Contribution of KKL to the Topical Peer Review on "Ageing Management of Nuclear Power Plants"

Technischer Bericht

BET/17/0117

Verteiler:

[redacted]

Anlage Zuordnung (AK, Klartext)	**Sachzuordnung, Stichworte**
	Alterungsüberwachung, Eidgenössisches Nuklear- und Sicherheitsinspektorat, Verfügung

Grundlagen	**Org. Geltungsbereich**	**Zeitl. Geltungsbereich**

Copyright©Kernkraftwerk Leibstadt AG
Alle Rechte vorbehalten

[redacted]

Revision Summary

Revision 0	Initial Issue in German
Revision 1	Translation of the original version into English
	Editorial changes

DISCLAIMER:
The English version is a translation of the original in German for information purposes only.
In case of a discrepancy, the German original, as provided in revision 0 of this report, will prevail.

Contents

1. General information

Switzerland is taking part in the 'Topical Peer Review on Ageing Management of Nuclear Power Plants' decided upon by the Council of the European Union [1]. With this report, KKL is participating in Phase 1 of the Topical Peer Review as instructed by ENSI [1]. The report created by KKL, is consolidated by ENSI together with the reports of the other Swiss nuclear power plants in a Swiss NAR for the Topical Peer Review [1].

2. Overall ageing management programme requirements and implementation

The following table presents the reference between the WENRA [2] specification and the ENSI directive [1] with the subsections of the section 'Overall ageing management programme requirements and implementation':

Number and title of the section			
WENRA specification		**Report BET/17/0117**	
2	Overall Ageing Management Programme requirements and implementation	2	Requirements on the overall AMP and its implementation
2.3	Description of the overall Ageing Management Programme	2.1	Description of the overall Ageing Management Programme
2.3.1	Scope of the overall AMP	2.1.1	Scope of the overall AMP
2.3.2	Ageing Assessment	2.1.2	Ageing assessment
2.3.3	Monitoring, testing, sampling and inspection activities	2.1.3	Monitoring, testing, sampling and inspection activities
2.3.4	Preventive and remedial actions	2.1.4	Preventive and remedial actions
2.4	Review and update of the overall AMP	2.2	Review and update of the overall AMP
2.5	Licensee's experience of application of the overall AMP	2.3	Licensee's experience of the application of AMPs

2.1 Description of the overall Ageing Management Programme

To understand the overall ageing management programme (AMP) applied in Switzerland, it is necessary to describe the development of the AMP in Switzerland. This will therefore be looked at first. Where it becomes necessary in the subsequent subsections, we will refer back to this content.

At the end of 1991, the Swiss NPPs were requested by the Swiss regulatory authority, ENSI, to introduce an ageing management programme for safety-relevant components and equipment and to maintain it up until the end of the period of power operations. Consequently, it was decided, within the framework of the Group of Swiss NPP Managers (GSKL), to charge a new working group 'Ageing Management in Swiss NPPs (AMP in CH-NPP)' with creating joint fundamental documents for surveying the ageing process. Its purpose is to ensure that the ageing management in all Swiss nuclear power plants is performed according to the same requirements and with the same quality. The procedure for implementing ageing management within the Swiss NPPs was carried out gradually.

- The GSKL programme for verifying the ageing management measures builds on many years of applied maintenance concepts of the Swiss NPPs, references the legal requirements and forms the basis for the ageing management of the Swiss NPPs. The document describes the physical ageing phenomena occurring in the NPPs in general and presents a procedure for the early detection and control of these phenomena.
- The ageing management is implemented in the relevant technical departments of the Swiss NPPs. In addition, an independent GSKL expert team was set up for each department, making it possible to monitor ageing with the necessary technical competence. By dividing the ageing management into three areas, electrical, civil and mechanical engineering, it was necessary to create a GSKL interface document that lists and clearly allocates interface and liaison points of each subject in the treatment of equipment and in doing so clearly assigns technical responsibilities.
- In terms of the ageing management of the civil engineering, the GSKL guide for the creation of fact sheets contains a listing and an assignment of ageing mechanisms relevant for the various construction materials.
- In the ageing management of electrical engineering and I&C, Part 1 of the fact sheets contains a listing of the most important function-impairing and qualification-influencing descriptions for the specified component with a link to the corresponding references. Part 2 of the fact sheets contains possible diagnostics and testing methods, as well as characteristics by which the ageing progress can be identified.
- The GSKL catalogue of ageing mechanisms for mechanical equipment (KATAM) identifies, classifies and describes in detail the ageing mechanisms relevant for light water reactors. After it was revised in 2011, this document was recognised by the regulator as an essential foundation for ageing management in the Swiss NPPs.
- GSKL guides for the creation of fact sheets for civil, electrical and mechanical engineering provide guidance for the practical implementation of ageing management and for documenting the results of the assessment of mechanical and electrical components and the civil engineering structures.
- Departments in each plant implemented the AMP in detail based on the specifications of the GSKL working group. The ageing assessments of civil engineering structures and/or SSCs are summarised in the plant-specific fact sheets.

2.1.1 Scope of the overall AMP

Section 6.3.1 of the ENSI-B10 [3] guideline specifies requirements for technical and scientific staff in the plants who are involved in ageing management. The licensee appoints this staff in accordance with ENSI-B10 [3]. Persons who are responsible for ageing management must be qualified to a higher educational degree in a scientific or technical subject and also have additional knowledge of methods for ageing management and sufficient experience in the relevant subject (electrical, civil or mechanical engineering).

As already mentioned in Section 2.1, the GSKL expert team, whose representatives are responsible for the AMP of their plants or who contribute to the area, not only work to ensure the reliable implementation of the GSKL foundations in their plants, but also ensure that information is fed back from the GSKL Working Group and its expert teams.

The ISO 9001 certified Management System TQM in KKL organised the overall AMP in the process P0514 ‘Ageing Management’, which is subdivided into the areas electrical engineering, mechanical engineering and civil engineering. Amongst other things, the processes define the responsibilities and list the higher level and applicable documents (guidelines, process instructions, work instructions).

In accordance with Article 35 of the Swiss Code of Nuclear Regulation (KEV), the licensee must perform systematic ageing management based on the AMP for all equipment and civil engineering structures whose function and integrity are important for safety and security. Ageing management requirements are specified in the guideline ENSI-B01 [4]. This guideline replaces the previous ageing management guideline HSK-R-51.

The scope of the systems, structures and components (SSCs) to be considered within the AMP primarily depends on the classification of the SSCs in accordance with guideline ENSI-G01, Safety Classification for Existing NPPs [5], and the relevant specifications of guideline ENSI- B01 [4]. Mechanical and electrical equipment, which in accordance with guideline ENSI-A06, Probabilistic Safety Analysis, [7], is relevant for safety based on PSA, must be identified as such and incorporated in the mechanical engineering and electrical engineering AMP. Essential data relating to electrical and mechanical safety classified components are to be periodically recorded or recorded when plant modifications occur, in component lists and/or component type lists in accordance with guideline ENSI-G01 [5]. These lists are to be made available to ENSI.
All SSCs are recorded with this relevant metadata in the database of the integrated plant management and maintenance system (IBIS), which permits automated identification and checks.

Civil engineering

Based on Section 5 of ENSI-B01 on ageing management [4], ageing management is to include all civil engineering structures classified according to ENSI-G01 [5]. In line with their significance for nuclear safety and radiation protection, civil engineering structures are assigned to two structure classifications, BK1 and BK2.

Civil engineering structures and substructures are complete buildings or large parts of buildings. Civil engineering systems are groups of civil engineering components which fulfil a common function, such as steel platforms or seals or fire protection elements. Again, civil engineering systems comprise civil engineering components such as anchor plates or fire protection doors.

Each classified building is assessed separately within the scope of ageing management. The fact sheets compiled for this purpose concern individual buildings or parts thereof.

Electrical engineering

According to Section 6 of the guideline ENSI-B01 [4], the AMP is valid for all electrical and I&C equipment classified as 1E in ENSI-G01 [5] and for all safety-relevant electrical equipment classified as 0E. According to ENSI-B01, fact sheets must be created for 1E components, whereas for 0E (0Ek) classified components ageing dossiers must be created. The scope of components and equipment subject to the AMP, are identified in the integrated plant management and maintenance system (IBIS).

As established in electrical engineering ageing management, similar component groups are assessed. The grouping in the electrical engineering and I&C division is implemented on a component-specific basis. Components that are similar in respect of design and technology are grouped together in component groups. The grouping is implemented in the GSKL AMP electrical engineering expert team. The plant-specific grouping of the 1E classified components and the 0E classified systems are documented in tables.

Mechanical engineering

The systematic ageing management for all vessels and piping assigned to safety classes 1 to 3 based on guideline ENSI-G01 [5], including their supports and pressurised equipment (pumps, valves, safety valves), must be documented according to section 7 of ENSI-B01 [4] for its use in Swiss nuclear installations (BRK). The ageing condition of the mechanical engineering equipment not covered by the systematic ageing management in accordance with ENSI-B01 [4], is tracked as part of the scheduled maintenance so that early action can be taken to prevent possible damage.

The data of the integrated plant management and maintenance system (IBIS) is taken into account when identifying structures to be included in the AMP.
All active[1] and passive components are assessed.

Guideline ENSI-B01 [4] specifies the SSCs which may be grouped together for assessment. Components that belong to safety classes 1 and 2 (SK 1 and 2) are not grouped. In general, components of the same or similar construction that are exposed to the same or similar conditions and which exhibit a similar ageing behaviour are grouped together. The groupings must be identified in the fact sheet in a transparent manner. It is not necessary to provide a detailed listing of the grouped components and component parts.

In keeping with the early development of AMPs in Switzerland, no unified AMPs have been used for all departments: these were only introduced in a first unifying approach in the USA at national level in 2001 via the US NRC document ‘Generic Ageing Lessons Learned (GALL)’ report [8]. By contrast, the AMP was introduced in Switzerland 10 years earlier. At international level, the IAEA’s project ‘International Generic Ageing Lessons Learned (IGALL)’ [9] adopted the GALL methodology (and consequently also AMPs). The IGALL report [9] was produced about 20 years later than the Swiss AMP.

As already presented in Section 2.1, the methods and requirements of the AMP have been set out in the fundamental documents of the GSKL. Moreover, the GSKL guidelines for the creation of fact sheets for civil, electrical and mechanical engineering are a guide for the practical implementation of ageing management and for documenting the results of the assessment of mechanical and electrical component as well as of civil engineering structures. On the basis of the specifications of the GSKL working group in KKL, the AMP was implemented in detail according to the requirements of the KKL quality management (QM) system. The ageing assessments of civil engineering structures and/or SSCs are summarised in the plant-specific fact sheets. The ageing mechanisms relevant for particular plant parts are identified by the ageing management. On this basis, existing programmes, especially maintenance for example, are checked as to whether ageing-induced damage can be avoided or detected at an early stage. Any omissions revealed by the check are closed in a documented manner. Embedding this in the national and international activities of GSKL's working group ‘AMP in Swiss NPPs’ ensures that the state-of-the-art of science and technology in the fields of materials and structural ageing as well as their analysis and diagnostic technology will continue to be considered in future.

Drawing on applicable trends and findings from performed maintenance, the effectiveness of ageing management and the additional measures resulting from it are evaluated annually in accordance with the state-of-the-art of science and technology on the basis of guideline ENSI-B02 [10].

The ageing management process is integrated in the KKL management system, which is itself ISO 9001 certified and subject to regular audits. Relevant data concerning the SSCs, including the maintenance history, is recorded in the IBIS. All AMP relevant reports are recorded in the IBIS document management system, which ensures correct document processing from review through to archiving.

[1] Here the concept ‘active’ is used in the sense of the US-American ‘Maintenance rule’, i.e. active components need not all necessarily be mechanically active in the sense of guideline ENSI-G11 [6].

Moreover, essential inspection and maintenance work is documented in the monthly and on-line and annual outage reports. Measured operating quantities such as logged temperatures and pressures are saved in the ANIS databases.

