feature
- Consider the potential rate and effect of the ageing on the functional performance
- Define an integrity management plan for the proposed period of life extension.

It is difficult to identify the areas or equipment that represents the highest risk in life extension. Items outside normal inspection programmes, such as pipework, pipe repairs, control and instrumentation systems (such as detectors, cabling, circuit boards, insulation), and moving parts on cranes all carry a greater degree of risk as the installation ages. Wear or damage to items such as damper or door seals, which can be overlooked in maintenance, can seriously undermine safety in the event of incident The physical infrastructure and environment, if not updated and properly maintained, can not only create a hazard itself but produce a detrimental negative attitude to safety among the work force.

Table 3 Example safety critical topside equipment associated with barrier systems on a typical oil and gas production platform

a) Hydrocarbon, sour, produced water and steam containing equipment

- Pressure vessels, separators, storage tanks
- Heat exchangers, coolers, boilers and steam systems
- Pumps and valves and actuating mechanisms
- Pipework, including small bore attachments and stem valves
- Flanged joints, seals and gaskets
- Pipe connectors, clamp and wrap repairs
- Lugs, saddles, legs, hangers, rollers, expansion joints and integral attachments

b) Emergency shutdown, isolation and blowdown systems

- Over pressure protection and relief valves and systems
- Blowdown, flare stacks and venting
- Emergency shutdown valves, surge and blowback valves
- Actuating mechanisms and closure times
- Cooling systems
- Drip trays, bunds and, drains

c) Gas and fire detection and alarm systems

- Gas, smoke and temperature detectors
- Emergency warning and control systems
- Emergency electrical supplies and cabling

d) Fire and blast protection and fighting systems

- Deluge system and control
- Fire fighting system, pumps and hoses
- Fire protective coatings and clothing
- Fire resistant structures and temporary refuge
- Blast walls

e) Temporary refuge

- Protective coatings, insulation, seals
- Ventilation system and HVAC dampers and fans
- Emergency power, batteries and control
- Emergency lighting, communications, control and tannoy

f) Evacuation, escape and rescue

- Walkways, ladders and platforms, and embarkation stations
- Survival suits
- Life boats and rafts
- Mooring points

g) Safety critical topside structure

- Bridges and walkways
- Cranes and lifting equipment
- Helideck and load bearing areas
- Vessel and pipe load bearing structure
- Fire, blast and explosion resisting structures
- Insulation, linings and protective coatings

1.3.3 Prioritisation of active and passive systems

A review of ageing management and life extension in the US nuclear power industry (Chockie, 2006) has highlighted the distinction made between 'active' and 'passive' systems and their structures, equipment and components with regard to their treatment for life extension. In the US nuclear industry, 'Passive' systems are those that perform their function without a change in configuration or properties, and include, for example, static structures, supports, vessels, piping, pump and valve bodies, and electrical insulation and cabinets. Active systems involve some level of movement, actuation or change in state as they function, and include for example, valves, pumps and compressors, motors and generators, circuit boards, power supplies, switches and switchgear, and batteries.

The US Nuclear Regulatory Commission has determined that the License Renewal Ageing Management Review can exclude consideration of those structures and components that perform active functions and those that are replaced based on a quantified life or specified time period. Its focus is on passive, long-lived systems components and structures. By focusing on safety critical passive and long-lived components it is argued that the life extension process can be reduced to manageable proportions.

The rationale behind this philosophy is seemingly based on the concept that age related degradation of active components has the characteristic of affecting their functional performance during normal operation. The effect may be immediate, (eg failure of power supply or a circuit board) or gradual (eg progressive reduction in pumping capacity or valve closure time). The effect of gradual degradation of active components is assumed to be detectable as the system operates to perform its function, and allows time for action to be taken before the component fails.

In addition, active components are often subject to a testing, maintenance or replacement policy either periodically, or when a fall off in performance is detected. Safety critical systems depending on components where there may be little or no forewarning of failure and which are intrinsically susceptible to failure, for example circuit boards or power supplies, are protected by redundancy within the system design. There is an implicit assumption that active components are monitored regularly through their operating performance, or are maintained or replaced at intervals where life extension is not an issue.

Age related degradation of passive components may not be as detectable as for active components because the system appears to function normally until the moment when the component fails (eg a pipe corroding but appearing to perform as required up the point of leakage). The degradation can only be monitored and trended by performing condition assessment on the fabric itself (such as inspection, testing and measurement). Functional testing (eg pressure, leak or deluge testing) is useful in so far as it provides assurance of functionality at the time of the test but may not provide any forewarning of impending failure or assurance for any period of further operation. Passive components tend to be long-lived and are maintained and inspected less frequently than active components.

The exclusion of active systems from the nuclear plant life extension process appears to depend crucially on the quality and perceptiveness of the on-line performance monitoring, and on the testing, maintenance and replacement schedules being up-to-date, possibly becoming more frequent consistent with the age of the equipment. The validity of this approach to equipment on offshore installations would need careful consideration, since the level of on-line monitoring may not be as great as for nuclear plant. Assurance would be needed that asset management of the active components was proactive and up to date. Given that significant backlogs in testing and maintenance are known to exist at certain installations, the approach would, at best, be applied to installations selectively. A special campaign to reduce testing and maintenance backlogs and a review of the monitoring and asset management arrangements for active components would be a minimum requirement before resources could be focused on passive components.

The definition of active and passive components may need to be adjusted for application to offshore installations. Equipment that is held in reserve or used or tested infrequently such as the fire deluge systems, the ESD valves or the HVAC dampers, although active in principle, may have to be treated as passive. It is not clear that the simple demarcation between active and passive components is sufficient to address the main risks to safety from ageing equipment offshore. Further study of how to prioritise the assessment of safety related equipment for life extension is required.

1.3.4 Organisational, management and human aspects of barrier systems

Factors that influence the performance of barrier systems include organisational controls, management processes, data and information, and procedures and human actions designed to prevent a hazard or mitigate escalation should a hazard occur. These performance influencing factors are complementary to the physical equipment and represent software, systems and the human interface. Examples of these aspects of barrier systems include the following:

- Corrosion and fatigue management systems
- Inspection procedures, maintenance, repair and replacement schedules
- Operational control procedures
- Weight management and lifting operations and routes
- Personnel knowledge and training on equipment and procedures
- Equipment records and databases
- Management of change procedures
- Emergency procedures, safety training and practices
- Senior Management attitudes to ageing processes.

Over time organisational aspects can become out-of-date or backlogged and this represents a form of ageing. The corrosion management system may no longer be suitable for current product chemistry, backlogs can develop in planned maintenance and inspection, and the plans themselves may need review or revision to reflect the state of ageing equipment. Equipment records may not be up to date with plant modifications, the impact of changes in weight and loading may not have been evaluated, and operating and maintenance manuals can become missing. An assessment of the extent and accuracy of available knowledge, and the adequacy of that knowledge to make sound judgements is an essential part of the life extension process.

At a human level, people age and change, and their level of knowledge and preparedness, particularly in the event of an emergency, have to be regularly tested and refreshed. Arrangements for maintaining a trained and competent work force with an awareness of equipment ageing and its effects is an issue to be addressed. Much of the current work force is acknowledged to be approaching retirement, and succession needs to be part of life extension planning. Loss of corporate knowledge with retiring staff is also an issue.

Demonstrating the competence of the workforce to manage ageing systems is an important challenge that the offshore industry needs to address. At present there is little guidance available on what determines suitable competence levels for offshore topside systems; the guidance in ISO 19902 relates primarily to fixed structures. However HSE Research Report 509 on Plant Ageing (HSE, 2006) proposes competences required for managing ageing pressure equipment. A list of the main ones is given below and could be used as a basis for developing suitable competences for managing topsides equipment offshore. These are:

- Understanding of relevant regularity requirements, codes of practice
- Knowledge of design and construction codes and practices
- Familiarity with the equipment concerned (design, construction)
- Understanding of relevant degradation processes
- Knowledge to plan inspection and maintenance for safety

- Experience of plant inspection, inspection techniques and NDT, and their limitations
- Knowledge and ability to undertake routine maintenance tasks and to know when to use specialist contractors
- Understanding of fitness for service assessment

The process of life extension provides an opportunity to ensure that organisational aspects of barrier systems are up-to-date and working properly. It would be inappropriate to approve life extension on an installation with a significant maintenance backlog exists or where procedures were not up-to-date, or arrangements for change management were not in place or working. As a minimum, it is suggested that these aspects would need to be remedied within a specified period as a condition for life extension to proceed.

