Strål
säkerhets
myndigheten
Swedish Radiation Safety Authority

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2017:36

Topical Peer Review 2017 Ageing Management Swedish National Assessment Report

Report number: 2017:36 ISSN: 2000-0456
Available at www.stralsakerhetsmyndigheten.se

SSM perspective

Executive summary

The European Union's Nuclear Safety Directive 2014/87/EURATOM (NSD) requires the member states to undertake topical peer reviews (TPR) every 6 years with the first starting in 2017. The member states, acting through the European Nuclear Safety Regulators Group (ENSREG), have decided that the topic for the first topical peer review is ageing management.
The Swedish Radiation Safety Authority (SSM) by the provision of the act of nuclear activities (1984:3) can decide by injunction that licensees take the necessary measures required in individual cases for compliance with the act. Based on this legislation SSM in February 2017 decided that licensees operating nuclear reactors should report relevant information according to the technical specification (RHWG Report to WENRA – TPR Technical Specification, 21 December 2016). This report, issued by SSM, is based on the licensee's assessments and the results from SSM's review.

Reports from all licensees were provided to SSM in June 2017. All information was processed and compiled in this report by SSM during July to October 2017, whereafter the licensees had an opportunity check for any factual inconsistences. Finally, the Swedish national report was completed and distributed to ENSREG in December 2017.

Based on SSM's performance based regulatory philosophy Swedish licensees have pursued slightly different paths to develop their respective overall Ageing Management Programmes, all with the goal to ensure the availability of required safety functions throughout the service life of the plant. SSM introduced the requirement to develop overall programmes for ageing management in late 2004.

In developing the overall Ageing Management Programmes, Swedish licensees have largely compiled information from already existing programmes, such as maintenance, component qualification, in service inspection and chemistry programmes. Using these programmes a lot of experience gained from the operation of the licensees reactors as well as external ageing related experience has been used. The overall Ageing Management Programme have therefore naturally become an interdisciplinary programme linking ageing perspective in a range of programmes. The key elements used by the Swedish licensees to assess ageing are based on the nine attributes in NS-G-2.12, which are similar to the ten elements described in NUREG-1801. It is SSMs opinion that since Swedish licensees started to develop their overall Ageing Management Programme after approximately 20 to 30 years of operation, it is natural that ageing assessment has been based on these programmes more than for instance on manufacturing documents. Additionally, Swedish licensee´s in order to check consistency, have used IAEA SRS 82 and NUREG-1801 in the ageing assessment. To have an international assessment of the overall Ageing Management Programmes, all three licensees have also conducted IAEA SALTO or pre-SALTO reviews.

Preamble

The Swedish report for Topical Peer Review 2017 Ageing Management National Assessment Report has followed the WENRA technical specification. Each licensee has performed an assessment of ageing management of their nuclear power plants and SSM has reviewed these assessments. The present report, issued by SSM, is based on the licensee's assessments and the results of the SSM review.
According to the specification from WENRA, each licensee has performed an assessment for electrical cables, concealed pipework, reactor pressure vessels and concrete containment structures. Calandria/pressure tubes (CANDU) and pre-stressed concrete pressure vessels (AGR) is not applicable to the Swedish national assessment report.

Due to the fact that the structure of the documentation of the three licensees assessments are not the same, the structure of the present report is not consistent with the template provided for the National Assessment Report in all parts.

Project information

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Content

1. General information

The Swedish licensees have reported separately according to the technical specification, [1]-[15]. Unless otherwise stated, the description below is valid for all licensees.

1.1. Nuclear installations identification

In Sweden, there are three licensees, Forsmarks Kraftgrupp AB (Forsmark), OKG AB (Oskarshamn) and Ringhals AB (Ringhals) operating a total of eight nuclear reactors, information on these reactors is listed in Table 1. Note that a licence to operate nuclear power plants in Sweden is granted without a time limit. Plants can continue to operate as long as the Swedish Radiation Safety Authority (SSM) considers them to fulfil the requirements of all applicable regulations. The scheduled shutdown date in Table 1 is considered a planning condition that the licensees have set, and it is not to be considered as a fixed end-date.

Table 1 - Operating nuclear power plants in Sweden as of January 2018

Licensee	Reactor	Type of reactor	Licensed thermal power level [MW]	Electric power output [MW]	Commercial operation	Scheduled shutdown[1]
Forsmark	Forsmark 1	BWR	2928	984	1980	2040
	Forsmark 2	BWR	3253	1120	1981	2040
	Forsmark 3	BWR	3300	1167	1985	2045
Oskarshamn	Oskarshamn 3	BWR	3900	1450	1985	2045
Ringhals	Ringhals 1	BWR	2540	910	1976	2020
	Ringhals 2	PWR	2660	847	1975	2019
	Ringhals 3	PWR	3144	1117	1981	2041
	Ringhals 4	PWR	2783	1181	1983	2043

All operating nuclear reactors listed in Table 1 are included in this National Assessment Report (NAR).

Please note that the two reactors Oskarshamn 1 and Oskarshamn 2 have been permanently shut down (June 2017 and October 2015, respectively) and are accordingly not in the scope of this NAR.

There are presently no research reactors operating in Sweden.

[1] The scheduled shutdown date in Table 1 is considered a planning condition that the licensees have set, and it is not to be considered as a fixed end-date.

1.2. Process to develop the national assessment report

SSM by the provision of the act of nuclear activities (1984:3) can decide by injunction that licensees take the necessary measures required in individual cases for compliance with the act. Based on this legislation SSM in February 2017 decided that licensees operating nuclear reactors shall report relevant information according to the technical specification (RHWG Report to WENRA – TPR Technical Specification, 21 December 2016). This report, issued by SSM, is based on the licensees' assessments and the results from SSM's review.

Reports from all licensees were provided to SSM in June 2017. All information was processed and compiled in this report by SSM during July to October 2017, whereafter the licensees had an opportunity check for any factual inconsistences. The original reports provided by the licensees in June 2017 are included as references to this report. Finally, the Swedish national report was completed and distributed to ENSREG in December 2017.

2. Overall Ageing Management Programme requirements and implementation

2.1. National regulatory framework

The objective with SSM's work is to protect people and the environment from the adverse effects of radiation, now and in future. SSM's work is legislated by the Act on Nuclear Activities (1984:3) and the Radiation Protection Act (1988:220) which stipulate that SSM may issue regulations concerning measures necessary in order to prevent the effects of malfunctions in equipment, improper handling, sabotage or other circumstances that could result in a radiological accident.

The SSM's regulatory approach is process oriented. This means that the regulations are general with a focus on the required licensee processes and the outcome of these processes. The manner in which these processes are performed is not specified. Even the regulations on design of nuclear power reactors are rather general, focusing on the principles of the design and what the safety functions must achieve.

In addition to the regulation, general advice on the interpretation of most of the safety regulations is issued. The general advice is not legally binding, per se, but cannot be ignored by the licensee without risking sanctions by the regulatory body. Measures should be taken according to general advice or, alternatively, by methods justified to be equivalent from a safety point of view and should be implemented. The general advice may, for example, contain references to more detailed guidance on a particular subject, such as IAEA safety standards, ASME standards etc.

The SSM regulations (SSMFS) concerning Safety in Nuclear Facilities, SSMFS 2008:1, are applicable, in a graded way, to all licensed nuclear facilities. The regulations aim to specify measures needed to prevent and mitigate radiological accidents, prevent the illegal handling of nuclear material and nuclear waste, and to conduct efficient supervision.
The regulations deal with:

- Application of multiple barriers and defense-in-depth
- Handling of detected deficiencies in barriers and the defense-in-depth
- Organization, management and control of significant safety activities
- Actions and resources for maintaining and developing safety
- Physical protection and emergency preparedness
- Basic design principles
- Assessment, review and reporting of safety
- Operation of facilities
- On-site management of nuclear materials and waste
- Reporting to SSM of deficiencies, incidents and accidents
- Documentation and archiving of safety documentation
- Final closure and decommissioning

Swedish nuclear power plants were originally designed and constructed for a period of operation of approximately 40 years. Following a referendum in 1980 the Swedish Parliament decided that all nuclear power plants would be phased out by 2010. After a new decision in the Swedish parliament 1997 the final date for nuclear power was removed, meaning that Swedish nuclear power presently has no operation limit. This means that the operation permit cannot be withdrawn as long as the provisions of laws, government ordinances, SSM's regulations and conditions and obligations under the license are met.

Following the decision to continue the use of nuclear power, the Swedish nuclear power inspectorate (SKI) issued updated regulations in 2004 (SKIFS 2004:1 Regulations and General Advice concerning Safety in Nuclear Facilities). In SKIFS 2004:1, a new requirement relating to ageing management was introduced in Chapter 5 Section 3. According to a provisional regulation, the Ageing Management Programme should have been implemented by licensees by 31 December 2005 at the latest.

Following the merger of SKI and the Swedish Radiation Protection Authority (SSI) to SSM in 2008, the ageing management requirement was transferred to Swedish regulations SSMFS 2008:1 Chapter 5 Section 3. However, the content of the requirement and the general advice with regard to ageing management were the same.

The requirement on ageing management states that a programme for management of ageing degradation and damage shall be in place. The programme shall be documented, reviewed and updated in the light of experience gained in science and technology as well as developments. General advice to this requirement further specifies that the programme for the management of ageing degradation and damage should comprise the identification, monitoring, handling and documentation of all the ageing mechanisms that can affect structures, systems and components as well as other devices that are of importance for safety. Additional guidance on maintenance and the management of ageing degradation can be found in the IAEA:s safety standard on maintenance, surveillance and in-service inspection in nuclear power plants. The general advice refers to IAEA's safety standards with regard to ageing management (NS-G-2.12 and safety report 57).

In addition to the requirement on ageing management Section 17 in Swedish regulations SSMFS 2008:17 states that barriers and equipment belonging to the safety systems of the nuclear power reactor shall be designed so that they can withstand the environmental conditions they may be subjected to in situations where their function is credited in the safety analysis report. In the general advice to this requirement it is stated that this can be accomplished by environmental qualification.

Time interval and extent of testing for in-service inspection of mechanical components is determined via a risk-informed approach according to Chapter 3 Section 1 in Swedish regulations SSMFS 2008:13.

2.2. International standards

All three licensees in Sweden have based their development of Ageing Management Programme on the IAEA documents NS-G-2.12 and SRS 57, in accordance with general advice to Chapter 5 Section 3 Swedish regulations SSMFS 2008:1. To check consistency, completeness and definitions of the overall Ageing Management Programme IAEA SRS 82 (IGALL) has been employed. Forsmark and Ringhals has also employed NUREG 1801 “Generic Ageing Lessons Learned (GALL)”, Rev 2.

WENRA Safety Reference Level Issue I (ageing management) has not explicitly been used for the development of the overall Ageing Management Programme.

2.3. Description of the overall AMP

In this section follows a description of the overall Ageing Management Programme (AMP) for the Swedish licensees.

2.3.1. Scope of the overall AMP

Assignment of responsibilities within the licensees organisation to ensure an overall AMP is developed and implemented

The licensees have documented the assignment of responsibilities in their respective Safety Analysis Report (SAR) and with regard to responsibilities specified it in the management system.

For Forsmark the responsibility for coordinating the overall Ageing Management Programme is assigned to the engineering department whereas for Oskarshamn and Ringhals this responsibility is assigned to the maintenance department.

Table 2 - AMP teams involved in ageing management work

Oskarshamn	Ringhals
Construction, mechanics, electricity, I&C, vessel and pipe components, and obsolescence	Primary system, mechanical systems, electrical systems, I&C instrumentation, civil structures and fuel

Oskarshamn
A coordinating group for ageing and AMP teams for each of the areas are responsible for overall ageing management at Oskarshamn as shown in Table 2. The work within the AMP teams consisting of representatives from all technology areas is controlled by instructions.

The instruction ensures that the overall AMP is complete and coordinates all activities related to ageing.
The AMP teams are responsible for:

- Documentation of the overall Ageing Management programme
- Developing new AMP’s (component-specific ageing programme)
- Evaluate and optimise the programme
- Hold meetings at least once a quarter
- Assess work orders, Licensee Event Report (LERs) and serve as expert support
- Operating experience as well as in house or external Research and development (R&D).

Ringhals
For Ringhals the responsibility for the operative Ageing Management is delegated to the six different Technical Areas shown in Table 2. Instrumentation and fuel will not be considered further in this report. To coordinate Ageing Management a group, called the AMP group, has been established. The AMP group consists of representatives from each Technical Area. A description of work assignments within the AMP group is documented. Furthermore, each Technical Area has two governing documents, a functional description and a description of duties. Structures and Components (SC) that are within the scope of Ageing Management are assigned a Technical Area. Each Technical Area will ensure detailed and adequate Ageing Management is developed. The AMP group is responsible to evaluate and optimise the overall Ageing Management programme and the leader of the AMP group reports back to the plant management regarding the work progress.

The AMP group is responsible for

- Documentation of the overall Ageing Management programme
- Ensure that the programme is complete
- Coordinate overall Ageing Management activities
- Evaluate and optimise the efficiency of the programme
- Exchange experience related to overall Ageing Management with external organisations
- Oversee that results from R&D related to Ageing Management is disseminated within Ringhals
- Make sure that information available and training is provided
- Report to management

Forsmark
Forsmark has chosen to assign certain departments different tasks to coordinate the overall Ageing Management Programme. The departments involved are, Engineering, Maintenance, Production, Human Resources, and Planning. The role of the different departments in ageing management are described below.

<u>The Engineering department (NE)</u> is responsible for maintaining, developing and decommissioning Forsmark's facilities. This involves developing the technical requirements and physical design of the plants as well as ensuring that requirements, facilities and documentation including SAR and technical specifications (STF) are consistent. The Engineering department is responsible for sustainable and long-term plant development. The department is to provide technical support and deliver demanded resources for refurbishments and plant equipment renewal projects. Part of the configuration management activities is the respon-

sibility to develop and maintain systematic ageing management analyses for systems, structures and components (SSC) important to safety. This includes identification and documentation of relevant degradation mechanisms and ageing effects for relevant SSC's.
Suitable programmatic actions are then. addressed to the assessed mechanisms and effects as preventive, detective and mitigating activities. Engineering also has the responsibility for performing and documenting Time Limited Ageing Analyses (TLAA) where applicable. The NEDS unit at Forsmark is responsible for establishing system health reports for all systems of importance to safety, including verification of status of structures and components identified in the ageing analyses (failure history, trends, and verification of the establishment of Ageing Management Programmes).

The maintenance department work is intended to maintain and record the status and performance of systems, structures and components of the plants. Observations and experiences from operational work at the plants is an important source of information for optimising future maintenance or developing of maintenance strategies. This activity is an important contribution to aggregated ageing management. The maintenance programme consists of condition monitoring, preventive maintenance, time-based maintenance and planned corrective maintenance. Department NM is responsible for the conduct of continuous review of the maintenance programmes, inclusive of ageing management related activities. The maintenance department is also responsible for management of obsolescence and the establishment of a programmatic approach

The operations department is responsible for the surveillance testing of safety related system performance which is a vital source of information regarding ageing effects. The operations department is responsible for routinely trending results from testing and status monitoring/reporting as an instrument in detecting effects of ageing. Inspections for detecting and managing the environmental conditions and the initiation of mitigating any adverse ageing stressors are part of this process. As part of the mitigation or prevention of ageing related degradation, plant operators are responsible for running the plant within the given operating limits and to continuously sample and monitor the chemical regimes of system media affecting the SSCs.

The Human Resources (HR) department is responsible for ensuring that skill development and training are conducted according to regulatory requirements and international standards. It shall also develop and provide tools and services as well as qualified support in the field so that line managers can assume responsibility for competence. It coordinate, plan, order and monitor skills development efforts taking into account the overall benefit for Forsmark. HR is responsible for supplying the means for business development as well as driving, supporting and following-up company-wide business development. Finally it supports, integrates, drives and follows-up company safety culture and human performance activities.

The Planning department is responsible for overall time and resource planning for operations, outage operations, maintenance operations, optimisation and coordination of technical and non-technical portfolios. Overall time and resource planning constitutes the basis for each department/unit resource acquisition. The planning department is also responsible for Forsmark's reporting regarding production and availability in order for activities to be implemented in a manner that supports Forsmark's short and long-term goals regarding nuclear safety, work environment, production and the environment. Another important responsibility is that for continuous work to enhance collaboration between production, protection, maintenance and engineering.

Methods used for identifying SSCs within the scope of overall AMP

For all three licensees all SSCs are classified according to their importance for safety. SSCs included in a barrier or needed to execute a safety function, directly or indirectly, are within the scope of the overall Ageing Management Programme. The SSCs and their respective classification is documented in the plant asset register. The plant asset register may be cross-referenced with the SAR, STF and different flow charts and drawings.

Forsmark and Ringhals
Forsmark and Ringhals also use probabilistic safety analyses (PSA) to identify SSCs within the scope of overall Ageing Management Programme.

For each system identified, data retrieved from the plant register forms a plant list of all SSCs included in the overall Ageing Management Programme.

In preparation for Long Term Operations (LTO), i.e. over 40 years, all three licensees have started projects to check whether all required systems are covered by the overall Ageing Management Programme.

Grouping methods of SSCs in the screening process

Forsmark
For Forsmark the process starts by grouping identified SSCs into areas according to Table 3. These areas are called analysis areas. Each analysis area is then sorted by the type of component or structure it encompasses, such as pumps, switches or valves. The final grouping is refined until each individual group only consists of components or structures which are physically comparable to each other based on factors that characterise the component by design, properties, environmental factors and operating conditions. So-called Commodity Groups (CG) are then formed. When possible each individual component is listed with its current position in the plan asset register.

Ringhals
For Ringhals to facilitate the Ageing Management Review (AMR) process the SCs are grouped together in Commodity Groups (CG) during the screening process by the Technical Areas as shown in Table 3. Grouping follow mainly the outline in IAEA documents SRS 57. The Technical Areas approaches the grouping in different ways, for example, electrical systems and civil structures deals with SCs that have different prerequisites and therefore the grouping is done differently.
As a general guide grouping is done by identifying and taking the following list into consideration:

- SCs structural material
- Operating environment
- Degradation mechanism
- Type of maintenance to be expected.

Active components that are represented in the Maintenance programme, Streamlined Reliability-Centered Maintenance (SRCM) and are replaced or serviced in specified time intervals are handled in a simplified Ageing Management programme.

Table 3 - Grouping in the screening process

Forsmark	Ringhals
Mechanical components, civil structures, Instrument and control components (I&C) and Electrical components	Primary system, mechanical systems, electrical systems, I&C instrumentation, civil structures and fuel

Oskarshamn
Oskarshamn groups components with plant-specific identification based on component type, environment, material and ageing mechanism and use Structured Query Language (SQL) formulated issues in a database.
For components with no plant identification grouping have resulted in areas such as:

- Cables.
- Buildings and structural components.
- Pipes and pipe components.
- Lifting equipment.
- SSCs without functional designations (components lacking functional ID and which are based on IGALL public table).

Generally Oskarshamn CG groups are based on component type, environment, material and ageing mechanism.

Methodology and requirements for evaluation of the existing maintenance practices and developing of ageing programmes appropriate for the identified significant ageing mechanism.

Forsmark
Based on grouping into CGs, Forsmark creates an AMP. For each AMP, detailed analyses of involved SC of possible ageing processes are conducted regarding material, function, medium, surrounding environment, experiences, current maintenance programmes and maintenance actions. This evaluation demonstrates that existing programmes and measures addressed to the CG are capable of handling identified ageing effects and that programmes meet the expected level for ageing management.

All existing programmes (e.g maintenance, chemistry, In-Service-Inspections (ISI)) for the different component groups should further be fully evaluated based on whether they meet the ten criteria described in the USNRC NUREG-1801. These ten criteria have been evaluated and been found to correspond to the nine criteria described in the IAEA NS-G-2.12. The results of the evaluation according to the above criteria aim to verify that ageing management constitutes an acceptable basis for managing the ageing of the SSC and to verify that adequate measures are in place for each CG to detect and handle ageing degradation. If any of the criteria is not met, current ageing management needs to be improved through changes to programmes and actions.

Ringhals
Ringhals uses the database Preventive Maintenance Basis Database (PMBD) which are available within the EPRI membership . For components covered by EPRI PMBD the spec-

ified degradation mechanisms should be used. Examples of methodologies and requirements used in different technical areas are presented in chapter for Concealed Piping, Reactor Pressure Vessel and Concrete Containment Structures.

Documentation structure and document types differ slightly between the Technology Areas. An example of this is the aging analysis called Strategic Maintenance Plan (SUP) or PV Report. Ringhals is describing overall aging management, by the term Aging Analysis.

Oskarshamn
From the CG grouping process at Oskarshamn, all SSCs with a functional ID and stated ageing mechanisms are forwarded to an AMR for evaluation if existing programmes (e.g. maintenance, chemistry, ISI) manage the identified ageing effects. In order to rationalise the AMR process, an IT tool is used (AMR Tool) in order to facilitate the review of all the CGs. At least 5 % of all SSCs with functional designation are reviewed in the AMR Tool. Part of AMR is also compared with IGALL AMR-table. All existing programmes (maintenance, operations, qualification, chemistry, radiation protection, ISI, surveillance) are also reviewed, as well as component specific AMPs, in relation to the nine attributes described in IAEA NS-G-2.12. Deviations between present plant programmes (including specific AMP) and the management of identified significant ageing mechanism during CG grouping are reported as deviations and for every deviation an issue is opened in the different AMP teams.

Quality assurance of the overall AMP

All three licensees uses different databases for the collection and storage of data for AMP purposes. Typically recorded data from reporting are failure modes, failed components, failure cause, spare parts and man-hours required, fault solutions, unavailability data, Time To Repair (TTR). The data trending system BiCycle is then used to analyse trends and data feedback.

Forsmark and Ringhals
Ringhals and Forsmark also require that maintenance and operational history be included as a mandatory part of creating a SUP report.
Experience feedback is recorded to NORDERF (a Nordic organisation for experience feedback) and experience is derived and trended from NRC, IAEA, damage databases and internal status reports etc.

For Forsmark indicators for specifically assessing the effectiveness of the ageing management process are at present still under development.

For Ringhals all events generating a LER or production loss are evaluated by the maintenance management team. The evaluation is a part of collecting data for the KPI for maintenance quality. Every second year an evaluation by Living SRCM is conducted using the Bi-Cycle tool. The department of maintenance technology is responsible and generates the trending analyses at Ringhals.

Oskarshamn
Oskarshamn started measuring the efficiency of ageing management at the beginning of 2016. The key performance indicator “a” is defined as a=A/T, where A= total number of

ageing related recorded fault reports, per unit, T= total number of recorded fault reports, per unit.

Work is also performed together within a joint forum (FORSAMP) for ageing issues involving Forsmark, Oskarshamn, Ringhals and Swedish Nuclear Fuel and Waste Management Co (SKB). Currently no common KPI:s has been created.

2.3.2. Ageing assessment

How key standards, guidance and manufacturing documents are used to prepare the overall Ageing Management Programme

The overall Ageing Management Programme has for all three licensees been developed in accordance to the guidelines in the IAEA Safety Report No. 57 and IAEA NS-G 2:12.

The handling of ageing related degradation and damage as described in the overall Ageing Management Programme requires access to support and information from closely related programmes and activity areas as:

- Maintenance programme, detecting and describing the effects of ageing, taking measures on the direction of how maintenance is performed and taking measures in the plant that prevent harmful degradation,
- Component qualification programme, defines environmental conditions and functional and performance requirements, defines qualified service life and development of requirements on testing and acceptance values and provide information about the outcome of testing,
- In-service inspection (ISI), identification of damage types and their underlying mechanisms,
- Surveillance testing programme, involves knowledge of the reactor vessel material and a critical foundation for the development of HTG (pressure-temperature limit) charts,
- Chemistry programme, measures to limit the corrosive effect of environment and activities that promote stable chemical conditions,
- Obsolescence programme, monitoring of the phasing out process of components, products and suppliers,
- Radiation Protection programme (Forsmark, Oskarshamn), radiation is an important ageing factor considered in the ageing analyses, deviations from expected values are reported to the coordinating group,
- Operations programme (Oskarshamn), adequate operating conditions and procedures are chosen to minimise ageing and degradation. Results from testing and monitoring form the basis used for the maintenance department, and

- Transient registering programme (Forsmark, Ringhals), outputs from transient analyses mainly supports ageing management regarding fatigue analyses of the primary system.

Ringhals
Ringhals have detailed section tables listing key standards, guidance and manufacturing documents that are used for Ageing Management for the different Technical Areas, Primary Components, Mechanical systems, Electrical systems and Civil structures.

Key elements used in plant programmes to assess ageing

The following key elements are used by the licensees to assess ageing:

- Material used in the SSC.

- Media, acting on / in the SSC. Media are defined for example regarding substance, temperature, radiation conditions, chemical conditions (dissolved substances, pH, etc.) or other parameters that can affect the material properties of the SSC's.

- The environment surrounding the component. May be for example ambient temperature, humidity, radiation, environmental and other factors that can influence the material and its properties.

- Experience (both internal and external) of the effects of ageing. Experience-based information can be retrieved from NORDERF, failure reports, damage database reports, analyses reports from the investigations carried out, other industry experiences. Information from the component specialist and experts is also considered.

Ringhals
Ringhals also use the following key elements:

- Object description and function
- Consequence of ageing degradation and failure
- Indicate relevant ageing mechanism according to the object description
- Location of degradation
- Mitigation methods, and
- Ageing management strategy

The identification of ageing mechanisms and their possible consequences

Forsmark
Forsmark has conducted an assessment demonstrating whether the current SSC meets the criteria for adequate ageing management. The assessment is evaluated against established criteria (attribute for ageing evaluation). Possible improvements are documented as recommendations.

Evaluation of which degradation mechanisms that may occur to a specific material needs to be made of expertise in materials issues (metallic, non-metallic, organic and inorganic materials) and surface treatment. The assessment of the programmes' contribution to ageing management should be done with the expertise of specialists in components and system engineers in all areas considered. Any examination of the components are based on the current plant documentation regarding the plant's performance and programme operation, testing and maintenance.

Within the framework of the FORSAMP cooperation forum, a common gross list of degradation mechanisms has been developed. The list has been divided into three areas: Mechanical Components, Civil Structures and Building Materials, and Electrical Components, Instruments and Control Devices.

The purpose of the gross list is to overview of the extent of degradation mechanisms taken into account by the Swedish licensees. provide support to administrators carrying out ageing analyses, provide input for progress to more comprehensive descriptions of different degradation mechanisms. The list cannot replace the need to involve material knowledge in the ageing analyses. The list was created through literature studies, primarily by IGALL, IAEA Safety Report Series No.82, Nordic Owner Group (NOG) report SEP 04-120, various EPRI documents, NUREG 1801 (GALL), and technology-specific documents.

Ringhals
Ringhals has developed ageing analysis in order to understand and document the basis down to an object level. This document is used in order to evaluate components and objects considering maintenance, in-service inspection as well as ageing management.

The main purpose of the ageing analysis is:

- To highlight occurrences of possible defects and modes of degradation that is applicable for the components different objects and provide recommendations in order to optimise maintenance and in-service inspection.
- To document the ageing analysis, evaluate current Ageing Management Programmes considering the applicable conditions and increase the awareness of relevant ageing mechanisms in components different objects and if possible mitigate or stop such effects.

A gross list with identified ageing mechanisms has mainly been derived from literature studies of IGALL-report, GALL-report, NOG Report SEP 04-120 and different EPRI documents. This list is used by individual engineers when writing the ageing analysis and is referred to as the FORSAMP gross list. This is a list that is used by all Swedish NPPs.

Oskarshamn
Oskarshamn base the identification of ageing effects on Areva's catalogue of defects, which in part is adapted to the conditions at Oskarshamn. This has subsequently been supplemented with own requirements and stipulations. In order to ensure that all potential ageing mechanisms, ageing effects and environments have been identified, comparisons have been made with the Forsamp gross list, IAEA IGALL Public Table, IAEA No. NS-G-2.12, *Ageing Management for Nuclear Power Plants*, VGB Powertech, *Definition of Damage mechanisms of Metallic and Plastic materials* and STUK, Guide YVL A.8 draft L5 *Ageing management of a nuclear facility*.

Establishment of acceptance criteria for ageing

Forsmark
For Forsmark acceptance criteria should ensure that the current SSC can maintain its intended function at the design basis events and during the operating life. The criteria should

be used to establish corrective measures at the appropriate time if necessary. The acceptance criteria are established following EPRI, water chemistry, chemical process parameters, qualifiers, vendors, standards, STF.

Ringhals
Ringhals have for each technical area established routines for determining ageing acceptance criteria for the objects within the scope of Ageing Management.

Example 1: Primary Components and Mechanical Technical Area
For each object to be inspected a failure tolerance analysis is performed which states the allowable defect size depending on the limiting mechanism from the ageing analysis. Other acceptance criteria can be found in a common licensee reports such as Technical Requirements for Mechanical Equipment, (TBM) and Technical Requirements for Surface Protection, (TBY).

Example 2: Electrical Systems
Insulation resistance (IR) reference value > 100 MΩ for electrical cables, according to TBE 101:1. If the insulation resistance falls below an accepted (user defined) value, or falling rapidly over time, then cable replacement is considered.

Example 3: Civil Structures
The acceptance criteria for the pre-stressing systems is defined in the Regulatory Guide 1.35. Acceptance criteria are established for minimum tendon force due to loss of prestress (relaxation, creep and shrinkage).

Oskarshamn
Oskarshamn has mainly established acceptance criteria based on its own experience and for instance IAEA IGALL's developed AMPs. Example of general acceptance criteria are the replacement intervals specified in the EQ programme and criteria for corrective measures.

Use of R&D programmes

Some in common R&D activities for Forsmark, Ringhals, and Oskarshamn are coordinated within the NOG and Swedish Energy Research Center (Energiforsk). Another common R&D project in Sweden is further the creation of the FORSAMP gross list of degradation mechanisms and a research project in the field of polymer degradation. One new task is the development of common metrics within the FORSAMP grope to measure the effectiveness of the individual AMP.

Forsmark
R&D is primarily carried out in areas of importance to the Forsmark results and long-term production capacity. R&D programmes are divided into six priority areas. Ageing R&D programmes are included in the Maintenance area. The research programme operates to develop new knowledge about ageing phenomena including influencing factors and models, development of analytical methods, development of effective control methods and measures to combat and prevent ageing. These results are continuously supplied and implemented in the ageing management works.

Ringhals
For Ringhals R&D is performed in different areas in which there are appointed specialists who are responsible for budgets and projects in their field of expertise. The goal of R&D is to strive for preparedness for future demands, to build competence, to develop methods and tools for Safety Analyses, Severe Accident handling and Human Factor Engineering and to follow research in the field and participate in joint projects between other Nuclear Operators and the Authority.
R&D is divided into three areas, Basic research, Applied research and Technology development. Each technical area uses R&D where relevant for developing ageing analyses.

Oskarshamn
R&D, is an important parameter in Oskarshamn's ageing management. R&D is a standing item on the agenda, discussed within Oskarshamn's coordinating group for ageing management as well as within the AMP teams established.

Use of internal and external operating experience

Internal experience is handled by designated departments while external experience is often discussed in a different forum or through membership in different organisations. One common organisation for all licensees is FORSAMP. Further details for the different licensees follow:

Forsmark
The engineering department at Forsmark conducts work on feedback from experience that helps to systematically handle internal and external experiences throughout the business. External experience exchange is conducted through e.g. NORDERF, WANO and USNRC. Through the experience process, Forsmark deals with its own safety-related discrepancies and LER. These are broken down to individual root causes which accumulate to information about which systems, components or other aspects that show recurring failures or safety deviations.

Information on deficiencies and safety deviations reported from nuclear power plants in the outside world are recorded and compared with Forsmark's own experiences and conclusions. One purpose is to draw lessons from own and others' experience in order to prevent malfunctions and maladministration from being repeated in Forsmark's facilities. Experience feedback is an important work for the entire business, all of which includes ageing management. Databases are used to search for experience and analysis input for ageing management and analyses. In terms of the responsibility for plant systems, membership in the EPRI Nuclear Maintenance Application Centre (NMAC) gives Forsmark access to the EPRI PMBD. The PMBD provides support for ageing analyses. In the database contains information about known degradation mechanisms and suitable preventive measures. The information is specific for each component type. In the working group, FORSAMP, experiences are discussed for joint development.

Ringhals
At Ringhals the work is conducted by a maintenance group called NU ERF Forum which consists of representatives from all maintenance units. The primary task is to process events, discrepancies, experiences and issues within different maintenance areas and activities. There is an appointed operating experience engineer that administers the ERF Forums work. The group holds regular meetings and the members of the NU ERF forum represents

every unit/group within the maintenance organisation. The appointed operating experience engineer monitors incoming reports in Corrective action programme (Avärs) where NU is appointed as the owning/performing organisation. Incoming reports can be related to experiences, issues, discrepancies, events and lessons learned of internal origin and thus communicated through the central ERF group, and also external reports from the APS (translated as Working Committee for Production Safety). The appointed operating experience engineer serves as a maintenance representative within both groups.

Each technical area uses relevant internal and external experiences when developing Ageing Analyses. Since the Technical areas uses EPRI guidelines ensures that relevant experiences and R&D are included in the Ageing Analyses.

Oskarshamn
Establishment of a coordination group and its support of the AMP teams ensure the coordinated and continuous ageing management at Oskarshamn. Results from testing and experiences gained from the operating and technical departments at Oskarshamn are submitted to the coordinating group and results that concern ageing shall be distributed to the coordinating group. All suggestions for improvements within the ageing management are handled in the coordinating group with the support of the AMP teams, and suggestions on measures to be taken are decided on at the coordinating group meeting.

The coordinating group shall act in an advisory function to the manager of the maintenance department on ageing related issues by giving recommendations based on the following selection criteria:

- events and deviations that may have resulted in forced ageing and hence degradation of function and performance.
- new knowledge of the status of the plants based on the outcome from testing activities.
- new knowledge of materials and ageing effects.
- new knowledge of the supplier market and access to replacement components.

The coordinating group also frequently gather information from NORDERF, regarding ageing experiences and if it is relevant for Oskarshamn.

2.3.3. Monitoring, testing, sampling and inspection activities

Programmes for monitoring condition indicators and parameters and trending

Forsmark
At Forsmark, testing of safety and process systems is done according to current instructions based on SAR and STF. Measurement values retrieved from calibrated instruments and quality control are governed by respective STF and relevant maintenance instructions. The results of all tests are documented, trended and evaluated by control room staff. As a complement, digital tools are used to identify trends leading to system or component performance degradation over longer periods of time. In addition to the daily follow-ups of test results, the system status reports are updated annually. This is the basic, systematic, control and reporting of age-related problems and deficiencies in the plant that the operations/Production Department conducts.

Ringhals
A set of AMP's are applicable to a specific object. Ringhals AMP's are based on NUREG 1801 GALL AMP's and used in Technical Areas Primary- and Mechanical Systems. In the other Technical Areas the AMP is an integral part of the ageing analysis.
AMPs are developed based on attributes according to a list and have for example the following contents:

- Parameters Monitored
    - Inspected Parameters monitored and inspected shall be described and reference documents shall be presented under this attribute.
- Monitoring and Trending
    - Condition indicators, parameters monitored and a description of data to be collected to facilitate assessment of ageing shall be described under this attribute, including reference documents.
- Administrative Controls
    - A description of administrative controls that document the implementation of the ageing management and actions taken.

Oskarshamn
Within Oskarshamn maintenance programme there are a number of monitoring activities included in the established preventive maintenance programme, such as visual inspections, testing and the like. There are also a number of component specific AMPs which have a monitoring purpose, including Specific Ageing programme for Concrete, Specific Ageing programme for Metallic Material in Valves, Specific Ageing programme for Metallic, Material in Pumps and Specific Ageing programme for Metallic Material in Pressure Vessels, Cisterns, Heat Ex-changers and Filters.

Inspection programmes

Inspections of mechanical devices are performed in accordance with Chapter 3 Swedish regulations SSMFS 2008:13. For each inspection area, this includes identification of possible ageing mechanisms, in order to subsequently develop adequate testing systems.

ISI is a support in the management of ageing. Based on an interpretation documented in a common licensee re-port (PBM 1-2), Forsmark, Oskarshamn, and Ringhals produced inspection programmes. Risk-informed inspection programmes are based on inspection group classification A-C and shall be documented with basic data in an adequate application adapted to its purpose. The application shall ensure that inspections are performed in accordance with a set programme. Moreover, it shall also ensure that inspections in inspection groups A-B are performed by qualified personnel with qualified procedures and equipment. i.e. qualified testing systems.

The amount of every device or part of device that must be inspected should as far as is as reasonable and possible be adapted to the damage types that may arise considering underlying mechanisms. The inspection programme shall be reviewed and approved by an accredited inspection body.

Surveillance programmes

The testing of functions specified in the STF is the main source of relevant data for the surveillance of plant safety function performance. Trend monitoring of surveillance testing data for safety functions is implemented and performed by the operations department. One example of a surveillance programme is that used for reactor material neutron irradiation embrittlement and aims to monitor the change in integrity of the ferritic material in the reactor pressure vessel core region.

The material change is in the surveillance programme for the reactor vessel inspected by using test specimens that contain reactor vessel material. These test specimens are located in circuits between the core shroud and the reactor vessel and are subjected to accelerated neutron irradiation. The test specimens are removed for testing in accordance with a preset programme. The results from the surveillance testing then form the basis of the development of HTG charts for the reactor vessel.

Provisions for identifying unexpected degradation

According to IAEA NS-G 2.12 measures shall be taken to prevent ageing of SSCs, and if ageing effects are identified there shall be a plan to prevent any further progression of the ageing effects. This will minimise the risk that ageing occurs and mitigate ageing progression. On a component level in safety-related SSCs, inspections are performed regardless of whether there is any ageing predicted or not. This is a precaution to help find any unexpected ageing effects. This is a part of the overall Ageing Management Programme and is mainly conducted through the maintenance programme. Everyone working in the plants shall observe and report all unexpected signs of ageing effects. Operations and maintenance staff performs visual inspections of a large part of the equipment, partly with the aim of detecting unexpected issues.