Steps and measures are defined in the QM Corrective Action Programme for checking results and processes and then necessary actions defined to the extent that unsatisfactory results are found or potential for improvement identified. In practice, NDT testing results, results from maintenance, function tests after maintenance, results from test sequences and function checks are evaluated and documented, and incorporated as feedback from experience in the ageing management process. Within the scope of updating of the AMP, such information is regularly assessed, evaluated in respect of the necessary adaptation of ageing management and the effectiveness of the programme checked in a subject-specific manner (see Section 2.2, Review and update of the overall AMP).

2.1.2 Ageing assessment

2.1.2.1 Basis

The GSKL programme for verifying ageing management measures builds on many years of applied maintenance concepts of the Swiss NPPs, references the legal requirements and forms the basis for the ageing management of Swiss NPPs. The document describes the physical ageing phenomena occurring in the NPPs in general and presents a procedure for the early detection and management of these phenomena

The division of the AMP into three areas, civil engineering, electrical engineering and mechanical engineering is defined in the GSKL interface document. GSKL guides for the creation of fact sheets for civil, electrical and mechanical engineering provide specifications for the practical implementation of ageing management and for documenting the results of the assessment of mechanical and electrical components as well as of the civil engineering structures. The component or group-specific assessment takes account of all relevant design and manufacturing documents (especially specifications, test programmes, results of qualification tests, bills of material, material certificates, manufacturing and prototyping testing certificates).

The ageing assessments of civil engineering structures and/or SSCs are summarised in the plant-specific fact sheets.

As also specified in the guideline ENSI-A03 [14], the key elements for effective ageing management are presented in the following list.
The basis here is the IAEA Safety Guide for Ageing Management [12]. The documentation of ageing management is provided by the licensee within the framework of the periodic safety review.

Attribute from [12]

1 Scope of the AMP based on the understanding of the ageing phenomena
2 Preventative activities for minimising and monitoring the ageing condition
3 Detection of ageing effects
4 Monitoring and trending of ageing effects
5 Mitigation of ageing effects
6 Acceptance criteria
7 Corrective actions
8 Operating experience feedback from research and development
9 Quality management

As described in Section 2.2., an important key element is the regular review and updating of the ageing management according to TQM Process P0514.

2.1.2.2 Relevant ageing mechanisms

The systematic identification of ageing mechanisms performed differently in the three departments.

- **Civil engineering:** All ageing mechanisms relevant to civil engineering are specified in Annex 1 of the guide for civil engineering fact sheets. In the case of inspections also defined in the guide, civil engineering structures are inspected at least every ten years for the relevant ageing mechanisms.
  The inspections may only be carried out by qualified and experienced persons who know how to interpret and evaluate any unexpected anomalies that might occur. When working within the framework of the AMP, the support of a specialist planner/engineer and, if necessary, a special expert is essential when using special diagnostic methods. The results of inspections are recorded in the fact sheets for the individual buildings, and any actions defined.
- **Electrical engineering:** The GSKL expert team of electrical engineering ageing management experts inspects, evaluates and documents the completeness and assessment of known ageing mechanisms, taking into consideration the state-of-the-art of science and technology and the world-wide experience in NPPs. Necessary adjustments and developments are permanently implemented. In order to ensure inclusion of the state-of-the-art of science and technology in the plant-specific fact after the initial fact sheet creation, the generic fact sheets Part 1 and Part 2 (‘Basis Documentation’) are continually checked by the GSKL AMP electrical engineering expert team at least every ten years and updated as necessary.
- **Mechanical engineering:** The GSKL team of mechanical engineering ageing management experts inspects, evaluates and documents the completeness and assessment of known ageing mechanisms taking into consideration the state-of-the-art of science and technology available and world-wide experience in NPPs. This includes, in particular, the ‘Catalogue of Ageing Mechanisms of Mechanical Equipment’ (KATAM), an essential, ENSI-recognised reference for assessing the relevance of ageing mechanisms. The following aspects are systematically dealt with and documented during the creation of fact sheets:
  - General information about the system and its components
  - Key parameter (media, operating conditions, material data)
  - Identification of relevant ageing mechanisms
  - Internal and external operating experience
  - Existing activities and programmes
  - Supplementary measures

  A special case is the ageing management of emergency diesel generators. Due to the very similar design in all Swiss plants, generic fact sheets were created here (as is normal in the electrical engineering department) for the identification of the relevant ageing mechanisms (Part 1) and possible diagnostics methods (Part 2) by the GSKL expert team, which are then only supplemented by plant-specific fact sheets (Part 3) in the individual plants.

2.1.2.3 Acceptance criteria

The acceptance criteria used in the implementation of ageing management measures ensure that a structure or a component maintains its functionality and/or integrity under all design conditions.

- **Civil engineering:** The GSKL guide specifies condition levels 1 to 5 for the civil engineering fact sheets. All components subject to assessment are evaluated according to these condition levels as part of the regularly performed inspections. Level 1 means 'very good condition', level 5 'poor condition'. For levels 4 and 5 short-term or immediate repair is necessary.
- **Electrical engineering:** Due to the diversity of electrical and I&C equipment there are no standardised acceptance criteria. The applied criteria are either taken from internationally recognised standards or derived from methodically analysed predictions (accelerated ageing tests in a test environment; inspection of removed components with known conditions of use; cable or component storage in the containment under extreme ambient conditions such as temperature, humidity, radiation, etc.) and the plant-specific ambient conditions.
- **Mechanical engineering:** The criteria for the mechanical engineering passive components are part or component specific. In the section relating to the reactor pressure vessel, the defined acceptance criteria for this component are looked at in more detail. Where RPV embrittlement and fatigue monitoring are concerned, ENSI defined precise specifications in Appendices 5 and 6 of the revision of the regulatory guideline on ageing management ENSI-B01 [4]. Regularly performed function tests of active components use appropriate acceptance or threshold values. If these values are not met a fault message is triggered, which then leads to maintenance and/or repair actions, so that the correct design condition of the component is recreated.

In Switzerland there are also higher-level criteria defined by the Federal Department of the Environment, Transport, Energy and Communications (DETEC) in the ordinance 732,114.5 on the temporary shut-down of NPPs. These relate to the embrittlement of RPVs, reductions in wall thickness and cracks in primary circuits, wall thickness reductions of steel containment structures of the primary containment and cracks and spalling of the containment concrete shell. The licensee is legally obliged to perform corresponding tests or analyses. This enables ENSI to monitor compliance with defined acceptance criteria.

2.1.2.4 Research and Development

KKL participates in on-going research and development programmes via the following institutions:

- EPRI
- VGB
- swissnuclear
- Paul Scherrer Institut (PSI)

Currently research activities are ongoing in the following areas:

- EPRI/BWRVIP: This is a research project. Based on the results, EPRI is developing inspection, mitigation and repair recommendations for the RPV internals of BWRs, that are applied both in Switzerland and in many other countries.

- EPRI/NDE: This is a research project that supports the development of efficient non-destructive inspection and monitoring techniques to maximise plant availability and safety.
- EPRI/NMAC: This project is aimed at developing guidelines for a maintenance strategy that increases plant availability and safety.
- EPRI/WRTC: This project is aimed at the development of new material types and methods for the welding and repair of nuclear components.
- PLiM: This project covers crack formation due to thermal fatigue in components made of austenitic steel. This PSI project analysed, for example, a pipe configuration (hot/cold feed) of a Swiss NPP.

In addition, licensees have access to the results of the following regulator-financed projects:

- SAFE-II: The SAFE-II project deals with materials problems, especially in respect of stress corrosion cracking and fatigue in the structural materials of light-water reactors. This internationally-recognised project supports and promotes the acquisition of know-how in environment-induced crack propagation, an area which is important for the operation of NPPs.
- NORA-II: Noble metal injection is used in both Swiss BWRs, to prevent or mitigate the occurrence of stress corrosion cracking in RPV internals. In particular this project investigated the platinum deposition of samples that were stored in the primary cooling water of the KKL NPP. The protective effect of Pt-injection in the two Swiss BWRs was improved based on the results of the investigation.
- CODAP database: For ENSI and the Swiss NPPs, this data collection and background information represents a direct and current source of international experience relating to damage cases occurring on classified mechanical equipment, which can be used directly for ageing assessments.

2.1.2.5 Operating Experience

New findings based on external sources and bodies such as EPRI, TÜV (Technical Inspection Agency), work groups of the VGB, BWROG, WANO, CODAP, IGALL, suppliers, exchange of technical experience with sister plants inEurope and the USA, EQDB etc. as well as from conferences and seminars and new, recognised diagnostic methods and models are discussed and evaluated in the GSKL AMP expert teams and decisions made about their application in the Swiss ageing management programme. Operation-induced damage cases occurring in the individual Swiss NPPs are also presented to the GSKL AMP expert teams and then discussed in respect of their relevance for the AMP (‘operating experience exchange“).

- **Civil engineering:** New findings such as methods or testing techniques for materials used in civil engineering such as concrete and steel, for plastics or coating materials have been discussed in the GSKL AMP civil engineering expert team and evaluated in respect of their application to the ageing management programme. Participation in courses and seminars ensures that knowledge of the state of the art is kept up to date (see Section 2.2).
- **Electrical engineering:** New findings from internal and external operating experience are presented and discussed within the framework of the GSKL AMP electrical engineering expert team. In the context of the reviewing and updating of fact sheets and ageing dossiers, the existing sources/references are scrutinised and current information identified which could be used to update the fact sheets. In conjunction with

the internal operating experience, the information obtained is regularly assessed and evaluated in respect of its effect on the existing activities (see Section 2.2).

- **Mechanical engineering:** The Catalogue of Ageing Mechanisms of Mechanical Equipment (KATAM) represents the current state-of-the-art of science and technology where the ageing mechanisms of light water reactors are concerned and is used in the power plants as a basic document for the implementation of mechanical engineering ageing management. This catalogue is thoroughly reviewed on a regular basis by the GSKL AMP mechanical engineering expert team to determine whether new findings are available that require the KATAM to be revised. To do so, relevant publications, conference proceedings, codes and standards are systematically reviewed and evaluated. A summary of the results of this review is presented in the annual reports of the power plants. In conjunction with the internal operating experience, the information obtained is regularly assessed and evaluated in respect of its effect on the existing activities (see Section 2.2).

2.1.3 Monitoring, testing, sampling and inspection activities

The essential components of the monitoring, testing, sampling and inspection activities for the technical equipment and consequently the relevant ageing mechanisms are:

- Operational monitoring
- Preventive maintenance, which also includes the in-service inspection programme (WHP)
- Periodic inspections (WKP) including functional tests

For the mechanical components of safety classes 1 to 4 subject to nuclear acceptance testing, inspection programmes are established according to specification NE-14 [13]. These include non-destructive testing (NDT), system and component walk-downs, pressure tests, function tests on safety valves and piping snubbers.
Relevant criteria such as the selection of suitable test methods and test parameters as well as classification and finding-dependent test intervals are specified in NE-14 [13]. The inspection programmes are reviewed and approved by ENSI and/or its technical experts, SVTI-N (Swiss Association for Technical Inspections - Nuclear Inspectorate). Periodic tests on safety systems and components are defined in the technical specifications of the licensee and generally include function and leak tests at defined intervals. The following programmes or activities, which the plant-specific AMP draws upon, are located in the different departments:

- Water-chemistry analyses based on internationally accepted guidelines and specifications
- Regular checking of consumables such as lubricants etc.
- Wall thickness measurement programmes (‘EROSKO’)
- Results from regularly performed function tests (SFT/IFT) on mechanically active components (e.g. discharge rates of pumps or valve closing times) and electrical and I&C components.
- Cable deposition programmes and inspection programmes
- Diagnostic measurements on actuators (MOV), solenoid valves and motors (stator winding)
- Periodic measurements on stationary battery systems

In accordance with guideline ENSI-B01 [4] surveillance programmes to detect embrittlement of the RPV material and monitor fatigue in relevant components of SK1 to SK3 are necessary. These two surveillance programmes are continuously performed so that the condition of the components mentioned can be continuously gauged and an extrapolation made to determine the expected service life.