2 Integrity Indicators

2.1 Design and operating lives

2.1.1 Original design life

At the time of construction of offshore installations, a minimum safe working life for the installation would for investment appraisal purposes have been specified as typically 20 or 25 years, although there are also examples of 60 years being specified. As a result, the purchaser would have specified a nominal design life for some equipment, particularly equipment that cannot easily be inspected. Other equipment would have been installed without a specified design life on the basis that it was fit for purpose and subject to periodic inspection and assessment.

The minimum safe working life reflected the foreseen income from the field and the minimum expected life of equipment based on current engineering knowledge and practice at the time. In some areas the design life, would have been used to set certain margins, for example, corrosion allowances or fatigue life, but more generally it would have implied a required level of quality to the purchaser, designer and fabricator. Beyond this, the significance of the design life and design assumptions has to be validated by actual experience in service.

As an indicator of integrity, the installation design life is a crude yet useful measure. It represents the limit of foresight and experience of the original designers. It is therefore a good time to take stock of degradation and integrity in the light of the future anticipated operating requirement. While integrity management to maintain safe operation is an on-going process, there is an implicit contribution to integrity assurance from the original design and specified design life. As equipment becomes older this contribution lessens until it becomes minimal when the design life is reached. At this stage it becomes appropriate to take a longer term view of integrity and provide a new basis for on-going assurance.

Duty holders are therefore expected to specify an original design life for their installations as a trigger for a life extension review. Where this information is not available, it is recommended that it is taken as 20 years from the date of commencement of commissioning offshore. A regulator could consider failure to declare a design life or undertake a life extension review after 20 years as a life terminating condition where a license to operate would be withdrawn.

2.1.2 Anticipated extended operating life

While not an integrity indicator, an estimate of the anticipated extended operating life is necessary in order for future integrity to be assessed. Therefore, it is recommended that the Duty Holder specifies in the application for life extension the operating life that is anticipated extending beyond original design life. The Anticipated Extended Operating Life (AEOL) enables a new benchmark assessment to be made that integrity will be maintained with adequate margin during this period and of the integrity management measures necessary to ensure this. While ageing of some items depends on their duty, for others it is a condition of service, unaffected by the level of production or activity. In order to cover all items and for clarity, it is best if AEOL is specified as a period of time with a specific end date.

In practice, in some cases operating life may be curtailed before that anticipated. In others, a further submission to extend life beyond that anticipated may be made. In all cases, the operating life provides a useful staging post for the purposes of regulating safety.

2.2 Compliance with standards

2.2.1 Issues to be addressed

As a potential indicator of integrity of systems, structures, and components ('equipment') for the purposes of justifying life extension, Duty Holders are recommended to determine the current extent of compliance in relation to the appropriate design, construction and functionality standards.

a) Is the equipment still compliant with the safety limits and functional requirements of its original specification and design and construction standards?

b) Would the equipment meet the requirements of modern standards? Have they been applied or incorporated on the equipment?

c) What was the quality of the original fabrication?

d) Can it be demonstrated that the equipment meets its current functionality requirements and is it fit-for-purpose?

In addition to these issues, and particularly where it is clear or significantly uncertain that equipment does not meet the original standards, it is recommended that Duty Holders also need to address:

e) Is the equipment likely to be fit-for-service during its envisaged extended operating life?

f) What changes are necessary before it can enter a period of life extension?

g) What additional life management improvements or integrity measures are needed to provide adequate assurance of integrity during the period of extended life?

Aspects a) to d) are now considered, while e) to g) are less indicators of integrity and more a criteria for life extension, which will be considered later.

2.2.2 Compliance with original specification and design and construction standards

In addressing this issue, it is recommended that Duty Holders need to determine whether the equipment still meets the safety limits and functional requirements of the original specification and design and construction standard, and evaluate if is operating within the limits prescribed. In the case of pressure equipment, relevant limits would include the design pressure and temperature, design minimum thickness, corrosion allowance, fatigue or vibration limits, environmental restrictions, safety valve and pressure relief requirements.

For active components, such as compressors or valves or heat exchangers, parameters such as pumping capacity, flow rates, closure times and heat transfer may be relevant. Other systems will have specified functional requirements for operational performance and/or sustainability in the event of fire or explosion, and these aspects need to be tested or evaluated non-destructively. Where equipment does not meet or is close to its original specified limits or functionality, further assessment of fitness-for-service is required.

2.2.3 Comparison with modern standards

For life extension, it is recommended that Duty Holders also need to consider the changes and improvements to safety and engineering standards that have been made since the equipment was constructed. A comparison with the original standards should be undertaken to determine those changes and improvements that could be relevant for the equipment installed. In some cases, old codes will have been replaced by new codes with a different methodology, or old materials and fabrication practices replaced with better more modern equivalents.

Strict compliance with modern standards is a matter to be discussed with the regulatory authority on a case by case basis, taking into account the extent to which the Duty Holder can demonstrate understanding of any risks from out-of-date practices, and has taken all reasonable practicable measures to reduce these. The comparison with modern standards can identify where the balance of an old design may need reinforcement, or where back-up systems or compensatory measures or additional integrity management tools may be usefully introduced, or where equipment should be replaced with more modern counterparts. An evaluation of the extent to which equipment meets modern standards may be helpful in this respect, but is not an essential part of the process, and may not be possible where data are unavailable.

As an example, pressure equipment and other welded fabrication designed to older codes may not have been designed or assessed for fatigue whereas this is now a requirement of more modern codes. Older equipment may have partial penetration welds for structurally significant joints which would now be full penetration, welds more susceptible to hydrogen cracking, and methods of NDT would now include ultrasonic testing, whereas the original method was only radiography. For this equipment, a fatigue assessment and management strategy would be needed if not already in place.

As another example, the thickness and type of fire protective coatings on equipment and the temporary refuge has evolved over the years, and survival and sustainability standards increased in line with technology development. Coatings on older equipment may not meet these criteria. In this instance, it might be reasonable to expect additional coating to be applied, or the original coating replaced, or additional fire mitigation measures or protection to be put into place. The extent of the response depends on what is reasonably practicable and proportionate in relation to the amount of life envisaged beyond original design life.

The design and construction of cranes for offshore duty has improved since the 1970s. For example, older cranes may have been designed with their main brake on the drive side of the gear box rather than the spool-side whereas modern practice would be to protect the active side. Protection against dropped loads then depends on the integrity of the gears and shafts in the gear box. In this case, a detailed inspection and integrity assessment of the active side components for wear and fatigue cracking would be appropriate. HSE report OTR 2001/088 (HSE, 2001) gives criteria for beyond life extension of offshore cranes.

As part of the process to justify life extension, Duty Holders should identify changes of this kind and put in place appropriate measures that would ensure modern standards of safety. Submissions for life extension more than five years beyond original design life require a greater degree of rigor than those for shorter periods, but there should be no step change in requirement for reassessment depending on the period sought. The response of the Duty Holder needs to be commensurate with the risk.

2.2.4 Standards of fabrication

The construction standards of the original fabrication are an important consideration with regard to life extension, particularly if a substantial period of life extension is envisaged. Poorly fabricated installations are more prone to ageing mechanisms, and the most vulnerable systems may require replacement or reinforcement. An assessment of the standards of the fabrication should be made, recognising features indicative of good or poor practice. Typical features indicative of poor fabrication standards include:

- Misaligned welds, partial penetration, weld repairs, welding spatter and defects
- Poor finishing such as incomplete or thin painting or coatings
- Poorly fitting joints, or overloaded seals, glands and gaskets, leaks, weeps
- Vibrating and out-of balance rotating equipment
- Stiffness or looseness in moving parts and mechanisms
- Insufficient fixtures and supports
- Damage or excessive force applied during installation.

2.2.5 Functionality requirements and fitness-for-purpose

In addition to determining if equipment still meets its original specification and design limits is determining if the equipment is functional and fit-for-purpose within its current application. The current conditions of operation may be less or more onerous to those originally assumed for the purposes of design. In some cases equipment may have been down rated to less demanding duty, but other equipment may be being used in environments more aggressive that those for which it was designed (eg sour service). An evaluation of functionality and fitness-for-purpose in current operation is an indicator of integrity.

For some equipment functionality or a lack of functionality may be obvious from visual inspection, performance or reliability. The functional safety of a corroded walkway or handrail is evident to a trained inspector, failure to start and break downs of active systems, and leakages from joints are clear and unambiguous. A systematic walkdown and review of plant performance of the plant will reveal many of these aspects.

More difficult to identify might be a fall-off in flow rate performance of pumps, valve closure times and internal corrosion of pipes and vessels, and longer term reliability problems and failures. In order to obtain the data from which an evaluation of functionality can be made requires monitoring, inspection, testing and trend analysis. This is considered next.