Forsmark
A broad-based training programme for staff members in detecting and reporting signs of ageing effects is performed in Forsmark. This training programme is part of the strategic development at Forsmark.

Ringhals
For Ringhals an ageing training programme is under development based on the Vattenfall Membership in EPRI NMAC. The training programme is developed at Forsmark and will be implemented after adaption to Ringhals conditions. Currently Ringhals is developing 4 different education programmes within the subject of ageing.

Oskarshamn
A broad ageing management training programme within Oskarshamn was developed in 2016. One of the aims of this basic training developed is that everyone working in the plant shall pay attention to ”abnormal” ageing effects, and report anything that seems abnormal.

2.3.4. Preventive and remedial actions

Forsmark
Forsmark require that for all systems within the scope of ageing management, a periodic system health report is created. This report is formed by a system health team with members from engineering, operations, maintenance and radiology department. From continuously

produced status reports, operational experiences and other information the team describes and documents the actual status or threats to the system and component health. The team also identifies any further need to develop the preventive maintenance and predicts any possible future need for system and component upgrades. The time frame for the study in the system health report varies from short term (upcoming 0-3 years), medium term (upcoming 3-10 years) and plant end-of-life (total 60 years).

All identified required actions are risk evaluated, prioritised and addressed to relevant handling processes and responsibilities. When system/equipment reliability or failures requires the need to further enhance or renew a maintenance programme or action, a formal process for analysing, proposing and approving such change is performed within the maintenance staff responsibility.

When reviewing new/changed maintenance or inspection programmes for safety related SSCs, evaluation is conducted to verify that the intention of the ten evaluative criteria for comprehensive ageing management, as described in NUREG-1801, is met. When an established acceptance criterion has been exceeded regarding any specified function, component or media, a failure report is filed in the maintenance system, FENIX. All failure reports are evaluated, prioritised and prepared in the work order process for further corrective or remedial actions. The work order process handles failure reports in a daily routine via operations, maintenance and engineering.

Ringhals
Within Ringhals preventive actions are to operate the plants within the STF and follow the conditions and service intervals set forth in the preventive and remedial AMPs. This ensures that the plant is operated within the analysed limits.

In the ageing analysis, it is mandatory to establish a plan for preventive measures to mitigate ageing degradation or prevent failures. The preventive actions are implemented in maintenance databases.

Remedial actions may be triggered by the detection of degradation or experience from internal or external sources. If inspection reveals a degradation, the matter is immediately taken care of to make sure if other objects may be affected. A root cause analysis is initiated to determine the degradation mechanism.

In some cases, regarding safety related objects, the root cause analysis is reviewed by an Accredited Inspection Body. Repairs, replacements and modifications follow the Swedish regulations SSMFS 2008:13. If repair is necessary it will be planned as a separate activity. Other preventive and/or remedial actions are to evaluate internal and external experiences in order to follow best practice.

Oskarshamn
Within Oskarshamn there is a so called task force whose assignment is to handle damages that occur. The group’s assignment is to coordinate, direct, analyse and initiate measures concerning damages that have occurred on systems and components.

The aim is to obtain a Certificate of Compliance (IOÖ) and a system ready for operation. Ageing related damages/defects shall be documented in the meeting minutes, and the group is tasked with establishing the probable cause of the damage/defect, and produce the documentation required for a report to SSM, if that is stated by the regulations in that particular case.

2.4. Review and update of the overall AMP

How licensee audit and inspection findings are implemented

Forsmark
Audit results and findings from SSM or from the Forsmark internal safety department are planned, actions addressed and followed up in the database FOCUS (CAP-system). Results and findings from other inspections and audits normally result in an autonomous actions plan managed by the line organisation. WANO peer review, IAEA SALTO/OSART-reviews always have a separate action plan and a due follow-up inspection. Implementation of actual physical changes in the plants is the responsibility of the respectively organisation departments, through the process of Plant Optimisation.

Ringhals
Audits within Ringhals may be performed by different entities, according to the following list.

- Internal audit by quality department, NQ
- Inspection by regulatory body, SSM
- Inspections by IAEA, SALTO/OSART WANO peer Review

All findings identified in audits are registered in the Corrective Action Programme, Avärs, and assigned a responsible engineer. Some of the findings may be handled within the AMP group.
The corrective action will be given a severity index based on the findings. This index determines the type of action that has to be taken and which report structure to follow.

Oskarshamn
Internal audits are performed systematically and on a regular basis on all activities with respect to the application of Oskarshamn's management system, its appropriateness and efficiency. The audit is based in the requirements stipulated in the requirements and guidelines document of the area concerned. The review is managed by representatives from the Safety and Quality department. Any identified deficiencies and areas for improvement are entered in Oskarshamn's CAP system, SAFE, for follow-up and monitoring. As a supplementary addition to the regular audits, topical audits are also conducted that are limited in scope and which can be performed with only limited advance planning, if required. Oskarshamn has also called for a pre-SALTO for the end of November 2017. This inspection is performed with the aim of giving Oskarshamn an objective assessment of the ageing management as well as of the LTO management.

Evaluation of internal and external operating experiences

Forsmark
At Forsmark line organisation responsibility has been assigned to the Experience feedback department NEQ group. The group is responsible for processing and returning external

experience within the company and perform risk and event investigations from a human technology organisation/human factors (HTO) perspective. NEQ performs the following tasks:

- External experience feedback are evaluated and managed with Forsmark expert group events managed in NordERF and reporting Forsmark events to WANO
- Representing Forsmark in NordERF, association between Nordic nuclear facilities.
- To attend the 14-day meeting, where NordERF representatives review the submitted cases from their own facilities as well as WANO (World Association of Nuclear Operators), to ensure quality assurance and coding of cases.
- To spread information about relevant external issues at the weekly production meeting.
- The WANO SOER coordinator follows up and supports the owners / managers of each Significant Operating Experience Report (SOER),
- To perform event and risk investigations with the HTO perspective, as well as provide support in HTO issues.

Ringhals
Evaluation of internal and external operating experience at Ringhals is done within specific technical networks and for the ageing analysis all relevant experiences are evaluated. When new experiences are encountered the ageing analysis is updated to reflect and evaluate the experience.

Evaluation of plant modifications that might influence the overall Ageing Management Programme

Forsmark
When the design and configuration process at Forsmark introduces new systems and component types through plant changes or component replacement, these component types will also be subject to ageing management. The projects accomplish this by carrying out analyses of new equipment according to established methodology. When choosing new qualified equipment, the designer uses component unavailability data (TUD) to ensure that the most reliable and suitable components are introduced into the plant.

The analysis methodology shows whether the component type can be included in an existing group of ageing monitoring groups or whether new formal ageing analyses with their own groupings are required. A maintenance representative is assigned to each plant modification project. The maintenance representative is responsible for developing and introducing a maintenance plan for the new or modernised SSCs. The maintenance plan incorporates ageing management strategies from day one of plant implementation and spare parts.

Ringhals
In accordance with the Ringhals process for plant modification, an analysis of the potential impact on the overall AMP shall always be performed. This ensures that requirements and constraints from the overall AMP are taken in to account in the plant modification. This is specified in the Design Assurance Process (DAP) which has to be followed when a plant is modified. The DAP was reviewed by SSM in 2013 and areas of improvements have been implemented. New routines are implemented to support individual technical engineers working with plant modifications to ensure that potential interactions with the AMP are addressed.

Oskarshamn
Oskarshamn has no established procedure applied to a systematic analysis of potential ageing effects at plant modifications. This is considered an area for improvement within Oskarshamn's overall Ageing Management Programme. However, possible ageing effects are examined in the design phase and governed by Oskarshamn's design instructions.

Evaluation and measurement of the effectiveness of ageing management

Forsmark
To measure reliability trends, Forsmark use the analysis tool Bi-Cycle. It can identify trends, both for system reliability and on a component reliability level. The tool is linked to either Forsmark's local maintenance history or to the component unavailability database (TUD) which contains data from all Nordic nuclear power-plants.

Ringhals
Within Ringhals the scope of KPI issued regarding Ageing Management effectiveness is limited but from areas where the AMP has been in place for an extended period of time, the conclusion is that the programmes and documents indicates that the underlying issues have been well managed and ensures an adequate ageing management, for example ISI, Water Chemistry and Surveillance of the Reactor Pressure Vessels (RPV) material.

Oskarshamn
Since 2016 Oskarshamn has used the key performance indicator "a" is defined as a=A/T, where A= total number of ageing related recorded fault reports per unit.

Evaluation of ageing analyses that are time limited

Forsmark
At Forsmark all safety class equipment qualified for a specified time and environment has a note in the plant register with the necessary data for qualification analyses. All qualification expiry dates are monitored with five years in advance for an early notification to start the process for requalification or replacement projects. Current environmental data is monitored with temperature, irradiation and pressure logs and reported annually. For the reactor material neutron irradiation embrittlement, a surveillance programme is run and approved by the regulatory authority.

TLAA are recalculated for 60 years, due to exceeding 40 years of operation, and as a part of the justification for continued operation in the Periodic Safety Review (PSR). The actual analyses are performed as part of an LTO project. According to both IAEA and NRC guidance, there are three approaches to managing a TLAA for LTO; verifying that current TLAAs are valid for the intended time extension, (re-)calculating relevant TLAAs for that time extension or applying AMPs that manage the ageing degradation effects. For example, for fatigue of plant over-head cranes, TLAA recommendations are provided in the relevant guidance. However, necessary historical load data to perform fatigue calculations are not available. In this case an AMP for monitoring and preventive measures are adopted.

Ringhals
Within Ringhals TLAA are those original analyses that had time-limiting pre-requisites and were used to estimate the operation of the SSC. When an estimated operation is about to be reached, the analyses must be re-evaluated and even re-done.
To ensure safe operation beyond the original design period the following criteria's must be proven to be met:

1. That the original analysis is applicable for the extended operation
2. That the original analyses has been up-dated to cover the extended operation
3. That all relevant degradation mechanisms that may be affected by ageing of handling are taken care of, for instance by additional inspection

To identify areas where there could be a need to evaluate TLAA a pre-study was performed that resulted in a list of potential TLAA. The list was extracted from information from the original analyses that used time-limited assumptions from SAR, regulations and investigations from the Authority, SSM and IGALL. Using the list as a base, a systematic evaluation was performed to determine if the identified TLAA were applicable, or if they already been handled within the programme that had been verified in the AMR process. The remaining TLAA, which were subject to analyses were divided into seven areas, Low Cycle Fatigue, Irradiation Embrittlement, Thermal Ageing, RCP fly-wheel, Containment Tendons, Fatigue of Cranes, CRDM step sequence.

The revalidation of the remaining TLAAs at Ringhals is ongoing and scheduled to be completed by the autumn of 2018, and to be included in the PSR.

Oskarshamn
The Oskarshamn 3 reactor at Oskarshamn was originally designed for 40 years of operation. In the modernisation and power upgrade project, completed in 2009, new analyses were conducted and the plant is now verified for 60 years of operation. For fatigue analyses a compilation of occurred transients and corresponding fatigue analyses is performed every year. Valid flaw tolerance analyses are compiled annually. Flaw tolerance analyses are used as a basis for ISI. For real defects, inspection intervals can also be based on the results from previous inspections and statistical data. Oskarshamn follows the IAEA guidelines in the LTO project. In order to identify relevant areas for which TLAA, need to be performed, Oskarshamn has used the IAEA database for TLAA 2015 edition. Other sources of information that have been used include the specific SSM reports in this area.

How current "state-of-art", including R&D results, is taken into account
The current state-of-art within the nuclear industry is continuously being monitored through strategic participation in various R&D forums. Results and findings derived through participation or monitoring of R&D projects are continuously being implemented into their respective fields of work via the line organisation within Forsmark, while Oskarshamn has a standing item on the coordination group agenda and Ringhals, in accordance with the AMP-group tasks to yearly review the overall AMP. Ringhals also uses EPRI guidelines for the Technical areas and Ageing Analyses. See also Chapter 2.3.2.

Consideration within the overall Ageing Management Programme of modifications in the current licensing or regulatory framework
The regulatory body, SSM, will issue a new framework in the coming years. An example of this is that the ageing management shall be implemented and the TLAA re-evaluated before the plant is operated beyond the design operating period.

Forsmark
At Forsmark the NES department is responsible for requirements management, including ageing management requirements and that these are described in SAR. The department for system health, NED oversees ageing management requirements in particular, and has a single point of contact (SPOC) designated for developing company-wide (i.e. Vattenfall) ageing management.

Ringhals
Similar to Oskarshamn, Ringhals has an appointed requirements analyst, whose assignment is to, for instance monitor changes in the regulatory requirements. Furthermore, Ringhals, in accordance with the responsibility of the AMP group's overall Ageing Management Programme, shall be evaluated against modifications in the current licensing or regulatory framework.

The current regulatory requirements are specified in a requirement matrix. In the event of any changes in the regulatory requirements, it is the requirements analyst´s responsibility to ensure that this is handled and complied with by, for instance, updating procedural descriptions or instructions.

Oskarshamn
Oskarshamn has an appointed requirements analyst whose assignment is to, for instance, monitor changes in the regulatory requirements. In the event of any changes in the regulatory requirements, it is the requirements analyst's responsibility to ensure that this is handled and complied with by for instance updating procedural descriptions or instructions.

Identification of the need for further R&D

Forsmark
At Forsmark, R&D is primarily carried out in areas of importance to the results and long-term production capacity. R&D programmes are divided into six priority areas. Ageing R&D programmes are included in the Maintenance area.

Ringhals
Within Ringhals each Technical Area the need for further R&D are identified and the following work/project are supervised within the same Technical Area. When writing the ageing analysis the engineer responsible may point out needs that have to be addressed within R&D. The AMP group is responsible.

Oskarshamn
R&D, is an important parameter in Oskarshamn's ageing management. R&D is a standing item on the agenda, discussed within Oskarshamn's coordinating group for ageing management as well as within the AMP teams established.

Strategy for periodic review of the overall AMP including potential interface with periodic safety reviews
Every ten years there is an PSR and in Chapter 7 of this review, both AMP and LTO are described.

Forsmark
The safety department at Forsmark is responsible for internal audits and review. This includes reviewing ageing management. The last internal audit that covered ageing management was conducted in the spring of 2017. Findings from the internal audit will be imposed as decided actions in the CAP-system FOCUS and implementation will be reviewed as part of internal follow-up. The continuous development and changes over time to the overall AMP shall be described and reflected in the upcoming PSR.

Ringhals
Ringhals conducts internal reviews and audits in addition to PSR. The quality department (NQ) is responsible for internal reviews. The last internal audit that covered AMP where conducted during the beginning of 2017.

All Ageing Analyses shall be updated and re-evaluated at least every fifth year or in closer intervals if new information is available that affects the analyses, in accordance with Ageing Analyses instructions.

IAEA has performed a pre-SALTO peer review on Ringhals ageing management. In 2018 there will be a full SALTO per review at Ringhals.

Oskarshamn
Internal audits are systematically performed at Oskarshamn within all activities with respect to the application of Oskarshamn's management system, its appropriateness, application and efficiency, which also includes the ageing management. In addition to the internal audit mentioned above, performed for the ageing management area, a follow-up of requirements is also performed, where the ageing management is reviewed based on the internal requirements in force. This kind of review is conducted every three years.

Incorporation of unexpected or new issues into the overall AMP

For Forsmark the responsibility for coordinating the overall Ageing Management Programme is assigned to the engineering department while for Oskarshamn and Ringhals this responsibility is assigned to the maintenance department. This is done within multi-disciplinary technical networks and for the ageing analysis all relevant unexpected or new issues are evaluated. When unexpected or new issues are encountered the ageing analysis is updated to reflect and evaluate the experience.

Use of results from monitoring, testing, sampling and inspection activities to review the overall AMP

This is managed similarly to the incorporation of unexpected or new issues into the overall AMP as stated above. Feedback in the form of annual result reports from inspections, maintenance and operations is of central importance for an effective ageing management process. Performance reports are selected for annual follow-up, and procedures for the review are established.

Periodic evaluation and measurement of the effectiveness of ageing management

Forsmark

To measure reliability trends, Forsmark uses the analysis tool Bi-Cycle. This tool provides analysis, both for system reliability and on a component reliability level. The tool is linked to either Forsmark’s local maintenance history or to the component unavailability database TUD which contains data from all Nordic nuclear power plants. No frequency of these measured reliability trends is given.

Ringhals

Ringhals presents the periodic evaluation and measurement of the effectiveness of AMP in the annual summary report from the AMP group. The report summarises the progress for all the six different Technical Areas that are represented in the AMP group. Internal audits are systematically performed and include ageing management.

Oskarshamn

Oskarshamn uses since 2016 the key performance indicator “a” is defined as a=A/T, where A= total number of ageing related recorded fault reports, per unit. This index is evaluated monthly.

2.5. Licensee's experience of the application of the overall AMP

Forsmark

The first strategic work specifically addressing ageing started at Forsmark in late 2006, after an injunction from the regulator SSM regarding the fulfilment of newly issued regulatory requirements. The injunction stated that Forsmark must supplement the maintenance programme to systematically manage ageing degradation for SSCs important to safety. To meet the requirement, Forsmark launched a comprehensive analysis project and formed a component scope focused on safety related equipment and structures.

The ageing management for the in-scope SSCs was reviewed in line with then existing guidelines, e.g. IAEA Safety Report Series No.15 and Nuclear Energy Institute NEI 95-01 (revision 3). Once it had finished the implementation phase of the project, Forsmark had renewed, supplemented or changed a multitude of actions, instructions and procedures to manage ageing-related degradations according to present review standards. Upon finishing the ageing analyses and project implementation, a preliminary suggested strategy was formed and issued in the organisation.

The strategy was intended to form a basis for an overall AMP with quality assurance through clearly appointed responsibility in the Forsmark quality management system. However, creating an overall AMP was proving more challenging than running a project with a designated staff, a scope and a project time frame. An overall Ageing Management Programme requires a continuous, clear assignment, support from and accountability to senior management, and aware and dedicated staff members with proper training and tools. This is more difficult and time consuming to achieve. To respond to the feedback and inspection remarks from the regulator SSM, Forsmark has launched two consecutive company programmes for implementing correctional and ageing management development actions, both to the SAR and quality management system as well as line organisation commitments.

These company programmes has paved the way for the upcoming LTO project and other requirements in enhancing the managing of ageing. The maintenance department is responsible for the preventive maintenance programme, which also means responsibility for implementing the necessary details for specific AM of SSC's. The maintenance organisation is also responsible for analysing and reporting of the present status and future requirements in maintaining the SSC's.

In general, the plant preventive maintenance programme was largely built and continuously updated over many years of local plant experiences and on-demand maintenance analyses in a number of historical organisational constellations. These circumstances did not contribute to a very detailed documentation on the thoughts and reasoning behind individual preventive maintenance tasks. Performing ageing management review, documenting the degradation mechanisms and ageing effects as part of justifying preventive, mitigating and detecting actions, forms a vital contribution to creating a documented background and motive to the composition of individual preventive maintenance tasks which constitute the plant preventive maintenance programme. The status reports have a decisive role in the plant optimization process and system health reports from which plant system ageing degradation issues are formed into managing strategies.

After a reorganisation of the Forsmark staff, the newly formed department for system health (NED) is responsible for managing the overall AMP. Integration of summarised conclusions from the specific AM results is an ongoing development within the system health process. Establishing and spreading knowledge and awareness regarding the effects of ageing degradation and the underlying ageing mechanisms and their respective environmental stressors, are an ongoing development challenge within the organisation. The particular importance of this awareness has been identified with regards to the operations and maintenance staff, when performing their daily routines and responsibilities. As a guide to the implementation of AM for LTO, Forsmark has performed an IAEA pre-SALTO review. This has been an important step in both the technical details of managing ageing issues as well as creating a companywide awareness of the necessities and requirements of operating the plant past its originally intended life span.

Ringhals

Ageing Management has been developed and implemented by Ringhals's line organisation, not a specific AM project. It has been a challenge to get the required engineering recourses for the development of the Ageing Management due to the fact that it is a time-consuming task. It took several years to reach an acceptable implementation level, but the benefit using engineers in the line organisation is that the implementation is done gradually. The in-house engineers have built knowledge and competence in the organisation and it is an opportunity to transfer competence.

Ringhals was involved at different development stages of the IAEA IGALL project which increased the understanding of the fundamental ageing management processes.
IAEA SALTO work-shops and Pre-SALTO reviews forced Ringhals to keep up the ageing management work. The IAEA reviews gave valuable feedback and an opportunity to exchange experiences with colleagues from the industry.
Another conclusion is that the Ageing Management programmes indicated that the underlying issues have been well managed in the past and ensured an adequate ageing management, for example ISI, Water Chemistry and Surveillance of the RPV material. The most significant improvement is achieved in areas where, historically, there has been less focus. Several AMPs produced in such areas have forced the formalisation of the activities, the roles and the responsibilities. It is in these areas that the clearest benefits from the ageing management can be perceived. Also, for multi-disciplinary objects the Ageing Management Programme processes have been established through the AMP group.

Oskarshamn

Oskarshamn has during the past few years been working intensely on implementing an Ageing Management Programme that meets the regulatory requirements in force. The majority of this work has been run in project activities, comprising scoping/screening, commodity grouping and AMR.

In parallel with this project, work was also initiated in 2015 within maintenance, the department responsible for ageing management, by establishing an organisation and a working method in order to handle continuous ageing management. This work resulted in a process, the hub of which consists of the coordinating group of ageing management and AMP teams. This process is based on IAEA NS-G-2.12.

The ageing management coordinating group started their work based on the process developed at the beginning of 2016 with recorded meetings, and ten such meetings were held in 2016. In order to further increase the understanding of ageing in the line organisation, a number of training courses were also developed in 2016 within the fields of:

- Basic ageing management.
- Systematic ageing management.

- Ageing of metallic materials.
- Ageing of polymeric materials.

The training courses stated above have been implemented in Oskarshamn's training tool and are also linked to an entirely new competence area, ageing, that has been developed. The project delivered a number of AMR reports at the end of 2016, submitted to the coordinating group of ageing management whose task is to handle the deviations identified within the AMR. The work on handling the deviations will continue in 2017/2018.

2.6. Regulatory oversight process

SSM regulatory oversight aims at assessing the licensees ability to lead and control operations from a radiation safety perspective - the licensees management is appropriate and includes well-developed internal control to provide the desired outcome. SSM's supervision can be both general, for example by inspection of the management system, and detailed, for example inspection of how ageing management of a specific system is conducted.

SSM’s oversight shall be conducted to provide the basis for well-founded assessments and conclusions. Assessments should be formulated to make it clear whether the requirements are fulfilled or not. Deficiencies are identified and documented when SSM considers that a requirement is insufficiently fulfilled or not adequately addressed. An assessment of the radiation safety significance shall be made in relation to the requirements for the defects.

SSM’s oversight efforts should be risk and need based, which means that the risk or potential consequences of short and long-term shortcomings should be part of the supervisory control. This approach should be reflected in the risk and need-based monitoring programmes.

As mentioned earlier the former SKI issued 2004 updated regulations (SKIFS 2004:1) introducing a new requirement of ageing management in Chapter 5 Section 3. According to a provisional regulation, the programme of ageing management would have been in operation on 31 December 2005 at the latest.

2.7. Regulator’s assessment of the overall Ageing Management Programme and conclusions

2.7.1. SSM´s assessment of the ageing management processes described

All three licensees in Sweden have develop their overall Ageing Management Programme based on international guides like IAEA NS-G-2.12, SRS 57 and use IAEA SRS 82 and NUREG 1801 to check consistency. The use of international guidance provides conditions for a comprehensive overall Ageing Management Programme to be developed and are in accordance with SSM requirement on ageing management given in Chapter 5 Section 3 Swedish regulations SSMFS 2008:1. The requirement is performance based with the final goal to ensure the availability of required safety functions throughout the service life of the plant.

The licensees have chosen slightly different paths to derive their respective overall Ageing Management Programmes.

The scope of the overall Ageing Management Programme are SSCs important to nuclear safety, which includes:

- SSCs important to safety that are necessary to fulfil the fundamental safety functions;
- Other SSCs whose failure may prevent SSCs important to safety from fulfilling their intended functions.

For resource effective ageing management SSCs included are often arranged into generic groups based on for example understanding ageing, monitoring ageing and mitigation of ageing effects (NS-G-2.12). Both Forsmark and Ringhals have based grouping of structures and components on factors such as similar function, similar design, similar materials, similar ageing management and similar environments. For these groups Forsmark and Ringhals have develop reports (systematic ageing analysis, strategic maintenance plan) in which the ten criteria given in NUREG 1801 (comparative to the nine attributes in NS-G-2.12) have been evaluated. This information can subsequently be used in order to compare with for example existing maintenance practices. If any of the criteria is not met, changes in the programmes need to be conducted.

Oskarshamn has chosen to define groups based on component type, environment and material as input in SQL formulated issues in order to identify the ageing mechanism. This grouping method involves that one specific structure or component can be present in a number of different groups, dependent for example on whether the component in question consists of different materials or that different ageing mechanism can affect the structure. Oskarshamn later analysed these groups in an IT tool to evaluate if all the attributes in NS-G-2.12 are covered by present programmes or not. Deviations are reported and necessary changes in Ageing Management Programmes are conducted.

SSM finds that generic groups reports formulated by Forsmark and Ringhals involves more information compared to how Oskarshamn formed grouping by SQL formulated issues. SSM considers that the way Forsmark and Ringhals have chosen is more consistent to an international approach (NS-G-2.12). Additionally, it is not clear to SSM how Oskarshamn in practise can use these groups for an effective ageing management in practise since many different groups has to be involved in evaluating every single structure and component.

None of the Swedish licensees have been working with quality management of the overall Ageing Management Programme in a systematic manner. It is only Oskarshamn that has started (beginning of 2016) to measure the efficiency of the Ageing Management Programme by defining the key performance indicator (a) defined as the relationship between number of faults related to ageing divided by the total number of recorded faults.

SSMs opinion is that quality assurance/management of the overall Ageing Management Programme is important to uphold a proactive approach. In this respect quality assurance/management should for example include administrative control that document implementation, indicators to facilitate evaluation of the overall Ageing Management Programme and a confirmation process to ensure that preventive and corrective actions are adequate and effective. SSM considers that quality assurance/management of the overall Ageing Management Programme can be improved amongst Swedish licensees.

With regard to ageing assessment most of the information used to prepare the overall Ageing Management Programme has been compiled from other programmes like maintenance, component qualification, in service inspection and chemistry programme. Using these programme a lot of experience gained from operation from licensees reactors as well as external ageing related experience has been used.

It is SSMs opinion that since Swedish licensees started to develop their overall Ageing Management Programme after approximately 20 to 30 years of operation (due to a new regulation issued 2004) it is natural that ageing assessment has been based on these programmes rather than for instance on manufacturing documents. However, in order to check consistency IAEA SRS 82 and NUREG 1801 have been employed by the Swedish licensees. The key elements to identify ageing mechanisms for SSCs involved in the overall

Ageing Management Programme have in all cases been material, medium (internal), environment (external) and operating experience. The procedure for identification of ageing mechanisms and their consequences have been developed in different ways between the Swedish licensees. Ringhals and Forsmark uses expertise in components and system engineers while Oskarshamn uses a purchased catalogue of defects which in part was adapted to Oskarshamn conditions.

SSM considers the process used by Forsmark and Ringhals to be more robust, using the inhouse expertise and experience in different areas more effectively. The use of purchased expert systems can be valuable for identifying ageing mechanisms but it should not exclude the use of the licensee’s own interdisciplinary expertise.

An important attribute in ageing management is the establishment of acceptance criteria for which the need of corrective actions are evaluated. Swedish licensees uses the high-level criterion that the SSCs shall maintain their intended function during design basis events and during operating life.

SSM considers that this high-level criterion should be more specified for example by a process for calculating specific numerical values to define conditional acceptance criteria to ensure the SSCs intended function.

Programmes for monitoring, testing and inspection are described in SUP, systematic ageing analysis or in component specific AMP and are mainly performed within the maintenance, inspection or surveillance programmes. For mechanical devices (i.e. SSCs made of metal subjected to pressure, mechanical load or SSCs that hold or guide other components) inspections are conducted in accordance with chapter 3 in Swedish regulations SSMFS 2008:13. In this respect identification of possible ageing mechanisms are performed for each inspection area and suitable inspection methods are chosen. According to chapter 3 in Swedish regulations SSMFS 2008:13 risk informed inspection programmes shall be employed. SSCs shall be divided into three groups, based on risk of damages on the nuclear fuel, radioactive release and criticality. Identification of possible ageing mechanism are consequently conducted within the overall Ageing Management Programme as well as the inspection programme.

SSM considers that there is an obvious risk of confusion between these two ways of identifying degradation mechanisms, which must be dealt with. To some extent the double identification of ageing mechanisms is based on SSMs regulations and a consequence of SSMs late introduction (2004) of a requirement for an overall ageing management.

Preventive and remedial actions are documented for SSCs involved in systematic ageing analysis and SUP (Forsmark and Ringhals respectively). These reports also contain information of parameters which must be upheld in order to uphold the preventive and remedial effect. These parameters are also measured within for example maintenance and chemistry programmes, at a frequency decided to prevent degradation from occurring. Oskarshamn has not yet finalised the documentation of the remedial and preventive actions within their work with the overall Ageing Management Programme, this will be completed within a few years.

SSM considers that systematic assessment of preventive and remedial actions is a very important feature in ageing management that need to be documented and continuously evaluated. Forsmark also requires that for all systems a periodic system health report shall be compiled. This report is formed by interdisciplinary team members and identifies any need to improve preventive actions and needs for system or component upgrades. The time frames for the system health reports varies from short (0-3 years) to intermediate (upcoming 3-10 years) and finally plant end of life (60 years). SSM finds that systematic work with three different time frames demonstrates a mature organisation with regard to ageing management and is an example of a good practice.

Review and update of the overall Ageing Management Programme is for Swedish licensees conducted in a similar manner as for updates in other programme. Findings from internal audits or external inspections by SSM, WANO or IAEA SALTO/OSART reviews normally results in tasks, documented in designated databases.

Involvement of external organisations for review and updates of the overall Ageing Management Programme is according to SSM important to uphold its validity in the light of experience gained as well as of developments in science and technology. It is SSMs view that results from international reviews of the overall Ageing Management Programme, should be regarded as one basic information given in PSR documentation handed in by the licensees to the regulator.

Ageing analyses that are time-limited (TLAA) are plant specific analyses of SSCs. The TLAAs consider those analyses for which time-limited assumptions were included in the original calculations to determine the design life of plant, which usually implies Long term operation (LTO). However, LTO is not defined in Swedish legislation or associated regulations, instead the term “continued operation” has been suggested (SSM2016-1287-2). It is further suggested that all SSM reviews of the licensees PSR will include taking position on continued operation to the date of the next PSR decided by SSM. One important part for licensees to justify continued operation is in this respect to show that identified TLLAs meet the criteria established. This includes that licensees have to provide a process for identification of the time limited analyses and corresponding updated evaluations for each occasion of a PSR. The TLLAs should consider the entire remaining period of time for which the continued operation is planned. Forsmark and Oskarshamn involve TLAAs in the overall Ageing Management Programme while Ringhals have chosen to manage TLAAs in the PSR process rather than as part of the overall Ageing Management Programme.

SSMs opinion is that to exclude analyses that use time limited assumptions in the overall Ageing Management Programme can cause unnecessary confusion, since the use of TLAA is one way to manage ageing. Internationally (e.g. NS-G-2.12) TLAAs are also incorporated into the overall Ageing Management Programme. Apart from this, SSM considers that the Swedish licensees in general follows international best practise for evaluation of TLAAs, stating that a TLAA is adequate if it meets all of the following cases (IAEA SRS 82):

- The analysis remains valid for the intended period of operation.
- The analysis has been projected to the end of the intended period of operation.
- The effects of ageing on the intended function(s) of the structure or component will be adequately managed for the intended period of operation. A specific Ageing Management Programme will be used to ensure that the ageing effects are adequately managed.

If a TLAA is not found to be acceptable under one of the above described cases, corrective actions are necessary to implement (e.g. to refine calculations, repair, increase preventive actions).

With regard to feedback from experience (internal/external) and how modifications in the current regulatory framework are considered, it is SSMs opinion that this follows a well-established methodology for the Swedish licensees. This methodology covers all operational issues including the overall Ageing Management Programme.

2.7.2. SSM´s experience from regulatory oversight

SSM has performed a number of inspections and reviews at the Swedish power plants. It has been done with various results.

After an inspection conducted by SKI 2005, all three licensees (i.e. Forsmark, Oskarshamn, Ringhals) 2006 received a decision (by an injunction) to implement overall Ageing Management Programmes. The main deficits found by SKI in 2005 concerned management system and the contents of the programmes. According to SKIs decision these deficiencies should have been rectified by the end of 2008. SKI also provide clear references to IAEA, WENRA and SKI documents to present the Swedish authority's view of an overall Ageing Management Programme.

New, and more detailed, inspections concerning licensees programme for ageing management were performed by SSM between 2013 to 2017. Results from these inspections showed that all licensees (Forsmark, Oskarshamn, Ringhals) in different degrees have interpreted the requirement given in chapter 5 section 3 in Swedish regulations SSMFS 2008:1 as well as the decision by injunction given by SKI 2006. All three licensees exhibited according to SSM still deficiencies in their programme for ageing management as well in management system in relation to the decision given by SKI 2006 and to present regulations. The results from the inspections conducted, led to new SSM decisions (by injunction) for Oskarshamn (2013, 2015, 2017) and for Forsmark (2016) to complete their programmes for ageing management and to implement changes into their respectively organisation. For the third Licensee (Ringhals) SSM found that no new injunction was necessary and that Ringhals had actions started to handle deficiencies found. SSM will conduct new inspections during 2017 and 2018 to assess fulfilment of SSM's requirement for an Ageing Management Programme (chapter 5 section 3 Swedish regulations SSMFS 2008:1).

The results from inspections of ageing management as well as reviews so far of PSR shows that SSMs expectation differs from the licensees view with regard to programmes for ageing management. SSM has, to some extent, contributed to today's status and SSMs analysis, with no internal ranking, of the reason for this is:

- The Swedish NPP licensees focus during the past decade on power uprating and safety upgrade work to fully comply with the Swedish regulations SSMFS 2008:17 regarding increase NPPs defence in depth has been given priority over development of programmes for ageing management.
- The coordination responsibility for ageing management at SSM has been unclear after the merger 2008 of SKI and SSI to SSM. This had the result that inspections and other oversight with regard to overall programme for ageing management by SSM was absent during a number of years.
- The performance/goal based regulatory philosophy used by SSM so far has resulted in too wide interpretations by the licensees of the requirement concerning programme for ageing management. It is evident that clearer regulations, more dialogue and oversight would have been beneficial for the licensees in the situation with much work, including comprehensive safety upgrades, to meet both SSMs and international expectations of overall Ageing Management Programme.

2.7.3. Conclusions

Based on the licensees reporting in the frame of this NAR as well as SSM oversight activities of the licensee's overall Ageing Management Programme between 2013-2017, SSMs conclusions are;

- Based on SSMs performance based requirement philosophy Swedish licensees have pursued slightly different paths to develop their respective overall Ageing Management Programme, all with the goal to ensure the availability of required safety functions throughout the service life of the plant. Since SSM introduced a requirement for an overall programme for ageing management in late 2004, all licenses had before that introduced "ageing management" within other programmes like maintenance, chemistry and in service inspection, even if it was not explicitly described as, or as comprehensive as an overall Ageing Management Programme described in NS-G-2.12. SSM now considers that Forsmark and Ringhals have overall Ageing Management Programmes that fulfil SSM requirements and international expectations. The third licensee Oskarshamn has developed an overall Ageing Management Programme that still needs to be implemented in the organisation. SSM has by a decision (by injunction) issued as a condition for operation, that Oskarshamn for reactor Oskarshamn 3 shall have an implemented overall programme for ageing management before the end of January 2018 (SSM2017-384-16).

- The scope of the overall Ageing Management Programmes used by the Swedish licensees are SSCs important to nuclear safety, which includes, SSCs important to safety that are necessary to fulfil the fundamental safety functions and other SSCs whose failure may prevent SSCs important to safety from fulfilling their intended functions. From SSMs perspective, the SSCs important to nuclear safety SSCs and SSCs whose failure may prevent SSCs important to safety from fulfilling their intended functions are required to be involved in the overall Ageing Management Programme. It is SSMs view that expanding the scope can be beneficial in that internal experience gained from ageing degradation involve more SSCs, but at the same time, the expanded scope could cause the time and resources needed for keeping the programme updated to increase.

- For resource effective ageing management, SSCs included are often arranged into generic groups based on for example understanding ageing, monitoring ageing and mitigation of ageing effects. Forsmark and Ringhals have defined groups in a similar manner while Oskarshamn has used a method in which specific structures and components can involve many different groups. SSM conclude that the way of defining groups conducted by Forsmark and Ringhals follows more an international practise (NS-G-2.12) whereas the Oskarshamn way is more unclear. SSM also conclude that it is still up to Oskarshamn to show how the defined groups are planned to be used in practise, to accomplish an effective ageing management.

- The procedure for identification of ageing mechanisms and their consequences have been defined differently between the Swedish licensees. Ringhals and Forsmark use expertise in components and system engineers while Oskarshamn uses a purchased catalogue of defects which in part was adapted to Oskarshamn conditions. SSM concludes that the process used by Forsmark and Ringhals is more robust, using the in-house expertise and experience in different areas more effectively. The use of purchased expert systems can be valuable for identifying ageing mechanisms but it should not exclude the use of own interdisciplinary expertise.