Analyses, investigations and special inspections are carried out or existing programmes, such as the in-service inspection programme or maintenance programme, are supplemented or independent surveillance measures implemented within the framework of the AMP. For example, measurements of the relative air humidity and temperature at electrical components are carried out to check the existing qualification. If necessary, in civil engineering, additional tests on civil engineering structures and laboratory analyses are carried out. Existing arrangements and routines can provide information about whether unexpected ageing-induced damage has occurred on SSCs:

- Walk-downs
- Anomalies during function tests
- Raising employee awareness so that they monitor the general state of individual parts during maintenance work that references relevant maintenance instructions.
- Weekday discussion and evaluation of anomalies occurring during operation.
- Water-chemistry monitoring (amongst other things, changes in chemical parameters can indicate internal leaks)
- Vibration monitoring of machinery

The feedback of such information which takes the form of fault reports and non-conformance reports, is ensured by the regular subject-specific reviewing of the AMP (see Section 2.2).

2.1.4 Preventive and remedial actions

The AMP of the Swiss NPPs is designed to ensure the timely detection of the relevant ageing mechanisms and the resulting ageing effects. This forms the basis for identifying and implementing any necessary preventive and remedial actions. The implementation of the respective activities then takes place in the respective departments based on the QM system, as for example in Process P05 ‘Plant Maintenance’ or P06 ‘Plant Modification’. The feedback of information into the AMP is then in turn ensured by the regular updating of the programme, as described in Section 2.2. Following implementation of a preventive or remedial action, the ageing management fact sheets are revised accordingly. Actual examples of applied preventive and remedial actions are contained in the following subject-specific sections of this report.

2.2 Review and update of the overall AMP

The overall contribution to reviewing and updating of ageing management is carried out in the GSKL working group ‘AMP in Swiss NPPs (CH-KKW)’. Heads of the expert teams of civil -, electrical and mechanical engineering are members of the coordination team of the working group. All persons responsible for the AMP in the plants are represented in the expert teams. The coordination team discusses overall aspects of ageing, updates the common overriding documents and defines joint measures and procedures in Switzerland. The common subject-specific specifications and principles for carrying out the AMP are compiled or updated by the expert teams for use in the plants. The tasks of the expert teams include the active participation in specialist events, national and international exchange of experience and the joint monitoring of the state-of-the-art of science and technology, which is documented in joint subject-specific documents and made available to each power plant to implement ageing management.

Below, comprehensive ageing management is considered at the level of each power plant. If necessary, reference is made to the tasks of the GSKL working group ‘AMP in Swiss NPPs (CH-KKW)’ described above.

Deviations and areas for improvement in ageing management revealed in audits, inspections and reviews (e.g. by ENSI, WANO, EDQM or SPN) and the creation or assessment of the periodic safety review are documented in the final report of the audit Unless specified by the supervising entity, the relevant organisational units of the licensee shall derive an action plan with clear tasks, responsibilities and deadlines. Where audits and reviews are concerned, a ‘Follow-Up’ takes place after an appropriate time interval, in which the representatives of the auditing body check and assess the effectiveness of the implemented actions.

During the periodic safety review based on guideline ENSI-A03 [11], the AMP is reviewed in accordance with the specifications contained in Section 5.4.1 Ageing Management of safety classified civil engineering structures and mechanical and electrical equipment. Within the scope of this review, the completeness, up-to-datedness and correctness of the ageing management programme and the current state of the programme and the actions implemented in the programme are presented and evaluated. Moreover, it is shown how ageing-induced progress in damage is measured taking into consideration the testing techniques applied and what improvement measures for the identification of detectable errors are being and have been taken.

In KKL, a specific department has been established for the evaluation of internal events (TQM Process S0602). Events that have occurred due to ageing are dealt with in cooperation with the persons responsible for ageing management. In addition, independent of Process S0602, the findings, deviations and modifications[2] to the plant are analysed and if necessary appropriate actions defined and monitored in a reproducible manner (TQM Process P0514). In doing so, changes to norms and standards are similarly traced and assessed (as part of reviewing of the state-of-the-art of science and technology by the expert teams of the GSKL working group). The results of the review are presented in the annual safety report.

In KKL a specific group has been established for the evaluation of external events (TQM Process S0603) that undertakes systematic screening of external events. Messages possibly relevant for ageing management are forwarded to the departments responsible for the ageing management. In addition, all plants receive prompt AMP-relevant messages from international operating experience via memberships and contacts in a wide range of organisations and working groups. Messages relevant for ageing are evaluated in ageing management and if necessary appropriate actions are defined and monitored in a traceable manner.

The review and update of the overall AMP is continuously performed in KKL based on the TQM Process P0514 for ageing management. Updating is a ‘feedback process’, which should ensure that the latest information from internal and external sources relating to an adaptation of the programme is evaluated. In our opinion, such regular assessments and evaluations are appropriate for detecting unexpected ageing phenomena and initiating counter-measures. The results of the reviews are presented in the annual safety report according to the specifications of guideline ENSI-B02 [10]. Here the effectiveness of ageing management is evaluated in the civil, electrical and mechanical engineering departments. In

[2] If changes are made to the plant or its operation, the departments affected are to be involved (according to TQM Process P06, Modification to the Plant). Changes to safety equipment and its method of operation are evaluated by experts and the regulator. In doing so, the effects of plant changes on ageing behaviour are considered.

addition to events at both KKL and other plants, the department-specific evaluations are based on findings and trends from the in-service inspection program and repeat tests (WHP and WKP), inspection findings, relevant maintenance events, modifications to the plant or mode of operation, trends identified from analyses carried out, such as fatigue monitoring.

The analyses which demonstrate that the component under consideration can be used without limitation up to a specified point in time include, in particular, qualifications for electrical components, the various analyses performed within the framework of fatigue monitoring and the fracture mechanics safety analyses of the RPV. Irrespective of which expert team in the plant performs the analyses, the analyses and their updating are subject to the ageing management performed in the different departments and are thus subject to TQM Process P0514, Ageing Management.

KKL is actively involved in the steering and control of material ageing research projects. Noteworthy here are the current research projects of the BWRVIP programme of EPRI, the swissnuclear project PLiM and the ENSI project NORA-II. KKL has been involved in the IGALL project or program of the IAEA, in which the state-of-the-art of science and technology is discussed and presented with direct reference to the AMPs, since 2010. The current state-of-the-art of science and technology is likewise monitored, evaluated and presented in the annual safety report within Process P0514 based on the activities of the expert teams from the GSKL working group ‘AMP in Swiss NPPs (CH-KKW)’ already described.

2.3 Licensee’s experience of application of the overall AMP

In KKL, overall AMP is implemented based on the principles prepared by the GSKL working group. Thus far, it has not been necessary to make any fundamental changes at this programme level. The common GSKL documents are regularly reviewed and revised by the coordination team and the associated expert teams. The changes made are either adaptations to the AMP resulting from changed regulatoryl requirements or adaptations to the subject-specific documents, so that their content is matched to the current state-of-the-art of science and technology, and the latest codes and standards.

The ageing management process in KKL was reviewed in 2011 when guideline ENSI-B01 was introduced to replace the ageing management guideline HSK-R-51. The process was matched to the new regulatory l requirements of the new ENSI-B01 guideline, revision 1 of the ENSI-B02 guideline and the procedure at the annual review, and adaptations were agreed upon between the departments.

In KKL, the AMP represents an essential, systematic complement to the existing maintenance programme and is continually updated:

- Ageing management in KKL identifies the relevant ageing mechanisms for safety-relevant components and structures and based on this, existing programmes, especially maintenance (including NDT), are reviewed to determine whether ageing-induced damage can be avoided or detected at an early stage. Any omissions revealed by the review are closed in a traceable manner.
- Embedding this in the national and international activities of GSKL's working group ‘AMP in Swiss NPPs’ ensures that the state-of-the-art of science and technology in the fields of materials and structural ageing as well as their analysis and diagnostic technology will continue to be considered in future.

The AMP is established in KKL and has proven its worth. As described, the programme is continually updated based on a specified procedure. This updating should ensure that ageing management tasks continue to be reliably fulfilled in the coming years.

3. Electrical cables

3.1 Description of ageing management programmes for electrical cables

The following table presents the reference between the WENRA [2] specification and the ENSI directive [1] with the subsections of the section ‘Electrical Cables’:

Number and title of the section			
WENRA specification		**Report BET/17/0117**	
3	Electrical cables	3	Electrical cables
3.1	Description of ageing management programmes for electrical cables	3.1	Description of ageing management programmes
3.1.1	Scope of ageing management for electrical cables	3.1.1	Scope of ageing management
3.1.2	Ageing assessment of electrical cables	3.1.2	Ageing assessment
3.1.3	Monitoring, testing, sampling and inspection activities for electrical cables	3.1.3	Monitoring, testing, sampling and inspection activities
3.1.4	Preventive and remedial actions for electrical cables	3.1.4	Preventive and remedial actions
3.2	Licensee’s experience of the application of AMPs for electrical cables	3.2	Licensee’s experience of the application of AMPs

3.1.1 Scope of ageing management

The basis for the scope of components that are subject to the AMP are the guidelines ENSI-B01 ‘Ageing Management’ [4] and ENSI-G01 ‘Safety Classification for Existing NPPs’ [5]. In accordance with these directives, all 1E-classified electrical and I&C systems and equipment are to be included in ageing management. This also includes cables,

- whose functioning for achieving a protection target is essential,
- that are necessary for execution and monitoring of a safety function,
- which are necessary to safeguard the electrical power supply to other 1E-classified electrical and I&C systems and equipment.

Cables required for the safe functioning of motive force power supply, actuation, measurement and monitoring components, so that mechanical equipment of safety classes 1 to 3 can fulfil their intended task are also part of the scope of ageing management. High levels of operational reliability and availability are achieved by selecting suitable, reliable and qualified cable types and materials. All cables included in the AMP are identified and recorded in the integrated plant management and maintenance system (IBIS).

The preparation of documents for the ageing management of cables (and other electrical equipment) takes place in Switzerland at the following two ‘levels’.

- The basis for ageing management in KKL are Fact Sheets Part 1 and Part 2 that are jointly compiled and maintained by the GSKL-AMP Electrical Engineering Expert Team. In Part 1 the relevant ageing mechanisms are identified and assigned to the individual cable components. In Part 2 of the fact sheets, the methods necessary to diagnose the ageing effects resulting from the ageing mechanisms are specified. As part of this joint work, all of the ageing mechanisms that act on the cables are considered, whether they originate both from operation of the cables themselves or result from the environmental influences that act (from the outside) on the cables.

- In KKL, the plant-specific Fact Sheet Part 3 is compiled and used to perform a check to determine whether all the actions specified in Part 2 of the fact sheets are implemented in KKL. Omissions identified here are traceably recorded and closed. The responsible implementation of ageing management measures ('diagnostics, monitoring and trending') and their adaptation takes place in KKL.

The GSKL-AMP Electrical Engineering Expert Team grouped the cables and connection points in creating Parts 1 and 2 of the fact sheets. This grouping took place as follows based on the functions and requirements for the electrical components:

- Medium voltage cables class 1E (WENRA [2]: High voltage cables greater than 3kV)
- Low voltage power and I&C cables class 1E LOCA (up to 1kV)
- Low voltage power and I&C cables class 1E (up to 1kV)
- Special cables for neutron flux instrumentation (MI cables)
- Terminals and terminal boxes

When components are referred to below, this relates to the above-mentioned cable groups.

3.1.2 Ageing assessment

The aim of ageing management is to ensure the long-term functionality of the cables both under normal operating conditions as well as under the influence of assumed incidents. This relates particularly to the electrical loading of cables under different accident scenarios and to loads arising as a result of changes to the ambient conditions resulting from the accident.

The relevant damage mechanisms that could impair the specified required functional characteristics are defined for all safety-relevant electrical and I&C technical installations in accordance with ENSI-B01 [4]. In KKL, where safety-relevant technical installations are concerned, only electrical cables with plastic insulation are used. The mainly used insulation materials are:

- XLPE Cross-linked polyethylene
- EPR Ethylene propylene rubber (primarily MV cables)
- EPDM Ethylene propylene diene monomer (silicone rubber)
- Polysulphone, polyethylene

The electrical properties of the cable are primarily defined by the insulation material of the cable cores/conductors and by the properties of the conducting material itself. Ageing of the insulation can result in a change of the insulation capacity of the individual cable conductors. Generally, the relevant ageing mechanism of the insulation materials is embrittlement.