2.3 Inspection, monitoring testing and data trend analysis

2.3.1 Overview

Management of ageing systems requires good knowledge of the current and previous structural states of an installation and its topsides. The quality of data available on these states improves the opportunity to make the case for life extension. Lack of relevant data may be a serious barrier to extending life without close monitoring.

2.3.2 Initial condition of an installation

The design, fabrication and installation (DFI) résumé provides data and information of these phases of an installation. NORSOK Z-001 “Documentation for Operation” (NORSOK, 1998) outlines the main objective of the DFI Résumé as providing the operation’s organisation with a concentrated summary containing the most relevant data from the design, fabrication and installation phases, including which areas are the most critical and a general description of the installation at the start of the operational phase. It also states that the DFI résumé should provide all the information required for inspection and maintenance planning throughout the entire lifetime of the installation. NORSOK standard N-005 on ‘Condition Monitoring of Load Bearing Structures’ requires operators to prepare a summary document containing key information to include details of the design basis, condition monitoring concept, areas of vital importance to the structural integrity and functional performance.

It is known that for several older installations the quality of the DFI résumé is limited with significant gaps in the data from the design, installation and fabrication phases. This problem is exacerbated when the owners of the installation have changed, if the original design companies are no longer operating, or some of the original equipment is no longer manufactured or supported. It may be possible to acquire data to supplement some of the original data, such as identifying the structural materials used, the detailed geometry of the installation or details of particular installed equipment.

NORSOK Z-001 also lists the system design reports required to provide sufficient details of the design relating to system parameters. These include operational data and limitations, bases for choice and use of corrosion inhibitors and details of the fire protection systems. It also states that an Operations Manual should be produced for each installation, which describes each system’s mode of operation. These include start-up and shut-down procedures, process and emergency shut-down systems, equipment data and safety procedures.

2.3.3 Inspection and maintenance data

Maintenance of topside equipment is a basic requirement for safety and operational performance. It is important that data on previous maintenance programmes and replacement histories are available for planning future inspections and in particular for assessing life extension. Performance test data is also a necessary requirement, both for assuring current operations and their safety and in justifying life extension.

In terms of the structural aspects of the topsides NORSOK standard N-005 on 'Condition Monitoring of Load Bearing Structures' (NORSOK, 1997) identifies an initial condition structural survey during the first year of operation of an installation, in order to enable an overall assessment of the structure to be undertaken to meet the defined acceptance criteria. Early damage or deterioration could also be identified (first stage of bath tub curve). In addition NORSOK N-005 states that periodic condition inspections should be carried out regularly, according to the prepared periodic framework programme.

The same standard also states that special inspections should be carried out after extreme/accidental events such as severe storms, dropped objects. The same type of inspection could also be needed to monitor repairs or other maintenance aspects. Data from all of these condition monitoring programmes is valuable input to life extension assessments.

Effective maintenance requires recording and analysing operating data about the equipment. This might include metrics of the condition at the time of maintenance, any defects or signs of ageing, repeated or more frequent replacement of consumables, and other relevant operating performance parameters. Information about failures and unscheduled shutdowns, abnormal operations, or from condition monitoring can be analysed and trended to provide insights to guide future maintenance strategy.

2.3.4 Monitoring and test data

While monitoring is the passive collection of data relating to integrity, testing is more a trial of functional performance. Various types of monitoring and testing are made on offshore installations for different reasons, and as life is extended and greater attention to integrity and performance is required, the scope and frequency of monitoring ad testing may need to increase. As a minimum a review of the adequacy of current arrangements is needed.

Typical monitoring activities relating to corrosion include the analysis of product composition, the activity of corrosion inhibitors, levels of cathodic protection, thickness loss measurements, coating assessments, and ingress of water under insulation. For fatigue, monitoring can include vibration displacement, and the logging of major operating cycles and transients and strain gauging and in conjunction with theoretical assessments. Process monitoring of gradual changes in pressures, flow rates and temperatures can often be good indicators of the effects of underlying ageing mechanisms. Trends of decreasing performance can be indicators of, for example, wear, fouling, leakage, or loss of insulation.

A range of testing is routinely undertaken on safety critical systems, such as the sensitivity of gas and smoke monitors, start-up and delivery of fire protection and deluge systems, ESD valve closure and blow-down times, HVAC damper efficiency etc. While the meeting of performance standards may be routine early in life, life extension requires that more attention is made to reductions in performance, even though standards may still be met. Reductions in performance are indicators that some action may be needed before performance standards are compromised.

For ensuring safety during life extension, Duty Holders need to consider new forms of monitoring and testing as may be needed to address the uncertainties. In some cases this may mean periodic destructive testing, such as the testing of fire protection tiles. Monitoring and testing need to be supported by appropriate analysis and response to data collected.

2.3.5 Failure and incident data

During the life of an installation it is likely that there will have been a number of failures of equipment requiring maintenance or replacement, as well as safety incidents and near misses. The response to equipment failure and other incidents and improvements identified are necessary input to an assessment for life extension. Valuable information can be obtained about the rate of degradation and failure mechanisms which could apply to other equipment. Inadequate investigation of safety related failures and incidents or failure to implement identified improvements are barriers to life extension.

2.3.6 Assessment of quality and trend of data in relation to life extension

As part of the case for life extension it is important that the quality of the data available from inspection, monitoring, maintenance and failure analysis is assessed, including that for the DFI résumé. Where data is missing or of poor quality it may be necessary to check with previous owners or designers to update the data. If this proves difficult, the case for life extension may require additional testing or inspections to provide adequate data to demonstrate fitness for purpose in the life extension stage. An alternative approach is to use higher than normal design safety factors to demonstrate integrity. These steps may form an important part of the life extension assessment process.

An analysis of data collected needs to be combined with an awareness of ageing mechanisms so that the significance of trends may be understood and correctly interpreted. Appropriate technical and engineering expertise is necessary to link the data to the equipment, and for the use of appropriate statistical analysis. Communication routes within the organisation may need to be enhanced or become more formalised during life extension so that the appropriate response from offshore operations to ageing trends can be made.

2.4 Risk factors, assessments and guidance

2.4.1 Factors influencing risk and rate of ageing

In reviewing equipment for life extension, Duty Holders need to be aware of any factors during the history of the equipment that could increase the risk and rate of ageing, and hence advance the time when its effects become significant. These risk influencing factors are leading indicators to what could later become a shortfall in integrity. The extent to which these factors will be recognised and known depends on the expertise of the Duty Holder and the organisation's corporate memory and records.

Examples of factors that increase the risk and rate of ageing of pressure and hydrocarbon containing equipment are given in Table 4 below. They are grouped according to the type of activity being undertaken during equipment life. The list is based on many years operating experience in the on-shore and offshore petrochemical industry. It is intended to draw attention to items where the justification to extend life may require extra work.

In proposing a case for life extension, Duty Holders need to demonstrate that they have undertaken a review that would have been capable of identifying the occurrence of such factors for all classes of safety critical equipment.

2.4.2 Fitness-for-service and remnant life assessment

Where ageing has taken hold and equipment is found in a degraded state, Duty Holders are expected to undertake a technical assessment, functional or overload testing or other action to demonstrate fitness-for-service and remnant life. The first action may be to make an assessment against the limits of original design code standard or performance specification. If these limits are not achieved a more specific demonstration of fitness-for-service and remnant life is required.

For structural and process equipment and welded components a range of assessment methodologies are now available in the public domain. These include:

- BS 7910 Assessment of flaws in metallic structures
- API RP 579 Assessment of fitness-for-service (refinery equipment)
- DNV RP F101 Assessment of corroded pipelines

The main types of assessments required are likely to be of wall thinning due to corrosion and of fatigue damage. A review of the suitability of the materials for resistance against environmentally assisted and stress corrosion cracking is advisable when there is a change of feed product or process or process conditions. The results of fitness-for-service assessment and the margins available are key indicators of the integrity of aged equipment.

2.4.3 Current guidance on the management of ageing and life extension

Despite the increasing importance of life extension for offshore installations the management of life extension of these structures and the associated process equipment is a field that has only recently received attention and there is relatively little guidance available in the public domain. The structural reassessment of fixed steel structures for life extension (Ersdal and Langen, 2002, Sharp et al, 2001 and 2002, Zuccarelli et al, 1991) has probably received more attention than topside equipment. While companies, regulators and inspection authorities have compiled data on the instances and effects of ageing equipment from inspections and incident investigations, very little of this data is openly available for transferring the experience across the industry.