- None of the Swedish licensees have been working with quality management of the overall Ageing Management Programme in a systematic manner. Only Oskarshamn has started to measure the efficiency of the Ageing Management Programme by defining a key performance indicator. SSM concludes that quality assurance/management of the overall Ageing Management Programme can be improved considerably amongst Swedish licensees.

- During development of the overall Ageing Management Programme Swedish licensees have largely compiled information from already existing programmes like maintenance, component qualification, in service inspection and chemistry programme. Using these programmes a lot of experience gained from operation from licensees reactors as well as external ageing related experience has been used. The overall Ageing Management Programme becomes therefore naturally an interdisciplinary programme linking ageing perspective in other programmes together. The key elements used by the Swedish licensees to assess ageing are based on the nine attributes in NS-G-2.12, which are similar to the ten elements described in NUREG-1801. It is SSMs opinion that since Swedish licensees started to develop their overall Ageing Management Programme after approximately 20 to 30 years of operation (due to a new regulation issued 2004), it is natural that ageing assessment have been based on these programmes more than for instance on manufacturing documents. Additionally, Swedish Licensee´s in order to check consistency have used IAEA SRS 82 and NUREG-1801 in the ageing assessment. To have an international assessment of the overall Ageing Management Programme, all three licensees have also conducted IAEA SALTO or pre-SALTO reviews. Experience gained from these reviews have subsequently been incorporated into their respective programmes.

- An important attribute in ageing management is the establishment of acceptance criteria against which the need of corrective actions are evaluated. Swedish licensees use the high-level criterion that the SSCs shall maintain their intended function at the design basis events and during operating life. SSM considers that this high-level criterion should be more specified, to explain for example a methodology for calculating specific numerical values to define conditional acceptance criteria to assure the SSCs intended function taking into account sufficient margins. According to SSM the purpose with acceptance criteria is to allow corrective action for SSCs to be implemented before loss of the intended function(s) for the SSC in question.

- Programmes for monitoring, testing and inspection are described in SUP, systematic ageing analysis or in component specific AMP and are mainly performed within the maintenance, inspection or surveillance programmes. For mechanical devices (i.e. SSCs made of metal subjected to pressure, mechanical load or SSCs that hold or guide other components) inspections are conducted in accordance with Chapter 3 in Swedish regulations SSMFS 2008:13. In this respect identification of possible ageing mechanisms is performed for each inspection area and suitable inspection methods are chosen. Identification of possible ageing mechanism is consequently conducted within the overall Ageing Management Programme as well as the inspection programme. SSM considers that there is an obvious risk of confusion between these two ways of identifying degradation mechanisms, which must be dealt with. To some extent the double identification of ageing mechanisms is based on SSMs regulations and a consequence of SSMs late introduction (2004) of a requirement for an overall ageing management programme. In order to identify unexpected degradation Swedish licensees have introduced broad-based training programmes for operations and maintenance staff members in detecting and reporting signs of ageing effects.

- Preventive and remedial actions are documented for SSCs involved in systematic ageing analysis and SUP (Forsmark and Ringhals respectively). These reports also contain information of parameters which must be upheld in order to uphold the preventive and remedial effect. SSM considers systematic assessment of preventive and remedial actions to be a very important feature in ageing management that need to be documented and continuously evaluated. Forsmark also requires for all systems that a periodic system health reports shall be reported. This report is compiled by interdisciplinary team members and identifies any need to improve preventive actions and needs for system or component upgrades. The periods for the system health reports varies from short (0-3 years) to intermediate (upcoming 3-10 years) and finally plant end of life (60 years). SSM find that systematic work with three different periods demonstrates a mature organisation with regard to ageing management and is an example of a good practice.

- Review and update of the overall Ageing Management Programme for Swedish licensees is conducted in a similar manner as for updates in other programmes. Findings from internal audits or external inspections by SSM, WANO or IAEA SALTO/OSART reviews normally result in tasks, documented in designated databases. Involvement of external organisations for review and updates of the overall Ageing Management Programme is according to SSM important to uphold its validity in the light of experience gained as well as of developments in science and technology. One important part for licensees to justify continued operation is to show that identified TLAAs meet the criteria established. The TLAAs should consider the entire remaining period of time for which the continued operation is planned. Additionally, it is SSMs view that results from international reviews of the overall Ageing Management Programme should be regarded as one basic information given in PSR documentation handed in by the licensees to justify that the programme is updated.

3. Electrical cables

3.1. Description of Ageing Management Programmes for electrical cables

The Swedish licensees have reported separately according to the technical specification on the area of electrical cables. Unless otherwise stated, the description below is valid for all licences.

Forsmark
The AMP for electrical cables in Forsmark covers electrical cables that are included in SSCs important to nuclear safety. This AMP is not completed yet. Forsmark is working to establish a complete AMP for electrical cables. The AMP will be based on the principles of IAEA Safety Guide No. NS-G-2.12 in order to support selection and create proactivity in the identification of threats and deficiencies.

Forsmark's current ageing management has been based on systematically developed ageing analyses. The basic principle is to coordinate existing programmes for maintenance, monitoring, control, technical analyses, internal and external experience feedback and R&D. Forsmark participates in and follows research and methodology development in the field of developing condition control methods for electrical cables. The scope of ageing analysis for electrical cables is to establish processes and methods to work with age related problems for most of the electrical cables. The methods have been developed based on Forsmark's accumulated experience and expertise in this area.

Oskarshamn
Oskarshamn has been working on ageing management issues, but without calling it ageing management. The aim of the ageing management at Oskarshamn is to coordinate existing programmes for maintenance, walk downs, qualification, and technical analyses together with internal and external experiences.

Ringhals
The AMP for electrical cables in Ringhals covers all electrical cables included in SSCs important to nuclear safety, and describes strategies for the condition control and/or exchange of cables. Ringhals is working with ageing management issues systematically. Ringhals AMP is based on the principles of IAEA Safety Guide No. NS-G-2.12.

One of the basic principles has been to coordinate existing programmes for maintenance, monitoring, control, technical analyses as well as taking part of internal and external experience feedback of R&D. Ageing analysis, ageing programmes and status assessments have been documented in a structured and coherent manner in accordance with IAEA SG NS-G-2.12 adapted to Ringhals organisation. Ringhals participates and follows research and methodology development in the field of condition control for electrical cables. Ringhals has established a cable ageing group with a task to establish a structured and more organized cable ageing programme.

3.1.1. Scope of ageing management for electrical cables

Forsmark

There is no single document describing the overall processes and procedures of AMP at Forsmark on electrical cables. However, there are a number of instructions and guidelines ensuring long-term operation of the cables in Forsmark. There are also instructions and delegations setting out the required fundamental management, quality control and procedures. The instructions clarify the responsibility, necessary competence and job description essential for successful ageing management. The ageing management for electrical cables is in general terms incorporated in the regular maintenance routines.

The ongoing work to establish an AMP for electrical cables at Forsmark is based on:

- Understanding ageing, ageing mechanisms and ageing effects.
- Preventive actions to minimise and control ageing degradation.
- Detection of ageing effects.
- Monitoring and mitigating actions for ageing effects supported by applicable acceptance criteria.
- Describing the global environment and existing hot spots.

Oskarshamn

The electrical functions at Oskarshamn 3 are classified according to IEEE 308 – Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations, but the none-safety functions are divided into 2E (operational functions) and 3E (service functions). The basis of the scope and screening regarding cables is Swedish regulations SSMFS 2008:1 Chapter 5 Section 3:

> *"Structures, systems, components and devices of importance for safety at a facility shall be inspected, tested and maintained on a continuous basis in such a way that they meet the safety requirements."*

Ringhals

The ageing management for all groups of electrical cables at Ringhals is based on:

- Exhaustive understanding of ageing, ageing mechanisms and ageing effects.
- Identification and initiation of preventive actions to minimise and control ageing degradation.
- Use of applicable methods for detection of ageing effects.
- Initiation of monitoring and mitigating actions to limit ageing effects, supported by applicable acceptance criteria.

Methods and criteria used for selecting electrical cables within the scope of ageing management

Forsmark

All safety classified cables (Class 1E) are considered in Forsmark AMP of cables. Also, non-safety classified cables are included if they are considered as important for plant availability and production.

Each cable has its unique identity and is represented in a database, which contains information regarding cable length, routing, cable type, electrical function class (safety class or not safety class), separation class and electrical sub. Forsmark considers that the adverse environment hot spots in rooms containing cables have to be documented, because these hot spots might challenge cable performance. Identification of hot spots is mainly done by performing visual inspections during a plant walk down with thermographic camera. The result of a plant walk down is documented as a report.

All visual inspections that result in a non-approved result are subjected to technical evaluation. Such an evaluation should consider the age and operating environment for which the specific cable is exposed to and what kind of problems that may occur. Corrective action can be to insert shielding such as double insulation of hot pipes or establish a new cable routing to avoid identified hot spots or alternatively move the object causing a hot spot.

Oskarshamn

All cables at Oskarshamn 3 are managed in a design tool and a routing tool (Master concept and Mapper), so the scope is the complete list of cables from these tools. Every cable has a unique number and is routed according to a node net, and each node has its location in a room. In each room the environmental data is recorded based upon measurements and analyses.

The cables inherit their electrical function class from the connected functions or components. A screening from the complete cable list was made, with the criteria of 1E-function and/or required testing scope according to the STF for Oskarshamn 3. This work was performed according to Oskarshamn's instruction for scooping and screening, and the result from this work is documented as a report.

All cables at Oskarshamn are divided into six different classes:

1. Power cables >1000 V.
2. Power cables ≤1000 V.
3. Control cables 60-250 V.
4. Control cables <60 V.
5. Coaxial cables for neutron flux monitoring system
6. Optical fibre cables.

Ringhals

All safety classified cables (Class 1E) are considered in Ringhals AMP of cables. Also, non-safety classified cables are included if they are exposed of such adverse environment that causes degradation of cables. Each cable is represented in a database. Each reactor unit has its own database which contains information regarding cable length, routing, cable type, fabrication and date of manufacture, electrical class (safety class, 1E, or non-safety class, 2E/3E), separation class and electrical sub.

Ringhals has collected and documented a global environment for different areas in another database to identify which areas have the most adverse environments. These databases present environment information during normal condition, design basis event condition and severe accident conditions. This means that the databases include information regarding temperature, radiation, pressure, humidity and chemical environment.

The existence of adverse environment hot spots for rooms including cables might challenge cable performance. Identification of hot spots is mainly done by usage of thermography camera when visual inspections are performed, i.e. during a plant walk down. The result of a plant walk down is documented and, if necessary, used to update the preventive maintenance plan. All visual inspection that gives a non-approved result is subject of a technical evaluation. Such an evaluation should consider the age and operating environment that the specific cable is exposed of and what kind of problems that may occur. An example of a corrective action can be to insert shielding such as double insulation of hot pipes or establish a new cable routing to avoid identified hot spots or alternatively move the object causing a hot spot.

Processes/procedures for the identification of ageing mechanisms related to cables

Forsmark and Ringhals
Within the framework of a cooperation forum FORSAMP a common gross list of degradation mechanisms, for all types of components, have been established. FORSAMP is a cooperation between Forsmark, Oskarshamn, Ringhals and SKB.

The purpose of the list is to:

- Provide an overview of the extent of degradation mechanisms which are taken into account at the Swedish utilities.
- Provide support to the coordinator carrying out the ageing analysis.
- Provide input to more comprehensive descriptions of various degradation mechanisms.

The list is created by studying literature, primarily IGALL, IAEA Safety Report Series No 82, Westinghouse NOG Report SEP 04-120, different EPRI documents, NUREG 1801 (GALL), as well as other area-specific technical documents. Additional information regarding degradation mechanisms of electrical equipment are obtained from: EPRI Report 1003057 *PSE License Renewal Electrical Handbook* and IEEE 1205-2000 IEEE *Guide for Assessing, Monitoring, and Mitigating Ageing Effects on Class 1E Equipment Used in Nuclear Power Generating Stations*.

Oskarshamn
Each cable is connected with a documented article, where the information about the cable is presented. This information covers the used materials in the cable, such as insulation, conductor, shield etc. Materials are analysed and the results are documented. The purpose of this document is to provide a general overview of all the ageing mechanisms and their effects for material used within Oskarshamn.

Grouping criteria for ageing management purposes
ForsmarkTable 4 below illustrates a rough correlation between the example of grouping in WENRA TPR and the grouping of cables at Forsmark.

Table 4 - grouping of electrical cables, WENRA and Forsmark

WENRA TPR grouping	**Forsmark cable grouping**
High voltage cables >3 kV	>36 kV (400 kV grid and 70 kV to startup transformers)
Medium voltage cables 380 V to 3 kV	>1 kV to 36 kV (6 kV and 10 kV)
	Low voltage cables <1 kV
Neutron flux instrumentation cables	Neutron flux instrumentation cables

70 kV cables are included in the scope of AMP even though they are not classified as important to safety. They are included because they are considered important to plant availability and production. These cables will not be handled by this report because they are not important to safety.

For the 400 kV there are no cables, just overhead lines without insulation. 6 kV and 10 kV cables important to safety for emergency cooling systems are situated in a dry and well ventilated indoor environment. They will not be included in this report, but they are included in the scope of the AMP.

The 1E classified cables are the most important. More precisely, Forsmark applies the following priority when control and power cables within AMP are considered:

- Covered by systematical ageing analyses for cables inside reactor containment 1E cables with LOCA requirements and 1E cables in general.
- Covered by systematical ageing analyses for cables outside reactor containment 1E cables with LOCA requirements, 1E cables in general, cables with the largest impact on plant availability and NSAS (Non Safety Affecting Safety) cables.

Oskarshamn

The first grouping criterion is whether the cable type has a qualification report or not, and with which qualification report the type is covered. The qualification report contains information on what type of environmental conditions the specific type of cable can be installed in. Not all cables have a qualification report, which automatically adds them to the second grouping criterion. If the cable type does not have a qualification report, the second grouping criterion for the cables concerns the polymer materials, used for shielding, insulation etc. Polymers have the most significant degradation of all materials used in the cables. Therefore, the polymers are used as grouping criteria.

Oskarshamn 3 has about 47 different commodity groups in total. This work was performed in accordance with Oskarshamn's instruction for commodity grouping, and the result from this work is documented in reports. According to other reports many types of material are described, with their ageing mechanisms and effects.

Oskarshamn 3 does not have any high-voltage cables that are subjected to an adverse environment due to plant design and instructions for the installation of cables. Rounds are performed according to instructions. The aim of the rounds is to detect and react to environmental changes.

Ringhals

The table below illustrates a rough correlation between the example of grouping in WENRA TPR and the grouping at Ringhals.

Table 5 – grouping of electrical cables, WENRA and Ringhals

WENRA TPR grouping example	Ringhals cable grouping
High voltage cables >3 kV	400 kV
	130 kV
Medium voltage cables 0.38 kV-3 kV	6 kV
	> 0.38 kV
Neutron flux instrumentation cables	Neutron flux instrumentation cables

Both 400 kV and 130 kV are more or less included in Ringhals AMP even though they are not classified as important to safety. More precisely, Ringhals applies the following priority when cables within AMP are considered:

1. 1E cables with LOCA requirements inside Containment.
2. 1E cables with HELB requirements outside Containment.
3. 1E cables in general.
4. 2E cables that are exposed to adverse environment.

3.1.2. Ageing assessment of electrical cables

Ageing mechanisms requiring management and identification of their significance

Forsmark

Forsmark has concluded that they need to consider different ageing mechanisms (oxidation, embrittlement etc.) and different ageing stressors (temperature, radiation, humidity etc.) that might accelerate ageing and its effects. Forsmark states that the effects (loss of flexibility, hardening, decreased insulation resistance etc.) of ageing mechanisms and detection of different ageing stressors are more easy to detect than the detection of ageing mechanisms themselves. Therefore, Forsmark's AMP focuses mainly on detecting these different ageing effects and stressors to manage the different ageing mechanisms.

At Forsmark, the important ageing stressors that accelerate different ageing mechanisms are temperature and radiation. These ageing stressors are incorporated in Forsmark's systematically analyses of cables. Other ageing stressors like moisture/water, vibration and exposure to chemicals etc. will also be considered in Forsmark's AMP if they are identified as a stressor of supplying ageing mechanisms. Although these types of ageing stressors are rare or even non-existent, they are mainly covered and handled by preventive maintenance. Of the two important ageing stressors mentioned above, temperature is the most significant stressor since it causes the material to harden (and lose its elasticity) and eventually it loses its tensile properties. It is also the most commonly encountered stressor because investigations done so far by performing plant walk downs, interviewing maintenance people, considering results from R&D, external experience etc. all indicate that temperature is the most significant stressor that causes ageing deficiencies.

Obviously, cables exposed to radiation are also important considerations, but most cables at Forsmark units are routed through a mild radiation environment. Radiation mostly becomes an issue when attempts to requalify cables are considered. At Forsmark there are no cables important to safety exposed to humidity/water during normal operation as they are all placed inside the buildings. So far, Forsmark has not identified any alarming ageing deficiencies when cables that have been exposed to radiation or humidity/water have been considered.

Oskarshamn

For the medium (250 V) voltage cables at Oskarshamn, the ageing mechanisms requiring management and identification of their significance are oxidation – regarding the insulation of the cable – and thermal ageing – regarding the jacket of the cable. The insulation and jacket consist of polymers: Cross-Linked Polyethylene (XLPE) for insulation and PO for jackets. The ageing mechanism for XLPE is oxidation resulting in cracks in the material. The ageing mechanism for PO is thermal ageing resulting in cracks in the material. Cracks in the polymer material can cause, for example, short circuits. This cable type is in class 4, and the AMP for this cable class is currently under production. This cable type is qualified for 15 years, and is tested/analysed to withstand its normal environmental conditions with a margin for accidents.

In this application, it is not necessary to take into account conditions including accidents, but this type of cable is used in other functions. The tests and analyses have shown that no preventive maintenance is needed as long as the environmental conditions are milder than the cable type is qualified for. Temperature measurements have been performed in these rooms, and will be performed if a design change is made which may affect the environment in these rooms. A change in environment will be noticed, performing the rounds according to instructions.

For the Neutron flux instrumentation cables at Oskarshamn, the ageing mechanisms requiring management and identification of their significance are oxidation regarding the insulation of the cable and the jacket of the cable. The insulation and jacket are consisting of Polyamide/PFA. The ageing mechanism for Polyamide/PFA is oxidation with the result of cracks in the material. Cracks in the polymer material can cause short circuits. This cable type is in Class 5, and the AMP for this cable class is currently under production. One experience from maintenance department regarding this cable is to exchange it at the same time as the connected sensor is exchanged. This is due to the design of the cable connection to the sensor.

Ringhals

Ringhals has concluded that they need to consider different ageing mechanisms (oxidation, embrittlement etc.) and different ageing stressors (temperature, radiation, humidity etc.) that might accelerate ageing and ageing effects. Ringhals states that the effect (loss of flexibility, hardening, decreased insulation resistance etc.) of ageing mechanisms and detection of different ageing stressors are more easy to detect than the detection of ageing mechanisms. Therefore, Ringhals AMP mainly focuses on detecting of these different ageing effects and stressors to handle the different ageing mechanisms.

At Ringhals, the important ageing stressors that accelerate different ageing mechanisms are due to temperature, radiation and moisture/water. These ageing stressors are incorporated in Ringhals' AMP of cables. Other ageing stressors like vibration and exposure of chemicals, etc., are also considered in Ringhals AMP if they are identified as a stressor of supplying ageing mechanisms. Although, these types of ageing stressors are rather rare if existing at all, they are mainly covered and handled by preventive maintenance.

Of the three important ageing stressors mentioned above, temperature is the most significant stressor since it causes the material to harden (loses its elasticity) and eventually loses its tensile properties. It is also the most encountered stressor because investigations done so far by using the global environment databases, performing plant walk downs, interviewing maintenance people, considering results from R&D, external experience, etc., all indicate that temperature is the most significant stressor causing ageing deficiencies. Obviously, cables exposed to radiation are also important considerations, but the major part of cables at Ringhals units are routed in a mild radiation environment.

Radiation mostly becomes an issue when attempts to requalify cables are considered. Cables exposed to humidity/water are generally not easy to inspect visually when they are routed in piping. Humidity combined with elevated temperature and/or radiation can cause the sheath and/or the conductor insulation to start swelling. Ringhals has not identified any alarming ageing deficiencies in cables that have been exposed to radiation and/or humidity/water.

Establishment of acceptance criteria related to ageing management
Forsmark

A number of R&D projects have been performed by Forsmark to analyse Lipalon cables, which are the most common cables within reactor containment at Forsmark unit 1 and unit 2. The analysis was performed on a number of cable samples collected from Ringhals and Forsmark. The goal with this analysis was to establish the remaining life time as a function of ambient temperature. This analysis showed that ageing is not an immediate threat to plant safety or availability when global effects (ambient temperature) are considered. It also showed the importance of identifying hot spots and to keep track of them.

At Forsmark unit 3, a requalification programme for cables in reactor containment was performed in 2012. This resulted in a remaining lifetime of 20 years counting from 2011. In this requalification programme the analysis was performed on a number of cable samples collected from Forsmark unit 3. One conclusion was that a new requalification programme needs to be started in 2025. To learn about ageing related degradation on electrical cables there is a special cable ladder placed inside the reactor containment at Forsmark unit 3. Various specimens have been placed in this cable ladder in order to track any degradation.

Forsmark is participating in a number of different forums in order to receive the latest R&D results and to exchange experiences. Below are listed a number of these exchange programmes:

- EKG, kabelgruppen, is a forum with participants from Swedish and Finnish utilities (Forsmark, Oskarshamn, Ringhals and TVO). This forum gathers at least once a year to present and exchange all kind of experiences regarding cabling including ageing effects.
- Kungliga Tekniska Högskolan, KTH, have performed a number of analyses of Lipalon cables for Forsmark and Ringhals.
- Representatives from Forsmark are actively participating in standardisation work in IEC TC45 and IEEE SC2 on the topic of ageing management and qualification methods.
- Forsmark was a partner in the Euratom project “Advance” regarding ageing mechanisms of cables inside reactor containment.

Specific ageing assessment of high-voltage cables (70 kV) as low and medium-voltage cables (<1 – 36 kV) are not applicable at Forsmark.

Maintenance of neutron flux cables (NIS cables) at Forsmark for all units has been based on the qualified lifetime and visual inspection of NIS cables. To keep track of qualified lifetimes, the cables are included in the Forsmark Environmental Qualification programme. No specific and scheduled activities have been undertaken to identify any ageing mechanism outcomes. Nor have any findings been identified that indicate any need for such activities. Most NIS cables in Forsmark are tested and analysed by time domain reflectometry (TDR) measurements at the yearly outage. Although this type of TDR testing is mainly used to identify deficiencies or changes in electrically considered cable parameters, it is also used to identify other cable degradation/changes.

To further support the interpretation of TDR measurements, Forsmark has developed an instruction describing the presence of typical electrical parameters like junctions etc. This type of testing is planned to be continued for the remaining life span. It states that the material of this cable's insulation is XLPE (KXL-760G), and the material for its jacket is Chlorosulfonated polyethylene (CSPE). As these cables are located indoors, the ageing stressors are heat, radiation, mechanical impact and humidity. Based on the ageing stressor, Forsmark has identified the insulation degradation, and insulation and jacket embrittlement as ageing mechanisms for these cables. The effect of these mechanisms for insulation and jacket are cracks, colour changes and stiffness. Forsmark uses visual inspection, TDR testing and isolation resistance testing to supervise these ageing effect.

Oskarshamn
At Oskarshamn, the acceptance criterion for ageing mechanisms for cables is that they fulfil their function. If a cable fails to do so, it will be replaced during a planned outage. The plant has four safety trains, so that one single cable fault does not jeopardise the safety of the plant. The STF define the time period before the plant has to be in cold shutdown after that kind of cable fault.

During the production of these AMP, the maintenance system ODU, will be one of the sources for input. In this system, all the faults reports are handled. An analysis of the fault reports concerning this cable class will be performed. If the analysis shows that there is a common fault, the preventive actions for detecting such a fault earlier will be handled in this AMP. The basis for these AMPs is the IAEA Safety Guide NS-G2.12.

Oskarshamn and Forsmark are participating in EKG Kabelgruppen in order to share information about cables according audits, standards and regulatory requirements, tests/analyses/walkdowns, qualifications and experiences. All representatives in this group share information about cables, according to these topics. The representatives from each plant work with design, maintenance or quality issues.

Ringhals
A number of R&D projects have been performed by Ringhals to analyse Hypalon/Lipalon cables, which are the most common cables in reactor containment. The analysis was performed on a number of cable samples collected from Ringhals 1 and 3. The goal of this analysis was to establish the remaining life time as a function of ambient temperature. The analysis also concluded that there is a significant correlation between an increased indenter module (i.e., a measuring ageing effect) and ambient temperature (i.e., an ageing stressor). As a result of this analysis, indenter reference values were elaborated and are used at Ringhals.

Ringhals finds it difficult to find applicable criteria for the requalification of cables. Ringhals has, for instance, not found any applicable acceptance criteria published by EPRI. Instead, Ringhals has started to establish indenter acceptance criteria by performing ageing tests of representative cables. These tests are governed by instructions developed by Ringhals with the involvement of elongation at break (EAB). Established indenter acceptance criteria are correlating to EAB of 50% with a high degree. Acceptance criteria, or reference values in this context, are also based on experience. With what is known today, it is important to determine “fingerprints” of new cables to be able to identify substantial changes of a cable when considering methods like Line Resonance Analysis (LIRA) or TDR, i.e., to be able to have an efficient change detection method. All reference values are used to alert and initiate the required actions when they are exceeded. For instance, an identified change presented by a LIRA measurement is not necessary a result of ageing, but it might be an indication that something has happened and the reason for this need to be clarified.

Ringhals is participating in a number of different forums in order to receive the latest R&D results and to exchange experience. Below, a number of these external forums are presented:

- EKG, Kabelgruppen, is a forum with participants from Swedish and Finnish utilities (Forsmark, Oskarshamn, Ringhals and TVO). This forum gathers at least once a year to present and exchange all kind of experiences regarding cabling, including ageing effects.
- Kungliga Tekniska Högskolan, KTH, have performed a number of analysis of Hypalon/Lipalon cables for Ringhals.
- Halden On-Line Monitoring User Group, HOLMUG, provide an update and discuss ongoing research and identify future research needs at Halden Programme Group (HRP).
- EPRI, Ringhals has for many years been participating at a number of EPRI Cable User Workgroup Meetings. This has contributed to how Ringhals AMP is executed.

Specific ageing assessment of high voltage cables (130 kV).
For a typical cable in this category, it states that the material of insulation is XLPE, and the material for its jacket is polyethylene with a conductive layer (PE). Ageing stressors according to the location of these cables outdoors environment are humidity/water and mechanical impact due to excavate. Based on ageing stressor Ringhals has identified that the insulation degradation, corrosion in cable connections as ageing mechanism for these cable. The effect of these mechanisms are “water treeing”, increased resistance in cable connection. Ringhals uses visual control when excavation takes place, thermography camera and outer sheath insulation resistance testing to supervise these ageing effect.

Specific ageing assessment of medium voltage cables (>0.38 - 6 kV).
For a typical cable in 6 kV category it states that the material of insulation is XLPE, and material for jacket is polyolefin. Ageing stressors according to the location of these cables indoors environment are heat, radiation, mechanical impact and humidity. Ringhals has identified that the insulation degradation, insulation and jacket embrittlement, poor cable connections as ageing mechanism for this cable depends on the ageing stressor. The effect of these mechanisms for insulation and jacket are cracks, colour change and stiffness, and increased resistance in cable connections. Ringhals uses visual inspection, thermographic cameras and isolation resistance testing to supervise these ageing effect.

Ageing stressors on cables outdoors and in ground culverts are humidity/water.
Depending on the ageing stressor, Ringhals has identified that the insulation degradation as ageing mechanism for this cable. The effect of these mechanisms are “water treeing”. Ringhals uses Very Low Frequency (VLF) Tan/Delta measurements, high voltage testing and partial discharge (PD) measurements to monitor these ageing effects.

For a typical cable in the < 1 kV category, it states that the material of insulation is XLPE, and the material for its jacket is polyolefin. As these cables are located indoors, the ageing stressors are heat, radiation, mechanical impact and humidity. Based on the ageing stressors, Ringhals has identified that the insulation degradation, insulation and jacket embrittlement, poor cable connections are ageing mechanism for this cable. The effect of these mechanisms on the insulation and jacket are cracks, colour changes and stiffness, and increased resistance in cable connections. Ringhals uses visual inspection, EAB, LIRA, indenter, thermography camera and isolation resistance testing to supervise these ageing effects.

Specific ageing assessment of NIS cables:
Ringhals has a slightly different approach regarding AMP of NIS cables, both regarding AMP of other cables but also Ringhals' different units. This difference is mainly due to the remaining lifetime of Ringhals nuclear units and NIS cable routing. Common to all units is that the AMP has been based on the qualified lifetime and visual inspection of NIS cables. To keep track of qualified lifetime, the cables are included in the Ringhals Environmental Qualification programme. No specific and scheduled activities have been undertaken in order to identify any outcome of ageing mechanism. Nor have there been identified any findings that indicate any need of such activities. Nevertheless, Ringhals is planning to expand its AMP of NIS cables.

At Ringhals 1, the most exposed parts of NIS cabling due to radiation/heat have been exchanged. The reason for this exchange was mainly because:

- Cable routing inside reactor containment, since these parts of NIS cabling are exposed to mechanical impact due to normal maintenance of other components nearby.
- Repeated problems with oxidation in the junction between NIS cable and socket.
- Qualified lifetime of these cables were about to expire.

However, the remaining parts of NIS cabling were able to be requalified in order to manage the remaining lifetime of Ringhals 1. Most NIS cables (PRM channels) in Ringhals 1 are tested and analysed by TDR and insulation resistance measurements at the end of each year's outage. Remaining parts of NIS cables (WRMN channels) are only tested by ordinary functional testing. Although this type of TDR/insulation resistance testing are mainly used to identify deficiencies or changes in electrically considered cable parameters, it is also used to identify existence of other cable degradation/changes. To further support the interpretation of TDR measurement, Ringhals has developed an instruction describing presence of typical electrical parameters caused by junctions for example. This type of testing is planned to be continued for Ringhals 1's remaining lifetime.

At Ringhals 2, 3 and 4, the qualified lifetime of NIS cables is about to expire. Most of this cabling has been exchanged and no significant presence of ageing has been identified so far. This means that currently used AMP has fulfilled its purpose. However, Ringhals is despite this planning to expand its AMP of NIS cables and mainly at Ringhals 3 and 4, since unit 2 will soon reach the end of its lifetime. So, besides exchanging the major parts of NIS cables, Ringhals also develop a more comprehensive AMP of these cables by collecting a chart of "fingerprints" (insulation values etc.) of each NIS cable, to be used in succeeding inspections. Also, an inspection frequency is added and managed by including it in a preventive maintenance plan. Ringhals 2, 3 and 4 are using TDR and Insulation resistance measurements when needed, although TDR is not used to the same extent as in Ringhals 1.

For a typical cable in this category it states that the first material of insulation is polymer LE (PEEK) and the second material is Cross-Linked low noise treated modified polyolefin, and the material for jacket is Cross-Linked low noise treated modified polyolefin. As these cables are located indoors, the ageing stressors are heat, radiation, mechanical impact and humidity. Based on these ageing stressors, Ringhals has identified that insulation degradation, insulation and jacket embrittlement, poor cable connections are ageing mechanisms for this cable. The effect of these mechanisms for insulation and jacket are cracks, colour changes and stiffness, and increased resistance in cable connections. Ringhals uses visual inspection, TDR testing and isolation resistance testing to monitor these ageing effects.

3.1.3. Monitoring, testing, sampling and inspection activities for electrical cables

Forsmark
There are a number of different monitoring, testing, sampling and inspection activities for electrical cables at Forsmark. The various activities are divided into non-destructive and destructive methods. Some of the methods are only used during qualification work. The non-destructive methods used by Forsmark are visual inspection, indenter, LIRA, insulation resistance (IR) testing and TDR. The destructive methods used by Forsmark are EAB and oxidation induction time (OIT).

The interval for the most commonly used methods like visual inspection, IR testing and TDR is managed in the preventive maintenance plan. Below follows a brief description of the common methods used at Forsmark.

- Visual inspection. Gives a quick first indication if something has happened with a cable. To avoid cables being located close to hot process piping, plant walk downs inside the reactor containment are executed with a thermographic camera. This is carried out in the beginning of an outage when the process systems are still hot. This is the most efficient method to identify hot spots that are difficult to detect during the outage. The advantage of a visual inspection is that it is a non-destructive method which can be carried out on all cable configurations. The disadvantage of a visual inspection is that it can be difficult to follow the cable routing for example when it is in a closed cable tray or in a pipe installation.
  At Forsmark, there are some reference values for walk downs with thermographic cameras. Outside the reactor containment, the correct actions need to be taken when the temperature is above 30ºC on a cable raceway. Inside the reactor containment, the corresponding temperature is above 55ºC.
- IR testing. This method is used on medium voltage, low voltage and NIS cables. It is normally used to detect conductor insulation damage that may have been caused during installation. Insulation resistance maintenance testing can be performed on a regular basis, and the collected data used to indicate if the conductor insulation is deteriorating over time. This type of test is a form of preventative maintenance. If the insulation resistance falls below an accepted (user dictated) value, or falls rapidly over time, then cable replacement is considered.
  Any maintenance on a powered component is followed by an insulation resistance test of the power circuit. It is usually done from the switchgear room or directly at the terminal of the object being tested with the power cable connected. In this case

Forsmark can verify insulation condition in the maintained object, the connection in the terminal and in the power cable up to the circuit breaker. The reference values are resistance > 100 MΩ (on a cable that is free in both ends).

- OIT. This method is used for qualification. The purpose of this method is to check the oxidation stability for a polymer. A small sample from a polymer is collected. In a typical oxidation induction time test the samples are heated in an inert atmosphere (nitrogen) to a temperature above the melting point of the sample. At a constant temperature (isothermal) the sample atmosphere is switched from inert to oxidative. The determination of the oxidation induction time is used to assess the stability of polymers.

Specific activities for high voltage cables (70 kV) and medium voltage cables (>1 – 36 kV) are not applicable at Forsmark.

For the low voltage cables (<1kV) at Forsmark there are specific activities.

- EAB. This is a destructive tensile strength test method to measure material properties. It is very common in the cable industry to test and evaluate the sheath and insulation of an electrical cable. It is considered to be very reliable and is often used as a reference when the usefulness of new methods are evaluated. Forsmark uses this method by purchasing a test from external supplier with the necessary equipment. The fact that you need to have a piece of cable that has been exposed to the same conditions as the cable you want to test to get a relevant result is a disadvantage for this test method.
- Indenter. Cable condition control with an indenter is similar in execution and approach to a mechanical hardness measurement. Indenter is a form of elasticity measurement and is normally not considered as a destructive method. A mandrel (probe) is pressed at a constant rate into the material until a predetermined maximum force is reached. In order to analyse the result, values of the original indenter module value of the cable is essential. At Forsmark, an indenter is used in cooperation with Ringhals when, for example, a hot spot is located and there exists a need to establish the amount of degradation of the cable. This method has no established frequency and it is only used on cables working at voltages of ≤ 1 kV.
- LIRA. This method can be used to detect any local or global (across almost the whole length of the cable) changes in the cable electrical parameters as a consequence of insulation faults or degradation. At Forsmark this method was evaluated earlier on. Experience has shown that it is not a viable method to identify reliable cable parameters at the first and last 1-5 metres of the cable. For the moment it is not used on a regular basis.

For the NIS cables at Forsmark there is a specific activity.

- TDR. This method is used on coaxial and triaxial cables for NIS cables. TDR checks terminations, penetration, cable and detector. Examples on faults that can be detected are faulty termination to the detector, damaged, clamped or aged cable. Reference values are unique for each cable, i.e. do not exist in general terms. Assessment is done by comparison with previous measurements on the same cable.

Oskarshamn

At Oskarshamn, monitoring, testing, sampling and inspection activities for high voltage electrical cables are not applicable.

For medium voltage cables, Oskarshamn says that these are routed in closed cable trays and plastic pipes, embedded in concrete. Therefore, visual inspections are not an option. These cables were installed in the plant during 2009 and are qualified for theirs function and environment for 15 years. According to Oskarshamn these cables are continuously monitored by a closed circuit current, which if interrupted alerts an alarm in the control room. If any problems occur with the cable, this will be reported with a fault report and after that the damaged cable will be replaced during a planned outage.

For the Neutron flux instrumentation cables, Oskarshamn states that the maintenance department inspects the sensor with the cable every year according to several maintenance tasks for test and calibration. The signal and equipment are inspected during an outage once every year. This cable is installed within a pipe, which makes it impossible to perform a visual check. This cable, the pipe and sensor were exchanged in 2016. The acceptance criteria depend on whether the signal can be adjusted on the amplifier for this equipment, which is controlled by maintenance instruction. If adjustment of the signal does not work, the sensor together and the cable are exchanged.

Ringhals

There are a number of different monitoring, testing, sampling and inspection activities for electrical cables at Ringhals. The various activities are divided into non-destructive and destructive methods. The non-destructive methods used by Ringhals are visual inspection, indenter, LIRA, VLF Tan/Delta testing, PD testing, IR testing, and outer sheath insulation resistance and TDR.
The destructive methods used by Ringhals are EAB and high voltage testing (if cable deficiencies exist).

The interval for the most commonly used methods like visual inspection, LIRA, IR testing and TDR is managed in the preventive maintenance plan.

Below follows a brief description of the common methods used at Ringhals.