In general, the cable jacket usually has no electrical function for the cable. Its primary use is mechanical protection of the cores/conductors. Changes or corrosion to the metallic cable conductors is only relevant for the areas of the interfaces of the cables with power units (e.g. motors, generators, drives) and other equipment. Corrosion in these areas has an effect on the conductivity (contact resistance) or the signal transmission behaviour.

To identify and evaluate the relevant ageing phenomena, the ageing-relevant loads for the cables are identified and their effect on the cable properties required according to the operating documentation assessed. In general, these loads are considered as early as the cable design stage and when selecting cable types, taking account of the materials used and the cable design.

The following load parameters are considered in detail for cable ageing management:

- Thermal load
  - Inherent heating of the cable resulting from the current load,
  - Cable routing (trays, pipes, conduits, etc.)
  - Cable heating due to the ambient temperature
- Radiation exposure
  - Change to the properties of the insulation material resulting from radiation-induced degradation of the molecular structure of the plastics used.
- Loading due to electric fields, voltage, frequency
  - Voltage as a load parameter amongst cables with a rated voltage > 1 kV for the insulation and the inner and outer semiconductor layer
  - Voltage/frequency as a load for the dielectrics in I&C cables (generally coaxial signal cables)
- Mechanical load due to field forces
- Water influences/moisture
- Contact with media (e.g. oil vapour)

In ageing management, the relevant design, manufacturing and operating documents are used and listed in detail in the fact sheets in Part 3. Current and relevant standards, regulations and guidelines are used in cable ageing management. The most important sources for ageing management of cables are listed below:

- IAEA-TECDOC-1188
  Assessment and management of ageing of major nuclear power plant components important to safety: In-containment instrumentation and control cables
- DIN EN ISO 527-1:2012-06
  Plastics -- Determination of tensile properties -- Part 1: General principles (ISO 527-1:2012) Test conditions, geometry of test specimens, measured value acquisition, testing speed and evaluation
- KTA 3706
  Ensuring the Loss-of-Coolant-Accident Resistance of Electrotechnical Components and of Components in the Instrumentation and Controls of Operating Nuclear Power Plants
- NUREG/CR-6704
  Assessment of Environmental Qualification Practices and Condition Monitoring Techniques for Low-Voltage Electric Cables
- NUREG/CR-7000
  Essential Elements of an Electrical Cable Condition Monitoring Program
- IEC/IEEE 62582-3 :2012
  Nuclear power plants - Instrumentation and control important to safety - Electrical equipment condition monitoring methods - Part 3: Elongation at break
- EPRI 1020804
  Plant Support Engineering: Aging Management Program Development Guidance for AC and DC Low-Voltage Power Cable Systems for Nuclear Power Plants

- EPRI 1020805
  Plant Support Engineering: Aging Management Program Guidance for Medium-Voltage Cable Systems for Nuclear Power Plants
- EPRI 1011223
  Aging Identification and Assessment Checklist
- IEEE 323
  IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations
- IEEE 383
  IEEE Standard for Qualifying Class IE Electric Cables and Field Splices for Nuclear Power Generating Stations
- IEEE Std. 400.2
  IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF)

When planning, adapting and performing ageing management, the evaluation of internal and external experience feedback in respect of damage and events is essential for electrical engineering components (see also Section 2.2). In summary, the following information is used:

- Results and findings from monitoring and its evaluation
- Results and findings from periodic inspections (WKP) and their evaluation
- Results and findings from maintenance
- Fault/defect reports and their evaluation
- Notifiable events of KKL and other plants
- Events from NPPs (GSKL, WANO reports, etc.)
- Findings from international research projects, such as in particular the research on the application of LIRA diagnostics[3] and results from the EPRI-projects on cable ageing [16] [17].
- Findings from the manufacturer's evaluation of experience
- Findings from exchange of experience between the licensees

Regular experience feedback is in our opinion also the most important precautionary measure for identifying unexpected damage.

3.1.3 Monitoring, testing, sampling and inspection activities

The following properties are decisive in defining the function of electrical cables:

- Insulation capacity (conductor-conductor and conductor-earth)
- Current load capacity and conductivity
- Signal transmission behaviour (for I&C and special cables)

These properties are considered in respect of ageing-induced changes over time. The following measured values are used to monitor and assess the effect of ageing on the

[3] See http://www.wirescan.no/the-lira-technology/

function-defining cable properties. The following measured variables are used to monitor the cables:

- Insulation resistance
- Dielectric loss factor (for MV cables)
- Cable resistance
- Checking of the signal transmission behaviour (TDR)
- Data from LIRA measurements
- Visual inspections
- Thermography for identification of hotspots/discontinuities
- Elongation at break of the insulation and jacket materials

The measurement methods and acceptance criteria are explained in more detail below.

Insulation measurements are performed for a number of reasons. On the one hand, the insulation resistance measurement proves adherence to the specified maximum leakage currents when operating the cable under normal conditions in compliance with the existing conventional body of rules (regulations and codes of practice). On the other hand, the insulation resistance measurement is established as a test method for cables to identify any ageing effects acting on the cable and then to be able to monitor them. The measured values are compared with the specified limits and the relevant applicable codes of practice. Additionally, trend monitoring over longer periods of time makes it possible to track individual results so that the ageing behaviour of the cable insulation materials can be evaluated.

In general, **measurements of the cable resistance** accompany insulation resistance measurements, coordinated with maintenance actions on electrical machinery and devices and also performed within the context of the periodic inspection of I&C measurement circuits. Here, the testing of the cable and associated connections form part of the measurements carried out. The permissible limits are specified in the relevant KKL maintenance rules.

LIRA (Line Resonance Analysis) measurements as additional random tests on selected cable sections. This relatively new method was developed at the Institute for Energy Technology (IFE) in Halden, Norway. The trigger was a requirement for non-destructive testing and diagnostics on cables in NPPs. This method permits the precise identification of cable damage so that any necessary measures can consequently be planned in advance. The method has no restriction on the length of the cable. It can be used for all types of cable insulation materials (XLPE, EPR, PE etc.). Adherence to permitted limits is indicated by experts from WIRESCAN who evaluate the measurements that have been carried out.

TDR (Time Domain Reflectometry) is a measurement method for locating and analysing faults in transmission cables. The method is applied to neutron flux instrumentation cables. Here, signal transit times are used to identify possible fault locations. A statement on the cable condition can be made based on the trend analysis. The permissible limit patterns are specified in the relevant KKL maintenance rules.

The **dielectric loss factor (tan delta measurement)** is a widely used and proven diagnostics method for testing MV cables. This test allows insulation damage in both plastic and paper/pulp insulated cables to be located in very short testing times, without degrading the quality of the surrounding insulation material. Loss factor diagnostics provides a differentiated statement on the ageing condition of EPR MV cables used in KKL. The short duration of the test means the cable is only minimally loaded. The values from [16] [17] are used as permissible limits. In addition, the experience values of diagnostic companies are considered.

Signal transmission behaviour of I&C cables for the transmission of analogue measurement signals is generally checked in conjunction with the testing of analogue measuring chains that also contain the cables under consideration. Where there are deviations in the measuring results from the expected values, the individual links of the measuring chain are investigated in respect of their influence. In this way, changes to the cables involved can be detected and appropriate measures derived. The permissible limit patterns are specified in the relevant KKL maintenance rules.

Visual inspections on cables are performed as part of routine walk-downs and also specifically in the form of special visual inspections within the framework of inspection and maintenance activities. Changes to the visible parts of the cable (e.g. local discolouration of the jacket surface) are evaluated and, dependent on the result, further measures initiated, e.g. additional tests and investigations to assess the condition of the cable concerned. Only fault-free cable jackets are permitted (no cracks or changes to the surface structure).

Thermography as a method for the contact-free measurement of surface temperatures of objects is also used in the monitoring of cables. In particular, thermography can be used to survey cables subject to high current loads. The method makes it possible to measure the absolute temperature of the observed cable and also to identify any local hotspots that may exist, the cause of which is primarily contact resistances in the vicinity of connection points. Thermography results can also be used to make statements about the actual thermal load of the installed cables in individual installation situations and thus to draw conclusions about the forecast ageing behaviour. The permissible limits are specified in the relevant KKL maintenance rules.

Elongation at break tests of cable insulation and jacket materials are used to monitor and evaluate the (ageing-induced) structural changes in the materials used. In general, the relative elongation at break is drawn upon as an ageing reference value. Here, the current elongation at break value of (aged) samples is compared with that for samples of the same material without ageing loading. From the reduction in the ductility of the material, conclusions can be drawn about the ageing-induced reduction of the mean chain length of the plastic molecules. If the value of this reduced ductility falls below a lower limit specified in [15], it triggers further investigations in respect of the insulation properties and as to whether the cable with the premature ageing behaviour can continue to be used.

In addition, cable samples that have been stored in high stress test areas for cable pre-ageing, where there is a high radiation and thermal load, are monitored in respect of their ageing behaviour. The high stress test area for cable pre-ageing in KKL was set up in 1997 and is located in the drywell directly above a fresh steam line. At regular intervals individual cable samples are removed and the change in the relative elongation at break is used as a reference point to estimate the change in the plastic material.
Moreover, if necessary, such pre-aged cable samples can be subjected to electrical testing under LOCA conditions (steam atmosphere with high temperature and pressure). The results obtained in this way can be applied to the cable used in the plant with the corresponding requirements.

Since electrical cables are simple and robust components for which extensive operating experience already exists, including from the non-nuclear area, the diagnostic methods described above do not necessarily have to be applied comprehensively. The selection of the appropriate diagnostics as well as the test triggers or test intervals takes place according to the safety requirements, the availability requirements and the cable technology of the cable under consideration. The following approach is adopted:

- Insulation resistance measurements on representative cables used with rated voltages > 1 kV within the context of periodic and special tests
- Performance and evaluation of diagnostic measurements of the dielectric loss factor in accordance with IEEE 400.2 [18] for MV cables at different voltages to assess the ageing condition of the insulation used.
- Period performance and evaluation of LIRA measurements on selected cable sections for condition-oriented assessment of the insulation strength where deterioration is caused by temperature, radiation, moisture or mechanical damage
- Periodic performance and evaluation of TDR measurements on MI cables used for neutron flux instrumentation to determine the condition and assess the strength of the insulation
- Performance of visual inspections to assess the state of the cable used, expanded if necessary by thermography measurements
- Inspection and maintenance accompanying checks on the cable as part of work on electrical consumers or I&C facilities
- High stress test area for cable pre-ageing above a fresh steam line in the drywell (high temperature and radiation) with test samples and specimens for evaluation of the ageing condition and proof of the retention of LOCA strength
- Periodic measurements on defined test samples from the high stress test area for cable pre-ageing
- Evaluation of measured results or failures of cables by cable type and, if necessary, by material, with, where applicable, assessments of the individual failures of cables and their causes. In doing so, indications of systematic effects, and thus also ageing effects, are evaluated in compliance with the above-mentioned single-failure concept.

3.1.4 Preventive and remedial actions

Based on the activities described above and the results and forecasts derived from them in the area of the ageing management of the cables, it can be concluded that the condition of these components is very good. For this reason, it has not so far been necessary to take any actions to delay the further advance of ageing nor to prevent it.

3.2 Licensee’s experience of the application of AMPs

Actual examples of actions taken as a result of internal and external experience are:

- The ageing analysis revealed that a systematic review of the qualified service life of components (including cables) was necessary. Revaluations were performed, with the actual operating and ambient conditions during operation being taken into account. The results of the evaluations have been included in maintenance planning.
- In 2005, on the basis of external damage reports to cables in other plants, extensive investigations and analyses were performed in a qualified laboratory on MV cables (10 / 6kV) with EPR insulation (conductors and jacket, halogen-free).
  The results obtained were compared with the applicable qualification requirements and confirmed the fault-free condition of the MV cables used in KKL, so that no actions were necessary.

Based on the activities described above and the results and forecasts derived from them in the area of the ageing management of safety-relevant cables, it can be concluded that the condition of these components is very good. This indicates that the selection and specification of the cable materials and cable types used within the framework of the design and corresponding qualification of the cables for the intended use is conservative.