In recent years, some progress has been made with regard to raising awareness and providing guidance for the management of ageing top-side equipment. In particular, the Key Programme 3 initiative (KP3) was launched with the aim of managing installation integrity on the UKCS, with the increasing number of ageing installations as one of the drivers. Much of this has been directed toward reducing the number of hydrocarbon leaks (Cutts, 2005). Further work on degradation mechanisms for particular safety critical elements, including fire protection systems, is in progress, supported by the UK Health and Safety Executive.

In 2006, the HSE published Research Report 2006/509 on Plant Ageing – Management of equipment containing hazardous fluids or pressure (HSE, 2006). This report is intended as an introduction to the management of pressure and process equipment, and sets out a structured approach that may be followed. It proposes that, for the purposes of lifetime management, it may be helpful to consider an item of equipment as having four stages in its life, each having certain characteristics and requiring a different integrity management, inspection and maintenance strategy. The report contains sections on the awareness and organisation required to management ageing equipment, as well as more technical Sections on identifying ageing and addressing equipment in an aged condition.

In 2001 HSE published a review of corrosion management for offshore oil and has processing (HSE, 2001). This is currently being updated through a project managed by the Energy Institute, which will produce Energy Institute Guidance on Management of Corrosion for Offshore Oil and Gas Installations. The Report presents a framework for managing corrosion based on the concept of the six stages of a safety management system. It includes a ‘Guide to Good Practice’, providing practical examples of how the framework can be implemented. Links are drawn to risk based inspection planning, corrosion under insulation, and corrosion protection systems and monitoring.

In support of its inspection inspectors, the HSE has published a guide to external corrosion offshore (HSE, 2007b). The guide is intended to ensure consistent judgement of the extent of external corrosion related to hydrocarbon and other systems. The guide identifies six common forms of external corrosion and provides information on where to look and what to look for. Examples of external corrosion are reproduced from the guide in Figures 4a-h of this report below.

HSE Information Sheet No 12/2007 (HSE, 2007c) provides advice on acceptance criteria for damaged passive fire protection (PFP) coatings. The causes and types of damage to

PFP coatings are reviewed, and three severity levels are proposed as a basis for establishing criteria for evaluation of allowable damage and deterioration consistent with the risk assessment. Examples of ageing to PFP coatings reproduced from the Information Sheet are shown on Figures 5a-c.

A Corrosion Work Group was established as part of the OLF Gas Leak Reduction Project, designed to reduce the number of gas leaks on the Norwegian Continental Shelf. The Corrosion Work Group reported in 2004 (OLF, 2004) and made a number of practical recommendations for the management of corrosion and fatigue. Particular attention was given to the positive identification of materials of all hydrocarbon systems subject to corrosion to verify whether they are according to specification and their suitability for current duty. The management of corrosion under insulation was considered with respect to NDT systems able to detect loss of wall thickness, hot-spots or moisture without removing the insulation. Major changes in operations or modifications were identified as requiring greater vigilance for vibration.

HSE Offshore Technology Report 2001/088 defines Beyond Lifetime Criteria for Offshore Cranes (HSE, 2001). It reviews current regulatory requirements and best practice to enable checklists to be produced that can assist the assessment of safety cases justifying continued operation of pedestal cranes. Once they have exceeded design life. The report highlights degradation mechanisms for different parts of the crane structure and actuating equipment, and proposes mitigating actions that can be taken.

An approach for identifying and ranking process piping systems according to their risk of vibration fatigue has been published by the Marine Technology Directorate (MTD, 1999). Follow-up work provided a screening assessment and guidelines for managing transient vibration for fast acting valves (HSE, 2002). These documents present a structured approach for identifying the sources of vibration, the factors that enhance the risk of vibration, and the locations most vulnerable to fatigue, such as small bore connections.

The management of maintenance of offshore assets, particularly topsides equipment offshore has recently been addressed by a joint industry project, involving HSE and four operators, organised by the Energy Institute. This project involved two of the authors of this report and developed an approach for good practice management based on using a capability maturity model. Management of ageing systems were implicitly included in the processes. The report is due to be published by the Energy Institute shortly (EI, 2008).

TWI and the authors of this report are currently involved in another project funded by the Energy Institute on developing performance indicators of ageing of safety critical elements for offshore installations. It is expected that this work will develop useful guidance that would relate to the requirements for life extension of installations in Norwegian waters. The work will be made available to the industry through the Energy Institute.

Table 4 Factors influencing the risk the rate of ageing

a) Design and construction (including fabrication and installation)

Accelerating factor	Resultant effects
Excessive force to (typically) fit pipework	Misalignment of flanges and uneven gasket sealing, high loading on pipework. Deformation of bellows
Misalignment of vessels	As above. Also uneven fluid distribution in exchangers
Uneven bolting of flanges	High flange loads; flange leaks
Stagnant areas Complex pipe routing	Local environments Air locks and non-draining. Pipework hammer.
Inappropriate storage of equipment	Corrosion prior to installation. Mechanical damage. Contamination of surfaces.
Use of contaminated water for pressure testing	Corrosion damage during pressure testing. Sensitisation to further corrosion damage due to (eg) pitting. Corrosion/blockage in service due to residues (possibly leading to overheating). Fouling/corrosion due to biologically active species.
Failure to remove transport stays (particularly on bellows)	Overloading of pipework or vessel. Damage to rotating equipment
Incorrect, inadequate or ineffective vent systems	Backflow from vent or into vent from contents & corrosion. Vacuum damage from reduced pressure
Local environment influences	Cooling exhaust drift, steam trap release, adjacent leaks, can all be environments which promote local corrosion.
Crevices or dead spaces from design / manufacture	Local environments created which may cause or accelerate corrosion
Inadequate support of small bore connections	Vibration and fatigue

b) Commissioning

Accelerating factor	Resultant effects
Over filling equipment due to lack of knowledge or calibration	Deterioration of safety items; eg contamination of relief valves, flame arrestors etc. Blockage or deposition in associated systems
Poor control in firing of heaters	Risk of damage to refractory linings. Overheating of internals and pressure boundary
Residual contamination in equipment	Blockage and associated problems such as overheating. Corrosion (similar effects to using contaminated water on pressure test, see above)
Poor process control	Operating conditions outside design limits, risk of excessive forces/temperatures causing damage or failure.

Table 4 (continued) Factors influencing the risk the rate of ageing.

c) Operation (direct control of plant)

Accelerating factor	Resultant effects
Poor water treatment	Corrosion (similar effects to using contaminated water on pressure test, see above). Fouling and blockage causing overheating.
Overload and thermal transients	Thermal fatigue loads. Mechanical stressing.
Poor flow control	Risk of fouling / deposits and blockage. Erosion. Cavitation. Water or steam hammer causing fatigue.
Poor temperature control (may be linked with flow control)	Increased corrosion rates. Risks of contaminant concentration mechanisms. Risks of condensation. Potential for sub-zero exposure (brittle fracture or freezing damage). Overheating traced lines.
Hot or cold starting	Thermal cycling and fatigue. Overstressing of components through expansion and contraction.
Control of 'idle' or temporary off line periods	Corrosion due to stagnant conditions. Ingress of air or moisture to 'dry' systems. Stratification in tanks. Freezing damage

d) Operation (indirect or external influences)

Accelerating factor	Resultant effects
Loss of cathodic protection	Increased corrosion rates
Trace elements	Eg chlorides or caustic in services (water, steam, air) causing local corrosion or cracking
Trace contamination or impurities in feedstock / product	Local corrosion or cracking. Product contamination. Risk of solids or sludge build up.
Change of feedstock source Sour service	Influence on plant control and performance Deterioration of unrated materials.
Supply interruptions (services, raw materials)	Cyclic running or rapid / uncontrolled plant shutdown
Poor or inadequate instrumentation	Control parameters exceeded
Effects of agitation or stirring	Locally increased flow rates

e) Maintenance and modification control

Accelerating factor	Resultant effects
Poor understanding of equipment by maintenance resource	Increased risk of deterioration or leakage after ineffective maintenance
Lack of specification of modification or repair	Increased risk of deterioration of repairs, failure of repairs
Retightening bolting	Shortened life of bolting or gasket
Changes of spares supplier from OEM	Risk of reduced integrity from inferior components
Defects or residue after maintenance	Increased risk of corrosion or blockage in plant
Sacrificial anodes not replaced	Ineffective cathodic protection leading to enhanced corrosion rates
Poor control of hydraulic pressure testing	Residues of water may cause corrosion. Deterioration of 'fragile' equipment by stressing
Damage to coatings not reinstated	Underlying material exposed to detrimental environment
Equipment modification	Design may be outside original limitations
Operating procedure modification	Operation may be outside original limits

Source HSE, Ref HSE 2007b

a)

Source HSE, Ref HSE 2007b

b)

Figure 4 Examples of external corrosion:
a) Wall thinning from external corrosion;
b) Corrosion of bolted connections.