- Visual inspection. Gives a quick first indication if something has happened with a cable. At Ringhals 2-4, visual inspections are carried out during plant operation. The interval is managed by a preventive maintenance plan. This is the most efficient method to identify hot spots that are difficult to detect during an outage. For Ringhals 1, this is carried out in the beginning of the outage when the process systems are still hot. The advantage of the visual inspection is that it is a non-destructive method which can be carried out on all cable configurations. The disadvantage of the visual inspection is that it can be difficult to follow the cable routing, for example, when it is in a closed cable tray or in a pipe installation. At Ringhals, there are some reference values for walk down with thermography camera. Outside the reactor containment, proper actions need to be taken when the temperature is above 30ºC on a cable raceway. Inside the reactor containment the corresponding temperature is above 55ºC.
- IR testing. This method is used on medium voltage and NIS cables. Visual inspection is normally used to detect conductor insulation damage that may have been caused during installation. Maintenance insulation resistance testing is performed on a regular basis, and collected data is used to indicate if the conductor insulation is deteriorating over time. This type of test is a form of preventative maintenance. If the insulation resistance falls below an accepted (user dictated)

value, or falling rapidly over time, then cable replacement is considered. Reference value: resistance value > 100 MΩ.

Specific activities for high voltage cables (130 kV).

- Outer Sheath Insulation Resistance (Screen wire test). This method is used on newer 130 kV cables to see if there is any damage on the sheath (mantle) of the cable. It's mainly done when a new cable has been installed to see that there is no damage during the installation.

Specific activities for medium voltage cables (> 380 V – 6 kV).

- EAB. This is a destructive tensile strength test method to measure material properties. It is a common method to test and evaluate the sheath and insulation of an electrical cable. It is considered to be very reliable and is often used as a reference when the usefulness of new methods is evaluated. Ringhals uses this method by purchasing a test from external supplier that has the necessary equipment. The fact that you need to have a piece of cable that has been exposed to the same conditions as the cable you want to test to get a relevant result is a disadvantage for this test method.
- Indenter. Cable condition testing with indenter is similar in approach to mechanical hardness measurement. Indenter is a form of elasticity measurement and is a non-destructive method. A mandrel (probe) is pressed with constant rate into the material until a predetermined maximum force is reached. When the maximum force is reached the mandrel springs back due to the elasticity of the material. The parameters that vary are the time (Δt in seconds) and penetration depth (Δx in mm) until the maximum force is reached. These parameters are measured and processed by indenter. In order to be able to analyse the result, values of the original indenter module value of the cable is essential. At Ringhals, indenter is used when, for example, a hot spot is located and there exist a need to establish the amount of degradation of the cable. It is only used at cables working at voltage ≤ 1 kV, excluding NIS cables.
- LIRA. This method is used to detect any local or global changes in the cable's electrical parameters (impedance). LIRA can detect effects of cable degradation and, most importantly, locate it. At Ringhals LIRA is mainly used during an outage as part of the search for hot spots and is considered as a bit premature when used as a method to identify ageing. However, it is believed to be useful as a change detection method, i.e., a method to detect changes in cable parameters caused by ageing. So if there is a significant indication of change, this is investigated further with any of the other non-destructive methods (preferring indenter). At Ringhals, LIRA is used on cables working at voltages of ≤ 1 kV, excluding NIS cables. Experience has shown that identifying reliable cable parameters at the first and last 1-5 m is not viable. Reference value: are unique for each cable, i.e. not in general terms. Assessment is done by comparison with previous measurements on the same cable.
- VLF Tan/Delta testing. This test is one method to find "water treeing" which may develop in a cable that has been exposed to moisture. Ringhals uses VLF Tan/Delta on some 6 kV cables, mainly those routed in the most adverse environment. Historically, this method has been used on the cables between the emergency diesel units and the respective switchgears since those cables are placed in ground

culverts at risk of contact with moisture and water. Reference value: in accordance with the evaluation tool provided by the manufacturer of the test equipment.

- PD testing. Ringhals uses this method on 6 kV cables. It is mainly used if work has been carried out on the cable ends and the connections. The method measures glimmering, i.e., small spark discharges at the weaker parts of the insulation. When the cable is energised, this results in high thermal loads at these points and the discharges will eventually break down the insulation.
- High voltage test. Normally used on 6 kV cables. Checks the strength of the cable connections and exposes weak parts in the insulation. The cable is charged with three times the phase voltage (in the case of 6 kV, this means 18 kV) with a frequency of 0.1 Hz. Compared to VLF Tan/Delta and PD testing this method is carried out on all phases simultaneously. The outcome of the test is “make” or “break”. If the result is “break” the test is destructive and normally this part of a cable can be repaired.

Specific activities for NIS cables.

- TDR. This method is used on Coaxial and Triaxial cables for NIS cables. TDR checks terminations, penetration, cable and detector. Examples on faults that can be detected are faulty terminations and damaged or clamped cable. Reference values are unique for each cable, i.e., not in general terms. Assessment is by comparison with previous measurements on the same cable.

3.1.4. Preventive and remedial actions for electrical cables

Forsmark

In order to prevent and find degradation on SSC important to safety and plant availability at Forsmark has planned maintenance activities on major objects (such as valves and electrical motors). These activities include measurements on the corresponding cables. The interval is managed in the preventive maintenance plan.

At Forsmark preventive actions for high voltage cables (70 kV) and medium voltage cables (>1 - 36 kV) are not applicable.

Preventive actions of low voltage cables (<1 kV). This category contains 500 V cables (Forsmark 1 and 2) and 380/660 V (Forsmark 3) from the switchgears to electrical motors and electrical actuated valves. Insulation resistance tests should be conducted when work has been carried out on an electrical object due preventive maintenance or repairs.
The electrical actuated valves are supervised by a dedicated computer system. In this system voltage and current are measured. Deviation may indicate a poor connection. As for all cables important to safety, there is also the visual inspection to be implemented of the cable raceways.

Preventive actions of NIS cables. Generally, NIS cables maintenance is based on qualified lifetime. Forsmark checks NIS cables, mainly using the TDR method.

For example, criteria for taking action, procedures and description of action on low voltage cables state that there were earth faults on some cables in the reactor containment at Forsmark unit 1 and unit 2. Further investigation showed that there was standing water in the protective hoses around the cables due to condensation. Water condensed inside the hoses and could not be released. The water almost boiled during operation. This caused fast degradation of the cables. In the following investigation to map the extent of this problem, thermography walk downs were also used. The solution was to change the protective hoses to hoses that release the water.

Oskarshamn
For medium voltage cables, no preventive actions are applicable. These cables have continuous monitoring, so a fault input signal will be directly detected. The remedial action is therefore to replace the defective cable during a planned outage. This replacement of cables starts with a fault report.

Neutron flux instrumentation cables at Oskarshamn are a part of the equipment connected to several maintenance tasks. One preventive action is replacement after the qualified life time has come to an end. The remedial action is to replace the cable during a planned outage.

Ringhals
In order to prevent and find degradation on SSC important to safety and plant availability, Ringhals has planned maintenance activities on major objects (such as valves and electrical motors). These activities include measurements on corresponding cables. The interval is managed in a preventive maintenance plan. All plant components that constitute a part of a safety function, with functional requirements of more than 0.1h during an accident and placed inside the containment, are labelled as part of a “Function chain”. All components and cables included in these chains are evaluated with regard to qualification level compared to established environmental requirements. The essential information of the “function chains” are stored in an environmental qualification database.

Preventive actions of high voltage cables (130 kV). At Ringhals, these cables are not classified as important to safety. They are included as they are considered important to plant availability and production. Ringhals uses two different kinds of 130 kV cables. One type is an oil isolated cable type. Indication of cable oil pressure and leakage is used to supervise the condition of this cable. The other type is a PEX isolated cable type. To monitor their condition, a visual inspection of cable ends and connections is performed once a year.

Preventive actions of medium voltage cables (> 380 V - 6 kV). This category contains everything from 500 V cables to electrical motors and electrical valves. There are also 6 kV cables between emergency diesel units and the switchgears, and between the switchgears and electrical motors. Insulation resistance tests may be conducted when work has been carried out on an electrical object due for preventive maintenance or repairs. Ringhals has an ambition to perform LIRA measurement every 5 years regarding the 500 V cables that are part of a “function chain”. The interval is managed by a preventive maintenance plan for the objects, that the cables are connected to. As for all cables important to safety, there is also the visual inspection of the cable raceways.
The 6 kV cables between emergency diesel generators and switchgear are placed in ground culverts. Therefore, there exists a potential degradation mechanism induced by moisture. These cables are tested with the VLF Tan/Delta method every ten years.

Preventive actions of NIS cables. Generally, NIS cables AMP is based on qualified lifetime. Ringhals 1 checks NIS cables mainly using the TDR and insulation resistance methods. At Ringhals 2, 3 and 4, AMP is based on qualified lifetime. Although, Ringhals is planning to elaborated NIS AMP as soon as all existing cables are exchanged.

For example, criteria for taking action, procedures and description of action states that for the two oil insulated high voltage cables between 130 kV switchgears and the start-up transformers (described as before outage 2016) demonstrated signs of ageing degradation at Ringhals 3 and 4. These cables are more than 40 years old. There was an indication of an oil leakage at the phase terminals not considered repairable because there are no spare parts available. The conclusion and assessment are to exchange these cables to oil-free PEX cables. The aim of the measure is to create good conditions for maintenance of safe and stable operation under the units remaining lifetime, to compliance with environmental judgment to reduce the risk of oil discharges to the ground and to reduce maintenance costs. The cable at Ringhals 3 was exchanged during the outage of 2016. The cable at Ringhals 4 was exchanged during the outage of 2017.

Regarding the medium voltage 6 kV cable, during the outage of 2013 at Ringhals 4 VLF Tan/Delta, measurements were carried out on the 6 kV cables from emergency diesel units. One emergency diesel cable's values were too high. This led to some further testing using LIRA, PD test and high voltage testing methods. The cable passed the tests with approved results. As those tests are considered to stress the cable, an additional VLF Tan/Delta test was carried out with a result about the same as before. The conclusion and assessment was that the cable should be exchanged, but that it can be done later. The completed PD and high voltage tests showed that the cable could handle stresses far above the normal strain on the cable – up to 3 times the phase voltage. These verifying tests showed that the cable could be expected to be operational in the coming operating season. The cable was later exchanged during outage 2014.

3.2. Licensee's experience of the application of AMPs for electrical cables

Forsmark

The Forsmark AMP for electrical cables is not yet fully implemented. Forsmark has experience applying the qualification status and maintenance programme in electrical cables. Forsmark has conducted ageing analysis and studies to investigate ageing and verify the lifetime of cables to ensure the functional status of cables. The following examples have some impact on electrical cables in Forsmark.

- Forsmark conducted an inventory of the cables in the reactor containment as well as cables inside the connection boxes. The cables of the 1E objects were visually inspected and verified. As a result, an action plan has drawn up to map the status of the cables in the reactor containment.
- Forsmark measure temperature and radiation by using different equipment such as a thermographic camera (IR camera), temperature loggers and Alanine dosimeters to indicate hot spots.
- Visual inspection (walk downs) with thermography camera is used for inspecting inside containment direct after shutdown of the plant.
- During operating season 2008-2009, Forsmark indicated that high temperatures were logged for cables in the reactor containment. At one point, the measured temperature was 80° C (a hot spot) which could affect the lifetime of the specific cable. This cable was placed inside a tube for mechanical protection. Forsmark replaced it and started to investigate the status of the old cable. Visual and manual hardness testing of the cable did not indicate any damage or any major deterioration

in the status of cable jacket. As a result, the cable has not been damaged. The mechanical protection might have helped to dissipate heat. The cable had probably not been exposed to high temperatures and the reason was that the cable was placed inside a tube for protection.

- Forsmark has conducted qualification of new cable types to meet LOCA requirements at NPPs. This is for replacements when the current cables reach the end of their life span.
- Forsmark has started an LTO project to ensure a safe long-term operation of Forsmark units 1, 2 and 3. The LTO project has performed in accordance with the IAEA Safety Report Series No.57. Forsmark has developed a methodology for "LTO verification" with support from Ringhals.

Oskarshamn

Oskarshamn does not yet have any experience on how correct the AMPs are, because the AMPs are currently under production.

In order to minimise fault reports on cables, Oskarshamn uses qualified cables for safety functions. These cables are qualified for their function and environment and, if necessary, also for accidental environmental conditions. These cables are thermally and/or radiologically aged, tested and analysed. The qualification is performed for a specific function and environment or more generally to increase the ability of usage. Before the qualified lifetime comes to an end an analysis can be performed using the actual values, for example for temperature and radiation to see if the qualified lifetime can be extended. Oskarshamn 3 had a project involving the replacement of all the cables inside the reactor containment in 2013/2014. All the installed cables were qualified for their function and environment and, if necessary, for accidental environmental conditions.

In order to close the deviations discovered by the AMR, work has been initiated in the ageing management teams. The electrical cables are included in two ageing management teams: electrical and I&C. Each cable class will have its own AMP. These AMPs are under production. Some of Oskarshamn's experiences from the LTO project are to define acceptance criteria for cables.

Ringhals

Ringhals has modified the maintenance programme, including AMP, regarding extent and use of methods. There modifications have been based on internal and external experience. Ringhals constantly performs improvement regarding the scope, methodology and frequency of the AMP of existing cables. Ringhals work by exchanging or installing new cables (safety classified and some of the non-safety) including the collection of suitable "fingerprints" or reference values in order to keep the AMP efficient.

The following examples have some impact on electrical cables in Ringhals.

- Ringhals has tested a number of 6kV PEX cables due to the possible existence of "water treeing". The cables are safety classified and a part of Ringhals AMP of cables. The outcome of these tests showed that all cables are in good condition and "water treeing" is neither present nor indicated. As a result, Ringhals concluded that existing AMP of these cables are working and could change its frequency of preventive maintenance.
- Ringhals has exchanged the old cables for Ringhals 1 when the requalification of these cables has failed. Ringhals installed new cables. To cope with the hot spots,

Ringhals conducted a rerouting of some cables, but also added/changed the insulation of identified hot spots. As a result, not only affected cables were exchanged but also a more comprehensive AMP of these cables based of the project experiences were elaborated and used today.
- At Ringhals 1, the main part of neutron flux instrumentation cables (NIS) are tested and analysed by TDR and insulation resistance measurements at the end of each annual outage. This is because experience has shown that these cables are often exposed to mechanical impact due to normal maintenance of other nearby components. The result of TDR/insulation resistance measurements is to identify deficiencies or changes in electrically considered cable parameters.

Another example of Ringhals' endeavour of searching for improvements for AMP and its suitability is the initiation of a project that aims to verify the Ringhals units for long-term operation. This is done in accordance with Ringhals' maintenance and investment strategies. All components that constitute a part of plant safety are included in this project. The project also includes an extensive audit of Ringhals' ageing management. If any deficiencies are identified, these are managed by an AMR-GAP list. The AMR-GAP list is gradually managed during the course of the project and is addressed to different departments for action. The project is called the LTO project and is conducted in accordance with a methodology developed by Ringhals, which in turn is based on IAEA Safety Report No. 57.

3.3. Regulator's assessment and conclusions on ageing management of electrical cables

SSM's assessment of the ageing management processes of electrical cables at Forsmark, Oskarshamn and Ringhals.

All three licensees in Sweden have develop their overall Ageing Management Programme based on international guides like IAEA NS-G-2.12. In detail the licensees have chosen slightly different ways to derive the overall Ageing Management Programme, but with the final goal to ensure the availability of required safety functions throughout the service life of the plant.
The scope of the Ageing Management Programme of electrical cables used by the Swedish licensees cover electrical cables included in SSCs important to nuclear safety, which includes:

- SSCs important to safety that are necessary to fulfil the fundamental safety functions;
- Other SSCs whose failure may prevent SSCs important to safety from fulfilling their intended functions.

Regarding identification of ageing mechanisms related to cables all three licensees have a cooperation within the framework of a FORS-AMPs forum, which has resulted in the establishment of a common gross list of degradation mechanisms for all types of components.

SSMs opinion is that the cooperation between the Swedish utilities is very important to understand and learn more about degradations mechanisms. This will as well support utilities to carry out ageing analysis.

Ageing assessment of cables at Forsmark and Ringhals is mainly focusing on detection of ageing effects and stressor to handle different ageing mechanisms. At Oskarshamn the Ageing Management Programme of cables is currently under production and in some cases when cables are qualified for a certain environment and time Oskarshamn uses qualified lifetime to analyze if preventive maintenance is needed or not. All three licensees apply qualified lifetime as a basis of maintenance for neutron flux instrumentation cables.

SSMs opinion is that the use of qualified lifetime as a basis of maintenance might be an applicable method but the utilities have to consider if there are any hot spots and ensure that these will not impact the basis of the components qualification.

Forsmark and Ringhals apply various methods for monitoring, testing, sampling and inspection activities for electrical cables. The type of method to be used and interval is managed through the maintenance plan. At Oskarshamn some cables are continuously monitored by a closed circuit current which if interrupted alerts an alarm in the control room.

Regarding preventive and remedial actions for electrical cables there are different methods and activities. One example is the measurement of insulations resistance. Another example is continuous monitoring when cables are routed in closed cable trays and plastic pipes, embedded in concrete that prevents visual inspections.

SSM assesses that the monitoring, testing, sampling and inspection of the electrical cables are fundamental and very important to give signs and indicate when cables start degrading. This also gives information that can be used to assess the interval and the applicability of preventive actions. SSM assesses that the aim of the Ageing Management Programme is to deal with ageing's issues and not to wait until the cables are degraded and must be replaced through remedial actions.

Regarding licensees experience of the application of AMPs for electrical cables Ringhals has modified the maintenance programme, including AMP, regarding extent and used methods. There modifications have been based on internal and external experience.
Ringhals perform constantly improvement regarding scope, methodology and frequency of existing AMP of cables. Ringhals work with the exchange or installation of new cables include collection of suitable "fingerprint" or reference value in order to keep an efficient AMP. Forsmark's AMP is not totally implemented yet but Forsmark has experience of application of the qualification status and maintenance programme in electrical cables. Oskarshamn does not yet have any experience on how correct the AMPs are, because the AMPs are currently under production.

SSMs opinion is that the experience of the application of AMPs for electrical cables is very important to modify the maintenance programme if needed, but also to perform constantly improvement regarding scope, methodology and frequency of existing AMP to ensure fulfilment of the objectives related to AMP.

SSM's experience from inspection and assessment as part of its regulatory oversight regarding Ageing Management Programme and environmental tolerance/ qualification

SSM has performed a number of inspections and reviews at the Swedish power plants. It has been done with various results.

SSM conducted a review at Forsmark in late 2014 regarding the fulfilment of section 17 in the Swedish regulations SSMFS 2008:17 which states that the barriers and equipment belonging to the safety systems of the nuclear power reactor shall be designed so that they withstand the environmental conditions that the barriers and equipment can be subjected to in the situations where their function is credited in the safety analysis of the reactor. As a result, SSM noted that Forsmark had not completed the analyses which demonstrate that components, where their function is credited in the safety analysis, can withstand the environmental conditions they will be subjected to during a pipe break (LOCA). SSM informed Forsmark that they shall apply for exemption from the section 17, including particular grounds to grant exemptions from these regulations without circumventing the aim of them. During 2015 Forsmark applied for exemption from the section 17. Some of the findings during SSMs review of Forsmark's exemptions application showed that the qualified life for some components had passed and also some components were not environmentally qualified. SSM also found that the documentations were insufficient for some components. Based on impact regarding safety systems in order to bring the reactor to a safe state, impact regarding instrumentation for monitoring the essential parameters and the compensatory measures conducted by Forsmark, the SSM granted Forsmark's application of exemption. According to SSMs decision Forsmark must:

- complete the analyses of components at the latest by November 2016 (performed and reported to SSM).
- inform and train operators and operations management about deficiencies concerning environmental qualification at the latest by March 2016 (performed and reported to SSM).
- annually (2016-2018) assess and report an overall assessment including performed measurement (for 2016 this was performed and reported to SSM).
- replace some components at the latest by 2018 or verify that they can withstand environmental conditions (for 2016 this was performed and reported to SSM).

SSMs work is still ongoing to ensure the fulfilment of SSM decisions by Forsmark.

During 2016 SSM conducted a review at Oskarshamn and Ringhals in a similar way as Forsmark regarding the fulfilment of section 17 in the Swedish regulations SSMFS 2008:17. SSMs review is still ongoing.

SSM noted that Oskarshamn for Oskarshamn 3 had replaced all the cables in the containment during 2013/2014 except cables for lighting. Oskarshamn considers this replacement as a measure to manage the aged cables in the containment.

SSM noted during SSMs review at Ringhals, that Ringhals had replaced the majority of the aged components in order to the fulfilment of section 17. SSM noted as well that Ringhals are planning to replace the residual components by the latest 2020.

During SSMs inspection at Oskarshamn in 2017 and regarding AMP for electrical cables SSM noted the following:

- AMP for electrical cables lacks surveillance or preventive measures,
- No acceptance criteria have been identified,
- AMP lacks process for handling deployed test cables, and
- No programmes for managing age mechanisms have been identified.

SSM noted as well that Oskarshamn does not consider hot spots in AMP for electrical cables. Oskarshamn says that there are no cables which can be subject to higher temperature than 55°C or for radiation dose rate higher than 50 mGy/h.
SSM has by a decision (by injunction) issued an obligation for operation, that Oskarshamn for reactor Oskarshamn 3 shall have an implemented overall programme for ageing management before the end of January 2019 and also to consider hot spots within AMP.

SSM concludes that the

- aim of the Ageing Management Programme is to deal with ageing's issues, which means to be proactive and not waiting until the cables are degraded and must be replaced through remedial actions,
- use of qualified lifetime as a basis of maintenance might be an applicable method but the utilities have to consider if there are any hot spots and ensure that these hot spots will not impact the basis of the components qualification,
- cooperation between the Swedish utilities is very important to understand and learn more about degradations mechanisms. This will as well support utilities to carry out ageing analysis and
- experience of the application of AMPs for electrical cables is very important to modify the maintenance programme if needed, but also to perform constantly improvement regarding scope, methodology and frequency of existing AMP to ensure fulfilment of the objectives related to AMP.

4. Concealed pipework

4.1. Description of Ageing Management Programme for concealed pipework

The Swedish licensees have reported separately according to the technical specification on the area of concealed pipework. Unless otherwise stated, the description below is valid for all licences.

4.1.1. Scope of ageing management for concealed pipework

Methods and criteria used for selecting concealed pipework within the scope of the ageing management

The scope of ageing management covers SSC important to safety, which generally can be identified through their respective safety classification 1-3, and non-safety (class 4). However, the scope of Swedish ageing management also covers non-safety SSC whose failure may impact SSCs performing safety functions, i.e., non-safety affecting safety (NSAS).

Concealed pipework may be regarded as a sub-group to pipework that is in the scope of ageing management and subject to in-service inspection, maintenance and oversight programmes. The concealed pipework is identified through the study of plant documentation, such as layout drawings, system descriptions, safety analysis reports and databases (e.g., component lists, maintenance management systems).

Processes/procedures for the identification of ageing mechanisms related to concealed pipework

Forsmark

To identify ageing mechanisms related to concealed pipework Forsmark evaluates each group and documents the results in reports according to six steps

1. which object(s) the commodity group consists of,
2. operating conditions and environment,
3. material,
4. manufacturing history, operation- and maintenance history, implemented modifications as well as current status,
5. internal and external experiences as well as research and development, and
6. degradation mechanisms that can possibly/reasonably occur.

Oskarshamn

Oskarshamn have identified ageing mechanisms related to concealed pipework based on environment, operating conditions, type of SSC and material.

Ringhals

In Ringhals' processes to identify and evaluate ageing mechanisms they utilise the flow charts of Appendix E in EPRI Non-Class 1 Mechanical Implementation Guideline and Mechanical Tools, Rev 4. The identification and evaluation of ageing mechanisms are performed in workshops where the material of the concealed pipework and its environmental conditions are known input parameters in the flow charts. The participants of the work shop meetings represent the chemistry department, material and structural integrity department and the maintenance department.

The licensees Forsmark and Oskarshamn have compiled information on plant relevant degradation mechanisms in reports (Forsmark's master list for degradation mechanisms and Oskarshamn defect catalogues, respectively).

Grouping criteria for ageing management purposes

The components that are identified as falling within the scope of ageing management are grouped by properties (material, environment, medium, operational temperature etc.) so that components, for which similar degradation mechanisms can be expected, form a group: a commodity group (CG). The result of this provides the input for monitoring and testing which shall be continuously performed on a representative component within a CG.

The Swedish licensees have implemented programmes for regular inspection and oversight of piping and pipe components. These programmes are judged to be sufficient to identify and handle recurrent damage and ageing mechanisms according to the programme approval criteria. Those pipes and pipe system which can be classified as concealed pipework are covered in the continuing ageing management work, by being covered by their respective system's programme or that of the component to which they belong. Therefore, there is no group specifically covering concealed pipework defined in the current ageing management activities, and no survey of such a group has been performed as part of these activities.

Forsmark

Forsmark identifies six groups

- F-a) Water channels and culverts
- F-b) Containment penetrations
- F-c) Pipe penetrations outside containment
- F-d) Ventilation penetrations outside containment
- F-e) Outdoor tanks, process system piping
- F-f) Diesel fuel system, piping

Oskarshamn

Oskarshamn identifies the cooling water channels, fire protection ring line and pipe penetrations as in scope of ageing management.

Ringhals

Ringhals have identified three groups of concealed pipework for ageing management, group R-a) and R-b) is according to GALL and group R-c) is according to IGALL

- R-a) Buried pipework (metallic, polymeric or cementitious) in direct contact with soil or cement
- R-b) Underground, in direct contact with air located where access for inspection is restricted
- R-c) Civil cooling water structures (rock/concrete) constructed as tunnels and culverts which are in direct contact with seawater (internal surfaces) and ground/soil (external surfaces)

The groups of concealed pipework included within the Ageing Management Programmes identified for Forsmark, Oskarshamn and Ringhals are shown in

Table 6.

Table 6 - Within the scope of ageing management, the following groups of concealed pipework have been identified. The underlined groups of concealed pipework will further be included in the national report

Concealed pipework \ NPP	Forsmark 1-3 (Forsmark 1-3)	Oskarshamn 3 (Oskarshamn 3)	Ringhals 1-4 (Ringhals 1-4)
Buried in soil	<u>Cooling water system</u> (group F-a)	<u>Cooling water system</u> Fire protection ring line	<u>Cooling water system</u> (group R-c) Fire protection ring line (group R-a)
Encased in concrete	Pipe penetrations (group F-c) Containment penetrations (group F-b)	Pipe penetrations	Pipe penetrations (group R-a) Pipework through extended containment for Ringhals 2-4 (R-a)
In covered trenches	Fire fighter water system (group F-e) <u>Fresh demineralised water distribution system</u> (Forsmark 12, group F-e) <u>Diesel fuel system,</u> portions in conduits (group F-f)	n/a	<u>Pipework under RWST</u> for Ringhals 2-4 in conduits (R-b)

To illustrate the detail of ageing management processes, the following underlined groups of concealed pipework will further be included in the national report.

Forsmark
Forsmark have for Forsmark 1-3 not identified concealed pipework that ***contain radioactive effluents***. The concealed pipework belonging to the <u>diesel fuel system</u> that ***transfers fuel for emergency power generation*** consists of a small section under the storage tank that are in conduits while the rest of the concealed pipework are in culverts (covered trenches). Reactors Forsmark 1-3 <u>Cooling water system</u> (buried in soil) as well as the <u>fresh demineralised water distribution system</u> (in covered trenches) belong to the group that ***provide essential service water providing cooling to SSCs important to safety***.

Oskarshamn
Oskarshamn have not identified concealed pipework for Oskarshamn 3 that ***contains radioactive effluents*** nor not ***transfer fuel for emergency power generation***. Reactor Oskarshamn 3's <u>cooling water system</u> (buried in soil) belongs to the group that ***provides essential service water for cooling to SSCs important to safety***.

Ringhals
Ringhals have not identified concealed pipework for Ringhals 1-Ringhals 4 that ***contains radioactive effluents*** and that doesn't ***transfer fuel for emergency power generation***. Reactors Ringhals 1-4 cooling water system (buried in soil) and the connection between process systems and refuelling water storage tanks, RWST, for Ringhals 2-4 (in covered trenches) belong to the group that ***provides essential service water providing cooling to SSCs important to safety***.

4.1.2. Ageing assessment for concealed pipework

Ageing mechanisms requiring management and identification of their significance
The *cooling water channel systems* of the Swedish NPPs consist of channels, tunnels and pipes usually placed in excavated solid rock, locally reinforced by concrete, and some sections are made of reinforced concrete culverts. The system supplies cooling water from the Baltic Sea (Forsmark and Oskarshamn) and Kattegat (Ringhals). Parts of the systems are constantly filled with sea water, while others may be drained for inspection. A summary of identified ageing mechanisms are shown in *Table 7*.

Forsmark
The degradation of the cooling water system in Forsmark is caused by sea water and air. This affects the concrete and rebar in the culverts that requires monitoring. Forsmark acquires relevant ageing mechanisms from the *Forsmark master list for degradation mechanisms* and identifies the following ageing mechanisms for

- Concrete
  - leaching
- Reinforced concrete
  - chloride induced rebar corrosion
  - biological growth (mussels)

Oskarshamn
Oskarshamn acquires relevant ageing mechanisms from the *defect catalogue* and identifies the following ageing mechanisms for

- Concrete
  - shrinkage, creep, sulphate attack, frost attack, erosion, wear, fatigue, alkali silica reaction (ASR), leaching and carbonating.
- Reinforcement steel
  - Chloride attack, galvanic corrosion and general corrosion.

Oskarshamn has not used detailed inputs such as design drawings, operational or environmental data for this ageing assessment. If the results from the structural analysis shows significant load or accumulated fault reports in a specific section, those specific sections of the cooling water system can be in focus for inspection activities. The existing Ageing Management Programmes are generally prepared on a higher level and are more general for various types of SSCs. Oskarshamn's intention with the ongoing revision of the plant-specific Ageing Management Programmes is to further take into account design loads, engineering, and experience gained from performed inspections.

Oskarshamn's experience is that the most significant ageing mechanisms are the galvanic corrosion and chloride attack that affect the reinforcement steel.

Ringhals
Ringhals identifies the following ageing mechanisms for

- Concrete
  - leaching, mechanical/biological/chemical decomposition, wear and sulphate attack
- Reinforced concrete
  - chloride-induced rebar corrosion
  - delamination/cracks in concrete due to rebar corrosion

Ringhals also states that there is a limited basis that the indicated ageing mechanisms are active.

Table 7 - identified ageing mechanisms for Cooling water system

Material	Identified ageing mechanism		
	Forsmark	Oskarshamn	Ringhals
Concrete	Leaching	Shrinkage, creep, sulphate attack, frost attack, erosion, wear, fatigue, alkali silica reaction (ASR), leaching and carbonating.	Leach, mechanical/ biological/chemical decomposition, wear, sulphate attack
Reinforced concrete	Chloride induced rebar corrosion, biological growth (mussels)	Chloride attack, galvanic corrosion and general corrosion	Chloride induced corrosion (on reinforcement) and delamination/cracks in concrete

Forsmark
Forsmark's *fresh demineralised water distribution system piping* (group F-e) for units Forsmark 1 and Forsmark 2 supplies the auxiliary feedwater system with make-up water from outdoor storage tanks. Most of the system is accessible for inspection, with the exception of parts located in active pipe culverts and rooms. The lower part of the storage tanks are sectioned so that a dedicated volume is reserved to each of the four trains of the auxiliary feed water system. Forsmark categorises the concealed pipeworks of the system as *Outdoor tanks and process system piping*. The process piping is made of carbon steel in a steel casing. The pipes are connected to the pump inlet and are therefore not subject to significant pressure and temperature variations, just static pressure. It is the exterior of the pipes, concealed under the tank, which is relevant in this assessment. The environment is therefore comparing to a controlled indoor environment, and only microbiologically induced corrosion (MIC) is identified as an ageing mechanism. Forsmark references the *Forsmark master list for degradation mechanisms* for this assessment. These sections of process piping are on the inlet side of the pump, causing limited transient loads. This means that degradation by Transgranular stress corrosion cracking (TGSCC)/Intergranular stress corrosion cracking (IGSCC) is of low importance for this group. The same applies to MIC, as the pipe exterior is not subject to an aggressive environment, i.e. low risk of corrosive chlorides.

Monitoring of this type of pipe takes place on a regular basis according to maintenance routine as per Swedish regulations SSMFS 2008:13. The inspection programme for the storage tanks takes place according to Forsmark's maintenance programmes. No indications of degradation due to MIC have been found.

Forsmark 1-2 have concealed pipework belonging to the *diesel fuel system* that transfers fuel for emergency power generation. The pipework consists of a small section under the storage tank that is in conduits while the rest of the concealed pipework is in culverts (covered trenches). Forsmark categorises the concealed pipeworks of the system as *Diesel fuel system, piping* (group F-f). For this group of pipe systems, material, ageing programmes, ageing mechanisms and symptoms are similar to the Group *Outdoor tanks, and process system piping* (group F-e) described above.

Ringhals
Ringhals 2-4 has *refuelling water storage tanks* placed outdoors with concealed pipework that is placed in conduits and connects via *pipework through extended containment* to the *safety injection system* and the *containment spray system*. The concealed pipework is made of austenitic stainless steels (304, 316) and Ringhals identifies ageing mechanisms requiring management according to the guidance provided in EPRI's NON-class 1 Mechanical Implementation Guideline and Mechanical Tool Appendix E. If EPRI's conclusions are not in line with Ringhals' own experiences or opinion, this is noted in the documentation from the workshops. Potential ageing mechanisms are MIC, TGSCC or outside diameter stress corrosion cracking (ODSCC). The latter two are the same degradation mechanism. In the US it is called ODSCC and in Ringhals it is called TGSCC. TGSCC is a well-documented degradation mechanism on external surfaces of stainless steel pipes that are exposed to chlorides.

Ringhals does not consider the potential ageing mechanisms (MIC and TGSCC) to be significant for structures and components of carbon steel and copper/copper alloys in group R-b, and therefore they do not need managing for following reasons:

- the pipes are not buried or exposed to condensation and leakage together with high concentrations of chlorides;
- the pipes are not exposed to an aggressive environment, and;
- the carbon steel pipes penetrating the containment wall are not exposed to moisture.

Establishment of acceptance criteria related to ageing mechanisms
For pipework included in the ISI programme, as per Swedish regulations SSMFS 2008:13, acceptance criteria is based on a damage tolerance analysis where the pipework is shown to keep its structural integrity and fulfil adequate safety margins with the presence of a postulated defect. The inspection technique shall be able to identify the presence of the defect (size), and the defect shall not be able to propagate so that the safety margins are challenged (inspection interval).

Forsmark
Forsmark inspects the exterior surface of the *Cooling water system* and states that the acceptance is "No leakage or unacceptable degradation found upon inspection". The regular monitoring and inspection of the *fresh demineralised water distribution system* and the *diesel fuel piping system* is performed according to the Swedish regulations SSMFS 2008:13 maintenance routine.

Oskarshamn
Oskarshamn states that for the existing Ageing Management Programme relevant to the *cooling water system* group, the acceptance criteria is "no indications of degradation". Each indication of degradation will be analysed if acceptable or if further measures are required

depending on the design load in the specific area. The work in progress at Oskarshamn 3 is to adapt the existing plant specific Ageing Management Programme and provide acceptance criteria for each identified ageing mechanism and corresponding ageing effects.

Ringhals
Ringhals acceptance criteria are defined to secure that the need of remedial actions are identified before the loss of a structure or components intended function has occurred. For the reinforced concrete, a series of general acceptance criteria to be considered during inspections is documented in the reinforced concrete AMP. The acceptance criteria is based on guides ACI 349.3R and SS137010 and is not to be regarded as definitive, but instead as guidance to the maintenance engineer making the condition assessment. At a visual inspection of the *cooling water system*, no signs of leakages or damages visible to the eye are acceptable.

4.1.3. Monitoring, testing, sampling and inspection activities for concealed pipework

Description of activities, frequencies and acceptance criteria – Forsmark

Inspection of the *cooling water system* is performed in conjunction with emptying of the channels, see Table 8 below. The inspection interval of tunnels and components varies depending on its status and plant experience. The various intervals and scheduled actions are listed in the maintenance plans. A specific test programme is generally put together on those occasions when a channel is to be emptied.

Table 8 - Forsmark 123 test and inspection of Cooling water system

Ageing mechanism	Surveillance activity	Frequency	Acceptance criteria
Leaching	Visual inspection	In conjunction with emptying	According to test programme
Chloride induced rebar corrosion	Fracture mapping Visual inspection Hammer test	In conjunction with emptying, interval based on status and prior experience, varying between 2-9 years	According to test programme
Biological growth	Visual inspection	In conjunction with emptying	According to test programme

As stated in section 4.1.2, no ageing mechanisms requiring management have been identified for the *fresh demineralised water system* and the *diesel fuel system.* These sections of concealed piping are on the inlet side of the pump, causing limited transient loads. This means that degradation by TGSCC is of low importance for this group. The same applies to MIC, as the pipe exterior is not subject to an aggressive environment, i.e. there is only a low risk of corrosive chlorides. This group of piping is designed with high resistance against corrosion via the choice of stainless steel or corrosion resistant carbon steel.

Description of activities, frequencies and acceptance criteria – Oskarshamn
The activities for inspection of the Cooling water system are based on destructive and non-destructive testing and visual inspections.

- Destructive testing
    - Chloride profile (concrete)
    - Compressive strength (concrete)
    - Microscopic examination (concrete)
    - Carbonation (concrete)
    - Water jetted windows (reinforced concrete)
- Non-destructive testing
    - Resistive surge (reinforcement steel)
    - Geo scanner (reinforcement steel and reinforced concrete)
    - Concrete cover surge (concrete)
    - Corrosion potential (reinforced concrete)
- Visual inspection
    - Pre-inspections performed with diver and remotely operated underwater vehicle (concrete and reinforced concrete)

One conclusion from a condition assessment project was that cathodic protection with DC power is the most effective solution to prevent degradation of the reinforcement in concrete. The equipment is, however, not yet installed.