The defined scope of inspection and/or the inspection volume specified in maintenance, also confirm the defined sample size, as shown by the two following examples:

- The scope specified for the high stress test area for cable pre-ageing in the drywell in respect of the removal and measurement of test samples has worked well in practice. The results of the evaluations demonstrate that the specified scope or the interval for the removal of test samples from the test area is suitable for continually monitoring the ageing process. In addition to the measurement of test samples from the test area, supplementary measurements on class 1E LOCA cables were performed by a test institute using the LIRA method. The evaluation of these measurements revealed very good results. They confirm that the cables are in operating condition.
- An evaluation of the results of the diagnostic measurements of the MV cable > 3kV made in accordance with IEEE 400.2 over a period of 5 years (2010 to 2014) yielded evidence of very good dielectric values. There is a very wide safety margin relative to the limits defined in the EPRI Report 1020805 [17]. The results indicate a very wide margin relative to the generally specified limits of certified testing institutes, who have available a huge database.

Summarising, it can be stated that based on current knowledge, the relevant ageing mechanisms for all components of the safety-relevant cables are identified. The occurrence of the ageing effects caused by the ageing mechanisms can be detected in a timely manner based on the implemented monitoring actions and consequently counter-measures implemented. Moreover, experience and findings both in KKL and in other plants are continuously monitored so that ageing management can be adapted as necessary.

4. Concealed pipework

The following table presents the reference between the WENRA [2] specification and the ENSI directive [1] with the subsections of the section 'Concealed Pipework':

Number and title of the section			
WENRA specification		**Report BET/17/0117**	
4	Concealed Pipework	4	Concealed pipework
4.1	Description of ageing management programmes for concealed pipework		*Not applicable*
4.1.1	Scope of ageing management for concealed pipework	4.1	Scope of ageing management
4.1.2	Ageing assessment for concealed pipework		*Not applicable*
4.1.3	Monitoring, testing, sampling and inspection activities for concealed pipework		*Not applicable*
4.1.4	Preventive and remedial actions for concealed pipework		*Not applicable*
4.2	Licensee's experience of application of AMPs for concealed pipework		*Not applicable*

4.1 Scope of ageing management

In KKL, there is no concealed pipework (buried in the ground, embedded in concrete, below inaccessible shafts) in the safety-classified area.
All safety-classified pipework is readily accessible in buildings[4]. Considering the safety-classified pipework that runs outside the buildings on the KKL site, the conclusion is again reached that there is no difficult-to-access or inaccessible pipework installed in the safety-classified area, as this piping is installed in accessible tunnels.

Special Emergency and Heat Removal system in the area of the groundwater pumps
With the exception of the piping sections directly adjoining the two groundwater pumps A and B, all pipework is located in buildings. The piping sections that directly adjoin the pumps are in the pump shaft which is accessible during regular pump overhauls. The next pipe run is different for pump A and pump B. The pipework of pump B runs directly via the pump shaft into the main building. The pipework of pump A runs from the pump shaft out via a horizontal tunnel to the main building. This pipe section is accessible from the pump shaft and the main building. Therefore, the pipework in the area of the groundwater pumps does not come within the scope of the section 'concealed pipework'.

Emergency Service Water
The system comprises three safety-classified cooling water lines each with a cooling tower located in a building and a groundwater pump for refill of the cooling water basin. The pipework outside the buildings is run in pipeline inspection passages. The exception here is the pipe sections immediately adjoining the three pumps. These are largely contained in the well chamber, which are accessible.. The well chamber can be accessed via a floor hatch. There is a short penetration pipe section (approx. 40 cm) embedded in the concrete of the wall adjacent to the cooling water basin. The well shaft and pump shaft are opened for the

4 Penetrations of pipework through building walls are not classed as concealed pipework.

regular pump overhaul and the pump with the associated pipe sections removed and dismantled. Therefore, there are no access restrictions. The pipework in the area of the groundwater pumps does not come within the scope of the ‘concealed pipework’ section.

<u>Auxiliary Cooling Water system</u>
The system comprises a total of five cooling systems, a water cleaning system and a return system. Here, only the components of two cooling systems, Loop A and Loop B are safety-classified. The pipework of Loop A and Loop B are in pipeline inspection passages (tunnels) and there are no restrictions in respect of access. Therefore there are no pipe sections that need to be considered within the scope of the ‘concealed pipework’ section.

5. Reactor Pressure Vessel

The following table presents the reference between the WENRA [2] specification and the ENSI directive [1] with the subsections of the section 'Reactor Pressure Vessel':

Number and title of the section			
WENRA specification		**Report BET/17/0117**	
5	Reactor Pressure Vessels	5	Reactor pressure vessel
5.1	Description of ageing management programmes for RPVs	5.1	Description of ageing management programmes
5.1.1	Scope of ageing management for RPVs	5.1.1	Scope of ageing management
5.1.2	Ageing assessment of RPVs	5.1.2	Ageing assessment
5.1.3	Monitoring, testing, sampling and inspection activities for RPVs	5.1.3	Monitoring, testing, sampling and inspection activities
5.1.4	Preventive and remedial actions for RPVs	5.1.4	Preventive and remedial actions
5.2	Licensee's experience of application of AMPs for RPVs	5.2	Licensee's experience of the application of AMPs

5.1 Description of ageing management programmes

5.1.1 Scope of ageing management

The structures of the reactor pressure vessel (RPV) comprise (see Annex 1):

- The bottom: Bottom head cap 001 and bottom ring 002
- The shell courses 003 to 007
- The vessel flange 008
- The head: Head flange 009, spherical ring 010 and top head cap 011

The individual components are connected by welding. On the inner surface the RPV is clad with austenitic steel. Attachments are welded onto this cladding. To close the RPV, the head is assembled onto the vessel with bolts.

Also included in the scope of this report are the nozzles welded on to the RPV courses. Up to the connection, i.e. the weld, they are considered as part of the corresponding pipes:

- Bottom: Nozzle for bottom head drain line N9, nozzle for core differential pressure N15 and for Standby Liquid Control SystemN43
- Shell course 004: Nozzle for jet pump instrumentation N10, for reactor water recirculation inlet and outlet N2 and N3
- Shell course 005: Nozzle for instrumentation water level N13
- Shell course: Nozzle for feedwater N5, for core spray N6, for Residual Heat Removal (RHR) and Low Pressure Core Injection (LPCI) N7, for Control Rod Drive (CRD) hydraulic return nozzle N11 (closed with end cap), for instrumentation water level N13
- Shell course: Nozzle for main steam N4, for vibration instrumentation N8, for instrumentation water level N13

- Head: Top head spray line N14, spare nozzle N42

The penetrations of the bottom head for the control rod and in-core monitor housings are also part of the scope.

The ageing mechanisms according to the GSKL catalogue of ageing mechanisms of mechanical equipment form the basis of the ageing study of the reactor pressure vessel, the fact sheet. In GSKL catalogue of ageing mechanisms, which is kept up to date by the GSKL AMP mechanical engineering expert team, the ageing mechanisms relevant for light water reactors are identified, classified and described in detail. This document is regularly reviewed in respect of its actuality by the GSKL team of mechanical engineering ageing management experts for Swiss NPPs. A further basic document for the implementation of the ageing assessment is the GSKL guide for the creation of mechanical engineering fact sheets. This document defines the specifications for the practical implementation of ageing management and the documentation of the results. Further, basic documents are plant-specific studies on ageing of the RPV, the IAEA document on ageing management of RPVs in BWRs [19] and the latest technical content of the IAEA IGALL (International Generic Ageing Lessons Learned) project [9]. Other relevant sources such as technical reports or detailed analyses and the CODAP-database of the OECD are also drawn upon for the assessment. Internal and external operating experience is assessed and possibly necessary measures for ageing management are derived from the evaluation of all partial aspects.

5.1.2 Ageing assessment

As already described, the ageing mechanisms according to the GSKL catalogue of ageing mechanisms of mechanical equipment and other relevant documents and sources are the basis of the ageing study of the RPV. With reference to the Topical Review specification [2], the following components of the RPV are to be considered in this report:

- The cylindrical part of the pressure vessel including base metal, weld metal and inner cladding
- The RPV head and the bottom head including all penetrations
- Vessel nozzles

5.1.2.1 Results of the ageing assessment

The ageing mechanisms relevant for the RPV based on guideline ENSI-B01 [4] are identified by ageing management. The relevant identified ageing mechanisms are found to be acceptable insofar that the ageing effects on the components caused by the ageing mechanisms, e.g. loss of fracture toughness or weakening of the load-bearing cross-section due to material abrasion or crack growth, can be detected at an early stage before the component integrity is compromised. Section 5.1.3 looks at the acceptance criteria in more detail.

If gaps are identified in the existing monitoring, these are closed in a traceable manner by appropriate measures; in KKL these are referred to as AMP clarifications.

The fact sheet for the RPV contains the results of the performed ageing. The relevant ageing mechanisms are identified for each RPV component, so that it is possible to check whether the existing maintenance programme and other programmes used for ageing management, such as the periodic inspection programme or the irradiation surveillance programme (see section 5.1.3 in this respect), are suitable for detecting the expected ageing-induced damage at an early stage.

The relevant ageing mechanisms for RPV components, which are detailed in the fact sheet with a statement of all individual items, the corresponding materials and the respective plant identifiers and identification numbers, are summarised in the following table.

Components/location	Material	Ageing mechanism
Cylindrical part of the pressure vessel		
Attachments on inner cladding	Austenitic steel	Stress corrosion cracking
Welding of the core support structure	Nickel-based alloy	Stress corrosion cracking
Base metal in the beltline	Low alloy steel	Embrittlement due to neutron irradiation
Weld metal in the beltline		
Inner cladding	Austenitic steel	Thermal embrittlement of stainless steel casting and welded structure
Attachments on inner cladding	Austenitic steel	Thermal embrittlement of stainless steel casting and welded structure
RPV head and bottom calotte		
Bottom penetration of the housing for control rod drives and in-core monitors	Austenitic steel Nickel-based alloy	Fatigue as a result of operating transients
Welds of the nozzles for core differential pressure and standby liquid control	Austenitic steel Nickel-based alloy	Fatigue as a result of operating transients
Head bolts	Low alloy steel	Fatigue as a result of operating transients
Bottom penetration of the housing for control rod drives and in-core monitors	Austenitic steel Nickel-based alloy	Stress corrosion cracking
Welds of the nozzles for core differential pressure and for standby liquid control	Austenitic steel Nickel-based alloy	Stress corrosion cracking
Vessel nozzles		
Feedwater nozzles in the area of the safe end	Austenitic steel	Fatigue as a result of the Thermal stratification
Inner cladding of the feedwater nozzles	Austenitic steel	Fatigue as a result of the Thermal stratification
Inside radius of the feedwater nozzles	Low alloy steel	
Welds on pipework	Austenitic steel	Stress corrosion cracking
Welds on pipework	Nickel-based alloy	Stress corrosion cracking
Safe ends on pipework	Nickel-based alloy	Stress corrosion cracking
Welds on safe ends	Austenitic steel	Thermal embrittlement of stainless steel casting and welded structure

Overview of the ageing mechanisms identified as relevant for the RPV

Based on this table, the significance of these ageing mechanisms can be discussed with reference to the corresponding components.

Fatigue as a result of operating transients: Fatigue due to operating transients is identified as a relevant ageing mechanism. The performed analyses show that the individual fatigue stresses are also acceptable for an extended operating period of 60 years (U < 1).

Fatigue/thermal stratification: Fatigue resulting from thermal stratification is classed as relevant for the feedwater nozzles.

- Stratification during low load operation: During plant start-up, it is possible that thermal fatigue due to backflow of the reactor water into the feedwater nozzles might occur in the first two operating years. Thanks to the introduction of ‘single-line operating mode’ in 1985, only very low thermal fatigue occurs here.
- Postulated leakage from the thermal sleeve: If such a leakage is presumed, then, in the area of the safe end and the following nozzle, fatigue-related stresses can result from the leak flow. The performed analyses show that such a fatigue stress would also be acceptable for an extended operating period of 60 years (U < 1).

The described items are included in the fatigue monitoring and are monitored by appropriate special instrumentation (see Section 5.1.3).