Source HSE, Ref HSE 2007b

c)

Source HSE, Ref HSE 2007b

d)

Figure 4 (continued) Examples of external corrosion:
c) Corrosion of valves;
d) Corrosion of valves.

Source HSE, Ref HSE 2007b

e)

Source HSE, Ref HSE 2007b

f)

Figure 4 (continued) Examples of external corrosion:
e) Corrosion of fire and deluge system;
f) Corrosion around supports.

Source HSE, Ref HSE 2007b

g)

Source HSE, Ref HSE 2007b

h)

Figure 4 (continued) Examples of external corrosion:
g) Corrosion under insulation;
h) Corrosion under coatings.

Source HSE Ref HSE 2007c

a)

Source HSE, Ref HSE 2007c

b)

Figure 5 Examples of damaged passive fire protection (PFP) coatings:
a) Unretained and disbonded material on supporting webs of fire/blast wall;
b) PFP eroded with retention mesh exposed but intact;

c) Source HSE, Ref HSE 2007c

Figure 5 (continued) Examples of damaged passive fire protection (PFP) coatings:
c) Surface cracks, chips, gouges, scrapes, spalling and topcoat loss but with reinforcement not exposed.

2.5 Stages of ageing

2.5.1 Classification of equipment

In order to assist management of the process of life extension, Duty Holders may find it helpful to classify safety critical equipment forming barrier systems into a staged scale of ageing according to the integrity indicators. A three stage classification scale for ageing equipment is suggested, corresponding approximately to the plateau and end of life regions of the classic accumulated damage versus time graph (Figure 6). This plot is the area under the bath-tub curve of failure or damage rate versus time (Figure 7).

For completeness, a fourth stage, Stage 0, that of initial burn-in after commissioning, can also be defined, where equipment ages as a result of bedding-in. This stage is unlikely to be present in a life extension context. The stages defined here correspond approximately to the four stages of equipment life given in the HSE Research Report 2006/509 on the Management of Plant Ageing (HSE, 2006).

Criteria for identifying the stage of ageing that equipment has reached are suggested as follows.

Stage 1 – Isolated

- Evidence of initial localised ageing (superficial damage, rust spots, blisters etc)
- Equipment still well within its design or performance limits
- Up to date records, knowledge and inspection data
- Minor backlogs or deferrals

Stage 2 – Rooted

- Ageing taken hold and is a cause for concern but still localised (cracking, corrosion)
- Equipment approaching its design or performance limits
- Records, history and inspection/operating data incomplete or not up to date
- Some significant maintenance/inspection backlogs or deferrals on particular items

Stage 3 – Widespread

- Accumulated and widespread ageing damage and effects
- Design or specified performance limits exceeded
- Fitness-for-service cannot be demonstrated or is in question
- Significant uninspectable regions of equipment susceptible to ageing
- Complete lack of records, history or inspection/operating data
- Substantial and long deferrals and backlogs in planned inspection and maintenance

Duty Holders are recommended to review their equipment to determine which stage is appropriate. As soon as at least one criterion is satisfied for a particular stage, the equipment should be classified into that stage. Classification in this way enables a more holistic view to be taken of the state and viability of the equipment for life extension.

2.5.2 Assessment of transitions in the stage of ageing

The stage of ageing can be determined by application of the definitions given above. The transitions between one stage and the next are not clearly defined, but a change in the damage and damage rate may give some clue. Within Stage 1 the damage rate is relatively low and constant and the equipment gives little or no cause for concern. Degradation is isolated and normally dealt with by routine maintenance. This stage is established after commissioning when any initial higher rate of damage accumulation (Stage 0) falls off.

The transition from Stage 1 to Stage 2 is marked by an upturn in the damage rate from being at a relatively low and constant to a higher rate that is increasing by a measurable amount within the interval between shutdowns. The degradation or change in performance

is quantifiable, and equipment is starting to approach its design limits. Lack of information or maintenance and inspection backlogs have reached a level where confidence in the continued reliable performance of the equipment has been eroded.

In the transition to Stage 3, damage becomes widespread and accelerating at a rate where fitness-for-service cannot be assured until the next shutdown. Design or performance standards may not be achieved, and temporary repairs or restrictions may be necessary to allow the equipment to continue to operate. There is no confidence that the equipment will operate or function reliably or for any specific period.

2.5.3 Integrity indicators according to stage of ageing

As equipment ages, the approach to the selection and application of integrity indicators should change. When ageing damage is isolated (Stage 1), integrity indicators are needed to *confirm* that the state of the equipment is as expected from design considerations. After ageing damage becomes established (Stage 2), a more *deterministic* and quantified approach is necessary as the level of damage and the rate at which it is accumulating are important inputs into the assessment of integrity and remaining life. When Stage 3 is reached and the ageing damage is widespread, indicators are needed to continuously *monitor* the equipment's condition as any further deterioration could threaten safe operation.

At the point when life extension is considered, the following indicates the expected approach to integrity management depending on the stage that ageing has reached.

Stage 1

- The type of inspection, the frequency and scope are sufficient to confirm the equipment remains in Stage 1 as it enters extended life.
- Only limited maintenance action beyond the routine is required for life extension.
- Records and documentation are brought fully up to date.

Stage 2

- A thorough condition-based and deterministic inspection is required for life extension.
- The type of inspection, frequency and scope are selected to ensure known or anticipated ageing damage are detected before safety margins are threatened.
- Fitness-for-service/remnant life assessment required for anticipated extended life.
- Repairs and major maintenance necessary before entering extended life.
- Backlogs in maintenance and records need to be addressed.

Stage 3

- Close condition monitoring is needed to justify any further service of equipment with widespread damage.
- Inspection techniques are selected with special relevance to detecting, quantifying and monitoring widespread damage due to ageing
- Maintenance data is frequently updated and regularly monitored.
- Major repairs and revalidation are required for life extension.
- Replacement or decommissioning required within a short period.

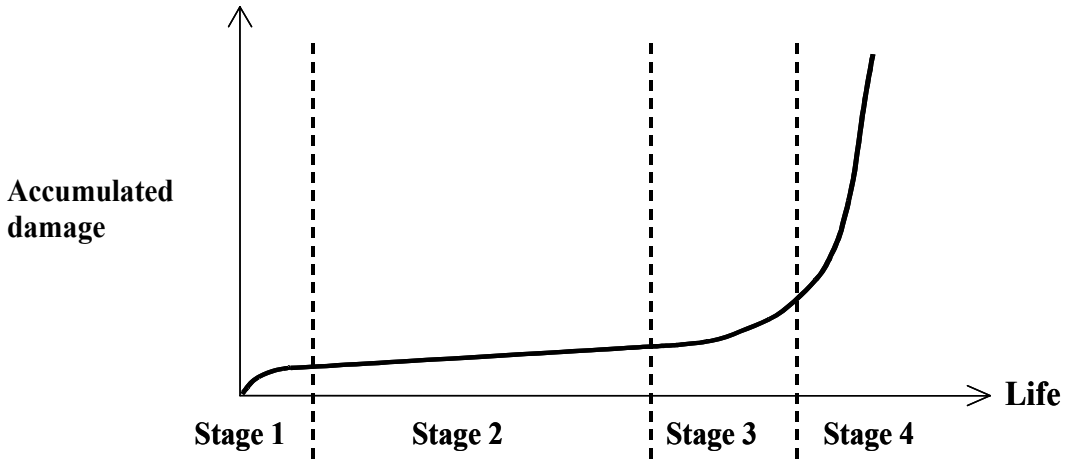

Figure 6 Idealised plot of accumulated damage versus time.

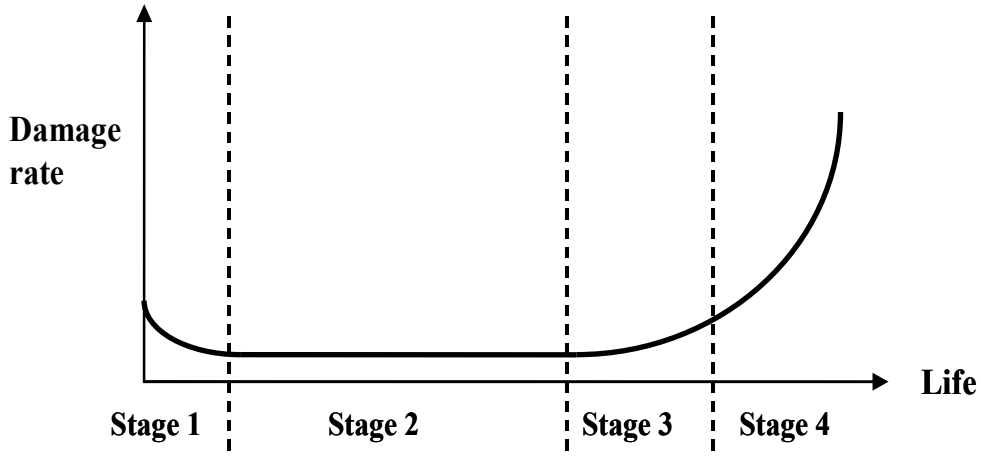

Figure 7 Idealised bath tub curve showing damage accumulation rate with time.