The existing maintenance programme can be further harmonised according to the discrepancies identified during ageing management reviews, but the work is scheduled and adaptation and updates to the programme is ongoing. Therefore, any specific frequencies cannot be reported at this time. During 2014 and 2016 an extensive condition assessment was performed within a project with the aim of identifying necessary repair actions as well as implementing a more extensive inspection programme for the cooling water system.

Research and development is managed by several external associations which Oskarshamn 3 is part of and gain experience and results from. The research and development is not limited to concealed pipework, but in this specific area most of the results and experience is related to cooling water systems, the area's concrete structures and concrete reinforcement. Several projects are finalised with a focus on ageing assessment on the cooling water system. Results from these projects are used as input in the ongoing investigation with the aim to clarify the status of concrete reinforcement in the cooling water system. A second objective of the projects has been to investigate the impact of chloride and galvanic corrosion on reinforcement steel. Repair methods and methods to prevent corrosion have been investigated within the projects. When these results are available they will be used as input for scheduled major maintenance measures in the channels.

Description of activities, frequencies and acceptance criteria – Ringhals
The general strategy for testing and inspections of concealed pipework is to apply a proactive and systematic evaluation so that potential degradation mechanisms and consequences are dealt with. The purpose of the activities is that the pipework shall remain within acceptance criteria for safe operation during the plant's lifetime.
Methods and frequencies used for detection of degradation mechanisms vary with material and environment for the current pipework. Detection of degradation mechanisms and effects of concealed pipework are performed according to AMP (AMP R-XI.M41), as summarised in Table 9 below.

Detecting degradation mechanisms and degradation effects is done by means of visual inspections of the external surfaces of the pipework or surface testing of the surface coatings. Cases where visual inspections are performed only when the surfaces are accessible for other reasons are called opportunistic. Surface tests are performed according to Ringhals' ISI programmes.

Table 9 - Ringhals test and inspection of concealed pipework

Material	Degradation mechanism	Detection method
Austenitic stainless steel	TGSCC	Surface test Visual inspection (opportunistic)[note 1]
Low alloy steel		Visual inspection (opportunistic)[note 2]
Copper and copper alloys		Visual inspection (opportunistic)[note 2]
Concrete	Leach, mechanical/ biological/chemical decomposition, wear, sulphate attack	Visual inspection Microscopic concrete analysis
Concrete reinforcement	Corrosion	Chloride analysis through drilling test
Polymer (joints)	Loss of elasticity	Visual inspection

Note 1 Performed aiming to verify that environment and piping status is equivalent as it is expected. For example under the outdoor tanks.

Note 2 There are no potential degrading mechanisms identified for these pipes. Visual inspection is performed aiming to verify that environment and piping status is equivalent as it is expected.

Places to be inspected are identified based on risk susceptibility assessments concerning degradation and consequences of degrading effects, i.e., concealed pipework of austenitic stainless steel has a risk for degradation in natural crevices, slots at piping supports etc.

When Ringhals determines intervals for tests and inspections of pipework, STF, regulatory requirements, recommendations from EPRI (EPRI report 11022955 Nuclear Maintenance Applications Centre: Passive Component Maintenance Guide for Nuclear Power Plant Personnel), any requirements and/or recommendations from suppliers and its own requirements, operating conditions, experiences and the actual status of the pipework are observed. Assessments of testing and inspection intervals are an ongoing process performed during the yearly review of pipework in the actual component group. Regarding the waterways (tunnels) of the cooling water system, the inspection intervals are normally between one and five years.

Acceptance criteria are defined to ensure that the need for remedial actions is identified before the loss of a component's intended function has occurred. Pipework shall meet current design requirements according to KBM (KBM, Quality Regulations for Mechanical Equipment) and acceptance criteria with respect to degradation according to Ringhals' ageing programme requirements. During visual inspections, no signs of leakages or damages are acceptable.

4.1.4. Preventive and remedial actions for concealed pipework

Forsmark
Forsmark has installed cathodic protection (anodes) in the majority of the cooling water tunnels. These are inspected at every outage and replaced if needed. Cathodic protection was not initially present and was installed after 2000 in order to counteract degradation after concrete repairs. Degraded steel parts are sandblasted and painted. Treated concrete surfaces may be milled/grinded and then retreated. The zinc treatment of the anodes is inspected annually by FMIB (Forsmark's structural maintenance department) as part of the ordinary maintenance procedure.

Forsmark have not identified a need for preventive and remedial actions for the other concealed pipework of the NAR examples.

Oskarshamn
For Oskarshamn, the criteria requiring preventive activities are based on the ageing mechanisms identified during ageing management reviews, where design loads and internal and external lessons learned are input parameters. The current cooling water system group in the preventive maintenance programme is being updated at this time. Remedial action needs to be taken when the acceptance criteria defined in the Ageing Management Programme is exceeded. The procedure for taking remedial actions is general for all SSCs and is based on the routine for reporting faults identified in the plant.

Faults are reported in the operation and maintenance database, evaluated, classified and prepared for taking action. All faults reported in the plant are marked with ageing if the defect was initiated by an ageing mechanism. Once a month, all historical fault reports are reviewed and the output is used to adapt the intervals in the maintenance programme, implement further preventive measures or update affected Ageing Management Programmes. Detected faults and defects may, after a decision has been made, be addressed in a second internal forum by a named taskforce. The taskforce group is assigned to investigate, coordinate, and schedule remedial actions. The group is also responsible for determining a route course and, if required, inform the regulator. If the fault was initiated by an ageing mechanism, the experience is documented and distributed to the coordinating group for ageing management.

Ringhals
As a preventive action, Ringhals checks the status of refilling material in the insulation box around buried pipework that is made of polymeric material. For carbon steel, copper and copper alloys, the surface coatings are checked according to requirements in TBM (TBM, Technical Regulations for Mechanical Equipment), meaning that the status of the surface coatings is checked in order to determine if the coating is intact and that degrading effects for the base material is not expected. For concealed pipework of austenitic stainless steel, no preventive actions are performed. Results from inspections that do not meet acceptance criteria, are evaluated to determine appropriate remedial (corrective) actions and the need for subsequent inspections.

The main preventive action that Ringhals performs for the cooling water structures is visual inspection. Cathodic protections (anodes) have been installed in the majority of the cooling water structures. These are inspected at every outage and are replaced if needed. Cathode protections were not installed in the beginning, but were installed after 2000 to counteract degradation after concrete repairs. Steel parts that have degraded are blasted and painted. Surface treated concrete may be milled/ground and then surface treated again. Impregnating agents are used on the concrete surfaces after repairs to prevent chloride ingress. Further preventive and remedial actions for reinforced concrete that Ringhals may consider are:

- Removal and recasting of concrete
- Increased concrete cover
- Surface coating, mitigate liquid and gas transport
- Crack sealing, mitigated liquid transport
- Substitute reinforcement with a pre-stressing system
- Complementary carbon fibre reinforcement
- Complementary steel plate reinforcement
- Cathodic protection
- Cast in or surface corrosion inhibitor
- Electric current corrosion protection
- Re-alkalisation
- SSC replacement

4.2. Licensee's experience of the application of AMPs for concealed pipework

Forsmark

Forsmark states that the ageing mechanisms affecting *the cooling water system* are complicated to detect. Assessing the risk for rebar corrosion in environments with complicated weathering mechanisms is even more complicated. Considerable damage is, however, required to affect the function of the channel. Many channels are, furthermore, designed for the primary cooling water flow, which is an order of magnitude larger than the auxiliary feedwater flow. Below are some examples of preventative and corrective maintenance that Forsmark performed between 2000-2010:

- During the 2000 outage, zinc anodes were installed in Forsmark 1's inlet channel 10-170 L4, Forsmark 2's outlet channel 20-172 L1, Forsmarks 2's inlet channel 20-170 L5 and during the 2003 outage in Forsmark 1's inlet channel 10-170 L5 and Forsmark 2's inlet channel 20-170 L4.
- In 2005, zinc sacrificial anodes were installed in outlet channel 10-172 L1 in order to limit rebar corrosion due to chloride attack. Both Forsmark 1 and 2's channels were found to be in good condition (min 60 mm concrete thickness), and the cooling water system's function was guaranteed until 2030.
- Upon inspection in 2007, in the cooling water outlet to the diesel generator buildings at Forsmark 1, damage in the form of rebar corrosion was found. The damage was primarily concentrated in splash zones. The corrosion was assessed to be caused by chloride penetration. In walls 300 mm thick, the concrete coverage of the rebar was found to be 30 – 70 mm.
- During the 2007 outage, the concrete structures of Forsmark 3's cooling water channel walls were inspected: L3 and L4 with associated pump sumps and tunnels. Sacrificial anodes were installed in and around the splash zone. Pump sumps were

completely refurbished (e.g., resurfacing of damaged concrete, respraying and zinc spraying).

- During the 2009 outages, damaged concrete in three pump sumps belonging to Forsmark 3's cooling water channels 30112 L1 (auxiliary feedwater inlet), 30112 L5 (auxiliary feedwater outlet) and 30112 L7 (inlet channel for primary cooling water) was inspected and repaired. Repairs were carried out in 2010 and 2011, with the cooling water tunnels' function ensured for another 25 years.
- According to ERFATOM (a former industrial network for Nordic BWR) no licensee event report due to ageing-related damage of *cooling water system* has been filed.

Forsmark's experience is that ageing-related degradation of concealed pipework in penetrations has not resulted in reportable damage. Problems with ageing-related damage are therefore considered to be limited in this group. This is primarily due to the fact that the concealed piping is very limited in quantity and not present in aggressive environments, but instead in a controlled indoor environment. The existing monitoring and maintenance programmes are also expected to locate degradation before it can lead to failure. No international experiences (e.g. from GALL) applicable to Forsmark have been found.

Oskarshamn

For Oskarshamn's *cooling water system*, the ageing phenomena have proceeded as expected. At Oskarshamn 3, an ageing management review was performed which resulted in a number of deviations with regard to the SSC-specific Ageing Management Programme and the preventive maintenance programme. Both programmes will be adapted with regard to details, frequencies and experience gathered from the extensive ageing assessment performed. In areas of the tunnels where the reinforcement steel has been exposed by water jet, the steel is corroded and some minor parts of the reinforcement steel are completely absent. As a result of the corrosion process, the outer layer of concrete has cracked in a number of places. None of these degradation mechanisms has required any measures because the structure withstands the calculated loads in the damaged sections with margin. During exchange of hatches, heat exchanger tubes and other components, the aim is to find a corrosive resistant material, such as brass, titanium or stainless steel. The lesson learned is that this could be at the expense of extensive wear on the nearby reinforcement steel. It is worth considering whether there should be a scheduled exchange of a less noble component in question instead of ending up exchanging major parts of the reinforcement steel in the concrete structure.

Ringhals

Ringhals' maintenance department (NU) has a common instruction for experience feedback in order to supply and distribute relevant experiences within Ringhals and also other similar national and international activities. All experiences relevant to ageing, both internal and external, are compiled in ageing analysis reports. International experiences regarding ODCCC (TGSCC) are compiled in the AREVA/Westinghouse White Paper (PA-MSC-0474 August 6, 2010 Outside Diameter Initiated Stress Corrosion Cracking Revised Final White Paper). Ringhals' experiences regarding ageing phenomena for concealed pipework have proceeded as predicted which can be summarised as follows:

- The only identified ageing mechanism for concealed (mechanical) pipework is TGSCC on the outside surfaces of stainless pipework in systems: 313 Reactor Coolant System, 321 Residual Heat Removal System, 322 Containment Spray System, 323 Safety Injection System and 334 Chemical and Volume Control System. These defects are handled through ISI.

- Ringhals experiences for concealed concrete pipework, i.e., tunnels in various dimensions either in naked rock or shotcrete, cast in place or prefabricated concrete pipes are that these are situated in an environment constantly filled with saltwater and high flows. The damage picture has been limited on these parts. Local damages have occurred in tunnel parts made of concrete where the iron bars have corroded and hence created local concrete damages. The damages have primarily been related to casting joints and small concrete cover deviations. To remedy this, cathodic protection (anodes) have been installed in large numbers since early 2000s and have well protected the iron bars against corrosion. Damages caused by erosion have been very limited.

4.3. Regulator's assessment and conclusions on ageing management of concealed pipework

Regulators assessment of the ageing management processes described in this chapter

From the review of the Swedish licensees ageing management of concealed pipework, with the scope set out in this report, SSM concludes that

- The scope is limited to safety and safety related SSCs, in accordance with Swedish regulations SSMFS 2008:1 chapter 1 section 1
- The licensees have not explicitly identified concealed pipework as a group per se, but rather regard it as included within scope of other existing groups, as
    - *Cooling water system* included in group structures/buildings, and
    - *fresh demineralized water distribution system* and the *diesel fuel system piping* included in the group of pipework.
- Only Ringhals have a specific AMP for concealed pipework
- The licensees have identified different ageing mechanism, as summarised in Table 10 (and in *Table 7*) for the cooling water systems
- Acceptance criteria are often stated in qualitative terms i.e. visible signs of degradation effects found upon inspection will lead to further analysis and, if deemed necessary, to remedial actions
    - But some guidance give quantitative acceptance criteria, as Ringhals reference SS137010 on the thickness of the covering concrete layer to the rebar
- Cathodic protection was installed in the cooling water systems by Forsmark and Ringhals as of 2000 as a preventive action, but has not yet been installed by Oskarshamn.

Table 10 - Summary of licensees identified ageing mechanism for concrete and reinforced concrete in cooling water systems

Material	Ageing mechanism	Forsmark	Oskarshamn	Ringhals
Concrete	Leaching	X	X	X
	Shrinkage		X	
	Creep		X	
	Sulphate attack		X	X
	Frost attack		X	
	Erosion		X	
	Wear		X	X
	Fatigue		X	
	Alkali silica reaction		X	
	carbonation		X	
	Biological/chemical decomposition			X
Reinforced concrete	Chloride induced rebar corrosion	X		X
	Biological growth	X		
	Chloride attack		X	
	Galvanic corrosion		X	
	General corrosion		X	
	Delamination/cracks in concrete		X	

Regulators experience from inspections and assessments as part of regulatory oversight

Swedish regulations SSMFS 2008:1 chapter 7 section 1 states that

"Events which have occurred and conditions which are detected and which have an essential impact on the safety of a facility shall, without delay, be reported to the Swedish Radiation Safety Authority in the manner described in Appendix 4" ,

Section 2 and 3 of the same chapter deals with reporting of less severe nature. These event reports are compiled into a database that SSM uses, and from that database no events due to ageing of the cooling water systems or other NAR examples, that may have had an impact on nuclear safety, are found.

Outside the scope of the NAR-examples, an event at the newly shut down reactor Oskarshamn 1 was reported to SSM 5 September 2017 (SSM2017-4133) concerning concealed pipework. After legal sampling water from the waste treatment is to be released to the recipient. In this particular event, the system could not release the water as planned and the maintenance department started troubleshooting and servicing of the equipment (pumps etc.). As the problem persisted after the maintenance of the equipment, the suspicion arose that a pipe between the waste facility and the heave shaft had suffered a defect and effectively halted the release to the recipient. In the systematic troubleshooting, it was finally decided to inspect the pipe that was in the heave shaft, which is difficult to access as it is covered with large concrete blocks. The inspection showed that pipe support for the inspected pipe had collapsed due to corrosion and thus created a crease on the pipe that prevented the flow. There is an ongoing investigation at Oskarshamn to see if the Ageing Management Programme should be updated concerning this issue. SSM is conducting oversight activities with regards to this matter and expect a final reporting from Oskarshamn by the end of December 2017.

Regulators conclusions on the adequacy of the Ageing Management Programmes described in this chapter

SSM concludes that the Swedish licensees Forsmark, Oskarshamn and Ringhals each have compiled an Ageing Management Programme that encompasses concealed pipework. The programmes are quite similar in scope while the results from the ageing assessment and the preventive actions taken differ slightly. SSM also finds that the programmes contains the steps and recommendations given in IGALL AMP 125 *Buried and underground piping and tanks*. Since no events with impact on nuclear safety have been reported from either licensee, SSM draw the conclusion that the ageing management is both adequate and sufficient for the respective nuclear power plants. On the other hand, SSM believes it to be beneficial if the licensees would cooperate more on the matter, and perhaps discuss such topics as acceptance criteria and the reasons behind the differences in identified ageing mechanisms illustrated in Table 10.

5. Reactor pressure vessels

The Swedish licensees have reported separately according to the technical specification on the area of reactor pressure vessels. Unless otherwise stated, the description below is valid for all licences.

5.1. Description of Ageing Management Programmes for RPVs

The 2018 Swedish reactor fleet consists of five BWRs and three PWRs, as outlined in Table 1. All five BWRs have been designed by the Swedish company ASEA Atom (which would become and is now known as Westinghouse Electric Sweden AB). One of the BWRs is designed with external pumps, and four are designed with internal pumps. The three PWRs are all Westinghouse designed 3-loop plants. Principal drawings of the RPVs for the different types of reactors are presented in Annex 10. Three of the BWRs are located at Forsmark (Forsmark 1-3). One BWR is located at Oskarshamn (Oskarshamn 3) and one BWR is located at Ringhals (Ringhals 1). All three PWRs are located at Ringhals (Ringhals 2-4).

The RPV of a BWR is larger than the RPV for a PWR. The typical inside diameter of a BWR RPV is about 6.4 m and the total height is about 21 m, corresponding to the typical dimensions for a PWR RPV which are 4 m and 11 m respectively. The main parts of an RPV are the reactor vessel head, a cylindrical part, the bottom dome and various nozzles. The reactor vessel head is attached to the cylindrical part by bolts. Both the BWR and PWR RPV's are clad inside, mainly with stainless steel.

The materials used for the production of the reactor vessel head, the cylindrical part and the bottom dome for the different RPVs are given in Table 11.

Table 11 - Materials in the different RPV's. ASME SA 533 grade B Cl.1 is plate material and ASME SA508 Cl. x is forged material.

Reactor	Reactor vessel head	Cylindrical part of the vessel	Bottom dome
Forsmark 1	SA 533 Gr B Cl 1	SA 533 Gr B Cl 1	SA 533 Gr B Cl 1
Forsmark 2	SA 533 Gr B Cl 1	SA 533 Gr B Cl 1	SA 533 Gr B Cl 1
Forsmark 3	SA 533 Gr B Cl 1	SA 508 Cl 3	SA 533 Gr B Cl 1
Oskarshamn 3	SA 533 Gr B Cl 1	SA 508 Cl 3	SA 533 Gr B Cl 1
Ringhals 1	SA 533 Gr B Cl 1	SA 533 Gr B Cl 1	SA 533 Gr B Cl 1
Ringhals 2	SA 508 Cl 3	SA 508 Cl 2	SA 533 Gr B Cl 1
Ringhals 3	SA 508 Cl 3	SA 508 Cl 2	SA 533 Gr B Cl 1
Ringhals 4	SA 508 Cl 3	SA 508 Cl 2	SA 533 Gr B Cl 1

Forsmark
All the three units in Forsmark are BWRs from ASEA Atom Design. The main designs of the RPVs in Forsmark 1, 2 and 3 are illustrated in a number of figures given in Annex 10. The cylindrical parts of the RPV for Forsmark 1 and Forsmark 2 consist of five rings made from rolled plate made of material SA533B Class 1, while Forsmark 3 has three forged rings made of material SA 508 Class 3, as shown in Table 11. A consequence is that Forsmark 1 and Forsmark 2 have both axial and circumferential welds in the cylindrical part of the RPV while Forsmark 3 only has circumferential welds in the cylindrical part (see also Figure 4 in Annex 10).

The vessel heads and the bottom domes are made from plate material welded together for all three reactors.

Forsmark 1 and Forsmark 2 have 8 steam outlet nozzles, 4 feed water nozzles, 2 nozzles for shut down cooling and 4 nozzles for emergency cooling. Forsmark 3 has 4 steam outlet nozzles, 4 feed water nozzles, one shut down nozzle and 4 nozzles for emergency cooling. All main nozzles are manually welded to the RPV. The main nozzles also have a safe end made of Alloy 600 attached to the nozzles.

There are no nozzles in the vessel head. All three reactors have 8 internal recirculation pumps. The bottom dome have 8 nozzles for the recirculation pumps, Forsmark 1 and Forsmark 2 have 161 penetrations for the control rods (Forsmark 3 have 169) and 65 neutron detector penetrations (Forsmark 3 have 64). Illustrations of some nozzles are shown in annex 5.

Forsmark uses methods and procedures for selecting SSC for AMP in accordance with the principles and guidelines expressed in Safety Report Series No. 57 – Safe long Term Operation of Nuclear Power Plants and IAEA Safety Guide NS-G-2.12 – Ageing Management for Nuclear Power Plants. There are a number of instructions and guidelines implicitly and explicitly ensuring long-term operation of the RPV's at Forsmark. There are also general instructions and delegations setting out the required fundamental management, quality control, organisation and procedures. The instructions clarify the responsibility, necessary competence and job description essential for successful ageing management. The general terms of ageing management for SCCs are incorporated in the regular operation routines.

Oskarshamn
Oskarshamn 3 is a BWR of ASEA Atom design. The original output was 1050 MW, but several upgrades have been performed over the years and today the output is 1450 MW which makes Oskarshamn 3 to the largest BWR in the world with respect to electrical output. Principle drawings of the reactor are presented in Annex 10. Oskarshamn 3 has eight internal main recirculation pumps. All main nozzles are positioned above the core region and so reduces the risk of a large LOCA. Oskarshamn 3 and Forsmark 3 have identical RPV designs.

The ageing management of the RPV are concentrated on the weld of the vessel plus its main nozzles. Also included is the RPV base material since it is exposed to neutron irradiation causing embrittlement, and a water chemical programme and the evaluation and monitoring of thermal and pressure transients.

Ringhals

Ringhals 1 is a BWR of ASEA Atom design with external main recirculation loops. Ringhals 2-4 are all 3-loop PWR of Westinghouse design. According to Ringhals' current plans, Ringhals 1 will be shut down in 2020 and Ringhals 2 in 2019. Ringhals 3 and Ringhals 4 will continue for a total of 60 years of operation, i.e. to 2041 and 2043 respectively.

The design of the RPV of Ringhals 1 is, in principle, the same as for Forsmark 1-2 except that Ringhals 1 has six external recirculation pumps, see figure 3 in Annex 10. The vessel head, bottom dome and the cylindrical part of the RPV are all made of plate material as shown in Table 11. The cylindrical part of the RPV has both axial and circumferential weld seams. There are eight steam nozzles, four feed water nozzles and twelve nozzles for the external main circulation loops. There are three small bore instrumentation nozzles in the vessel head and one head spray nozzle.

The following penetrations are installed in the bottom dome:

- Control Rod Drive: 157 Penetrations
- In Core Instrumentation: 58 penetrations, 16 of which are plugged and not in operation
- Core Spray: 10 penetrations
- Boron Injection: two penetrations
- Drainage Penetrations: two penetrations, plugged and not in operation

The RPVs for the PWRs Ringhals 2-4 are made mainly from forged material, see Table 11. All three reactors currently have replacement vessel heads. The purpose of replacing the original vessel heads was to exchange materials sensitive to Primary water stress corrosion cracking (PWSCC) with less sensitive materials such as Alloy 690 and Alloy 52. The Ringhals 2 head has one circumferential cap weld, whereas the heads for Ringhals 3 and 4 are all forged without welds.

There are three inlet nozzles and three outlet nozzles. In the bottom dome there are instrumentation nozzles, and in the vessel head there are nozzles for control rods and instrumentation.

Ringhals' overall ageing management covers components of importance for safety, but also components that may limit the remaining time of operation or cause significant loss of income. All major primary system components are considered to be safety related without exception.

Ringhals' overall Ageing Management Programme is based on the principles in IAEA Safety Guide No. NS-G-2.12. This safety guide does not provide any detailed guidelines for how an ageing management process is to be organised on a component or object level. The primary system technical area has therefore analysed and evaluated a number of different ways of developing an ageing management methodology and established that the concept used in the USA provides the most comprehensive basis. Here is a coordinated and quality ensured process which is clearly defined from the view point of the regulator as well as the licensee.

In order to form a basis for analysis and guidelines, Ringhals has chosen to expand the membership in EPRI to include the materials reliability programme (MRP) and the steam generator management programme (SGMP). The memberships provide access to international guidelines and applicable ageing management practices down to an object level.

In order to ensure that an internationally recognised requirement level is achieved, the primary system technical area field will continuously review ageing management and benchmark against NRC NUREG-1801 rev. 2, GALL report. There are also considerations given to the IAEA Safety Guide No. NS-G-2.12 and IAEA Safety Reports Series No. 82, within the engineering field of primary systems. The primary system technical area has developed an ageing methodology, process and document structure described below.
Figure 1 shows this as a schematic.

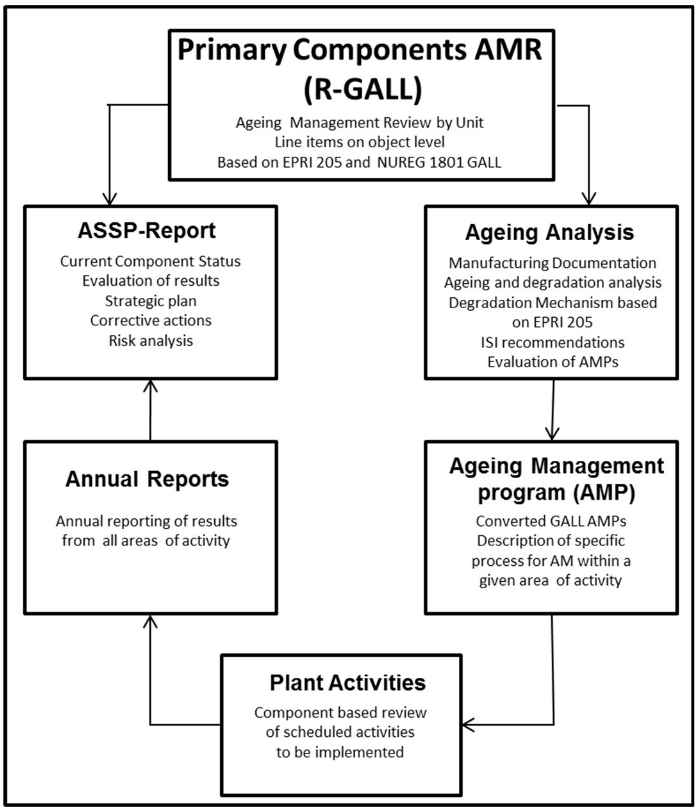

Figure 1 - Overview of the primary system technical area ageing management

Primary system AMR, Ringhals generic ageing lessons learned (R-GALL):

- Within the primary system technical area there is one AMR for each unit, so called R-GALL. The purpose of this document is to provide an overview of the ageing management document status broken down to an object level which is presented in an AMR table.
- The basis of the objects and their factual entries which are grouped and registered in the AMR table comes from EPRI MRP 205 (PWR) issue management tables or BWRVIP-167 NP BWR issue management tables.
- In order to ensure an internationally recognised requirement level, relevant facts from NUREG 1801 rev. 2 are attached to each object.
- Finally, Ringhals' specific verifications and references have been associated with each object in order to show how each object is managed. To ensure that all objects in a

component is assessed, a systematic review of the manufacturing documentation is performed, specifically the manufacturing drawings. A component specific documentation compilation of the manufacturing documents forms the basis of this work.

Ageing Analysis: (PV-rapport):

- According to the IAEA the key to an effective ageing management process is a basic understanding of each object and ageing mechanisms which could affect it. In order to understand and document the basis down to an object level the PV report is developed. This is the document that the primary system technical area uses in order to evaluate components and objects considering in-service inspection as well as ageing management.
- The main purpose of the ageing analysis is:
    - To highlight occurrences of possible defects and modes of degradation applicable to the components and different objects, and to provide recommendations in order to optimise in-service inspection.
    - To document the ageing analysis, evaluate current Ageing Management Programmes considering the applicable conditions and increase the awareness of relevant ageing mechanisms in components different objects and if possible mitigate or stop such effects.
- A procedure for writing PV reports has been developed. Existing reports are also compiled.

Ageing Management Programme (AMP):

- The purpose of the Ageing Management Programme is to describe an area of activities through a number of attributes. The development of a programme provides the opportunity to thoroughly examine specific area procedures in a quality ensured manner.
- A combination of several Ageing Management Programmes can therefore be attached to each object and constitute an object-specific and complete set of documentation of how ageing management is to be properly implemented. The Ageing Management Programmes developed within field of primary system technical area are based on a selection of AMPs listed in chapter XI in NUREG-1801 rev. 2.
- The Ageing Management Programmes are adapted to the Swedish regulatory conditions and Ringhals' specific circumstances. Where detailed Swedish regulations and guidance are missing, the aim is to fulfil the requirements and recommendations of the original Ageing Management Programme. In addition to the selection of Ageing Management Programmes gathered from NUREG-1801 rev. 2, programmes can be developed to fulfil Ringhals' specific needs in different technical areas as they are identified. A procedure describing how to write an Ageing Management Programme has been developed and contains a list of all current Ageing Management Programmes.

Operational Plan:

- The programmes for maintenance, in-service inspection and ageing management leads to activities and measures implemented on the primary system components. In order to ensure that the activities are planned, prepared and implemented in a satisfactory manner the activities are coordinated via an operational plan.
- A guideline for the operational plan and associated procedures are available.

Annual Result Reports:

- Feedback in the form of annual results reports from inspections, maintenance and operations is of central importance for an effective ageing management process. Performance reports are selected for follow up and working practices for review are documented.

Current Status and Strategic Plan:

- The current object status is documented in table form down to an object level, much like R-GALL, to provide a snapshot. An annual summary report is created and based on the contents in the tables. The report focuses on the objects where the probability and effect on safety and availability is considered to be the greatest, and the most appropriate strategy to manage these risks.
- A guideline for the creation of the annual status and strategic plan (ASSP) is available.

5.1.1. Scope of ageing management for RPVs

Methods and criteria used for selecting the components within the scope of ageing management.

All major primary system components are considered to be safety-related without exception. In practice this means that all RPV objects and its nozzles shall be covered by ageing management.

Processes/procedures for the identification of ageing mechanisms for the different materials and components of the RPV

Forsmark
It is stated in the AMP procedures that the assessment of the potential degradation mechanisms for materials (steel etc.) under consideration shall be made with expertise in materials.

The processes and procedures are based on the guidelines in IAEA Safety Report No 57 and NS-G-2.12.

Oskarshamn
A commodity group (CG) called RPV was formed consisting of all welds in the RPV and its nozzles. The base material of the RPV is also included in the CG. All ageing mechanisms for the group were identified. The identified ageing mechanism are retrieved from the in-service inspection handbook and were verified to be in agreement with the NUREG 1801 rev.2.

To obtain control of all ageing mechanisms in the RPV case, the authority's regulation for ISI was followed, demanding an ISI programme for all the welds and nozzles in the RPV. The corresponding method for the RPV base material is to follow the regulation for a surveillance programme. The surveillance programme also include the weld material in the beltline region of RPV.

Ringhals
The identification of ageing mechanisms for each object is based on EPRI MRP 205 PWR issue management tables or BWRVIP-167 NP BWR issue management tables. A Ringhals internal review of EPRI identified and defined ageing mechanisms have been documented. When an ageing analysis is developed the engineer has to take the ageing mechanisms from the relevant Issue Management Table and evaluate the applicability for each object. If needed, ageing mechanisms may be added based on Ringhals' own experiences if there is a gap between Ringhals' knowledge and EPRI's issue management tables.

Examples of objects within the RPV that are subject to ageing management are shown in Table 12 below.

Table 12 - Main objects in RPV subject to ageing management

Object	BWR	PWR
Shell, Reactor Pressure Vessel		
Base Material	X (adjacent to the weld)	X (adjacent to the weld)
HAZ	X	X
Weld	X	X
Cladding	X	X
Penetrations, Vessel Head		
Control Rods		X
Heat Cooling	X	
Instrumentation	X	X
Penetrations Bottom Dome		
Control Rods	X	
Incore Instrumentation	X	X
Nozzle, inlet and outlet, upper part		
Inner radius	X	X
Attachment weld	X	X
Nozzle to safe end weld	X	X
Nozzle to pipe weld		X
Nozzle Bottom Dome[2]		
Inner radius	X	
Attachment weld	X	
Nozzle to pipe weld	X	

5.1.2. Ageing assessment of RPVs

Ageing mechanisms requiring management and identification of their significance

Possible ageing mechanisms identified for the *RPV, cladding and welds* are:

- Irradiation embrittlement due to the neutron flux during operation of the reactor

[2] The inlet nozzles for the external recirculation loops of Ringhals 1 (BWR).

pressure material, low alloy steel, (LAS), base material and weld material.
- Stress corrosion cracking (SCC) of the LAS.
- Low cycle fatigue (LCF) due to mechanical and thermal loads.
- Thermal ageing, possible mechanisms for the RPV material.
- Under cladding cracks (UCC, manufacturing defects), possible mechanism for RPV material adjacent to cladding.

Possible ageing mechanisms identified for *penetrations at the vessel head and the bottom dome* are:

- IGSCC (BWR) or PWSCC (PWR)) – relevant for austenitic stainless steel and nickel base alloys.
- LCF

Possible ageing mechanisms identified for *the inlet and outlet nozzles*:

- IGSCC – relevant for austenitic stainless steel and nickel base alloys.
- LCF

The most significant ageing mechanism for the RPV base material (LAS) and the weld material is irradiation embrittlement. The neutron irradiation of the RPV LAS base and weld material affect the mechanical properties such that the transition temperature between ductile and brittle behaviour (DBTT) increases and the fracture toughness decreases. The embrittlement is monitored by the surveillance programme.

IGSCC and PWSCC are significant ageing mechanisms for nickel-based material such as Alloy 600 (base material) and Alloy 182 (weld material) in BWR and PWR environments. However, IGSCC or PWSCC are not relevant mechanisms for stainless steel weld materials. The cladding on the inside of the RPVs is mainly made out of stainless steel weld material.

SCC is not very relevant for LAS as the RPV material is covered with stainless steel cladding on the inside. However, in some cases, if the reactor water is in contact with LAS or if cracks propagate through the A182 butter layer, the risk of SCC needs to be evaluated.
LCF is considered in the design of the RPVs according to the rules in ASME III Boiler and Pressure Vessel code.

Thermal ageing of LAS is a possible mechanism for long-term operation. However, at low temperatures below 300°C, thermal ageing is a very slow process. This mechanism is partly take into account in the surveillance programme where specimens of LAS are subjected to neutron irradiation at full reactor temperature. Thermal ageing of LAS could be a degradation mechanism for the PWR's vessel head as the operational temperature is slightly above 300°C in the upper part of the RPV. PWRs Ringhals 2-4 have all had pressure vessel head replacements. The vessel heads were replaced in 1996, 2005 and 2004 for Ringhals 2, Ringhals 3 and Ringhals 4 respectively. According to the current plans, Ringhals 2 will be shut down in 2019 and Ringhals 3 and Ringhals 4 will continue until 60 years of operation have elapsed, i.e. to 2041 and 2043 respectively. The replacement vessel heads for Ringhals 3 and Ringhals 4 will then have a total operating time of less than 40 years. Based on research results, Ringhals makes the assessment that thermal ageing will not be a limiting degradation mechanism for the pressure vessel heads for the intended operating life time of Ringhals 2-4.

Table 13 give examples of significant ageing mechanisms identified for objects within the RPV. All relevant mechanisms for a specific object are evaluated in an object-specific ageing analysis. Table 13 also show in which documents acceptance criteria for each ageing mechanisms are defined.

Table 13 - Summary of significant ageing mechanism of the RPV objects

Object	Significant degradation mechanism	Acceptance Criteria
Shell, Reactor Pressure Vessel		
- **Base metal**	Irradiation Embrittlement	
- **HAZ**		Defined in TLAA[3]
- **Weld**		
- **Cladding**	UCC (manufacturing defect)	
Penetration, Lower dome		
- **Control Rods (BWR)**	IGSCC	Defined in STA[4]
- **Incore Instrumentation (BWR)**	IGSCC	Defined in STA
- **Incore Instrumentation (PWR)**	PWSCC	Defined in STA
Penetration, Pressure Vessel Head		
- **Head cooling and instrumentation (BWR)**	IGSCC	Defined in STA
- **Control Rods and instrumentation (PWR)**	LCF	Defined in STA
Nozzle, inlet and outlet, upper part		
- **Inner Radius (BWR)**	LCF	Defined in STA
- **Attachment Weld (BWR)**	LCF	Defined in STA
- **Nozzle to Safe End Weld (BWR)**	LCF, IGSCC	Defined in STA
- **Nozzle to Pipe Weld (BWR)**		
- **Inner Radius (PWR)**	LCF, IGSCC	Defined in STA
- **Attachment Weld (PWR)**	LCF	Defined in STA
- **Inlet Nozzle to Safe End Weld (PWR)**	LCF	Defined in STA
- **Outlet Nozzle to Safe End Weld (PWR)**	PWSCC	Defined in STA
	LCF	Defined in STA
Nozzle, Lower Dome (Ringhals 1)		
- **Inner Radius**	LCF	Defined in STA
- **Attachment Weld**	LCF	Defined in STA

[3] TLAA Time Limiting Ageing Analysis
[4] STA Damage Tolerance Analysis

Establishment of the acceptance criteria related to the ageing mechanism

The governing requirements for the design and evaluation of surveillance programmes is given by SSM Regulation 2008:13. The regulation code specifies the following:

> *Irradiated specimens of reactor pressure vessel material must undergo surveillance testing to verify structural integrity and the maximum permissible limiting values for reactor pressure at different temperatures (P-T limiting curves). This testing shall involve the relevant material for the reactor pressure vessel in question. The Swedish Radiation Safety Authority must approve the programme for such testing.*

From the start of their operation, all Swedish RPVs had individual surveillance programmes with specimens from the actual reactor pressure vessel material. The surveillance programmes are mainly based on 10 CFR 50 Appendix H, ASTM E-185 and Regulatory Guide 1.99 rev. 2. The number of surveillance capsules vary between the different reactors. The BWRs with internal pumps (Forsmark 1-3, Oskarshamn 3) have three capsules, where one is intended to be a stand-by capsule. The stand-by capsules may be used for the extended surveillance programme for operating times beyond 40 years. The BWR with external pumps (Ringhals 1) has six capsules and the PWRs (Ringhals 2-4) have six to eight capsules. The results from mechanical testing of the irradiated specimens in the capsules are input for the evaluation of the pressure-temperature (P-T) limit curves. As the dose rate in a PWR is higher compared to the BWR's, the shift in DBTT is normally higher for a PWR.