Stress corrosion cracking: This ageing mechanism is considered for austenitic steels and nickel-based alloys that are exposed to the reactor water. The corresponding items are regularly tested within the scope of the WHP (in-service inspection programme), see Section 5.1.3. Stress corrosion cracking for components in contact with the reactor water is counteracted by the introduction of the online NobleChem process (see also Section 5.1.3).

Embrittlement due to neutron irradiation: Based on the available results from the irradiation surveillance programme (see Section 5.1.3), it is expected that the reductions in fracture toughness as a result of neutron irradiation for the RPV material of KKL will also be low over long operating periods. The irradiation programme will be continued until final shutdown.

Embrittlement/thermal: In a KKL-internal study on the ageing behaviour of the RPV, thermal embrittlement is designated a ‘potentially relevant’ ageing mechanism because its occurrence cannot be categorically ruled out. There is no evidence from global operating experience that would imply any actual occurrence of damage caused by thermal embrittlement. The corresponding items are monitored by non-destructive testing.

5.1.2.2 Use of relevant specifications and sources

The GSKL-guide for the creation of fact sheets is used for the implementation of ageing assessment. On this basis, the following documents are systematically considered and, insofar that the document contains relevant information, referenced to assess whether an ageing mechanism is relevant for a component or module.

- Plant documentation: Documents with information on the material, manufacturing processes, load conditions (physical, chemical, normal operation, transients, etc.) and history of the components from the maintenance, operation and in-service inspection programme. The content of relevant studies and calculations, such as fatigue and embrittlement analyses, must be considered.
- Information from the fleet and component manufacturers: use of this information means that experience from other plants or damage to similar components is considered.
- Further information from relevant external sources, for example EPRI, NRC, VGB and similar reports with reference to the ageing of RPV components. With this information, experience from other plants or damage to similar components is also considered.

Below, with reference to RPV ageing management, the following relevant specifications and sources are looked at in more detail:

- Standards, regulations and guidelines
- Design, manufacturing and operating documents
- Research programmes
- Internal and external operating experience

Standards, regulations and guidelines: The standards, regulations and guidelines used for the ageing assessment essentially comprise the following documents:

- The design specification used for RPV construction, ASME Section III, Component Design and Construction Rules for Construction of Nuclear Facility Components
- Guideline ENSI-B01[5] Ageing Management
- Guideline ENSI-B02, Periodic Reporting of Nuclear Installations
- Guideline ENSI-B10, Vocational training, Recurrent Training and Continuing Education of Personnel
- Standards and guidelines referenced by Guideline ENSI-B01:
  - Ageing Management of Nuclear Power Plants, IAEA Safety Standards, IAEA-Safety Guide No. NS-G-2.12
  - ASTM E 1820, Standard Test Method for Measurement of Fracture Toughness
  - U.S. Nuclear Regulatory Commission, Regulatory Guide 1.99, Radiation Embrittlement of Reactor Vessel Materials
  - ASTM E 1921, Standard Test Method for Determination of Reference Temperature T0 for Ferritic Steels in the Transition Range
  - NUREG/CR-6909, Effect of LWR Environments on Fatigue Life of Reactor Materials, 2007
- SVTI Specification NE-14, Repeat tests on mechanical components subject to nuclear acceptance testing of safety classes 1 to 4, Revision 6, 01/01/2005
- ENSI Guideline B06, Safety classified vessels and pipes: maintenance, Revision 2 of 1 June 2013
- ASME Boiler and Pressure Vessel Code, Section XI, In-service Inspection of Nuclear Power Plant Components
- HSK Guideline B07, Safety classified vessels and pipes: Qualification of non-destructive tests, September 2008
- Institute for Energy, EUR 22906 EN, European Methodology for Qualification of Non Destructive Testing, - third issue -, August 2007, ENIQ Report Nr. 31, EUR 22906 EN
- KKL Technical Specification TSL-1713-01, Rev. 28 'Technical Specification Leibstadt (TSL)'
- GSKL programme for reviewing and optimising ageing management measures
- GSKL catalogue of ageing mechanisms of mechanical equipment
- GSKL guide for the creation of fact sheets for mechanical engineering components

[5] The contents of the ENSI guideline are matched to the international standards, WENRA Reactor Safety Reference Level Issue I and IAEA Safety Guide NS-G-2.12.

<u>Design, manufacturing and operating documents:</u>
The relevant design and production documents are taken into account for RPV ageing management. Design documents have in particular been used for the irradiation programme and fatigue monitoring. The following production documents were used for the detailed assessment of the components to be evaluated:

- Production of the base metal, factory and site assembly
- Repair reports and non-conformance reports
- Third party inspection of fabrication and construction
- Stress analyses and their third party review

Of particular importance here are the base materials used, the welding specifications used and relevant anomalies during manufacture, such as repairs to welds on surfaces coming into contact with the medium.

Changes to the configuration of components after commissioning (‘plant modifications’), and operating parameters have been assessed in respect of their influence on the ageing behaviour. For example, the influence of the increase in power output in the period up to 2002 and the trend in the relevant water chemistry parameters, such as the content of chloride and sulphate, since commissioning in respect of its influence on the ageing behaviour. An important milestone here is the introduction of the Hydrogen Water Chemistry (HWC) with noble metal injection to prevent stress corrosion cracking (abbreviated as: OLNC (On-line Noble Chem) operating mode).

Operational events, such as scrams, temperature and pressure transients and pressure tests on the RPV are considered in the fatigue monitoring in relation to the load transients specified during design.

<u>Research programmes:</u>
Where RPV ageing management is concerned, the results from the following research programmes are particularly relevant (see also Section 2.1.2.4).

- EPRI project BWRVIP: This relates to an internationally recognised research project, that carries out research into environmentally assisted crack growth and component integrity, on the basis of which inspection and mitigation recommendations are formulated.
- PSI project SAFE: The project deals with materials problems, especially in respect of crack corrosion and fatigue in the structural materials of light-water reactors. The relevance of the current research results relates to the ageing behaviour of welds on nickel-based alloys, austenitic steels and low-alloy RPV steels.
- PSI project NORA: This project investigated the platinum deposition on samples that were stored in the laboratory and primary cooling water of the KKL NPP. Based on the findings, the OLNC injecting, which was introduced to protect RPV components (and internals) against stress corrosion cracking, was modified to improve its protective effect.
- OECD project CODAP: The information made available in this database on damage occurrences on mechanical equipment is systematically evaluated as external operating experience.

<u>Internal and external operating experience</u>
The evaluation of the internal and external operating experience is used in ageing management to learn from the operating experience of KKL and other plants (and in so doing to identify possibly unexpected ageing phenomena).

The evaluation of internal operating experience is based on the evaluation of non-conformance reports, plant modifications, maintenance reports and other relevant sources, such as the monitoring of water chemistry parameters. Additionally, information gained in TQM Process 50602, Internal Operating Experience, is taken into account.

External operating experience and reports on external operating experience collected in line with TQM Process 50603 are traceably documented in the AMP. They are also analysed, systematically evaluated in respect of their ageing relevance and (if relevant) considered in the assessment. Of particular interest here are reports from General Electric, the Original Equipment Manufacturer (OEM). In addition to the reports collected in the plant on external operating experience, the OECD CODAP database and information from the IGALL are evaluated and used for ageing assessment

5.1.3 Monitoring, testing, sampling and inspection activities

Based on the following table the measures for ageing management of the RPV components are described in more detail:

Components / location	Ageing mechanism	Monitoring measures
Cylindrical part of the pressure vessel		
Attachments on inner cladding	Stress corrosion cracking	ISI: Visual inspection (VT-1, IVVI)
Welding of the core support structure	Stress corrosion cracking	ISI: Visual inspection (VT-1, IVVI)
Base metal in the beltline	Embrittlement by neutron irradiation	ISI: Mechanized ultrasonic inspection
Weld material in the beltline		
Inner cladding	Thermal embrittlement of stainless steel casting and welded structure	ISI: Visual inspection (IVVI, VT-1) in the area of the attachment welds
Attachments on inner cladding	Thermal embrittlement of stainless steel casting and welded structure	ISI: Visual inspection (VT-1, IVVI)
RPV head and bottom		
Bottom penetration of the housing for control rod drives and in-core monitors	Fatigue as a result of operating transients	Fatigue monitoring ISI: Mechanized visual inspection (VT-2/VT-3, leak monitoring)
Welds of the nozzles for core differential pressure and for standby liquid control	Fatigue as a result of operating transients	ISI: Mechanized visual inspection (VT-3) Fatigue monitoring
Head bolts	Fatigue as a result of operating transients	ISI: Mechanized eddy current inspection, magnetic particle inspection Fatigue monitoring
Bottom penetration of the housing for control rod drives and in-core monitors	Stress corrosion cracking	ISI: Mechanized visual inspection (VT-2/VT-3)

Components / location	Ageing mechanism	Monitoring measures
Welds of the nozzles for core differential pressure and for liquid level monitoring	Stress corrosion cracking	ISI: Mechanized visual inspection (VT-2/VT-3)
Vessel nozzles		
Feedwater nozzles, in the area the safe end	Fatigue as a result of the thermal stratification	ISI: Mechanized ultrasonic inspection Fatigue monitoring (special instrumentation)
Inner cladding of the feedwater nozzles	Fatigue as a result of the thermal stratification	Fatigue monitoring (special instrumentation)
Inside radius of the feedwater nozzles		ISI: Mechanized ultrasonic inspection
Welds on pipework	Stress corrosion cracking	ISI: Mechanized ultrasonic inspection ISI: Mechanized eddy current inspection ISI: Surface crack inspection on the outer surface
Safe Ends	Stress corrosion cracking	ISI: Mechanized ultrasonic inspection ISI: Mechanized eddy current inspection ISI: Surface crack inspection on the outer surface
Safe ends on pipework, welds on pipework safe ends"	Thermal embrittlement of stainless steel casting and welded structure	ISI: Mechanized ultrasonic inspection ISI: Mechanized eddy current inspection ISI: Surface crack inspection on the outer surface

Overview of monitoring measures

ISI = In-service inspection programme

VT-1 = Targeted inspection for surface defects, such as breaks, cracks, erosion, corrosion or wear according to the SVTI Specification NE-14

VT-2 = Inspection for leaks or leak indications

VT-3 = Inspection for deformation, corrosion, erosion or wear

IVVI = In Vessel Visual Inspection, inspection for surface defects in the filled reactor

<u>In-service inspection programme:</u>

In KKL, a comprehensive inspection programme is implemented in accordance with the applicable regulations (NE-14 [13] or ENSI-B06 [20]) for all safety classified components. The requirements of the regulations primarily consider known damage mechanisms, their identification using non-destructive testing methods and their consequences. Trending is carried out for indications that are subject to registration. For this purpose, the results of the latest inspections are compared with previous inspections(s) to identify any changes. This comparison means that changes can be identified before the assessment threshold is reached.

With reference to the previous table, the following inspections are performed:

Type of inspection	Interval and scope	Acceptance criteria
Visual inspection	RPV internals according to the specifications of the EPRI project BWRVIP (IVVI, indirect VT-1) Penetrations of the control rod drive housing and housing for the core monitoring in the RPV bottom (indirect VT-2/VT-3, leak monitoring), annually	According to ASME XI, IWB- 3520 or fracture mechanics analysis (Flaw Evaluation Handbook)
Mechanized ultrasonic inspection	All welds of the RPV, 100% volumetric every 10 years. Included is the base metal on both sides of the weld over 1/2 the wall thickness Nozzle welds and nozzle inside radius every 10 years	According to ASME XI, IWB- 3510 or analysis according to ASME XI, IWB- 3600
Mechanized ultrasonic inspection	All nozzles and safe ends, base and weld metal, 100 % of all inspectable areas at the same interval as dissimilar metal welds of the nozzle in question Dissimilar metal welds with nickel-based alloy, base and weld metal: the inspection intervals are defined in a maintenance and ageing management concept accepted by the regulator and lie between 3 and 10 years	According to ASME XI, IWB- 3512 or analysis according to ASME XI, IWB- 3610 or IWB-3620 According to ASME XI, IWB- 3514 or analysis according to ASME XI, IWB- 3640
Surface crack inspection: Automated eddy current inspection Dye penetrant testing Magnetic particle inspection	All nozzles and safe ends, base and weld metal every 10 years Head bolts, 10 years	According to ASME XI, IWB- 3514 or analysis according to ASME XI, IWB- 3640

Acceptance criteria

For the early detection of possible ageing-induced damage and its development over time (‘damage progress’) the inspection engineering requirements (inspection instructions, inspection personnel and inspection equipment) have been qualified according to guideline HSK-B07 since 2008.
This is fixed in the TQM Process P0512, Qualification of Non-destructive Testing (NDT) and was developed in conjunction with the licensees, the regulator HSK or ENSI and the expert body SVTI-N. The initial position for the qualification is provided by detailed information about the components to be tested and the relevant damage mechanisms that originate from the AMP. Together with the definition of the qualification error, this ensures the effectiveness of inspections. Moreover, the qualification process provides evidence that the required test volumes are fully covered and the performance level of the inspection system (sensitivity) meets the requirements of the qualification. In this context, the continued development of inspection systems is considered.