3 Generic Framework for Life Extension

3.1 Application for consent to life extension

The aim of the application for consent to life extension is to demonstrate and document that the installation is fit for continued safe operation during the life extension period. The application should describe the barrier systems that underwrite safety and contain an analysis of their current and predicted integrity and performance. The information can be presented in a synthesized and evaluated and, and reference made to other more detailed reviews and assessments as appropriate.

Typical contents of the application should:

a) State the original design life and anticipated extended operating life of the installation.

b) Define each barrier system in terms of the hazards it is designed to prevent or mitigate, and the safety critical equipment, structures and components constituting the system.

c) Identify the integrity/functionality of the equipment/structures/components required in order that the barrier systems can perform their function to an appropriate standard.

d) Assess the design and current performance of the barrier systems against modern standards, and, where reasonably practical for the period of extended life anticipated, initiate improvements to bring the performance and design to modern standards.

e) Report on the historic performance of the barrier systems in terms of their performance indicators, reliability, failures and reportable incidents, repairs and replacements.

f) Determine the mechanisms and effects of ageing of the equipment and components, both historically and potential threats during the life extension period, which may reduce the performance of the barrier systems and limit safe operation.

g) Report on the current performance and condition of the barrier systems in terms of the stage and magnitude of ageing of their equipment/structures/components in relation to the original specification or design and construction standard, and identify any gaps/uncertainties in knowledge.

h) Report on the current state of scheduled maintenance, and identify where gaps/uncertainties in maintenance exist.

i) Provide an assessment of the expected future performance of the barrier systems in terms of the fitness-for-service of their equipment/structures/components during anticipated extended operating life, and identify any reduction in margins, gaps/uncertainties or life limiting features predicted within this period.

j) Review and report any changes to current asset management plans (monitoring, inspection and maintenance schedules, testing, repairs, replacements) that will ensure the continued performance of the barrier systems and address any gaps/uncertainties within the anticipated extended operating life.

k) Where such measures are not available at reasonable cost, to determine the period of life extension that would be acceptable to the regulator.

l) State the management structure, competencies and numbers of asset specific and support work force that would be employed or contracted to manage and maintain the ageing installation during the life extension period.

The application will need to draw on a wide range of data including inspection and test reports, operating and maintenance records, design and construction data, manufacturers' data, failure and incident reports, and technical assessments. Specific ageing threats, such as corrosion and fatigue, may be treated within the context of their respective management plans. A conclusion with regard to the acceptability and limits of life extension is required.

3.2 Organisation and management

While it is the responsibility of each Duty Holder to decide on the organisation and management that are most appropriate to prepare the application for life extension, and to manage the life extension phase it subsequently, there are some important attributes. The organisation should have a sufficient level of maturity and systems in terms of being able to obtain and analyse condition and performance data, to anticipate change, and to react appropriately when ageing effects become significant. The application for life extension therefore needs to address management and work-force issues, and in particular:

a) To demonstrate that the organisation has recognised the challenges from ageing installations within its management structure and responsibilities.

b) To show that the work-force and contractor support has adequate experience, competence and training in place with respect to ageing issues.

c) To define the key roles and responsibilities required to manage ageing issues, with appropriate resources and communications.

d) To highlight the management measures that will differentiate consideration of life extension and longer term ageing issues from day to day operations.

e) To show that the organisation is suitably connected to benefit from the experience of ageing installations worldwide.

Many organisations will appoint a multi-disciplinary life extension team under a senior manager responsible for developing the life extension application. The team would typically contain operations, inspection, maintenance, design, integrity, and safety engineers, with inputs from specialists such as metallurgists and chemists as required. While the team should address the life extension issues of a particular installation, representations from other installations with similar equipment, contractors and consultants with appropriate experience can be beneficial to the process.

The processes for preparing and implementing an application for life extension are a matter for each Duty Holder to decide. As an example, the following flow diagram (Figure 8) indicates many of the processes and stages that might be expected. It would be normal for the Duty Holder to provide the regulator with a process map specific to the installations under consideration, and to discuss the approach and results at each stage.

Some Duty Holders may find it helpful to hold a series of life extension review meetings or workshops, each centred on one or more barrier systems. The meetings would bring together a wide range of experience and expertise relating to the engineering, maintenance and integrity of the system under consideration, including appropriate, contractors and consultants. The aim of the meeting would be to foresee the threats from ageing that could arise in extended life from a wide ranging discussion of the engineering and materials, functionality and operating history, maintenance and inspection data, and predicted future conditions of the system. An outline for such a workshop is given in the Appendix.

The output from the workshop would form the basis for the development of future integrity management plans and inspection and maintenance schedules. Areas where there was uncertainty could be identified for more detailed analysis. An expert elicitation of this kind is a good way of stimulating open discussion and interdisciplinary thinking about ageing.

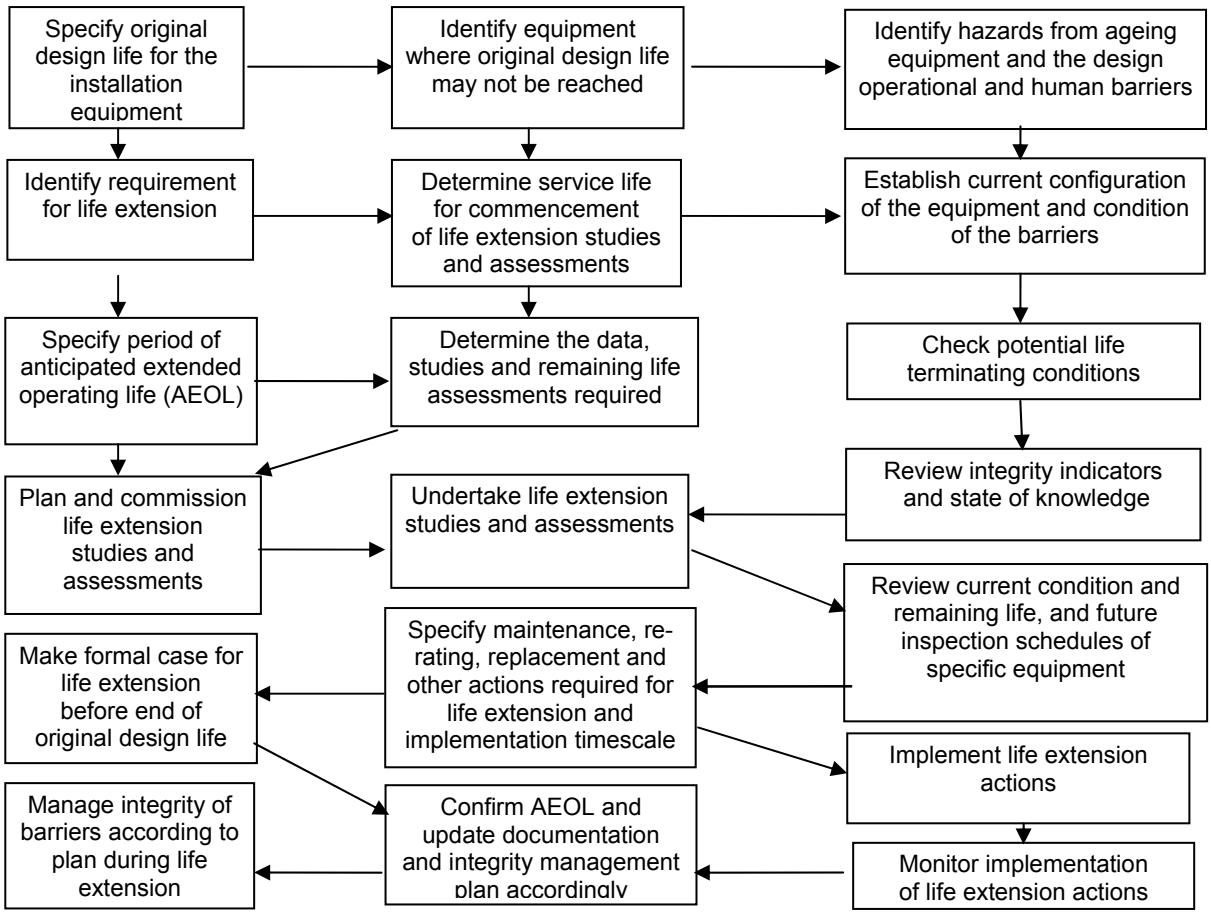

Figure 8 Example process flow diagram for life extension application.