Embrittlement of the RPV material can be a limiting degradation mechanism for the PWRs as the fluence level is considerable higher. The PWR RPV's should be verified to the pressurised thermal shock (PTS) screening criterion according to the PTS rule 10 CFR 50.61. If the screening criterion is not fulfilled, the RPV must also be analysed according to the alternative pressurised thermal shock rule 10 CFR 50.61a.

Acceptance criteria for IGSCC and SCC cracks are dependent on the ISI method and its detection target for the material and degradation mechanism in question. In some cases, the crack propagation rate of a postulated crack may determine the acceptance criteria. Regulations for ISI are given in SSM regulation code 2008:13 and are further described in the following section.

Acceptance criteria for LCF of the RPV and the nozzles are given by the design work and the number of allowable thermal and pressure transients for the analysed period of time. The key applicable standards, manufacturing and operating documents used to establish the acceptance criteria are listed in

Table 14 - Applicable standards, manufacturing and operating documents for determining acceptance criteria

Object	Standard / Guidance (including document ID)	Design / Manufacturing documents	Operating documents
All objects	EPRI MRP 205 BWRVIP 167	SAR KFM (design prerequisites)	STF (Tech. Spec.) Chemistry programme Transient Trending

		Drawings Material Certificates Welding procedures Manufacturing-Inspections	ISI reports Operating-Experience
Additional to Shell, Reactor Pressure Vessel	ASTM E185 RG 1.99 rev.2 10 CFR 50 app. H 10 CFR 50.61-61.a	Surveillance programme	ERG, LTOP, P-T Limit

R&D programmes

As mentioned above, thermal ageing of LAS is, to some degree, taken into account in the surveillance programme. The acceptance criterion for thermal ageing of LAS is the same as for embrittlement of the material due to neutron irradiation.

In order to learn more about the thermal ageing of materials as it relates to BWR and PWR applications, SSM and the Swedish licensees have jointly started R&D projects. Two projects have been running since 2013 and are focused on the thermal ageing of cast austenitic stainless steel (CASS) and stainless steel weld material. One further research project was started in 2016. This project will study extracted material from the RPV of Barsebäck 2, a BWR with external main recirculation pumps of Swedish design. The reactor were shut down in 2005. The project will study both the effect from thermal ageing and the effects of irradiation on material properties and the combined effectof both. The project is scheduled to be finished within 4-5 years.

In addition to these projects, Ringhals is running a research project were samples extracted from a replaced pressuriser from Ringhals 4 are investigated. The work is focused on the thermal ageing of the weld material. The weld material is similar to the weld material that has been used for the manufacturing of the RPVs for Ringhals 3-4, Forsmark 1-3 and Oskarshamn 3. The operating temperature for a pressuriser is, of course, higher than for a PWR or BWR PRV, but the results of the project give valuable input for the evaluation of possible risks of thermal ageing during LTO of PWR and BWR RPVs. Ringhals also finances a PhD student working on irradiation and thermal ageing of LAS with a focus on microstructural characterising using TEM and Atom Probe Tomography.

Between the Nordic utilities there are R&D groups both within structural verification (BG Group) and materials (MG Group). The BG group handles specific assignments within fracture mechanics, fluid dynamics and solid mechanics. The MG group handles, for example, crack growth rate of nickel-based alloys and other material related issues.
The Swedish licensees have also formed a working group for ISI-related topics. In at least three meetings per year this group discusses common topics and new findings related to Non destructive testing (NDT) issues, together with new experiences from Sweden and abroad.

The Swedish licensees and SSM participate in the Halden Reactor Project.

Forsmark, Oskarshamn and Ringhals are members and actively take part in different organisations specific to nuclear issues such as EPRI (BWRVIP), PWROG, NOG, etc.
Other examples include Swedish licensees' participation in EU-funded projects such as LONGLIFE and Perform60. Some funds within the R&D budget are allocated to allow

personnel to attend international meetings and conferences where common issues can be discussed, including IGRDM, ICG-EAC, Env. Deg. Conf. and Fontevraud Conf.

Internal and external operating experiences

Internal and external experiences are handled through a network that gather expertise from different technical disciplines. Operating experiences are processed via an internal database.

When appropriate, a WANO report of internal experiences is created for external distribution.

External experiences are obtained from different external forums, for example from vendor-specific meetings. External experiences have led to, for example, inspection being performed checking for hydrogen flakes in the pressure vessels' base materials, cracks in the bottom mounted instrumentation penetrations or in the pressure vessel head penetrations.

Below is a list of examples of experiences and how they are handled for RPVs.

Example 1: PWR vessel head penetrations

- Operating experience from France, 1991 – defects in penetrations
- Inspection at Ringhals 2, 1992 – defects in penetrations
- Remedial action: replace vessel head
- Vessel head replaced in 1996 at Ringhals 2
- Continued ISI of Ringhals 3 and 4 vessel head penetrations, first indications found in 1998
- Remedial action, replace vessel head
- Vessel head replaced in 2004 at Ringhals 4 and 2005 at Ringhals 3

Example 2; PWR outlet nozzle to safe end weld Ringhals 3 and 4

- Critical Inconel 182 weld, ISI detected surface braking defects year 2000 at Ringhals 3 and 4
- Remedial action, remove defects and perform weld inlay
- 2003 Ringhals 3, defects removed and inner surface part of Inconel 182 weld removed. A new 10 mm layer of Inconel 52 weld inlay was introduced to cover and protect the original 182 weld
- Corresponding repair performed at Ringhals 4 in 2004

Example 3; Vessel Shell Base Materials, Hydrogen Flakes

- Doel 3 and Tihange 2 detected hydrogen flakes in their forged vessel shells during a routine ISI inspection in 2012, the vessels are manufactured at the Rotterdam Dockyard

- Ringhals 2 RPV is also manufactured at the Rotterdam Dockyard and there were suspicions that this vessel might have hydrogen flakes. The 10-year RPV ISI was planned for 2012. It was immediately decided to extend the inspection and search for hydrogen flakes in one quarter of the vessel shell, ranging over the whole axial length – no hydrogen flakes were detected

- RPV Ringhals 3 and 4 were manufactured by Uddcomb Sweden AB. Ringhals 3 and Ringhals 4 RPVs have also been inspected and no indications of hydrogen flakes were found

- The cylindrical part of the RPV for Forsmark 3 and Oskarshamn 3 are made from forged rings, i.e. of a similar design as for the PWR RPVs. Forsmark and Oskarshamn have performed comprehensive reviews of the manufacturing and inspection records of the forged rings for the RPV. No indications of any problems with hydrogen flakes could be found. The RPVs for Forsmark 3 and Oskarshamn 3 have been manufactured by Uddcomb, Sweden, and the forged rings were made by Japan Steel Works.

Example 4: Vessel Shell Weld Material (Ringhals 3 and 4) – high nickel content

- In the mid-1990s it was suspected that the weld materials in the belt-line weld on units 3 and 4 had a higher transition temperature increase than predicted

- Around the year 2000 it became apparent that this was an issue that needed attention in order to ensure a long-term operational scheme. The suspicion was that the high nickel and manganese level in the welds was producing the larger shifts

- In collaboration with vendors, institutes and other networks, a larger project has evaluated the data from units 3 and 4 and this has resulted in a foundation for material data and analysis that shows that the pressure vessels are fit for 60 years of operation if the outward flux from the reactor core is controlled by the preventive action of using shielding fuel assemblies in some of the core periphery positions

- The same weld material with high nickel content has been used for the manufacturing of RPVs for Forsmark 1-3 and Oskarshamn 3. However, the fluence for a BWR RPV is lower than a PWR RPV and thus is the corresponding shift of the transition temperature lower. The embrittlement of the weld material is expected not to be a limiting factor for LTO, but the situation is being carefully monitored by the surveillance programmes.

Example 5: PWR lower dome penetrations

- Based on its experience, Ringhals is aware that the lower dome penetrations are susceptible to PWSCC.
- The lower dome penetrations are the focus and the ISI programmes are adjusted due to operating experience. A full volumetric inspection of all penetrations is performed with

a 10 year interval. In addition, visual inspections of all penetrations are performed from the outer surface under the vessel dome. The visual inspections focus on indications of leakages. No indications have been reported so far.

5.1.3. Monitoring, testing, sampling and inspection activities for RPVs

The RPV, cladding and welds

The monitoring, testing, sampling and inspections activities are performed as part of several activities within the AMP, such as the surveillance programme, the programme for ISI, monitoring and evaluation of temperature- and pressure transients and the water chemistry programme.

The main requirements in the regulations for surveillance programmes have been shown above in section 5.1.2 of this report. Additionally the mechanical testing of withdrawn samples is required to be carried out by a laboratory that is accredited for the mechanical tests in question, and the evaluation of fluence monitors must also be done by an accredited laboratory. The results of the tests and a validated P-T limiting curve for the RPV in question shall be reported to SSM no later than one year after the withdrawal of the monitoring capsule.

SSM recommends the withdrawal of surveillance capsules to every 15th year for BWRs and every 10th year for PWRs. However, this recommendation has not been always strictly followed as can be seen by the two following examples:

- For Oskarshamn 3, the first capsule was withdrawn for analysis in 2002 after 17 cycles of operation. The next withdrawal is planned for the outage of 2017.
- For Ringhals 3, the first capsule was withdrawn for analysis in 1984 and the following in 1996. Two capsules were withdrawn in 2000 and two in 2007. The last two capsules were withdrawn due to overly accumulated fluence that exceeded the expected realistic life time for the reactor. The specimens in one of the capsules were tested 2010.

The acceptance criteria for the surveillance programme is the analysed P-T limit curve valid to the next capsule withdrawal or for the intended remaining operation time for the reactor in question.

All BWR RPVs will have a low fluence even after 60 years of operation. Embrittlement of the RPV material is, therefore, predicted not to be a time limiting degradation mechanism for continued operation of the BWRs. However, knowledge about the fluence and the embrittlement of the RPV material is still important as it is an input in the analysis of P-T limit curves.

Ringhals 3 has the largest predicted DBTT shift and has been verified against the alternate pressurised thermal shock rule in 10 CFR 50.61a. The PTS analysis was carried out because the weld material in the belt line of Ringhals 3 RPV had a predicted reference temperature after about 42 years of operation that was larger than the applicable screening criterion for PTS according to 10 CFR 50.61. It was a prerequisite of the analysis that generation 1 shielding fuel assemblies be installed in the core periphery positions for the remaining planned operation time of the reactor. The purpose of the shielding fuel assemblies is to reduce the accumulated fluence and the embrittlement of the critical weld material. However, after having performed the alternative PTS-analysis, Ringhals decided to develop the concept with shielding fuel assemblies with the goal of screening the PTS criterion for the predicted reference temperature so that it will not be reached before 60 years of operation have elapsed. In 2016, Ringhals installed generation 2 shielding fuel assemblies with a higher shielding factor compared to generation 1. With the generation 2 shielding fuel assemblies installed in the core analysis shows that the predicted reference temperature for the weld material will not be higher than the screening criterion for PTS after 60 years of operation.

Ringhals 2 and Ringhals 4 have predicted reference temperatures for the base and weld materials that are lower than the screening criterion for PTS for their intended life time. External dosimetry has been installed for Ringhals 1-4. The purpose is to evaluate the accumulated fluence for long-term operation. The exchange interval of the dosimeters is 5 years, but the intervals may change if the operational parameters change.

Forsmark have plans to install external dosimetry for Forsmark 1 and Forsmark 2 in 2023 and 2018 respectively. External dosimetry was installed in Forsmark 3 in 2016. Exchange and evaluation of dosimeters are planned for 2018 and 2022.
ISI of the RPV's welds is regulated in Chapter 3, Section 4 of the Swedish regulations SSMFS 2008:13 as follows:

Butt welded joints and main flange joints in the reactor pressure vessel and welded joints in the reactor pressure vessel nozzles must undergo in-service inspection with intervals that must not exceed ten years.

Furthermore, the inspections shall be carried out by a third-party, independent, accredited laboratory with an inspection system qualified for detection, characterisation and sizing of the kind of defects that might occur in the weld and base material. The licensee shall ensure that the qualification of the inspection system is monitored and assessed by a body having an independent and impartial status; a suitable organisation possessing the necessary professional skills for the tasks in question as well as having a quality assurance system that is fit for purpose. This qualification body (QB) must be approved by SSM.

Inspection systems refer to equipment and personnel, in addition to the procedures and accompanying instructions governing performance. Qualification of these systems should comply with the principles stated in the European regulatory bodies' consensus document on qualifications using rules for applications developed and documented by the European Network for Inspection Qualification (ENIQ). The qualifications should normally refer to all steps of testing, i.e., technique and manipulators, personnel and procedures/ instructions.

The qualification of an inspection system is valid as long as none of the technical equipment has changed. Personnel qualifications are valid for five years. After five years a requalification must be carried out.

Detection target for the ISI of Oskarshamn 3 RPV welds are 15x40mm (depth x length) which is the detection target for the qualified inspection system. Acceptance criteria differ from case to case. The acceptance criteria depends on the size of the defect, its orientation in the object and estimated stresses in the defect's vicinity.

In addition to the surveillance programme and the ISI of the RPV, transients (mechanical, thermal and pressure related) are monitored and evaluated. The number and magnitudes must not exceed the values noted in the SAR.

The vessel head and the bottom dome including penetrations and the inlet and outlet nozzles

ISI of the RPV penetrations and nozzles are performed in accordance to the requirements in Chapter 3 of the Swedish regulations SSMFS 2008:13. All mechanical components shall be classified into three inspections groups. The inspection groups shall comprise the following:

- A: components for which the relative risk is deemed as highest;
- B: components for which the relative risk is deemed as lower than for group A but not insignificant, and;
- C: components for which the relative risk is deemed insignificant.

The classification of each component shall be determined while taking into consideration the relative risk of nuclear fuel damage, the external release of radioactive materials, unintentional chain reaction and deficiencies in general safety levels owing to damage that might occur in the mechanical components. The classification into inspection groups shall be reviewed annually in relation to operational experience, modifications to facility design or to its operational conditions. Operational experiences include lessons learned from national and international findings.

ISI of the RPV penetrations and nozzles belonging to inspection groups A and B is to be performed using inspection systems qualified for detection, characterisation and sizing of the kinds of defects that might occur in the relevant type of component. The same roles apply as for the ISI of the RPV welds, i.e., the inspections shall be carried out by a third-party, independent, accredited laboratory and the qualification of the inspection system is monitored and assessed by a QB approved by the SSM.

Most of the systems and components assigned to inspection group A should undergo in-service inspections. As far as systems and components assigned to inspection group B are concerned, a carefully considered inspection based on random samples may be sufficient. This random sampling should mainly be aimed at systems and components potentially subject to damage owing to known mechanisms. In cases without such potential and where inspections are justified by reasons of defence in depth, the extent of the random sampling should be a minimum of 10 per cent of the systems and components in question.

In order to achieve inspection programmes well adapted to safety needs, the intervals between the in-service inspections should be based on:

- the various components' propensity for damage;
- potential for damage to develop and the damage tolerance during the loads that may occur;
- consequences of damage, and;
- the effectiveness of inspections.

In practice, the intervals between ISI are often determined by fracture mechanics calculations based on crack propagation rates and stress analyses with established safety factors. For inspection groups A and B, the interval between the inspections must not exceed 10 years.

The principles, methods and procedure for classification into inspection groups, determination of the scope, and intervals of inspections must be notified to the SSM before the inspection programme is applied.

The ISI programme applied, including annual updates, shall be reviewed and assessed by an accredited inspection body.

Table 15 shows examples of objects for ISI with classified inspection groups, frequency and acceptance criteria. Note that the acceptance criteria is the detection limit for the inspection in question.

Table 15 - Examples of inspection criteria for RPV objects

Object	Inspection Group	Frequency	Activities	Acceptance Criteria
Shell, Reactor Pressure Vessel - **Base** - **HAZ** - **Weld** - **Cladding**	F[5]	10 years	UT[6] and ET[7]	Weld Incl. HAZ Min 12,2x73,2
Penetration, Lower dome				
- **Control Rods**	C	-	-	-
- **Incore (BWR) Instrumentation**	C	-	-	-
- **Incore (PWR) Instrumentation**	C	3 (10)	VT[8] (UT/ET)	-
Penetration, Pressure Vessel Head				
- **BWR Head cooling and instrumentation**	A	3	PT[9],UT	5x22,1
- **PWR Control Rod**	C	3 (10)	VT (UT/ET)	-
Nozzle, inlet and outlet, upper part				
- **Inner Radius (BWR)**	B	10	UT	22,32x133,9
- **Attachment Weld (BWR)**	F	10	UT	25,76x54,5
- **Nozzle to Safe End Weld (BWR)**	B	3/10	UT	19,56x117,3
- **Nozzle to Pipe Weld (BWR)**	B	3/10	UT	15,09x90,5
- **Inner Radius (PWR)**	B	10	UT/ET	156,1x936,6

[5] F=Prescribed inspection, object not classified into any inspection group.
[6] Ultrasonic Testing
[7] Eddy Current Testing
[8] Visual Testing
[9] Dye Penetrant Testing

- **Attachment Weld (PWR)**	F	10	UT	16,8x100,8
- **Inlet Nozzle to Safe End Weld (PWR)**	F	6	UT/ET	32,4x64,8
- **Outlet Nozzle to Safe End Weld (PWR)**	F	10	UT/ET	19,9x59,7
- **Nozzle to Pipe Weld (PWR)**	B	10	UT/ET	45,6x273,6
Nozzle, Lower Dome				
- **Inner Radius**	B	10	UT	11,4x68,4
- **Attachment Weld**	F	10	UT	20,65x123,9

5.1.4. Preventive and remedial actions for RPVs

In order to minimise the risk of SCC and other ageing related degradation it is important to maintain good water chemistry. All reactors have a unique chemistry programme. The chemistry programme is designed to optimise the water chemistry of each reactor to minimise corrosion and dose-rate build-up, and prevent ageing-related degradations and damage.

The chemistry programmes are mainly based on reactor suppliers' recommendations and has been added to over time. In principle, the chemistry programmes for the BWRs follow EPRI BWRVIP water chemistry guidelines.

Hydrogen water chemistry (HWC) is applied in Ringhals 1 to prevent SCC. In Ringhals 2-4 the H-content is controlled to minimise the risk of PWSCC and material losses from general corrosion, and to avoid the consequent dose-rate build-up.

The four reactors with internal pumps, Forsmark 1-3 and Oskarshamn 3, do not apply HWC. Tests with HWC in reactors with internal pumps have shown that it is very difficult to establish mitigating environmental conditions at the bottom of the RPV.

The plant-specific chemistry programmes consist of a large number of instructions and guidelines. The programme specifies how the water in the process systems are to be monitored, and takes into account relevant material, system configuration and operation mode. This ensures that the chemical conditions in the process systems are stable and adjusted depending on the materials in the system.

Monitoring is performed by online measurements and regular sampling analysis comprehensive enough to detect significant deviations in order to make corrections before degradation occurs. The programme comprises all chemical, radiochemical and other routine analyses that must be done. The results are assembled in a database, which in turn provides the basis for trend analyses. Trends are analysed for certain key parameters that have been identified as important to ensuring the integrity of materials and radiation levels in the systems.

Due to high nickel and manganese content in the beltline weld on unit Ringhals 3 and Ringhals 4, extensive action has been taken in order to reduce fast neutron flux at the reactor pressure vessel wall. At Ringhals 3 and Ringhals 4, twelve fuel assemblies specifically designed to shield the RPV wall from fast neutron flux are used in the core design. The shielding assemblies are placed on the main axes in rows of three and are separated by 90º azimuth. For the rest of the core a low leakage loading pattering is applied to minimise the core neutron leakage to optimise fuel economy and reduce fast neutron flux to the RPV (see Example 4 in Chapter 5.1.2).

It is well known that Alloy 182 (A182) is prone to SCC. At Ringhals 1, a project was performed in 2003 where A182 in the feed water nozzle was removed and replaced with Alloy 82 (A82) which has better resistance to SCC. Replacement of A182 by A82 has also been done in RPV nozzles at Forsmark 1-3.

Remedial actions may be triggered upon the detection of defects, or by experience from internal or external sources. If a defect is detected during an inspection, a series of actions are initiated:

- The scope of inspection has to be extended to include other similar objects;
- A root cause analysis to determine the damage mechanism;
- Analyse how long operation can continue before repair is necessary. The defect size is compared to the acceptable defect size and possible operation time is estimated with the aid of disposition curves of crack propagation rates. The analysis is reviewed by an accredit inspection body;
- If the defect must be removed, with or without a subsequent repair, it shall be done according to a qualified repair programme. The licensee shall ensure that qualification of repair programmes is monitored and assessed by an accredited inspection body if the measures are relate to components assigned to quality classes 1 and 2.

Requirements for the actions to be taken and repairs, replacements or modifications are given in the Swedish regulations SSMFS 2008:13.

Remedial actions are incorporated into the procedures and instructions of the chemical programme. Regarding the BWRs the actions levels, time and actions to be taken are similar to the recommendations given in EPRI BWR Water Chemistry Guidelines.

During the 1989 outage for Forsmark 1, one indication in the DMW (a nozzle to safe end weld) was detected in one of the main feed water nozzles in the main feed water system (system 415). The safe end is a short transition piece of pipe segment (often made of Alloy 600) between the reactor nozzle and the connecting pipeline. The indication was evaluated as IGSCC. However, a later evaluation concluded that the defects were initiated from a fabrication defect (hot cracking). The defect was excavated and the pit was filled with alloy 82. The inside surface of the DMW were removed and replaced with alloy 82 to a depth of approximately 4.5 mm.

For Forsmark 1-3, the remaining main nozzles in the main feed water system (system 415), residual heat removal system (system 321) and emergency core cooling system (system 323) and all DMWs (nozzle to safe ends) were later overlaid with alloy 82 in the same way as mentioned above for the main feed water nozzle. The welding material of alloy 182 was replaced with alloy 82 since the latter is considered to be more IGSCC resistant.

Defects in the attachment welds between the RPV closure head and the beams supporting the upper part of the internals in Forsmark 1 and Forsmark 2 have, since 1990, been detected repeatedly. However, the defects have been weld repaired.

As result of the ISI in Forsmark 2 during the 2003 outage, some surface breaking indications were detected in the main circulation pump nozzle, denoted as W80, W79 and C27. The indications were located to a very limited surface and could only be detected by means of eddy current testing (ET). The indications were evaluated as surface scratches from mechanical impacts during the installation, i.e., with no need for further actions being identified.

Also, in the past, some other indications have been detected as result of the ISI. However, the follow-up evaluations has not resulted in repairs or other hardware measurements.

Defects were recently detected in two of the core shroud support legs (CSS) in Forsmark 1. The defects were initiated in and limited to the buttering material of alloy 182. There were no defects detected in the base material (LAS). The defects were removed by EDM. During the outage in 2016 NDT based inspections of the CSS in Forsmark 2 revealed no indications. No indications are expected in Forsmark 3, but corresponding investigations and inspections of Forsmark 3 and Oskarshamn 3 are to be addressed during the outage in 2018.

Ringhals 1 has experienced cracking in the cladding at the feed water nozzles caused by temperature fluctuations from misaligned thermal sleeves/ejectors. After redesign and repair, no further cracking has been detected.

The pressure vessel heads on all PWR units (Ringhals 2-4) have been replaced due to defects in the penetrations. This was triggered by external experiences and are described in Example 1 at the end of Chapter 5.1.2.

On Ringhals 3 and Ringhals 4, the outlet nozzles' safe end welds were repaired in 2003 and 2004 due to defects being found. 10 mm of the innermost layer of alloy 182 were removed and replaced with alloy 52 with weld inlay. See Example 2 at the end of Chapter 5.1.2.

5.2. Licensee's experience of the application of AMPs for RPVs

All three licensees report that the experiences of the ageing programme and the underlying programmes, i.e. surveillance programme, ISI programme and water chemistry programme, clearly show that the programmes covers the significant ageing mechanisms. None of the three licensees reported any finding of unexpected degradations or issues that were not foreseen in the programmes.

External and internal experiences have affected the programmes. The programmes have been updated in accordance with these experiences.

For example, defects were found at the bottom dome of Forsmark 1 close to the core shroud support legs. The number of CSS legs tested was increased at Forsmark 1. Similar positions in Forsmark 2 were tested in 2016 and there are plans to undertake ISI in those positions for Forsmark 3 and Oskarshamn 3 in 2018.

Another example is the detection of hydrogen flakes in the RPV material of Doel 3 and Tihange 2 in Belgium. All three PWR RPVs in Ringhals have been inspected with respect to hydrogen flakes, but no indications were reported from those inspections. Forsmark and Oskarshamn have performed a review of the control documentation from the manufacturing of the RPV for Forsmark 3 in respect of Oskarshamn 3. As noted earlier in this report, the cylindrical shell of Forsmark 3 and Oskarshamn 3 are both made from forged material, SA 508 Cl. 3. This material could theoretically be affected by hydrogen flakes. The outcome of the reviews is that there are no indications in the documentation of any problems with hydrogen flakes or similar issues.

A third example is the weld material with high nickel and manganese content that has been used for the welding of the RPVs in Forsmark 1-3, Oskarshamn 3 and Ringhals 3-4. This weld material is sensitive to neutron irradiation and will show a comparatively large shift in DBTT with fluence. The surveillance programmes for Ringhals 3 and Ringhals 4 have been affected. Complementary testing has been done at the Halden reactor. Ringhals has taken mitigating actions to avoid the embrittlement of weld material from becoming a limiting issue. The surveillance programme has been modified accordingly. The embrittlement of the weld material is predicted not to be a limiting factor for BWRs as they have lower fluence compared to the PWR. However, the weld material is included in the surveillance programmes and the DBTT shift will be carefully monitored.

5.3. Regulator's assessment and conclusions on ageing management of RPVs

Regulators assessment of the ageing management processes described in this chapter

SSMs conclusion regarding the Swedish licensees ageing management of the RPVs are:

- Ringhals have a Technical area that manage the AM of the primary system which include the RPV.
- Forsmark have specific AMP procedures for selecting objects to be included in the AM.
- Oskarshamn have formed a commodity group for the AM of the RPV.
- Forsmark, Oskarshamn and Ringhals have all included in the AMP of the RPVs four sub programs (surveillance program, ISI program, monitoring of transients and water chemistry program).
- The licenses have verified that the identified significant degradation mechanisms for the RPV are in agreement with international guides such as NUREG-1801 rev. 2 and BWRVIP-167.
- Forsmark and Ringhals has taken preventive actions in order to reduce the risk for harmful degradation.

Regulators experience from inspections and assessments as part of regulatory oversight

Results and analysis from the ageing management of the RPVs are reported in connection to the periodic safety reviews (PSR) and some results are also input for time limited ageing analysis (TLAA).

As describe in section 5.1.3 the RPV nozzles and penetrations are classified into inspections groups A-C for ISI. The methods, principles and procedures for the classification into inspections groups in addition to determination of the scope and intervals between inspections must be subjected to a safety review and notified to SSM. The ISI program shall also be reviewed and updated annually in relation to operational experiences (internal and external), modifications to facility design and the facility's operational conditions. The modifications, scope and suitability of the ISI program is annually reviewed by an accredited inspection body. Inspections of object in group A and B are performed by an independent accredited laboratory and with inspection systems that are qualified for detection, characterizing and sizing of the kind of defects that might occur in the inspected object.

Requirements for in service inspection programs for the Swedish reactors have been in place since the start of the reactors. Requirements for monitoring and review of the programs by an independent accredited inspection body have been in place since 1995 when the Swedish regulations SKIFS 2004:1 came into force. SSMs experiences of the ISI programs are that they meet their purpose and malicious degradation is detected in time from a safety point of view. An indication of the effectiveness of ISI programs is that about 94% of all defects detected in Swedish NPPs were detected by ISI. Only about 6 % of the detected defects were detected by other methods such as detection of leakage.

According to the requirements in the Swedish regulations SSMFS 2008:13 shall the surveillance programs be approved by SSM. The requirements also state that changes of the programs and results and analyses from tests of irradiated specimen shall together with the P-T curve intended to be applied be notified to SSM. The surveillance program for the Swedish reactors are all based on the requirements in ASTM E185-82, 10 CFR 50 appendix H and USNRC Regulatory Guide 1.99 rev.2. However, during the years have the programs been changed and modified to adopt to the special condition that apply to the Swedish reactors. One example is the weld material with high nickel and manganese content that have been used for the manufacturing of the RPVs for Forsmark 1-3, Oskarshamn 3 and Ringhals 3-4. This material is sensitive to neutron irradiation and shows a higher degree of embrittlement compare to weld materials with lower content of Ni and Mn. A consequence is that the trend curves given in different standards, i.e. ASTM E 900, under estimate the embrittlement of this weld material. For Ringhals 3 and 4 have unique trend curves for 60 years of operation been developed by RAB. The unique trend curves are based on surveillance data and test reactor data. RAB also uses higher margins for the estimation of the reference temperature compared to what normally used.

The same weld material has also been used for the manufacturing of the BWRs, F1-3 and O3. The end of life fluence for the BWRs is lower compared to PWR and the embrittlement of the weld material will thus be substantially lower. There are only three capsules with test specimens installed in the RPV for Forsmark 1-3 and Oskarshamn 3. In order to broaden the database for the evaluation of the adjusted reference temperature an integrated surveillance program for the four BWRs has been proposed. The integrated program will also incorporate an adequate external dosimetry program.

SSM have over the years reviewed the changes of the surveillance programs as well as the reported test results and the P-T curves intended to be used to the next withdrawal of test capsule. For some reactors have also the surveillance program and the P-T curve been updated due to power upgrade.

SSMs assesses based on the reviews that the surveillance programs meet internationally accepted standards in the field and that the adaptation of the programs to the special conditions for Swedish RPVs have been done in an acceptable manner.

Regulators conclusions on the adequacy of the Ageing Management Programmes described in this chapter

SSM finds that the Swedish licensees Forsmark, Oskarshamn and Ringhals all have a suitable Ageing Management Program for the RPV. The programs are similar in scope as they include four subprograms, in agreement to requirements in applicable Swedish regulations. The sub programs have been in place, with various modifications, since the start of operation of the reactors.

SSM notes that Ringhals have a Technical area that manages the AM for the primary system. This is a consequence of the differences in the design of the primary system between a PWR and a BWR.

SSMs overall conclusion is that the ageing management programs are adequate and sufficient. However, with respect to the plans for LTO of Forsmark 1-3 and Oskarshamn 3 SSM considers that the surveillance programs for those reactors needs to be further developed. Surveillance programs for Ringhals 3 and 4 that cover LTO until 60 years of operations are already in place.

6. Calandria/pressure tubes (CANDU)

This chapter in not applicable to the Swedish NAR, with reference to Table 1.

7. Concrete containment structures

The Swedish licensees have reported separately according to the technical specification on the area of electrical cables. Unless otherwise stated, the description below is valid for all licences.

7.1. Description of Ageing Management Programmes for concrete structures

7.1.1. Scope of ageing management for concrete structures

The concrete structures within the scope of this chapter are the concrete containment structures with embedded steel liners for PWRs, BWRs and the reactor buildings that surround the BWR containments.

The concrete containment structures for the PWRs in Sweden have similar structures with only minor variations. They are designed in accordance to the large dry containment designs concept. The containment walls consist of cylindrical pre-stressed single-walled concrete with horizontal and vertical tendons. The tendons are placed in grease filled ducts for protection against corrosion. A pre-stressed concrete dome serves as a ceiling. The steel liner consists of numerous steel plates which are welded together creating a channel system of joints. The channel system is used to locate potential leakages in the welds. At the walls and in the bottom, the steel liner is embedded in concrete to protect it from degradation, rapid temperature fluctuations and missiles. At the top of the containment the steel liner is placed on the inner surface of the ceiling and painted with corrosion protective paint.

The main functions of a PWR containment are:

- to withstand maximum internal pressure and other loads in case of accidents, and to be leak-proof to radioactive compounds to prevent these escaping into the surroundings;
- to prevent radioactive discharges to the surroundings in the case of an accident or during ordinary operation. The steel liner which encloses the entire containment is there mainly to ensure that no (or an absolute minimum of) radioactive release occurs from the containment during operation or in the case of an accident.
- to manage loads from the suspensions of pipelines during normal operation as well as accidental loads and to manage loads associated with heavy lifts using the polar crane and loads due to pipe penetration.

See 10.2 and Figure 5 for a section drawing of Ringhals 4 which is one of three PWRs in Sweden.

The concrete containment structures for the BWRs are constructed in accordance to the pressure suppression design strategy, i.e., by subdividing the containment into two main compartments: a dry-well compartment and a wet-well compartment. The compartments are separated by internal concrete structures and the intermediate concrete floor.

The containment walls consist of pre-stressed single-walled concrete with an embedded steel liner. The vertical and horizontal tendons are located in cast-in ducts which have been cement injected as a corrosion protection. The cast in ducts at Forsmark's BWRs are ventilated with dry air to protect the tendons from corrosion.

On major parts of the celling, an inner reinforced concrete shell protects the steel liner. Around the toroid in the ceiling, the steel liner is visible and treated with corrosion-resistant paint. In the bottom of the wet well the steel liner is unprotected by a concrete layer. The roof consists of a partially pre-stressed concrete ring beam. The foundation consists of a concrete slab founded on the reactor building. The reactor pools for e.g. handling and storage of nuclear fuel, are located on top of the containments. The walls of the pools are pre-stressed horizontally and vertically as some of the vertical tendons in the cylinder wall are anchored on top of the pool walls.

For BWR Ringhals 1, the upper part of the containment wall is cone-shaped reinforced concrete where the steel liner is located on the inner surface of the wall. A reinforced concrete circular slab connects the cylinder wall to the top cone. The cylinder slab and the cone are connected to the reactor pool structure located above the reactor containment. The top of the containment consists of a metal dome. The containment was built on solid rock with the steel liner covering a thick concrete slab.

The main functions of a BWR containment are to:

- act as a radiation barrier to the reactor building during operation and in case of an accident;
- house the reactor tank and other safety classed equipment;
- protect the surroundings from uncontrolled radioactive discharge in the case of internal accident;
- enable controlled oxygen content in the containment during operation;
- enable the pressure suppression design principle of the containment;
- withstand structural loads and load combinations in case of an accident.

See 10.2 and Figure 6 for a section drawing of a typical BWR in Sweden.

The reactor buildings that surround the BWR containments are made of reinforced concrete. A reactor building consists of several floors where the top floor is the reactor pool hall, located above the concrete containment. The reactor buildings at Forsmark have corrugated galvanised steel covering the exterior of the walls. The main structural system of the roof above the reactor pool hall at Forsmark consists of two post-tensioned main girders supporting a prefabricated, pre-stressed element. On top of the prefabricated elements, the climatic barrier consists of reinforced concrete topped with roofing felt.

The main functions of the reactor building are to:

- enclose the reactor containment;
- protect the personnel and surroundings from radiation during operation;
- house safety equipment that is to be used in case of an accident;
- manage all loads and load combinations relevant for the structure during ordinary operation;
- control the climatic conditions for the reactor containment.

See 10.2 and Figure 7 for a layout of one reactor building in Sweden.

Regarding methods and criteria used for selecting components from the containment and reactor building within the scope of the ageing management.
The licensees have selected all safety classed structures in accordance to SAR[10] classification list. All systems belonging to safety class 1-3 were automatically included in the Ageing Management Programme. Systems not belonging to safety class 1-3 which, by malfunctioning, may affect the function of a safety-classed system have also been included in the Ageing Management Programme.

Regarding processes or procedures for the identification of ageing mechanisms for the different materials and components of the concrete structures.
Ringhals reports that the requirements for the concrete components and structures related to ageing mechanisms are based on the norms through exposure classes and lifetime expectancy. These norms are not the same as when the reactor containments at Ringhals were built, but were implemented at a later stage. The standards, SS-EN 206:2013[11], include specification of, e.g., material composition, fresh and hardened material properties, and specifications of the concrete. Additional national standards, SS 137003[12] and SS 137010[13], are also used. These cover supplementary material components and test methods not included in SS-EN 206:2013 as well as certain applications that are required in Sweden.

Oskarshamn describes reports that all ageing mechanisms and their corresponding information is required from two different Oskarshamn defect catalogues.

7.1.2. Ageing assessment of concrete structures

The ageing mechanisms requiring management and identification of their significance for the PWRs, BWRs and the reactor buildings are presented in the tables below.