<u>Surveillance program for the reactor pressure vessel:</u>
To be able to track the reduction in fracture strength that takes place with operating time due to neutron irradiation of the RPV material, neutron dosimeters and encapsulated specimen

sets comprising material identical to the RPV (Charpy, tensile and bending specimens) were inserted in the RPV at locations with a high neutron fluence prior to commissioning. After 14 operating years, the first irradiation sample set was removed and then after 24 operating years in 2008 the second irradiation sample set was removed from the RPV and then the specimens and monitors (neutron flux and thermal) tested. According to Annex 5 of the guideline ENSI-B01 [4] the relevant characteristic values for the tensile test (room and operating temperature) and Charpy impact test (as a function of temperature) taken were determined. The evaluation of the two specimen sets came to the conclusion that, based on the mechanical tests on the Charpy impact specimens, the increase in the ductile-brittle transition temperature was at the most only a few degrees centigrade, indeed, partially a reduction in the reference temperature was identified. These results cannot be traced back to the inception of a loss of material ductility, but rather result from scatter in the material data, as the comparison with the evaluation of the first specimen set indicates. For the change in the reference temperature ART
(Adjusted Reference Temperature) to 60 operating years (51 Effective Full Power Years (EFPY) a maximum value of 4 °C was determined according to US-NRC Regulatory Guide 1.99 [21]. For the value of the upper shelf energy after 60 operating years (51 EFPY a minimum value of 130 J was determined according to US-NRC Regulatory Guide 1.99. These results show that the neutron embrittlement of the RPV materials in KKL does not represent any limitations in respect of the long-term operation of the power plant. The thresholds (ART ≥ 93 °C in ¼ wall thickness, high shelf energy < 68 J) for neutron embrittlement triggering the temporary shutdown of power plants according to the DETEC ordinance SR 732.114.5 are not reached according to the current state of knowledge for a KKL operating life of 60 years.
The surveillance programme will continue based on the current state-of-the-art of science and technology. The removal time points of the specimen sets provided for testing are defined in the Leibstadt technical specification. Four further specimen sets are still available for subsequent operating years.

Fatigue monitoring:
In KKL, a fatigue surveillance programme is implemented according to the applicable guideline ENSI-B01 for the safety-classified components. The requirements of the guideline essentially consider the thermohydraulic loads, the known damage mechanisms, the measurement based data logging and storage as well as the assessment. The KKL programme is implemented using the plant instrumentation and the "FatiguePro" software package. The programme includes the following activities:

- Documenting fatigue-related events
- Determinating the current level of fatigue usage
- Analysing of whether the loads occurring are conservatively covered by the originally specified loads
- Identifying possibly fatigue-relevant, originally not specified loads
- Implementing and recording of additional monitoring measures
- Deriving necessary actions, if specified acceptance criteria are exceeded

The monitoring takes place by recording, permanently storaging and evaluation of the number of fatigue-relevant events that occur by measuring the relevant pressure and temperature transients using the operational instrumentation. Special instrumentation is installed to monitor the fatigue due to thermal stratification at all six feedwater nozzles.

The result of the monitoring is determination of all the current fatigue usage factors due to the actually occurring transients in KKL over the entire operating period. The fatigue usage trend based on the existing operating duration is used to obtain a forecast for the coming operating years. These analyses are updated annually, documented in the form of a technical report and submitted to the regulator for information.

In this way, given the current operating mode of the plant, it can be shown that the calculated fatigue level will remain in the permissible fatigue usage range ≤ 1 during the following assessment period and beyond. The monitoring is on-going and should this acceptance criterion be exceeded during the planned operating period of the plant based on the compiled analysis, suitable measures can be implemented in a timely manner, such as additional non-destructive tests or mechanical retrofitting.

<u>Monitoring of the water chemistry:</u>
This programme monitors compliance with the specified water chemistry parameters in the reactor water and, based on this, the quality of the reactor water chemistry is ensured by appropriate actions. Where ageing management of the reactor pressure vessel is concerned, the content of sulphates and chlorides in the reactor water is kept as low as possible to counter the occurrence of stress corrosion cracking. These parameters are monitored by regular sampling three times per week and continual conductivity measurements; the maximum permissible values are specified in a plant-internal specification for chemical quality requirements.
The trends of these essential parameters is monitored and presented in each monthly report. Decision criteria for the implementation of measures should specific action levels be exceeded are based on the specifications of the EPRI Water Chemistry Guideline for Boiling Water Reactors [19] and the technical specification of the power plant. If action and limit levels are exceeded, actions must be implemented which, depending on the type of deviation, extend as far as the immediate shutdown of the power plant. The chemistry laboratory is responsible for carrying out the actions required for control of the parameters and their documentation (monitoring of the chemistry).

<u>Provisions for detecting unexpected damage</u>
Information about unexpected damage can be obtained through the regular evaluation of internal and external operating experience and the feedback process in general for updating ageing management (refer to Section 2.2, Review and update of the overall AMP) and, based on such information, adaptations can as necessary be made to the ageing management. In addition, according to Specification NE-14 [13], an overall inspection programme on the RPV is carried out that exceeds the scope of the described ageing management activities. This means that a large number of items are repeatedly inspected, for which no relevant ageing mechanism is identified.

5.1.4 Preventive and remedial actions

Actions that have been executed or implemented so far are described below.

- <u>On-Line Noble Chem procedure with Hydrogen Water Chemistry</u>
  This procedure is based on continuous injection of hydrogen and additional injection of noble metals into the feedwater. The modifications necessary to the plant are carried out based on process P06, Plant Modification. The OLNC procedure means that the electrochemical potential (ECP) at the metal surfaces in contact with the reactor water is effectively lowered and consequently the initiation and advance of stress corrosion cracking is prevented or delayed. The monitoring of the effectiveness of the procedure is carried out by measuring the ECP in the recirculation line, the oxygen and hydrogen dissolved in the reactor water and feedwater and the availability over time of hydrogen injection based on process P01. Assessment of the effectiveness is based on EPRI specifications and is carried out annually based on the internationally established EPRI indicators (‘mitigation performance indicators for OLNC+HWC’) [19].

- Weld overlay
  In August 2012, a non acceptable ultrasonic indication, according to ASME Section IX, was found on a dissimilar metal weld of the feedwater nozzle (according to the TQM Process P0505, In-Service Inspections). Based on TQM Process S602, Internal Events and Findings, this triggered the procedure for internal event processing. Alongside the notification requirement and the in-depth event analysis, the process triggered a maintenance task for repair within the framework of process P0502, Planned Maintenance. The nozzle was repaired in the presence of the expert body and regulator by means of a Full Structural Weld Overlay with the corrosion-resistant nickel alloy Inconel 52M. Alongside the ASME Code, Section III, Subsection NB, the essential bases for qualification and performance of the repair were the ASME-Code Case N-740-2 and ENSI Guideline ENSI-G11 [6].

In addition to the already performed action, the following actions were or will be prepared for application:

- Mechanical Stress Improvement of Dissimilar Metal (DM) welds
  KKL has developed a concept for stress improvement of the feedwater nozzle weld using the MSIP (Mechanical Stress Improvement Process) which was approved by the regulator in May 2017. KKL is now preparing the technical specification for the MSIP for approval by ENSI. Alongside ASME Code, Section III, Subsection NB, the essential bases for qualification and performance of the mechanical strengthening are the ASME-Code Case N-770-1 and ENSI Guideline ENSI-G11 [6].
- Preparation of the roll repair
  The roll repair procedure (roll expansion) is an internationally recognised method for leak sealing in the area of the bottom head penetration of the housing of the control rod drives and in-core monitors. In recent years, KKL has drawn up all documents to qualify the procedure in a preventive fashion and submitted them to ENSI for approval.
  The essential bases for the qualification and implementation of the roll expansion procedure are ASME-Code Case N- 730, N-769, N-769-1 and ENSI Guideline ENSI-G11 [6].

5.2 Licensee's experience of the application of AMPs

The following experience from internal and external sources has led to adaptations with direct reference to the relevant components of the RPV [2]:

- Bottom head penetrations:
  Due to the leaks occurring at the bottom penetrations of US-American designed BWRs, an annual mechanized visual leak inspection of all penetrations has been performed since 2006 using a pivoting colour zoom camera during the main annual outage. As already described in Section 5.1.4, the OLNC injection in use since 2008 has prevented the occurrence of stress corrosion cracking. Additionally, in KKL a suitable repair method, namely the roll expansion method, has been qualified, which in the event of a leak would be put into use.
- Vessel nozzles[6]:
  A concept for the maintenance and ageing management of the nozzle welds at the RPV using Inconel weld metal has been prepared and accepted by the regulator in connection with the 2012 findings in a feedwater nozzle. It was possible to demonstrate that an occurrence of non-acceptable indications can be prevented by adjusting the ultrasonic inspection intervals.

[6] The single line operating mode introduced in 1985 for preventing fatigue-relevant loads on the feedwater nozzles will not be described in any more detail here. Nevertheless, this example shows that long before the introduction of the AMP in 1992, relevant ageing mechanisms were already identified and their effects contained through the taking of appropriate actions

Summarising, it can be stated that based on current knowledge, the relevant ageing mechanisms for all components of the RPV are identified. The occurrence of ageing effects caused by the ageing mechanisms can now be detected in a timely manner based on the implemented monitoring actions and thus controlled in a satisfactory manner. In addition to the ageing management activities, preventive and remedial actions such as the ONLC applications and the preparation of the roll expansion procedure at the bottom penetrations, have been carried out or are in progress. As described in Section 2.4 Review and update of the overall AMP, experience and findings in KKL and in other plants are continuously monitored so that if necessary the ageing management of the reactor pressure vessel can be adapted.

6. Concrete containment structures

The following table presents the reference between the WENRA [2] specification and the ENSI directive [1] with the subsections of the section ‘Concrete Containment Structures’:

Number and title of the section			
WENRA specification		**Report BET/17/0117**	
7	Concrete containment structures	6	Concrete containment structures
7.1	Scope of ageing management for concrete structures	6.1	Description of ageing management programmes
7.1.1	Scope of ageing management for electrical cables	6.1.1	Scope of ageing management
7.1.2	Ageing assessment of electrical cables	6.1.2	Ageing assessment
7.1.3	Monitoring, testing, sampling and inspection activities for electrical cables	6.1.3	Monitoring, testing, sampling and inspection activities
7.1.4	Preventive and remedial actions for electrical cables	6.1.4	Preventive and remedial actions
7.2	Licensee’s experience of the application of AMPs for electrical cables	6.2	Licensee’s experience of the application of AMPs

6.1 Description of ageing management programmes

6.1.1 Scope of ageing management for concrete structures

With reference to the Topical Review specification [2], Section 7, the following components of the concrete containment are to be considered:

- Reinforced concrete shielding building
- Reinforced concrete containment base mat

Based on guideline ENSI-G01 [5], these structures are assigned to BK1.