3.3 Application assessment, acceptability and checks

The assessment by the regulator of an application for consent to life extension should examine the evidence put forward for meeting the requirements for life extension outlined earlier in this report. The process of assessment should require inputs from several disciplines, including specialists in safety, offshore engineering, and human and organisational factors. At the end of the application assessment process, the regulator should be convinced that the following acceptance criteria are satisfied:

a) That there are no design criteria fundamental for safe operations that are predicted to be compromised within the life extension period by ageing or other influences.

b) That the current condition and functional performance of the barrier systems is known from recent data, and any areas of deficiency or uncertainty identified are being addressed in order to meet required standards of performance.

c) That any backlog in maintenance and inspection has been reduced to a minimum, and that all reasonable steps have been taken to resolve outstanding issues and review future schedules in accordance with current knowledge and prudent foresight.

d) That there are adequate measures in place to ensure that the integrity and performance of barrier systems will be monitored, maintained and tested during the life extension period, and that any significant improvements that would benefit integrity and safety during life extension are being initiated.

e) That the organisation has the management, resources, skills and capability adequate to manage ageing during life extension.

Table 5 provides examples of checks that could be made to verify the criteria above from the documentation supplied, interviews, audits and physical inspection.

Areas of plant that cannot be inspected require particular attention. The Duty Holder should be expected to evaluate the types of failure that could occur in these areas, determine if failure would be localised or more general, the safety significance of the consequences resulting from each type of failure, and whether there is any evidence from any source of ageing taking place and impending failure. In areas where there is real cause for concern a sample destructive examination of the locations most likely to be vulnerable may be appropriate.

Alternatively, a degree of failure may need to be assumed and suitable mitigation measures put in place where the consequences of such failure would reduce safety. Measures might include extra monitoring, detectors, strengthening, secondary containment, reinforcement, and additional fire and blast walls. In some situations, leak-before-break arguments may be applicable, where the leak can be safety contained and readily detectable, but this may be difficult with HC gas systems. The development of non-destructive testing techniques to gain future access to areas that cannot be inspected should be encouraged.

Life extension is inevitably a period where there is greater degree of uncertainty and where increased vigilance is required by both the Duty Holder and the regulator. There needs to be increased emphasis on the specification of inspection, maintenance and test schedules and the use of on-line monitoring where appropriate. The systems for the review and analysis of results from these measures needs to be sufficiently rapid and thorough as to be able to pick-up and respond to a change in the rate at which ageing is occurring. Major failures and other incidents as a result of ageing need to be investigated and reported at a sufficiently senior management level. Ageing damage resulting in defective equipment should not be allowed to become widespread to a point where safe operation is threatened.

Table 5 Checks and follow-up actions for application assessment criteria

Criterion	Example checks	Possible issues outstanding	Mitigation actions recommended
Assess design criteria for maintaining safe operations during extended life	Assess comparisons of original design against modern standards.	Determine gaps and changes in standards since original build	Assess implications of gaps for safety
	Examine range of ageing mechanisms considered within original design basis.	Identify any omissions (eg equipment not designed for fatigue)	Analyse with modern methods. Plan for inspection to manage remaining issues
	Identify areas where original construction may not meet modern safety requirements.	Safe operation could be compromised during life extension without improvements	Suggest Duty Holder plans improvements that are reasonably practicable
	Determine if the HAZOPS analysis is valid for current configuration and operating procedure.	Configuration has been changed without reassessment of HAZOPS	Suggest Duty Holder revises HAZOPS and includes potential ageing issues
Assess barrier condition, survey performance tests and technical assessments	Examine evidence of condition from selected survey inspection reports	Uninspected areas and other uncertainties	Ensure that alternative measures are in place to compensate for lack of knowledge
	Examine results of selected performance tests and assessments	Evidence of deterioration in barrier condition and performance	Request analytical review to predict future performance and sensitivity to range of uncertainty
	Identify any gaps/uncertainties regarding fitness for service over the life extension period	Fitness-for-service cannot be guaranteed over the life extension period on the basis of current knowledge	Ensure that inspection and monitoring are sufficient to address gaps/uncertainties in current knowledge
Assess level of inspection and maintenance backlog, and whether all reasonable steps and improvements have been taken or are in hand	Examine level of any inspection and maintenance backlog against schedule	Backlog is not as low as could reasonably be expected	Insist that backlogs are addressed within a specific period as a condition for life extension
	Obtain list of proposed improvements and date for implementation	Identify any significant improvements absent from Duty Holders list and request justification	Where improvements are not available at reasonable cost, ask Duty Holder to revise the period of life extension that is acceptable

Table 5 (continued) Checks and follow-up actions for application assessment criteria

Criterion	Example checks	Possible issues outstanding	Mitigation actions recommended
Monitoring, maintenance and testing of barrier systems during life extension	Examine integrity management plans and inspection schedules for selected equipment subject to ageing	Integrity management plans and inspection schedules do not address potential new ageing mechanisms	Ask Duty Holder to revise plans and schedules to meet regulatory goals.
	Determine justification for how regularly these will be reviewed	Justification is based largely on historic data	Suggest Duty Holder strengthens review frequency criteria.
	Determine the trend in the level of maintenance and inspection that the Duty Holder planning during life extension	Trend in resource planning is static or decreasing	Ask to Duty Holder to justify maintenance and inspection plans.
Review adequacy of organisation management, resources, and capability	Determine if the management responsibilities for ageing issues during life extension are clearly defined and sufficient to deal with expected issues.	Management proposes no or little change to current arrangements despite new threats emerging.	Suggest Duty Holder appoints a life limiting features manager/team to advise on ageing issues.
	Assess the level of technical expertise available in areas such as corrosion/fatigue management, materials engineering, defect and fitness-for-service assessment, welded and non-welded repairs.	Organisation has limited in-house capacity and only occasional contact with external advisers	Suggest Duty Holder increases in-house expertise or developments appropriate partnerships with external organisations.
	Determine if offshore work force has received any training to improve their awareness of ageing issues.	Work force has received no special training.	Suggest Duty Holder provides specific ways to make work force more aware of ageing issues.
	Determine what changes in organisation have made following incidents and failures due to ageing.	Any changes implemented are not sufficient to prevent a reoccurrence.	Suggest Duty Holder undertakes root cause analysis at a sufficiently senior management level.
	Determine whether the Duty Holder is accessing experience of ageing from across the offshore industry	Duty Holder relies on internal experience only	Suggest Duty Holder gets more involved in industry groups, forums, joint industry projects, professional institutions, research.

3.4 Obstacles and conditions to life extension

The following may be regarded as obstacles and conditions for consent to life extension.

a) **Failure to declare an original design life or anticipated extended operating life**

In the event that a Duty Holder fails to declare an appropriate original design life for the installation for the purposes of applying for life extension, the regulator is recommended to enter discussion with the Duty Holder to agree a timetable for the process to commence. The authors of this report suggest the time for commencement of the life extension application should take account of any evidence of component failures as a result of ageing and any other concerns. Failure to agree a timetable for life extension within a reasonable period, would, in these circumstances, limit operation beyond a certain date.

In a case for life extension, the Duty Holder should ideally declare an anticipated extended operating life beyond original design life against which assessments of remaining safe life of the equipment can be judged. It is envisaged that the anticipated extended operating life will usually be a small proportion of the original design life (eg 20%), and that life extension beyond (say) ten years would require an exceptional justification. Where it is not possible to declare a meaningful AEOL, the regulator is recommended to enter discussion with the Duty Holder to agree a maximum period at which a further review would be due.

The end of the anticipated extended operating life is another point at which the requirements for further life extension would need to be reviewed again. The extent of the assessment and review would be an updating of the life extension case for a further declared period, and possibly require an even more demanding case as the installation is now even older. In principle, life could be extended in this way for several cycles provided that a suitable case can be made. There would then no need to declare an end of life until a final decision to decommission the installation has been made.

b) **Failure to specify or demonstrate fitness-for-service of barrier systems**

For consent to life extension, the Duty Holder should demonstrate that the barrier systems are fit-for-service and have adequate remaining life with a suitable integrity management plan. The barrier systems will have been specified in terms of safety critical systems, structures, equipment and components, whose current state will have been determined by examination or assessment. Any degradation in integrity or performance will have been assessed against the relevant criteria and standards. Where repairs or replacement are necessary, either immediately or in the future, a plan for these should be established. Failure to demonstrate fitness–for-service of barrier systems without an acceptable plan for further assessment or remedial action may be an obstacle for life extension.