NAR example	Component	Degradation mechanism	Ageing affect
Concrete	Concrete bottom slab, outer containment wall), outer dome	Chloride initiated reinforcement corrosion	Concrete surface spalling, concrete surface crack formation
	Concrete bottom slab, inner and outer containment wall	Carbonation initiated reinforcement corrosion	Concrete spalling, concrete surface crack formation
	Inner and outer containment wall and dome	Thermal exposure	Surface crack formation, mechanical degradation
	Outer containment wall and dome	Frost attack	Internal and surface frost attack, scaling, spalling, internal cracking, mechanical degradation

10 Safety analysis report
11 SIS, "Concrete - Specification, performance, production and conformity". SIS/TK.190 SS-EN 206:2013. (2013)
12 SIS, "Concrete - Application of EN 206-1 in Sweden", SIS/TK 190, SS 137003. (2015)
13 SIS, "Concrete structures - Concrete cover", SIS/TK 190, SS 137010. (2002)

	Outer cylinder wall and dome	Saline freeze/thaw attack	Surface scaling spalling, surface cracks, mechanical degradation
Steel reinforcement	Concrete bottom slab, outer containment wall), outer dome	Chloride initiated reinforcement corrosion	Corrosion on reinforcement.
	Concrete bottom slab, inner and outer containment wall	Carbonation initiated reinforcement corrosion.	Corrosion on reinforcement.
Pre-stressing systems		Relaxation, shrinkage, creep, corrosion (cable breakage)	Loss of pre-stressed force
Liner, toroid steel		Water line corrosion	Pitting, loss of material
		Corrosion	Loss of material
Water stops, seals and gaskets and protective coating	Surface coatings, joints, seals	Polymer degradation	Colour deterioration, Cracking, Increased stiffness

Table 16 PWR

NAR example	**Component**	**Degradation mechanism**	**Ageing affect**
Concrete	Concrete bottom slab	Chloride initiated reinforcement corrosion	Concrete surface spalling, concrete surface crack formation
	Concrete bottom slab, inner and outer containment wall	Carbonation initiated reinforcement corrosion	Decrease of pH, concrete spalling, concrete surface crack formation
Steel reinforcement	Concrete bottom slab	Chloride initiated reinforcement corrosion	Corrosion on reinforcement
	Concrete bottom slab, inner and outer containment wall	Carbonation initiated reinforcement corrosion	Corrosion
Pre-stressing systems		Relaxation, shrinkage, creep, corrosion (cable breakage)	Loss of pre-stressed force
Liner, toroid steel		Water line corrosion	Pitting, loss of material
		Corrosion	Loss of material

Water stops, seals and gaskets and protective coating	Surface coatings, joints, seals	Polymer degradation	Colour deterioration, Cracking, Increased stiffness

Table 17 Ringhals BWR

NAR example	**Component**	**Degradation mechanism**	**Ageing affect**
Concrete	Pool walls	Leaching	Surface cracking, Blistering of surface coating
	All concrete components	Temperature, shrinkage, carbonation	Concrete surface cracking and spalling. Reduction in cross-sections of concrete. Reduction of bond between concrete and reinforcement. Delamination.
	Foundations, bottom slabs.	Chloride induced corrosion.	Concrete sur-face cracking and spalling. Reduction in cross-sections of concrete. Reduction of bond between concrete and reinforcement. Delamination.
	Foundations	Degradation due to oil leakage.	Loss of strength
	All concrete components	Structural loading. Shrinkage of concrete.	Cracking and reduction of load bearing capacity.
	Exterior walls, foundation, roof.	Settlements, Shrinkage, Temperature, Structural loading.	Cracking. Crack widths exceeding 0.2 mm may compromise the water tightness of the concrete.
Steel reinforcement	All concrete components	Carbonation induced corrosion.	Precipitation of corrosion products. Reduction in cross-sections of reinforcement. Reduction of bond between concrete and reinforcement.
	Foundations, bottom slabs, exterior walls.	Chloride induced corrosion.	Precipitation of corrosion products. Reduction in cross sections of reinforcement. Reduction of bond between concrete and reinforcement.
Pre-stressing systems		Relaxation of steel, Shrinkage and creep of concrete	Loss of prestress forces.
		Atmospheric corrosion (unbonded tendons)	Loss of prestress forces.

Liner	Containment steel liner	Carbonation of concrete, Atmospheric corrosion, Galvanic corrosion	Loss of leak tightness
	Steel liner in pools	Galvanic corrosion	Loss of water tightness
	Stainless steel liner in pools	Mechanical abrasion from water jetting	Loss of water tightness, Leakage
Water stops, seals and gaskets and protective coating	Sealing for intermediate flooring, seals	Natural embrittlement, High temperature, Radiation.	Cracking, Reduction of elasticity, Reduction in tensile capacity,
	Water stops, seals and gaskets	Loss of plasticizers in polymers due to: Oxidation, Radioactive radiation,	Cracking, Reduction of elasticity, Reduction in tensile capacity
Anchor plates		Atmospheric corrosion, Galvanic corrosion	Reduction of load bearing capacity.
		Fatigue due to structural loading	Cracking in steel and concrete. Loss of load bearing capacity.

Table 18 Forsmark BWR

NAR example	Component	Degradation mechanism	Ageing affect
Concrete	Slab, wall, roof	Temperature, T > 80-100 ºC	Deteriorated stress and compression strength, internal stress, force of constraint and decay. The stress strength reduction is only marginal up to 100ºC degrees. The stress strength generally decreases with increasing temperature.
		Shrinkage	Dehydration, material deformation, cracks
		Creep	Material deformation, forces of constraint, and cracks
		Erosion due to particles flowing in water	Material loss
		Attrition due to mechanical impact from traffic and objects.	Material loss
		Fatigue due to vibrations.	Decay, cracks

		Dehydration when T>100-200 degrees	Moisture transport, micro cracks
		ASR, alkali-silica reaction	Cracks, decay, loss of strength
		Leaching	Decay, loss of strength
		Carbonation	The passive oxide layer of steel embedded in concrete is damaged. Contributes to corrosion when the concrete pH-level drops below 9, and by influence from moisture.
Steel reinforcement		Corrosion, ferric oxide, pitting	Material loss, fractures
Pre-stressing systems		Corrosion, ferric oxide, pitting	Material loss, fractures
Liner		Corrosion, ferric oxide, pitting	Material loss, fractures
Water stops, seals and gaskets		Oxidation, Chain breakage, Chain bond/cross linking	Colour deterioration, Cracking, Increased stiffness
Service openings, Anchor plates		Corrosion, ferric oxide, pitting	Material loss, fractures

Table 19: Oskarshamn BWR

NAR example	**Component**	**Degradation mechanism**	**Ageing affect**
Concrete	Concrete bottom slab, Outer containment wall(Ringhals 2 – Ringhals 4), Outer dome (Ringhals 2 – Ringhals 4)	Chloride initiated reinforcement corrosion	Corrosion on reinforcement, concrete surface spalling, concrete surface crack formation
	Concrete bottom slab, inner and outer containment wall	Carbonation initiated reinforcement corrosion	Decrease of pH, corrosion, concrete spalling, concrete surface crack formation
	Inner and outer containment wall and dome	Thermal exposure	Surface crack formation, mechanical degradation

	Outer containment wall and dome (Ringhals 2 – Ringhals 4), Reactor building outer wall and roof (Ringhals 1)	Frost attack	Internal and surface frost attack, scaling, spalling, internal cracking, mechanical degradation
	Outer cylinder wall and dome, Reactor building outer wall and roof (Ringhals 1)	Saline freeze/thaw attack	Surface scaling spalling, surface cracks, mechanical degradation
Steel reinforcement			
Pre-stressing systems		Relaxation, shrinkage, creep, corrosion (cable breakage)	Loss of pre-stressed force
Liner, toroid steel		Water line corrosion	Pitting, loss of material
		Corrosion	Loss of material
Water stops, seals and gaskets and protective coating	Surface coatings, joints, seals	Polymer degradation	Colour deterioration, Cracking, Increased stiffness

Table 20 Ringhals Reactor building

NAR example	**Component**	**Degradation mechanism**	**Ageing affect**
Concrete	Pool walls	Leaching	Surface cracking, Blistering of surface coating
	All concrete components	Temperature, shrinkage, carbonation	Concrete surface cracking and spalling. Reduction in cross-sections of concrete. Reduction of bond between concrete and reinforcement. Delamination.
	Foundations, bottom slabs, exterior walls.	Chloride induced corrosion.	Concrete sur-face cracking and spalling. Reduction in cross-sections of concrete. Reduction of bond between concrete and reinforcement. Delamination.
	Foundations	Degradation due to oil leakage.	Loss of strength
	All concrete components	Structural loading.	Cracking and reduction of load bearing capacity.

		Shrinkage of concrete.	
	Exterior walls, foundation, roof.	Settlements, Shrinkage, Temperature, Structural loading.	Cracking. Crack widths exceeding 0.2 mm may compromise the water tightness of the concrete.
Steel reinforcement	All concrete components	Carbonation induced corrosion.	Precipitation of corrosion products. Reduction in cross-sections of reinforcement. Reduction of bond between concrete and reinforcement.
	Foundations, bottom slabs, exterior walls.	Chloride induced corrosion.	Precipitation of corrosion products. Reduction in cross sections of reinforcement. Reduction of bond between concrete and reinforcement.
Liner	Steel liner in pools	Corrosion	Loss of water tightness
Water stops, seals and gaskets and protective coating	Waterstops, seals and gaskets	Embrittlement	Cracking, Reduction of elasticity, Reduction in tensile capacity
Anchor plates		Corrosion	Reduction of load bearing capacity.
		Fatigue	Cracking in steel and concrete. Loss of load bearing capacity.

Table 21 Forsmark Reactor building

NAR example	Component	Degradation mechanism	Ageing affect
Concrete	Slab, wall, roof	Shrinkage	Dehydration, material deformation, cracks
		Creep	Material deformation, forces of constraint, and cracks
		Sulphate attack	Internal breaking and decay, swelling reaction, loss of strength
		Frost attack	Internal decay and/or frost erosion
		Erosion due to particles flowing in water	Material loss
		Attrition due to mechanical impact from traffic and objects.	Material loss
		Fatigue due to vibrations.	Decay, cracks
		ASR, alkali-silica reaction	Cracks, decay, loss of strength
		Leaching	Decay, loss of strength

		Carbonation	The passive oxide layer of steel embedded in concrete is damaged. Contributes to corrosion when the concrete pH-level drops below 9, and by influence from moisture.
Steel reinforcement		Corrosion, ferric oxide, pitting	Material loss, fractures
Water stops, seals and gaskets		Oxidation, Chain breakage, Chain bond/cross linking	Colour deterioration, Cracking, Increased stiffness
Service openings, Anchor plates, Hatches (relief), Doors		Corrosion, ferric oxide, pitting	Material loss, fractures

Table 22: Oskarshamn Reactor building

All licensees in Sweden have identified the environment conditions for the SSC required to be able to identify the relevant degradation mechanism for each SCC.

Forsmark and Ringhals
Forsmark and Ringhals use the conclusion from a project conducted by the NOG: the BWR reactor containment can be divided into four different climatic zones. Based on this division and additional climatic data regarding temperature, humidity and radiation, the exposure classes according to SS-EN 206-1 were identified for the different concrete components of both the reactor containment and the reactor building. Based on this information, the relevant degradation mechanisms for each concrete component were identified. This procedure was also used for other non-concrete components in the reactor containment and reactor building, such as the steel liner and the pre-stressing systems. However, in these cases no exposure classes were applicable according to SS-EN 206. Ringhals states they use SS EN ISO 12944-2[14] for the steel environment class. Forsmark declares that, in addition, experiences from the generic ageing lessons learned (GALL) are incorporated in the ageing analysis.

Oskarshamn
Oskarshamn states that the environment in which the containment and its parts are located affect the ageing impact. The concrete surfaces are coated in accordance with a standardised surface protection system. The coating is not included in Oskarshamn's AMP because the coating is not covered by safety classes 2-3. Since adequate coating is an important prerequisite in order to prevent ageing effects, the coating has its own ageing programme including governed inspections and acceptance criteria, and requirements on measures.

[14] SIS, "Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 2: Classification of enviroments", SIS/TK 146/AG 62, SS-EN ISO 12944-2. (1998)

Research and development in the area of civil engineering is mainly conducted within the Swedish Energy Research Center (Energiforsk) in cooperation with the Swedish licensees, the SSM and the Finnish licensees. For example research has been conducted within degradation and ageing mechanisms in concrete structures, non-destructive testing of concrete structures, post-tensioning systems and climatic conditions.

Forsmark

Forsmark declares that results from research and development are, when applicable, incorporated in the maintenance programme. For example, Forsmark has implemented the following research results in their maintenance programme for the pre-stressing systems:

- Statistical information regarding measured tendon forces in all Swedish containments were compiled in two research reports. The information has been developed further and the statistical data has been incorporated in the development of Forsmark's inspection programme.
- Research results about where actual moisture conditions inside both the containments and the concrete were investigated have been used to estimate the pre-stress losses. The method has been applied for all tendons in Forsmark's containments.
- A PhD thesis on methods for measuring the remaining tendon forces in tendons influenced by friction using hydraulic jacks.
- A project about long term stability of tendons where warnings have been raised regarding the re-tensioning of tendons. These results have been implemented in the guidelines for re-tensioning of tendons.

In a research project, a number of tendons in one of Forsmark's containments have been instrumented with load cells which have provided valuable results regarding short-term losses in the pre-stressing system. In addition, the load cells are now part of the surveillance system for the tendons.

Forsmark and Ringhals

Vattenfall, the owner of Forsmark and Ringhals, also conducts research in civil engineering. Forsmark and Ringhals also declare that reactor safety issues are identified continuously and forwarded, after processing by NRC, IAEA, WANO, ERFATOM/NOG, WOG, FROG and Westinghouse, to the nuclear power companies. Representatives from the Swedish licensees take part in some of these networks/organisations. At Forsmark and Ringhals, a common advisory function, SÄK, addresses the dissemination of these external experiences, but also internal experience that should be considered. Instructions for Forsmark's and Ringhals' maintenance and ageing management for concrete structures are based on new experiences disseminated within the organisation and continuously updated when needed.

Oskarshamn

Oskarshamn has analysed concrete cores from two of their nuclear power plants and concluded that the concrete has not been effected by radiation. The tests were conducted on concrete cores from 1990 and 2015 respectively and from units that have been in operation since 1972 and 1974 respectively.

Ringhals

Ringhals states that acceptance criteria governing the reactor containment and the reactor building are described in the SAR and considers structure, fire, operation condition, accidental conditions, leak tightness etc. Furthermore, Ringhals states that there is an acceptance criteria for the un-grouted pre-stressing systems defined as a minimum allowable tendon force due to loss of prestress. The acceptance criteria for the pre-stressing system is defined through the Regulatory guide 1.35. The reactor containment leak tightness is based on 10CFR50 App.J[15] and GDC 52, 53 and 54[16].

Ringhals states that a series of general acceptance criteria to consider during inspection for reinforced concrete are based on ACI 349.3R[17] and SS137010[18] and defined in their reinforced concrete guide for AMP's. The acceptance criteria are not considered to be definite but the Ringhals maintenance engineers are using them as guidance when making the condition assessment for the concrete structures. Furthermore, Ringhals reports that the condition and status of the concrete structures should be evaluated according to requirements and intended functions. The evaluations are based on the expertise of the appointed maintenance engineer and the general acceptance criteria. Ringhals claims that this approach enables qualitative acceptance criteria, in accordance to IAEA, through qualitative assessment of responsible engineer when performing an ISI.

Oskarshamn
Regarding acceptance criteria Oskarshamn reports that they have no defined acceptance criteria related to ageing mechanism.

7.1.3. Monitoring, testing, sampling and inspection activities for concrete structures

In Sweden there are no third party certification organisations used for monitoring, testing, sampling and inspection activities for concrete structures.

NAR-example	Description of activities	Frequencies	Acceptance criteria
The Concrete	In the preventive maintenance programme, Oskarshamn is undertaking visual inspections of the concrete surface to check for discoloration and precipitation. They are also performing crack mapping. Ringhals conduct in service inspection	Oskarshamn: Minimum of every 3 years. Ringhals: 5 years interval . Forsmark: Annually	When the extent of an ageing effect is considered to be significant, Oskarshamn decide on further analysis, examination or repairs. Ringhals: Absence of leaching, drummy areas, scaling and spalling, any signs of corrosion in steel reinforcement or

[15] NRC, "Primary Reactor Containment Leakage Testing for Water-Cooled Power Reactors", Code of federal regulation Series 10 Part 50 Appendix J
[16] NRC, "General Design Criteria for Nuclear Power Plants", Criteria number 52, 53, 54. Code of federal regulation Series 10 Part 50 Appendix ARinghals:
[17] ACI, "Evaluation of Existing Nuclear Safety Related Concrete Structures", ACI 349.3R (2002)
[18] SIS, "Concrete structures - Concrete cover", SIS/TK 190, SS 137010. (2002)

	usually of visual inspection and NDT and if needed DT. Forsmark: Condition assessment of the concrete structures in the reactor containment are performed by visual inspection and, if deemed necessary, complemented with DT and/or NDT.		anchorage details, deleterious crack-patterns and visual cracks>0,2 mm Forsmark: Limits on the concretes crack width is the only acceptance criteria.
The steel reinforcement	Oskarshamn: Occurrence of corrosion of reinforcement by mechanical impedance (Z(f) = F(f) / v(f)). Forsmark: Visual inspection and, if deemed necessary, complemented with DT and/or NDT.	Oskarshamn: Minimum of every 3 years Forsmark: Annually	When the extent of an ageing effect is considered to be significant, Oskarshamn decide on further analysis, examination or repairs.
Pre-stressed tendons	Oskarshamn is doing visual inspection to look for cracks in the concrete surrounding the anchor plates. Ringhals: Inspections for Ringhals 1-Ringhals 4 and also material and lift off tests for Ringhals 2-Ringhals 4. Forsmark: Inspections and also material and lift off tests.	Oskarshamn: Minimum of every 3 years Ringhals: 5 years for inspections and 10 years for tests. Forsmark: 10 years for Forsmark 12 and 5 years for Forsmark 3.	When the extent of an ageing effect is considered to be significant, Oskarshamn decide on further analysis, examination or repairs. Ringhals, Forsmark: The criteria states the lowest acceptable tendon forces needed for securing the leak tightness during the design pressure. Ringhals: There are acceptance criteria on the grease and on the steel properties defined in RG 1.35.

Liner	CAT[19] are conducted to validate the leak tightness. In the bottom of the containment where the liner is visible at Oskarshamn 3, Oskarshamn performs inspections to look for occurrence of corrosion, indentations and cracks. Ringhals: Inspection of the bottom visible liner at Ringhals 1. Dome line inspection for Ringhals 2-Ringhals 4. Forsmark: Visual inspection were the liner is accessible and, if deemed necessary, complemented with DT and/or NDT.	CAT 3 times every 10 years. Oskarshamn: Inspections minimum every 10 years. Forsmark: Annually for the inspections.	When the extent of an ageing effect is considered to be significant, Oskarshamn decide on further analysis, examination or repairs. Ringhals, Forsmark: The acceptance criteria for leak tightness is based on 10CFR50 App.J[20] and GDC 52, 53 and 54[21] and is a maximum allowed leakage, 1 vol-% of the containments total volume during 24 h period.
Service openings	Oskarshamn performs visual inspections to look for occurrence of corrosion, indentations and cracks.	Oskarshamn: During every outage.	When the extent of an ageing effect is considered to be significant, Oskarshamn decide on further analysis, examination or repairs.
Fastening system	Oskarshamn performs visual inspections to look for occurrence of corrosion, indentations and cracks.	Oskarshamn: Minimum of every 3 years	When the extent of an ageing effect is considered to be significant, Oskarshamn decide on further analysis, examination or repairs.

[19] Containment Air Test
[20] NRC, "Primary Reactor Containment Leakage Testing for Water-Cooled Power Reactors", Code of federal regulation Series 10 Part 50 Appendix J
[21] NRC, "General Design Criteria for Nuclear Power Plants", Criteria number 52, 53, 54. Code of federal regulation Series 10 Part 50 Appendix A

Seals, gaskets, waterstops	Oskarshamn and Ringhals conduct visual inspections and leakage tests. Forsmark are testing samples of seals from the intermediate flooring in Forsmark 12. For Forsmark 3 the assessment is based on visual inspections of the sealing.	Oskarshamn: During every outage. Ringhals: Joints and sealants are inspected, tested and exchanged with specific intervals depending on the exposure environment. The intermediate floor sealant is exchanged every 15 years. Seals for containment hatches are exchanged in most cases every year.	When the extent of an ageing effect is considered to be significant, Oskarshamn decide on further analysis, examination or repairs. Ringhals: Maximum stiffness at 100 % elongation of the floor sealing. Minimum tightening force for the bolts used for fastening the intermediate floor sealing. No visual corrosion of steel components for the intermediate floor. For Forsmark 3 the acceptance criterion is an ultimate strain corresponding to 85 % of the ultimate strain according to SS-ISO 37[22].
Protective coating	Ringhals and Forsmark: Visual inspection, that focuses on discoloration, cracking or other visible defects , as well as bound strength tests.	Forsmark: Every 3 years.	Ringhals: Minimum adhesion between coating and concrete.

Table 23 Activities for concrete structures

Oskarshamn

Oskarshamn has implemented IAEA Safety Guide NS-G 2.12 in their existing AMPs. They do not perform any trending on a regular basis. Oskarshamn also states that CAT has not yet been credited in the maintenance programme. Oskarshamn has no provisions for identifying any unexpected degradation.

[22] SIS, Rubber, vulcanized or thermoplastic – Determination of tensile stress-strain properties, SS-ISO 37, 2010.

Ringhals
Ringhals describes a general inspection of concrete structures consisting of: a status evaluation of the structure, an analysis of future functionality, identification of degrading mechanisms, quantification of damages, quantification of degrading propagation, assessments of health and safety risks with regards to, degradation, structural stability, potential worksite safety issues.

Ringhals consider that their way of evaluate or assesses the concrete containment can be defined as a qualitative acceptance criteria in accordance with IAEA. Ringhals is continuously inspecting all the civil SSCs with different intervals depending on the type and location of SCC. The inspection intervals are described in their maintenance plan for reactor containments. According to Ringhals there are no specific qualitative acceptance criteria for the concrete or the concrete structures. The evaluation or assessment is performed by specialists through the primary ISI[23] method for concrete containments and evaluated based on current knowledge, requirements and safety assessments.

The Acceptance criteria in Table 23 for the concrete are general acceptance criteria. The most common NDT[24] methods used by Ringhals are:

- optical tools such as camera and binoculars to detect signs of ageing effects;
- electromagnetic measurements for reinforcement detection and concrete cover;
- hammer (acoustic) to detect delamination or defects in concrete, it is normally used to detect corrosion of reinforcement.

The most common DT[25] methods used by Ringhals are:

- concrete core samples for compressive strength, chloride content and carbonisation;
- concrete cores for microscopic analyses e.g. air content, composition, cracks and water-cement ratio;
- moisture content in concrete in drilled holes.

Forsmark
Forsmark describes that the main objective of the condition assessments is to identify and register all degradation and damages which compromises the integrity and function of the reactor containment. This includes, e.g., measurements and follow-ups of observed crack widths in the concrete, and measurements of carbonation depths. Focus is also on the structural bearing capacity, durability and fire safety of the SSC as well as health, safety and environmental aspects. The most common NDT used in by Forsmark are:

- measurement of the climatic condition inside the reactor containment;
- (acoustic) hammer to detect delamination or defects in concrete.

The most common DT -methods used by Forsmark are:

- concrete core samples for assessment on the impact of identified degradation mechanisms.

[23] In-service inspection
[24] Non-destructive testing
[25] Destructive testing

7.1.4. Preventive and remedial actions for concrete structures

Oskarshamn
For Oskarshamn the preventive and remedial actions for concrete structures are the same as the one described in chapter 7.1.3 monitoring, testing and inspection activities for concrete structures.

Forsmark
According to Forsmark, the preventive and remedial actions for concrete structures are controlled through their maintenance programme, FENIX and performed in accordance with the asset optimisation strategy. Their maintenance philosophy for the asset optimisation strategy is to maintain the original function of each SSC.

Ringhals
Ringhals describes that the process for reparation is based on the process presented in SS-EN 1504-9[26] with the following main activities:

- Structural assessment
- Identification of active degrading mechanisms
- Selection of protection and repair alternatives
- Selection of suitable principles for repair and protection
- Selection of method
- Define the function of the products and the systems
- Specify the maintenance strategy for the repaired and protected SSC

Ringhals uses the following different preventive and remedial repair methods for reinforced concrete:

- Removal and recasting of concrete
- Increased concrete cover
- Surface coating, mitigate liquid and gas transport
- Crack sealing, mitigated liquid transport
- Substitute pre-stressing system
- Complementary carbon fibre reinforcement
- Complementary steel plate reinforcement
- Cathodic protection
- Cast in or surface corrosion inhibitor
- Electric current corrosion protection
- Re-alkalisation
- SSC replacement

[26] SIS, "Products and systems for the protection and repair of concrete structures - Definitions, requirements, quality control and evaluation of conformity", SIS/TK 192 SS 1504

7.2. Licensee's experience of the application of AMPs for concrete structures

NAR-example	Experience
The Concrete	**Oskarshamn:** • They plan to update and revise the maintenance instructions to be more plant specific. • They conclude that material analyses should be conducted and continuously trended in order to anticipate, monitor and trend the occurrence of ageing mechanisms. **Ringhals:** • They are experience that the degradation mechanisms for the reactor containment concrete structures are slow processes. As an example they mention that they experience the carbonization of the concrete to be slow. **Forsmark:** • Results from their condition assessments of the concrete structures in both the reactor containment and reactor building show no unexpected signs of deterioration of the concrete affecting the safety of the structures.
The steel	**Oskarshamn:** • Through continuous trending that Oskarshamn described for the concrete above, the carbonation front can be anticipated when it enters the steel reinforcement, carbonation combined with moisture in the concrete gives rise to steel reinforcement corrosion. • Oskarshamn believes that an inspection method must be developed which clarifies the actions required at deterioration and damages.
Pre-stressed tendons	**Oskarshamn:** • They plan to update and revise the maintenance instructions to be more plant specific. • As a way to monitoring the pre-stressed containment structures they plan during 2017 to evaluate if the measure of the containment deformation during a pressure test is to be permanently implemented. All in accordance with regulatory guide 1.90.

	Ringhals: • They experience that the post-tensioning systems in the reactor containment has a good to acceptable status. **Forsmark:** • Forsmark's experiences from the monitoring programme for the pre-stressing system show that the loss of tendon forces are significantly slower than what was predicted during the design phase. In addition, the monitoring programme was updated based on R&D performed within the Energiforsk concrete research programme.
Liner	**Oskarshamn:** • They plan to update and revise the maintenance instructions to be more plant specific. • As a method of inspecting the global status of embedded liner they conducts integral leakage testing in accordance with 10CFR50 Appendix A GDC 16 and 50, and trends the results. **Ringhals:** • During 2014 Ringhals discovered corrosion on the bottom slab which led to extensive repair work. **Forsmark:** • Results from their testing of the leak tightness of the reactor containment show that the leak tightness has been maintained and no sign of any deterioration has been observed.
Service openings	**Oskarshamn:** They consider that visual inspections are sufficient. The tightness is verified through leakage testing.
Fastening system	**Oskarshamn:** They consider that visual inspections are sufficient. They have initiated a clarification regarding system boundaries.
Seals, gaskets, water stops	**Oskarshamn:** These are replaced in the event of cracks and defects, and the tightness is verified through leakage testing. Standards applied must be stated in the instructions.
Protective coating	**Forsmark:** They have observed some age related deterioration of the surface coatings on the concrete in the reactor containment. However, no need for corrective actions have been deemed to be necessary by Forsmark.

Table 24 Licensees' experience

Oskarshamn
Oskarshamn also states that, for the concrete, steel, pre-stressed tendons and liner, an inspection method must be developed which clarifies the actions required when there is deterioration and damage. Relevant and non-relevant experiences should be evaluated and valued, and clear standpoints should be taken in a coordinating manner from the R&D programmes. Standards applied must be stated in the instructions.

Ringhals
Ringhals states that the strategic maintenance plans are continuously updated and based on internal and external new knowledge from e.g. IAEA AMPs, EPRI[27], NRC[28] and GALL[29]. The updates are done every fifth year or more frequently if needed.

Forsmark
Forsmark states that their AMPs are currently under development as part of the work securing the LTO of the reactors:

- The licensee need to implement their programme for ageing management and develop and revise their AMPs.

The licensees need to perform more trending analyses on a regularly basis in order to prevent the structure from degradation related to ageing.

7.3. Regulator's assessment and conclusions on ageing management of concrete structures

7.3.1. SSM´s assessment of the ageing management processes of concrete structures described in this chapter

According to the licensees have all systems belonging to safety class 1-3 been included in the Ageing Management Programme. Systems not belonging to safety class 1-3 but may, if those systems malfunctioning, affect the function of a safety classed system have also been included in the Ageing Management Programme.

SSM find this to be an reliable method and criteria for selecting components from the containment and reactor building within the scope of the ageing management. SSM would like to point out the importance of a plant walk-down as a way to help identify those systems which might, if they malfunctioning, affect the function of a safety classified system.

SSM agrees with the licensees approach to identify the environment conditions for the SSC in order to be able to identify the relevant degradation mechanism for each SCC. SSM's assessment, of the ageing mechanisms requiring management and identification of their significance for the PWRs, BWRs and the reactor buildings, is that the licensees presents degradation mechanisms that differs partially from each other, see Table 25 and Table 26. Two of the licensees report they are using the conclusion from a project conducted by NOG but SSM notice that the degradation mechanisms still differs when they are compared with each other. For e.g. electric cables all three licensees have a cooperation within the framework of a FORS-AMPs forum, which has resulted in the establishment of a common gross

[27] Electric Power Research Institute
[28] Nuclear Regulatory Commission
[29] NRC, "Generic Ageing Lessons Learned (GALL)", NUREG-1801, Revision 2, (2010)

list of degradation mechanisms for all types of components. SSM finds this to be a good example and our opinion is that the cooperation between the Swedish utilities is very important in order to understand and learn more about degradation mechanisms. Therefore, we propose the licensees to cooperate more within the area of concrete structures degradation mechanisms.

NAR example	Degradation mechanism	Ringhals	Forsmark	Oskarshamn
Concrete	Chloride initiated reinforcement corrosion	X	X	
	Carbonation initiated reinforcement corrosion	X	X	X
	Leaching		X	X
	Temperature, shrinkage,		X	X
	Degradation due to oil leakage.		X	
	Structural loading. Shrinkage of concrete.		X	X
	Settlements		X	
	Erosion due to particles flowing in water			X
	Attrition due to mechanical impact from traffic and objects.			X
	Fatigue due to vibrations.			X
	Dehydration when T>100-200 degrees			X
	ASR, alkali-silica reaction			X
Steel reinforcement	Chloride initiated reinforcement corrosion	X	X	X
	Carbonation initiated reinforcement corrosion	X	X	X
Prestressing systems	Relaxation, shrinkage, creep, corrosion	X	X	
	Corrosion	X	X	X

Liner, toroid steel, Steel liner in pools	Water line corrosion	X		
	Corrosion	X	X	X
	Mechanical abrasion from water jetting		X	
Water stops, seals and gaskets and protective coating	Polymer degradation	X		
	Natural embrittlement,		X	
	High temperature,		X	
	Radiation.		X	
	Oxidation		X	X
	Chain breakage, Chain bond/cross linking			X
Anchor plates	Atmospheric corrosion, Galvanic corrosion		X	X
	Fatigue due to structural loading		X	
Service openings,	Corrosion			X

Table 25 Degradation mechanisms BWR

NAR example	Degradation mechanism	Ringhals	Forsmark	Oskarshamn
Concrete	Chloride initiated reinforcement corrosion	X	X	
	Carbonation initiated reinforcement corrosion	X	X	
	Thermal exposure	X	X	
	Frost attack	X		
	Saline freeze/thaw attack	X		
	Leaching		X	
	Shrinkage, Temperature		X	

	Degradation due to oil leakage.		X	
	Structural loading. Shrinkage of concrete.		X	
Steel reinforcement	Chloride initiated reinforcement corrosion	X	X	
	Carbonation initiated reinforcement corrosion	X	X	
Prestressing systems	Relaxation, shrinkage, creep, corrosion	X		
Liner, toroid steel	Water line corrosion	X		
	Corrosion	X	X	
Water stops, seals and gaskets and protective coating	Polymer degradation	X		
	Embrittlement		X	
	Oxidation, Chain breakage, Chain bond/cross linking			X
Anchor plates	Corrosion		X	X
	Fatigue		X	

Table 26 Degradation mechanisms, Reactor building

SSM asses it to be very good that the licensees are part of the group led by Energiforsk where research and development are conducted within the area of civil engineering and that the licensees incorporate results from research and development, when applicable, in the maintenance programme. SSM believes it is good that licensees have carried out attempts at suspected concerns about degradation mechanisms on concrete structures. In SSM's opinion the Swedish licensees would benefit from being part of more international research programmes which enables them to understand and learn more about ageing management of concrete structures.

Acceptance criteria are defined different by all Swedish licensees. One licensee reports that they have no defined acceptance criteria related to ageing mechanism other than when the extent of an ageing effect is considered to be significant. Another licensee reports there are no specific qualitative acceptance criteria for the concrete or the concrete structures but that the structure is evaluated by a specialist.

SSM's opinion is that the acceptance criteria needs to be more developed in order to be able to make an accurate ageing assessment. Even here SSM's opinion is that the cooperation between the Swedish utilities is very important in order to define acceptance criteria related to ageing mechanism. SSM finds that the lack of acceptance criteria can lead to miscalculations of the structures condition assessment.

SSM concludes that the licensees do not preform trending on a regular basis. It is SSM's opinion that trending on a regular basis would help the licensees to make informed decisions on when to take preventive or remedial action in order to prevent the structure from ageing related degradations.

From the licensees' experience of the application of AMPs for concrete structures some improvements have been identified. SSMs expect that the programmes are updated accordingly since they would benefit from these improvements. SSM furthermore believes that it would be beneficial for the programmes if the licensees were to share their experiences identifying these improvements and in implementing their solutions amongst each other.

7.3.2. SSM's experience from regulatory oversight

SSM has performed a number of inspections and reviews at the Swedish power plants. It has been done with various results.

SSMs assessment from an inspection is that one licensee has not until today been able to implement their Ageing Management Programme in their operation. That lead to a SSM decision (by injunction) that the licensee need to complete their programme for ageing management and to implement changes into their organisation before the end of January 2019, see chapter 2.7.2 The licensee itself had identified that a new AMP for concrete containment needs to be developed and that existing AMP:s for concrete structures needs to be revised with respect to e.g. acceptance criteria and degradation mechanisms.

Another inspection showed that a licensee used walk-downs when doing inspections on civil structure in the maintenance programme. When degradations are discovered action is taken and an investigation is made to see if it is age-related. The inspection also showed that the licensee performs trend analysis on pre-stressed tendons. The licensee reported during the inspection that they use grease as a preventive way to protect the ungrouted tendons from corrosion. Strategic maintenance plans which are part of the Ageing Management Programme where, when the inspection took place, not produced for every civil structure.

One inspection showed that a licensee had systematically gone through all the civil structure parts belonging to the reactor containment in order to identify the parts that effects safety. The same inspection noticed that the list of degradation mechanisms where not complete in all ageing management document regarding concrete. Employees whished for a system to make it easier to preform trending analysis in a better and more accurate way. The licensee reported during the inspection that they ventilate with dry air as a preventive way to protect the ungrouted tendons from corrosion.

7.3.3. Conclusion

SSM concludes that

- the licensees each have compiled an Ageing Management Programme that includes concrete containment structures and reactor buildings. The programmes are quite similar in scope and the licensees' methods and criteria for selecting components from the containment and reactor building within the scope of the ageing management are reliable. SSM would like to point out the importance of a plant walk-down as a way to help identify those systems which might, if they malfunctioning, affect the function of a safety classified system.
- the licensees presents degradation mechanisms that differs partially from each other and that acceptance criteria needs to be more developed in order to be able to make an accurate ageing assessment. SSM's opinion is that a cooperation between the Swedish utilities is very important in order to understand and learn more about degradation mechanisms and acceptance criteria. Therefore, we propose the licensees to cooperate more within the area of concrete structures degradation mechanisms and acceptance criteria
- the licensees incorporate results from research and development, when it is applicable, in the maintenance programme and asses it to be in accordance with SSM's regulations
- the licensees should handle issues they conclude are missing or should be improved in order to develop and improve their aging management programme for concrete structures. SSM further-more believes that it would be beneficial for the programmes if the licensees were to share their experiences identifying these improvements and in implementing their solutions amongst each other.
- that one licensee need to implement their programme for ageing management and develop and revise their AMPs
- the licensees need to perform more trending analysis on a regular basis in order to prevent the structure from degradation related to aging.

8. Pre-stressed concrete pressure vessels (AGR)

This chapter in not applicable to the Swedish NAR, with reference to Table 1.

9. Overall assessments and general conclusions

Kap 2
Generic info:
Based on SSMs performance based requirement philosophy Swedish licensees have pursued slightly different paths to develop their respective overall Ageing Management Programme, all with the goal to ensure the availability of required safety functions throughout the service life of the plant. Since SSM introduced a requirement of overall programme for ageing management in late 2004, all licenses had before that introduced “ageing management” within other programmes like maintenance, chemistry and in service inspection, even if it was not explicitly described as, or as comprehensive as the overall Ageing Management Programme described in NS-G-2.12. SSM now considers that Forsmark and Ringhals have overall Ageing Management Programmes that fulfil SSM requirements and international expectations. The third licensee Oskarshamn has developed an overall Ageing Management Programme that still needs to be implemented in the organisation. SSM has by a decision (by injunction) issued as a condition for operation, that Oskarshamn for reactor Oskarshamn 3 shall have an implemented overall programme for ageing management before the end of January 2018 (SSM2017-384-16).

During development of the overall Ageing Management Programmes Swedish licensees have largely compiled information from already existing programmes like maintenance, component qualification, in service inspection and chemistry programme. Using these programmes a lot of experience gained from operation from the licensee’s reactors as well as external ageing related experience has been used. The overall Ageing Management Programme therefore naturally becomes an interdisciplinary programme linking ageing perspective in other programmes together. The key elements used by the Swedish licensees to assess ageing are based on the nine attributes in NS-G-2.12, which are similar to the ten elements described in NUREG-1801. It is SSMs opinion that since Swedish licensees started to develop their overall Ageing Management Programme after approximately 20 to 30 years of operation (due to a new regulation issued 2004), it is natural that ageing assessment has been based on these programmes more than for instance on manufacturing documents. Additionally, Swedish licensee´s have used IAEA SRS 82 and NUREG-1801 in order to check consistency in the ageing assessment. To have an international assessment of the overall Ageing Management Programme, all three licensees have also conducted IAEA SALTO or pre-SALTO reviews. Experience gained from these reviews have subsequently been incorporated into their respective programmes.

Findings:
SSM finds that none of the Swedish licensees have been working with quality management of the overall Ageing Management Programme in a systematic manner. Only Oskarshamn has started to measure the efficiency of the Ageing Management Programme by defining a key performance indicator. SSM concludes that quality assurance/management of the overall Ageing Management Programme can be improved considerably amongst Swedish licensees.

An important attribute in ageing management is the establishment of acceptance criteria against which the need of corrective actions are evaluated. Swedish licensees use the high-level criterion that the SSCs shall maintain their intended function at the design basis events and during operating life. SSM considers that this high-level criterion should be more specified, to explain for example a methodology for calculating specific numerical values to define conditional acceptance criteria to assure the SSCs intended function taking into account sufficient margins. According to SSM the purpose with acceptance criteria is to allow corrective action for SSCs to be implemented before loss of the intended function(s) for the SSC in question.

Programmes for monitoring, testing and inspection are described in SUP, systematic ageing analysis or in component specific AMP and are mainly performed within the maintenance, inspection or surveillance programmes. For mechanical devices (i.e. SSCs made of metal subjected to pressure, mechanical load or SSCs that hold or guide other components) inspections are conducted in accordance to chapter 3 in Swedish regulations SSMFS 2008:13. In this respect identification of possible ageing mechanisms are performed for each inspection area and suitable inspection methods are chosen. Identification of possible ageing mechanism are consequently conducted within the overall Ageing Management Programme as well as the inspection programme. SSM considers that there is an obvious risk of confusion between these two ways of identifying degradation mechanisms, which must be dealt with. To some extent the double identification of ageing mechanisms is based on SSMs regulations and a consequence of SSMs late introduction (2004) of a requirement for an overall ageing management. In order to identifying unexpected degradation Swedish licensees have introduced broad-based training programmes for operations and maintenance staff members in detecting and reporting signs of ageing effects.

Good Practice:
Preventive and remedial actions are documented for SSCs involved in systematic ageing analysis and SUP (Forsmark and Ringhals respectively). These reports also contain information of parameters which must be upheld in order to uphold the preventive and remedial effect. SSM considers that systematic assessment of preventive and remedial actions is a very important feature in ageing management that needs to be documented and continuously evaluated. Forsmark also requires that for all systems a periodic system health reports shall be compiled. This report is formed by interdisciplinary team members and identifies any need to improve preventive actions and needs for system or component upgrades. The periods for the system health reports varies from short (0-3 years) to intermediate (upcoming 3-10 years) and finally plant end of life (60 years). SSM find that systematic work with three different periods demonstrates a mature organisation with regard to ageing management and is an example of a good practice.

Kap 3 Electrical cables
Findings:
All three licensees in Sweden have develop their overall Ageing Management Programme based on international guides like IAEA NS-G-2.12. In detail the licensees have chosen slightly different ways to derive the overall Ageing Management Programme, but with the final goal to ensure the availability of required safety functions throughout the service life of the plant.
Ageing assessment of cables at Forsmark and Ringhals is mainly focusing on detection of ageing effects and stressor to handle different ageing mechanisms. At Oskarshamn the Ageing Management Programme of cables is currently under production and in some cases when cables are qualified for a certain environment and time Oskarshamn uses qualified lifetime to analyze if preventive maintenance is needed or not. All three licensees apply qualified lifetime as a basis of maintenance for neutron flux instrumentation cables.
SSMs opinion is that the use of qualified lifetime as a basis of maintenance might be an applicable method but the utilities have to consider if there are any hot spots and ensure that these will not impact the basis of the components qualification.

Regarding preventive and remedial actions for electrical cables there are different methods and activities. One example is the measurement of insulations resistance. Another example is continuous monitoring when cables are routed in closed cable trays and plastic pipes, embedded in concrete that prevents visual inspection.
SSM assesses that the monitoring, testing, sampling and inspection of the electrical cables are fundamental and very important to give signs and indicate when cables starts degrading. This also gives information that can be used to assess the interval and the applicability of preventive actions. SSM assesses that the aim of the Ageing Management Programme is to deal with ageing's issues and not to wait until the cables are degraded and must be replaced through remedial actions.

Good Practice:
Regarding identification of ageing mechanisms related to cables all three licensees have a cooperation within the framework of a FORS-AMPs forum, which has resulted in the establishment of a common gross list of degradation mechanisms for all types of components. SSMs opinion is that the cooperation between the Swedish utilities is very important to understand and learn more about degradations mechanisms. This will as well support utilities to carry out ageing analysis.

Kap 4 Concealed pipeworks
Findings:
SSM concludes that the Swedish licensees Forsmark, Oskarshamn and Ringhals each have compiled an Ageing Management Programme that encompasses concealed pipework. The programmes are quite similar in scope while the results from the ageing assessment and the preventive actions taken differ slightly. SSM also finds that the programmes contains the steps and recommendations given in IGALL AMP 125 Buried and underground piping and tanks. Since no events with impact on nuclear safety have been reported from either licensee, SSM draw the conclusion that the ageing management is both adequate and sufficient for the respective nuclear power plants. On the other hand, SSM believes it to be beneficial if the licensees would cooperate more on the matter, and perhaps discuss such topics as acceptance criteria and the reasons behind the differences in identified ageing mechanisms illustrated in Table 10.

Kap 5 Reactor Pressure Vessels
Findings:
SSM finds that the Swedish licensees Forsmark, Oskarshamn and Ringhals all have a suitable Ageing Management Program for the RPV. The programs are similar in scope as they include four subprograms, in agreement to requirements in applicable Swedish regulations. The sub programs have been in place, with various modifications, since the start of operation of the reactors.
SSM notes that Ringhals have a Technical area that manages the AM for the primary system. This is a consequence of the differences in the design of the primary system between a PWR and a BWR.
SSMs overall conclusion is that the ageing management programs are adequate and effective. However, with respect to the plans for LTO of Forsmark 1-3 and Oskarshamn 3 SSM considers that the surveillance programs for those reactors needs to be further developed. Surveillance programs for Ringhals 3 and 4 that cover LTO until 60 years of operations are already in place.

Kap 7 Concrete Containment Structures
Findings:
SSM concludes that the licensees each have compiled an Ageing Management Programme that includes concrete containment structures and reactor buildings. The programmes are quite similar in scope and the licensees' methods and criteria for selecting components from the containment and reactor building within the scope of the ageing management are reliable. SSM would like to point out the importance of a plant walk-down as a way to help identify those systems which might, if they malfunctioning, affect the function of a safety classified system.
SSM concludes that the licensees presents degradation mechanisms that differs partially from each other and that acceptance criteria needs to be more developed in order to be able to make an accurate ageing assessment. SSM's opinion is that a cooperation between the Swedish utilities is very important in order to understand and learn more about degradation mechanisms and acceptance criteria. Therefore, SSM propose the licensees to cooperate more within the area of concrete structures degradation mechanisms and acceptance criteria.
SSM concludes that the licensees should handle issues they conclude are missing or should be improved in order to develop and improve their aging management programme for concrete structures. SSM further-more believes that it would be beneficial for the programmes if the licensees were to share their experiences identifying these improvements and in implementing their solutions amongst each other.
SSM concludes that the licensees do not preform trending on a regular basis. It is SSM's opinion that trending on a regular basis would help the licensees to make informed decisions on when to take preventive or remedial action in order to prevent the structure from ageing related degradations.

Good Practice:
The licensees incorporate results from research and development, when it is applicable, in the maintenance programme and asses it to be in accordance with SSM's regulations.

10. Annexes

10.1. Principal drawings of RPV's discussed in chapter 5

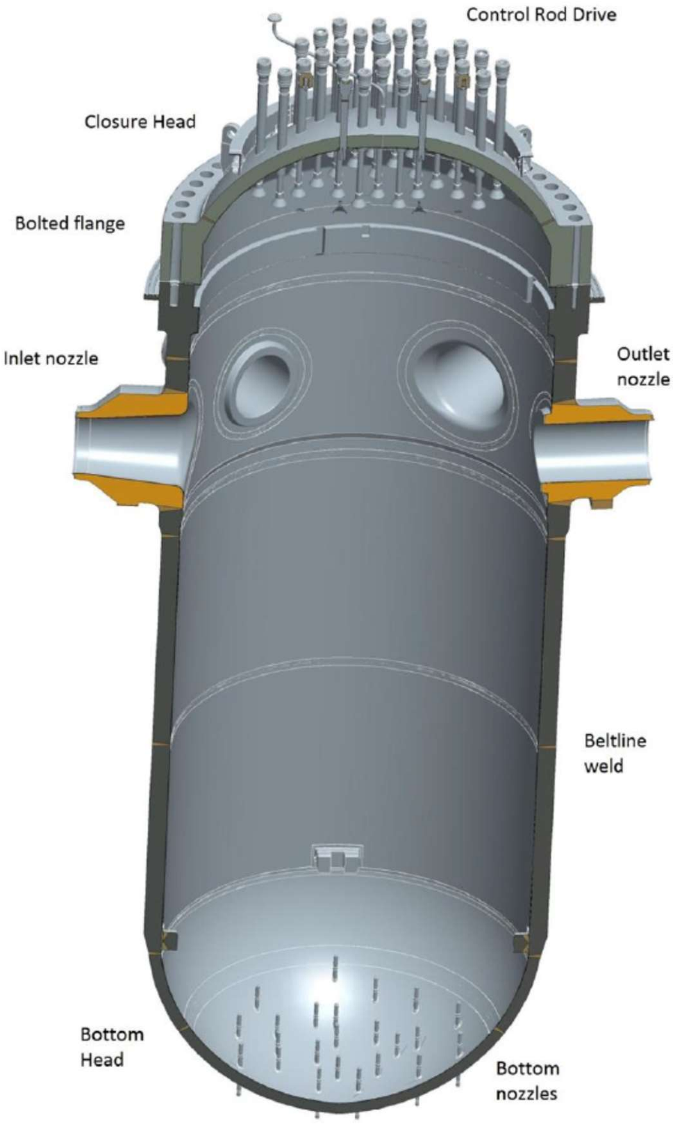

Figure 1 - Reactor pressure vessel PWR (Ringhals 2-4)

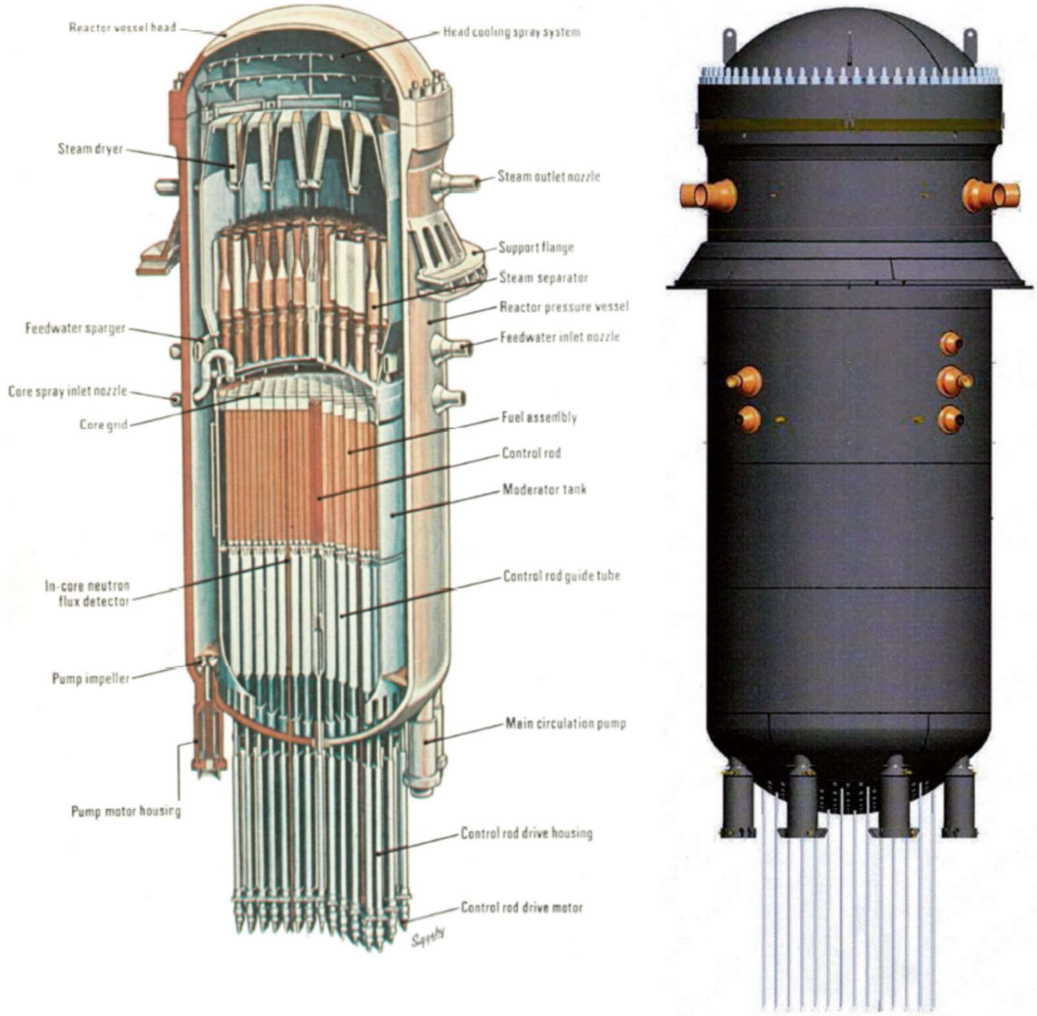

Figure 2 - Reactor pressure vessel BWR with internal pumps (Forsmark 1-3, Oskarshamn 3)

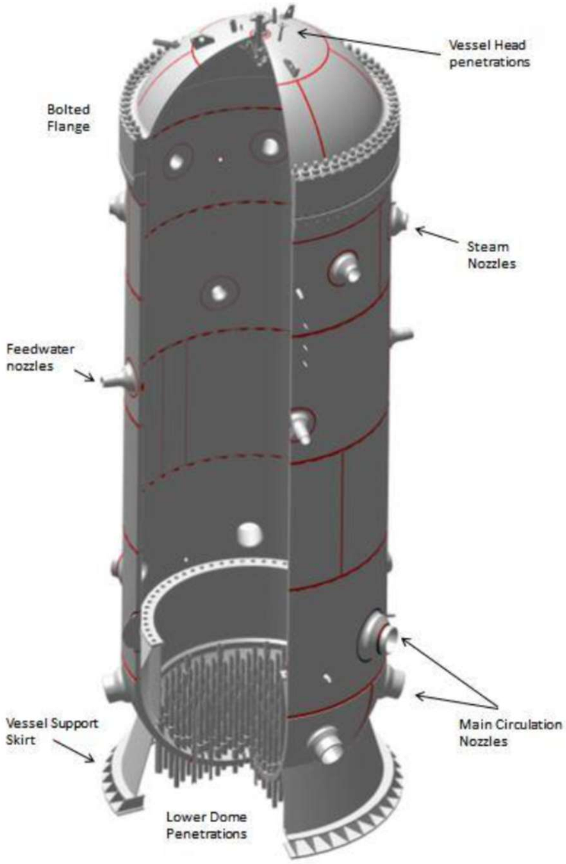

Figure 3 - Reactor pressure vessel BWR with external pumps (Ringhals 1)

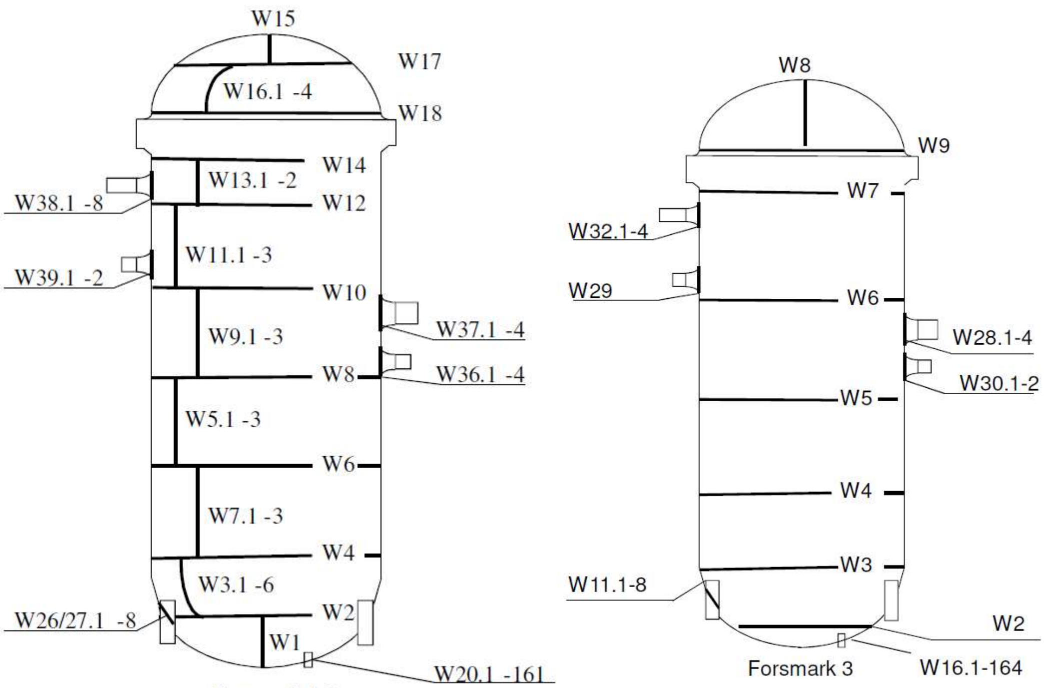

Figure 4 - Weld locations in RPV Forsmark 1 and 2 (left) and Forsmark 3 (right). Forsmark 3 and Oskarshamn 3 are similar. These welds are subjected to prescribed periodic inspections with qualified methods.

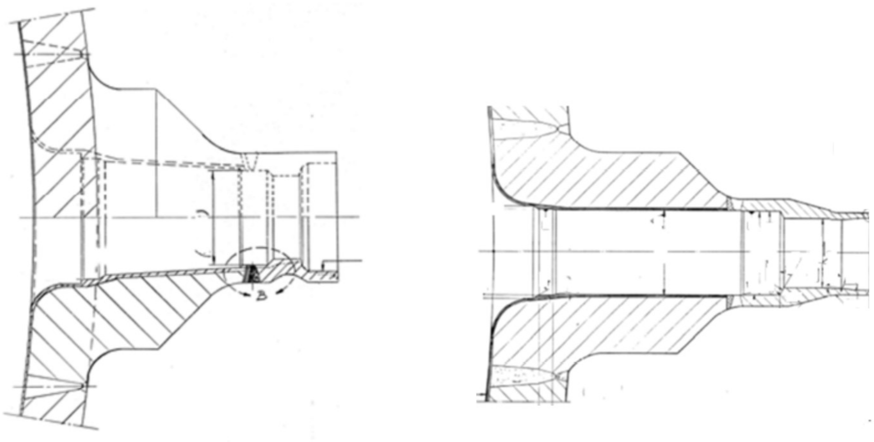

Figure 5 – Illustrations of BWR RPV nozzles with safe end of Alloy 600. Left: Feed Water Nozzle. Right: Emergency Core Cooling Nozzle.

10.2. Concrete containment structures discussed in chapter 7

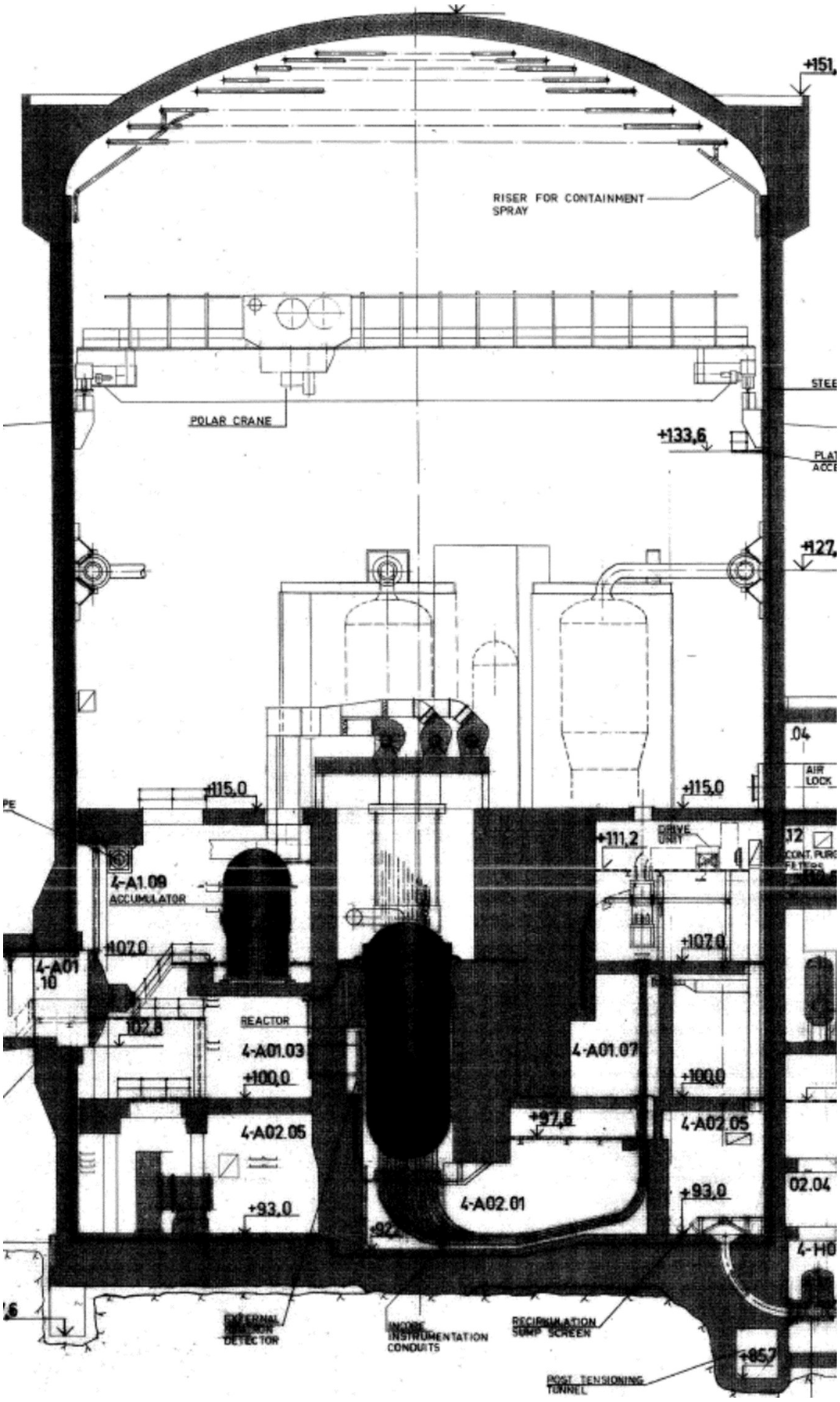

Figure 5 Section drawing of Ringhals 4

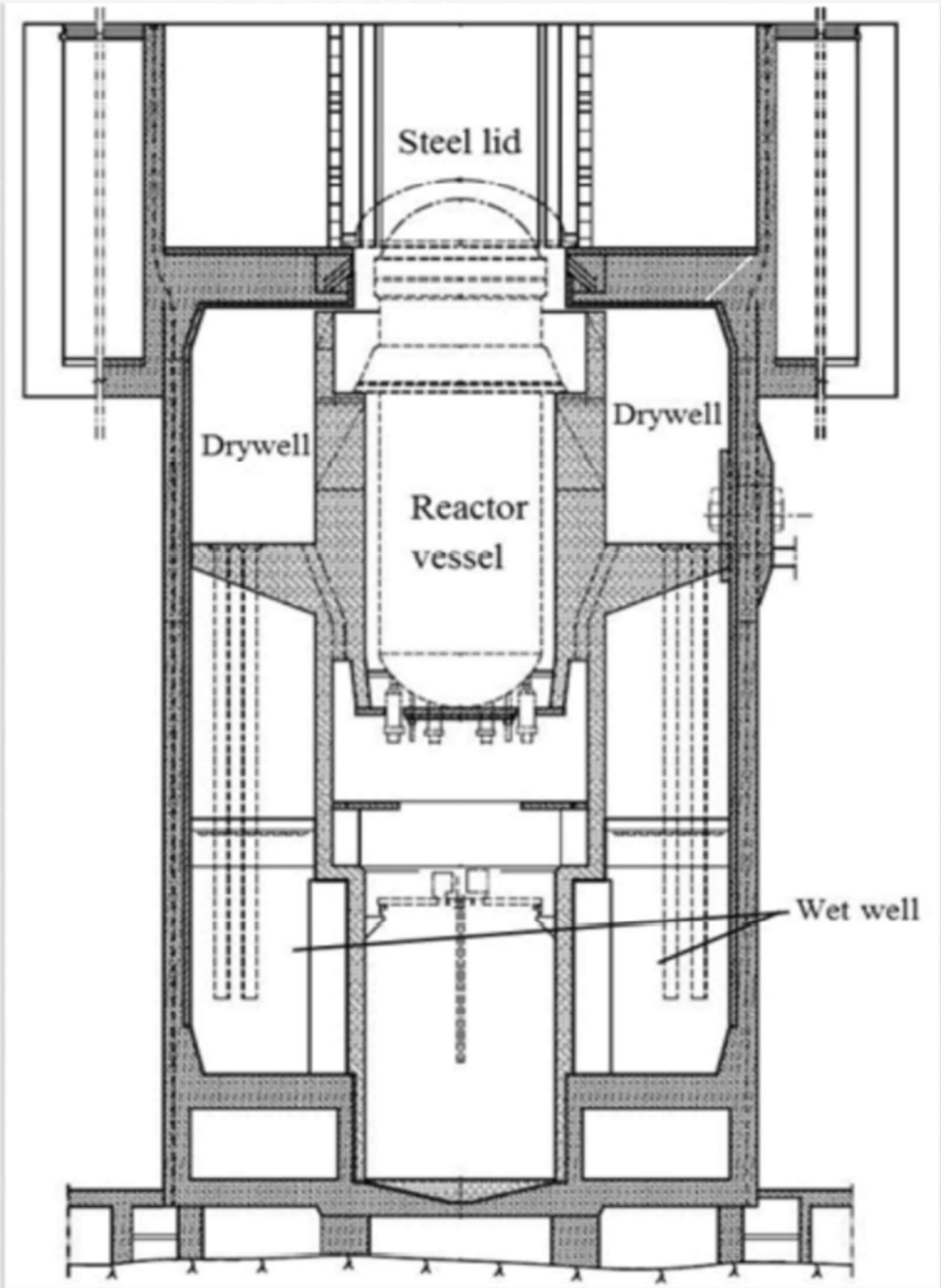

Figure 6 Section drawing of a characteristic BWR in Sweden

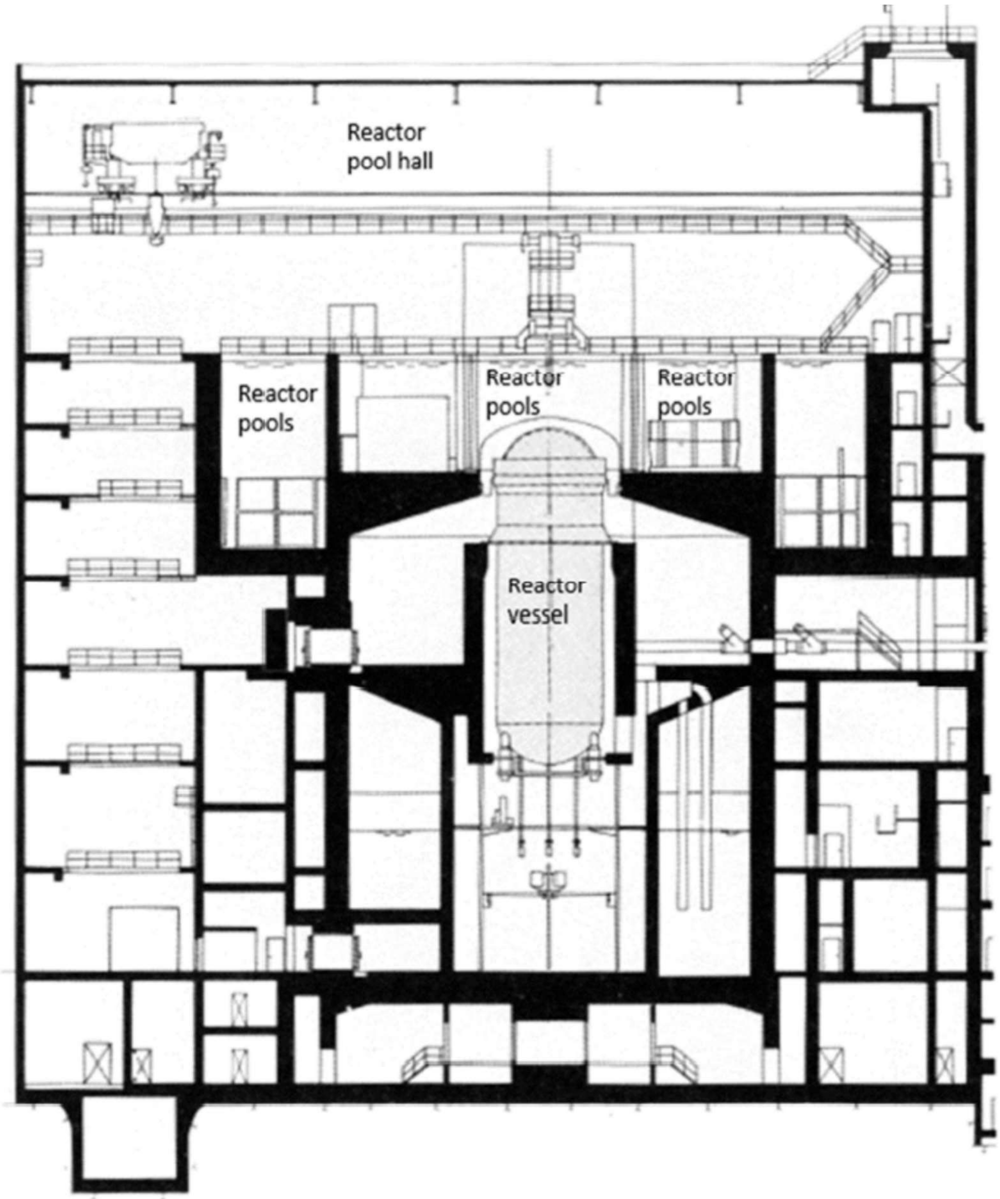

Figure 7 Section drawing of a characteristic reactor building in Sweden

11. Abbreviations used in this report

Abbreviation	Meaning
AMP	Ageing Management Programme
AMR	Ageing Management Review
APS	Working Committee for Production Safety Ringhals
Avärs	Corrective Action Program Ringhals
BG Group	R&D group structural verification
BiCycle	Data trending system
CASS	Cast austenitic stainless steel
CG	Commodity Groups
CSPE	Chlorosulfonated polyethylene
CSS	Core Shroud Support
DAP	Design Assurance Process
DBTT	Ductile to Brittle Transition Temperature
DT	Destructive Testing
DMW	Dissimilar Metal Weld
EAB	Elongation At Break
EKG Kabelgruppen	EKG, Kabelgruppen, forum with participants from Swedish and Finnish utilities
Energiforsk	Swedish Energy Research Center
ENIQ	European Network for Inspection Qualification
ET	Eddy current Testing
FENIX	maintenance system Forsmark
FOCUS	CAP-system at Forsmark
FORSAMP	Joint forum for ageing issues involving Forsmark, Oskarshamn, Ringhals and SKB
Forsmark	Forsmarks Kraftgrupp AB
Forsmark 1	Forsmark unit 1
Forsmark 2	Forsmark unit 2
Forsmark 3	Forsmark unit 3
GALL	Generic Ageing Lessons Learned
HOLMUG	Halden On-Line monitoring User Group
HR	Human Resource
HRP	The Halden Reactor Project
HTG	Pressure-Temperature Limit
HWC	Hydrogen Water Chemistry
IGALL	IAEA Generic Ageing Lessons Learned
IGSCC	Intergranular Stress Corrosion Cracking
IOÖ	Certificate of Compliance
IR	Insulation Resistance
ISI	In-Service-Inspections
KBM	Quality Regulations for Mechanical Equipment
KTH	Royal Institute of Technology
LAS	Low Alloy Steel
LCF	Low Cycle Fatigue
LERs	Licensee Event Report
LIRA	Line Resonance Analysis
LTO	Long Term Operations

MG Group	R&D group material
MIC	Microbiologically Induced Corrosion
MRP	Materials Reliability Programme
NAR	National Assessment Report
NDT	Non Destructive Testing
NIS	Neutron Flux Instrumentation Cables
NMAC	Nuclear Maintenance Application Centre
NOG	Nordic Owners Group
NORDERF	A Nordic organisation for experience feedback
NSAS	Non-Safety Affecting Safety
NWC	Normal Water Chemistry
ODSCC	Outside Diameter Stress Corrosion Cracking??
ODU	Oskarshamn maintenance system
OIT	Oxidation Induction Time
Oskarshamn	OKG AB
Oskarshamn 1	Oskarshamn unit 1
Oskarshamn 2	Oskarshamn unit 2
Oskarshamn 3	Oskarshamn unit 3
PD	Partial Discharge
PEX	Cross-Linked Polyethylene
PMBD	Preventive Maintenance Basis Database
Polymer LE (PEEK)	Polyether ether ketone
PSA	Probabilistic Safety Analyses
PSR	Periodic Safety Review
PTS	Pressurised Thermal Shock
PWSCC	Primary Water Stress Corrosion Cracking
QB	Qualification Body
R&D	Research and Development
Ringhals	Ringhals AB
Ringhals 1	Ringhals unit 1
Ringhals 2	Ringhals unit 2
Ringhals 3	Ringhals unit 3
Ringhals 4	Ringhals unit 4
RPV	Reactor Pressure Vessels
SAFE	CAP-system at Oskarshamn
SAR	Safety Analysis Report
SC	Structures and Components
SCC	Stress Corrosion Cracking
SGMP	Steam Generator Management Programme
SKB	Swedish Nuclear Fuel and Waste Management Co
SKI	Swedish Regulator Swedish Nuclear Power Inspectorate (until 2008)
SKIFS	Swedish Nuclear Power Inspectorate Regulations (until 2008)
SPOC	Single Point of Contact
SQL	Structured Query Language
SRCM	Streamlined Reliability-Centered Maintenance
SSC	Systems, Structures and Components
SSI	Swedish Radiation Protection Authority
SSM	Swedish Radiation Safety Authority
SSMFS	Swedish Radiation Safety Authority Regulations

STF	Technical Specifications
SUP	Strategic Maintenance Plan
TBM	Technical Requirements for Mechanical Equipment
TBY	Technical Requirements Surfaces protection
TDR	Time Domain Reflectometry
TGSCC	Transgranular Stress Corrosion Cracking
TLAA	Time Limited Ageing Analyses
TTR	Time to Repair
TUD	Component Unavailability Data
UCC	Under cladding cracks
UT	Ultrasonic Testing
VLF	Very Low Frequency
XLPE	Cross-Linked Polyethylene

12. References

[1]. Forsmarks Kraftgrupp, F-0055676, WENRA TPR 2017, Chapter 02
[2]. Forsmarks Kraftgrupp, F-0053469, WENRA TPR 2017, Chapter 03
[3]. Forsmarks Kraftgrupp, F-0053791, WENRA TPR 2017, Chapter 04
[4]. Forsmarks Kraftgrupp, F-0051000, WENRA TPR 2017, Chapter 05
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[12]. Ringhals AB, 2390318, WENRA TPR 2017, Chapter 03
[13]. Ringhals AB, 2391524, WENRA TPR 2017, Chapter 04
[14]. Ringhals AB, 2390514, WENRA TPR 2017, Chapter 05
[15]. Ringhals AB, 2392747, WENRA TPR 2017, Chapter 07

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The Swedish Radiation Safety Authority has a comprehensive responsibility to ensure that society is safe from the effects of radiation. The Authority works to achieve radiation safety in a number of areas: nuclear power, medical care as well as commercial products and services. The Authority also works to achieve protection from natural radiation and to increase the level of radiation safety internationally.

The Swedish Radiation Safety Authority works proactively and preventively to protect people and the environment from the harmful effects of radiation, now and in the future. The Authority issues regulations and supervises compliance, while also supporting research, providing training and information, and issuing advice. Often, activities involving radiation require licences issued by the Authority. The Swedish Radiation Safety Authority maintains emergency preparedness around the clock with the aim of limiting the aftermath of radiation accidents and the unintentional spreading of radioactive substances. The Authority participates in international co-operation in order to promote radiation safety and finances projects aiming to raise the level of radiation safety in certain Eastern European countries.

The Authority reports to the Ministry of the Environment and has around 300 employees with competencies in the fields of engineering, natural and behavioural sciences, law, economics and communications. We have received quality, environmental and working environment certification.

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Arkitektkopia AB, Bromma, 2017