Accumulated and widespread damage to key support structures and major equipment can often be a life terminating condition as the costs of replacing fixed infrastructure and large components are usually prohibitive. While isolated damage may be amenable to assessment and repair, widespread damage raises the possibility of general weakening and loss of redundancy, where the effect of interactions between different damage sites may be difficult to analyse. Examples of accumulated and widespread damage might include extensive corrosion to major structural members and supports including walkways, piping systems where the bolted flanged joints are seized with rust, stress corrosion cracking, or corrosion of fixings of fire protective walls and blast structures.

The judgement of whether damage is accumulated and widespread is usually clear to an experienced engineer. Doubt over the equipment's immediate fitness to perform its function and the creation of an obvious safety hazard are two possible tests. The damage is usually beyond a state where any sort of analytical assessment would be feasible. The necessary repairs or replacement would have a significant effect on the infrastructure and the ability of the installation as a whole to operate.

c) **History of HC leaks and safety alerts due to ageing effects**

A history of hydrocarbon leaks and safety alerts as a result of equipment ageing could be an obstacle to consent to life extension. Such a history marks the failure of the Duty Holder to manage ageing effectively, and does not provide confidence for safe operation during the life extension phase, where ageing effects are likely to increase. A review of reported HC leaks and safety alerts, together with the Duty Holder's response and effectiveness of declared improvement actions, is necessary to make an assessment.

Included under this category is a history of failure of safety critical systems to pass tests on demand. Safety valve closure times, blow-down, emergency diesels, fire pumps, HVAC dampers, fire doors and seals etc. are typical items. Where there is repeated failure of such systems, or evidence of decreasing performance, replacement or other remedial action with a satisfactory test should be considered as a condition for life extension to proceed.

Leaks and discharges can also threaten environmental standards for emissions. A history of unacceptable leaks and discharges as a result of old or ageing equipment could also be an obstacle if remedial actions are not put into place.

d) **Design and configuration of safety critical systems do not meet modern standards**

On some installations there may be safety critical systems whose design or configuration no longer meets modern standards. Better materials, improved functionality, with greater redundancy may be available in modern designs. Where it is reasonably practicable, Duty Holders are recommended to use life extension as an opportunity to upgrade their systems. Failure to do so without good reason would indicate an attitude in the Duty Holder organisation inconsistent with that expected for life extension to proceed.

Duty Holders should be particularly aware of systems where a single or common fault can render a safety system ineffective. Systems vulnerable to a single failure of electrical supplies, contaminated diesel, or corrosion at multiple sites might be examples. For such systems the Duty Holder should consider the robustness of the integrity case.

e) **Failure to address significant maintenance backlog for safety critical systems**

The end of original operating life before life extension is a good time for addressing any backlog in scheduled maintenance. A history of maintenance backlogs and failure to address this before the start of the life extension phase could be an obstacle to consent to life extension. It is recommended that Duty Holders review their maintenance schedules at this point and consider whether these need to change in the life extension phase.

f) **Uninspectable regions and undetectable damage for safety critical equipment**

Areas of safety critical systems that cannot reasonably be accessed for inspection or where non-destructive testing may not be able to quantify the degradation need to be identified. For example, this might apply to hydrocarbon systems, vessel internals, structure under coatings and inaccessible areas such as flare lines. The extent and function of these areas, knowledge of similar areas, the likelihood of degradation, the consequences of failure and mitigating measures are factors that will determine whether further action is needed as a condition for life extension. Further actions might include limited destructive examination with replacement/repair, or providing additional mitigation measures such as improved leak detection, secondary structures and restraints.

g) **Inadequate competence and organisation to manage integrity**

Duty Holders need to be able to demonstrate sufficient experience, capability, competence and organisation exists within their workforce to manage the integrity of equipment during life extension effectively. Doubt about whether a sufficient level exists may be an obstacle to life extension. Evidence of effectiveness could be from manning levels, roles and responsibilities, training and experience records and organisation and management charts.

3.5 Increased vigilance during life extension

The life extension phase carries a greater risk of ageing mechanisms affecting integrity, performance and safety. Increased awareness of ageing effects and vigilance for change in condition or performance should be required from both the Duty Holder and regulator. In practice this means greater and more regular dialogue about ageing issues, both within the company (offshore and on-shore) and between the Duty Holder and the regulator.

The form that this vigilance and dialogue will take will vary according to the installation and the company. For example, it might be expected that inspection and maintenance schedules would be reviewed more regularly, and that there would be a programme of up-grading or replacing ageing facilities on an on-going basis. The stock of spares for safety related equipment would be maintained at an adequate level where spares are no longer easily available. The analysis of inspection, monitoring and test data, and of failure and incident reports would become more rigorous. Access to technical expertise and experience on ageing mechanisms and fitness-for-service assessment would be strengthened.

For the regulator, increased vigilance may mean more frequent meetings with the Duty Holder to ensure that the appropriate management is in place to manage ageing, possibly accompanied by offshore site inspection visits. For those companies that fail the challenge of maintaining safety of ageing installations, the regulator needs to take appropriate action. The regulator also has a role in encouraging awareness and research into ageing issues, and of assisting the transfer of information and good practice across the industry.

4 Conclusions and Areas for Further Work

1 Life extension of fixed offshore installations is possible providing the integrity of the topside equipment, structures and components is properly managed. The application for consent to life extension provides a point in time for taking stock of the extent and effects of ageing on performance, and for planning for the period of anticipated extended operating life. Leading and lagging integrity indicators and risk factors, combined with fitness-for-service assessment, performance monitoring and effective maintenance provide the basis on which the case for life extension should be made.

2 During the final stages of this project, HSE published the final report on its KP3 initiative associated with asset integrity. A brief review appears in Section 1.1.2. The KP3 report identified weak Leadership, Engineering and Learning as underlying causes leading to poor performance. An evaluation of the impact of KP3 on the Norwegian approach to life extension is recommended.

3 The definition and treatment of active and passive components need greater clarity for the purpose of prioritising and focusing the life extension assessment task. Key systems and tests that could be representative of the more general condition could be identified. Greater attention should be given to assessing the management and workforce readiness to accept the responsibility of extended life operation. Further examples of typical structures, equipment and components in different stages of ageing would be helpful to illustrate the different ageing stages.

4 The issue of demonstrating appropriate competencies to manage life extension is briefly referred to in Section 1.3.4 and the Appendix. However it is considered that this is an important area which deserves further consideration of suitable competencies along the lines of those recommended for structural integrity management in ISO 19902 and management of ageing pressure equipment in HSE report RR 509.

5 TWI and the authors of this report are currently involved in a project funded by the Energy Institute on developing indicators for ageing of offshore safety critical elements. It is expected that this work will develop useful guidance that would relate to the requirements for life extension in Norwegian waters.

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Appendix

Proposed workshop for assessment of ageing processes and management of the life extension phase

In-house workshops under the guidance of an external chairman or consultants can form an important role in identifying and assessing ageing processes. They can make an important input into the application for life extension and the management of the life extension phase. Similar workshops form a key part in undertaking, for example, a HAZOP study.

In Section 3.2 it is recommended that many organisations should appoint a multi-disciplinary life extension team under a senior manager to be responsible for developing the life extension application. A workshop or series of workshops involving the team and suitably qualified people outside the organisation is a good way of focusing the collective experience and planning how ageing is managed during the life extension phase. In order to get most value out of a workshop, teams (or their leaders) will find it useful to examine the purpose and role of such a workshop in advance and to address the questions below:

- What should be addressed in the workshop?
- What is the preparation required for the workshop?
- Who is expected to take part in the workshop?
- Who should be the chairperson and what is his/her role?
- What training (if any) is required before the workshop?
- What should be the deliverables from the workshop?
- What should be the follow-up actions from the workshop (if any) eg further workshops covering specific ageing topics?

The constitution of the workshop is important and the team would typically contain:

- Operational staff
- Inspection & maintenance staff
- Safety engineers
- Data management personnel
- Specialists such as metallurgists, corrosion engineers and chemists as required, depending on the life extension issues to be assessed
- Representatives from other installations with similar equipment,
- Relevant contractors concerned with the installation
- Consultants with appropriate experience

In preparation for the workshop relevant operational data should be available, together with performance and maintenance data (eg status of back-log). Examples of the data required are provided in earlier parts of this report (eg Sections 2).

The expected deliverables from the workshop need careful attention, as these could form a significant part of any proposal for life extension. Section 3.1 identifies the typical contents of an application for life extension.