The following structures from [2] are not considered in KKL because they are fitted neither in the shield building under consideration nor in the base mat:

- Pre-tensioning systems
- Liners
- Connection elements between the liner and the concrete structure, such as anchors in the concrete (e.g. bolts or other steel components) or anchors in the foundation slab of the containment

The **concrete containment structure** comprises the shielding building wall and the containment base mat (see Annex 2). The shielding building with a wall thickness of 1.20 m, a diameter of 42 m and an overall height (including the dome) of about 65 m is completely separated from the surrounding auxiliary building ZC1 and the fuel building ZD1 by a 5 to 10 cm wide gap. It forms the outer structure of the reactor building and protects all internal structures against external forces. Important external accidents or external effects are: Safe shutdown earthquake and aircraft impact. The structure fulfils the following requirements:

- Absorbing of the loads of building and system components in accordance with the load plan
- Dissipation of these loads into the containment base mat
- Enclosure of the primary containment
- Air tightness (slight internal vacuum under operation)
- Absorbing internal excess pressure in an accident
- Retention of radioactive materials

The containment **base mat** is circular. It is made from reinforced concrete and serves as a platform for all building parts of the reactor building. Its diameter is 42 m and thickness 4.50 m. On the surface it is clad with a leak-tight skin, the bottom line and stands on a drainage and sealing layer. If is completely separated from the surrounding auxiliary building by a 5 – 10 cm wide gap. The structure fulfils the following requirements:

- Absorbing the loads of building and system components in accordance with the load plan
- Dissipation of these loads into containment base mat
- Protection and surrounding of the primary containment
- Air tightness (slight internal vacuum under operation)
- Absorbing internal excess pressure in an accident
- Retention of radioactive materials

All known civil engineering ageing mechanisms for the relevant building materials are listed in a GSKL guide created and kept up to date by all Swiss NPPs. Using this as a basis, the following building structures of the concrete containment are periodically checked and assessed:

- Weathered external concrete structures
- Internal concrete structures
- Reinforcement steel

The relevant ageing mechanisms are identified in the mentioned guide for these civil engineering structures and components (Annex 3).

6.1.2 Ageing assessment

Ageing management is performed based on Guideline ENSI-B01 [4]. The basis for the ageing management programme in Swiss NPPs is the guide of the GSKL civil engineering group. This was last revised in 2015 by the GSKL AMP civil engineering expert team and then approved by the regulator. It contains the most important basic documents for ageing management and defines the layout of a fact sheet and the scope of the AMP. The stressors, the ageing mechanisms and the resulting consequences for the concrete structures, i.e. the concrete and the reinforcement steel, are likewise described in the GSKL civil engineering guide.

The most important underlying documents for the GSKL civil engineering guide are in particular:

- Guideline ENSI-B01, Ageing Management
- Guideline ENSI-B02, Periodic Reporting of Nuclear Installations

- SIA 269:2011 Principles, Preservation of supporting structures
- SIA 469:1997, Preservation of structures
- SN EN 13306:2010, Maintenance - maintenance terms and definitions
- SIA 260:2013, Principles of the planning supporting structures

Fact sheets specific to civil engineering are created by the nuclear power plants. They list the respective building materials and the corresponding relevant ageing mechanisms. Additionally, they define the target condition levels for civil engineering structure parts. The section ‘List of documents’ contains the drawings, structural engineering calculations and reports.

The ageing mechanisms most significant for the outer envelope of the containment are:

- Frost: on porous outer surfaces and on areas re-profiled during maintenance or mended areas, damage caused by penetrating and freezing water occurs. This damage is highly localised. The possibly affected structures are monitored and can be repaired with a minimum of effort and cost.
- Carbonation: The loss of alkalinity and the resultant possible loss of corrosion protection of the reinforcement is probably the most important ageing mechanism. Structures that may be affected are monitored, and provided any intervention is performed in a timely manner, the effects of carbonation can be controlled without any corrosion damage.

Annex 3 lists and describes the relevant ageing mechanisms for the concrete containment structures under consideration as well as the reinforcement steel.

Internal and external operating experience and changes to the current state of the art are discussed in the GSKL AMP civil engineering expert team and classified according to their ageing relevance. The new findings of relevant events are recorded and included in ageing management. A summary of the evaluated findings is given in the annual safety report of the individual NPPs. Additionally, internal and external operating experience is first independently evaluated in KKL independently of the GSKL AMP civil engineering expert team. New findings found here in turn are fed back to the expert team.

6.1.3 Monitoring, testing, sampling and inspection activities

The basis for the ageing management programme of the Swiss NPPs is the guide of the GSKL AMP civil engineering expert team. The general inspection plan for civil engineering structures is defined in the guide. The inspection plan specific to civil engineering structures is individually presented in the plant-specific fact sheets. The base inspection is the first main inspection and takes place at the beginning of a civil engineering structure inspection programme. Intermediate and main inspections take place alternately at 10-year intervals. A supplemental inspection can be carried out at any time for any given reasons.

The focus of the inspections is to determine the current condition of the civil engineering structures and components. The aim of the investigations is to determine the current state in respect of nuclear safety plus to be able to assess the fitness for purpose and to make possible a comparison with the target state and the results from earlier inspections (‘trending’).

Possible detection methods for the different materials are described together with the aims of the investigations in the guide. The selection of the detection method is dependent on the type, scope and aim of the inspection and is defined by qualified specialist personnel. The following procedures are used for assessment of the reinforced concrete:

- Key to the inspections is a visual inspection of the concrete structure. In the visual condition analysis, an inspection is performed to see whether cracks, spalling, inhomogeneous surfaces, efflorescence or discoloration are present. Crack widths are determined using a crack width comparison standard. The position of the findings are entered on drawings and summarised in tables in the findings inventory. The most striking points are photographed and documented.

- Moreover, to assess the risk of corrosion, the covering of the reinforcement is measured and compared with the carbonation depth determined from drilled cores. Further, laboratory tests are carried out on the drilled cores, such as determination of the concrete density, the compressive and tensile strength and, based on microsections, determination of the microstructure quality.
- Upon suspicion of, and to identify active reinforcement (“Rebar”) corrosion, electrical potential measurements and electrical potential field measurements are taken on rebar .

The evaluation of the acceptance criteria yields the condition levels. The following table provides a general description of the condition levels.

Evaluation	Description
1: Very good condition	The defect/damage has no influence on the durability, structural integrity and nuclear safety of the component/civil engineering structure. No measures are needed for repair.
2: Good condition	The defect/damage may limit the service life and/or the structural integrity of the component in the long-term. Nuclear safety is ensured. Repairs are required in the long-term.
3: Adequate condition	The defect/damage limits the service life and/or the structural integrity of the civil engineering structure/component, the nuclear safety may be affected. Repairs are required in the medium-term may also be needed in the short-term to prevent the damage from spreading.
4: Inadequate condition	The defect/damage will limit the service life and/or the structural integrity of the civil engineering structure/component. The deviations in component condition, material quality or component dimensions have reached the tolerance limits. Nuclear safety may be affected. Repairs must be performed at short notice.
5: Poor condition	The defect/damage will considerably limit the service life of the civil engineering structure/component. The deviations in component condition, material quality or component dimensions have exceeded the tolerance limits. Nuclear safety may be affected. Repairs must be performed immediately.

The GSKL guide also contains condition tables with direct reference to the assessed materials, such as concrete or steel.

Alongside the periodic inspections, plant walk-downs are performed both by plant staff and also by the authorised civil engineering experts.

Unexpected anomalies during the inspections are documented and evaluated. If necessary, special inspections are carried out. The assessment of the resulting findings together with the regular evaluation of the external operating experience represent a precaution against unexpected damage.

The results of the ageing management, that is the results of the visual in-situ inspection of the components and the materials science investigations, are recorded in inspection reports. The summaries of the results are documented in the fact sheets. The findings are evaluated and compared with the target condition of the individual civil engineering structures given in the civil engineering guide. The findings are acceptable when the most recently determined condition level at least corresponds to the permissible condition level. In general for the components considered here, this is condition level 2.

6.1.4 Preventive and remedial actions

Findings thus far are generally acceptable in respect of their permissible condition level and are evaluated by civil engineering and incorporated in the maintenance plan, where it can be assumed that they could, within an inspection interval, fall to a condition lower than the permissible condition level due to degradation. Minor damage such as local concrete spalling, efflorescence, corrosion points is, however, frequently repaired on an ongoing basis because, in general, the degradation increases exponentially and waiting would not be economical. Frequently ‘cosmetic’ considerations also trigger on-going repairs because the ethos at KKL is one of maintaining a clean and tidy appearance.

A hydrophobising water-repellent treatment has been applied to the outer surface of the concrete containment as a preventive action. This action retards the ingress of water, humidity and CO_2, so that the progress of carbonation and the risk of reinforcement corrosion are reduced

6.2 Licensee’s experience of the application of AMPs

The new guideline for ageing management, ENSI-B01, which came into force in 2011, resulted in the revision and updating of ageing management in the civil engineering area. Thanks to the close cooperation between the plants and ENSI, the guides for the civil engineering fact sheets were revised within just a few years, and brought up to date in terms of the latest state-of-the-art of science and technology (concluded end of 2015). The new ageing management guideline ENSI-B01 and the associated updating of the guide for the civil engineering fact sheets have not resulted in significant omissions being detected in the methodology nor in the overall ageing management programme having to be adapted.

The ageing management as it has been applied with periodic inspections in KKL, has not thus far revealed any unexpected findings due to ageing that would require an adaptation of the AMP or the investigation methods.

As part of the collaborative work in the GSKL civil engineering group, experience in ageing management, ageing mechanisms and investigation methods and knowledge about the state of the art is exchanged. The exchange in this platform likewise confirms that the applied methodology is successful. According to this exchange, no unexpected ageing events have arisen at any other Swiss plants.

The inspections certify all civil engineering structures and the components being evaluated in KKL as either of condition 1 or 2. In a few cases, condition 3 is assessed on a local basis, which generally also triggers a repair. This good to very good quality of the civil engineering structures and components is a result of the good design of the plant but also of appropriate and effective ageing management as an important accompanying measure in the defence in depth safety concept.

7. Overall assessment and general conclusions

The overall AMP was developed at a relatively early stage in all relevant areas by the GSKL AMP working group, with all Swiss NPPs participating actively from the beginning. In KKL, this overall AMP is implemented based on the principles prepared by the GSKL working group. The common GSKL documents are regularly reviewed and updated by the working group. The changes made are either adaptations to the AMP resulting from changed regulatory requirements or adaptations to the subject-specific documents, so that their content is matched to the current state-of-the-art of science and technology and the latest codes and standards.

In KKL, the AMP represents an essential, systematic complement to the existing maintenance programme and is continually updated:

- Ageing management in KKL identifies the relevant ageing mechanisms for safety-relevant components and structures and based on this, the existing programmes are reviewed to determine whether ageing-induced damage can be avoided or detected at an early stage. Any omissions revealed by the check are closed in a traceable manner.
- Embedding this in the national and international activities of GSKL's working group ‘AMP in Swiss NPPs’ ensures that the state-of-the-art of science and technology in the fields of materials and structural ageing as well as their analysis and diagnostic technology will continue to be considered in future.

The AMP is established in KKL and has proven its worth. The programme is continually updated based on a specified procedure. This updating will ensure that ageing management tasks continue to be reliably fulfilled in the coming years.

Summarising, it can be stated that based on current knowledge, the relevant ageing mechanisms for all structures and components (considered in this report) are identified. The occurrence of ageing effects caused by the ageing mechanisms can be detected in a timely manner based on the implemented monitoring actions and consequently appropriate counter-measures can be put into effect. Moreover, experience and findings both in KKL and in other plants (fleet experience) are continuously monitored so that ageing management can be adapted as necessary

8. Annexes

Annex 1	Reactor Pressure Vessel: Component Information and general outline
Annex 2	Containment: Cross-section view
Annex 3	Excerpts from the guide of the GSKL AMP civil engineering expert team

9. List of abbreviations

ANIS	Plant Information System
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AMP	Ageing management programme for the Swiss nuclear power plants
BWRVIP	Boiling Water Reactor Vessel and Internals Program of EPRI
CH-KKW	Swiss nuclear power plants
CODAP	Component Operational Experience, Degradation and Ageing Programme of the NEA/OECD
ECP	Electrochemical Potential
ENSI	Swiss Federal Nuclear Safety Inspectorate
EPRI	Electric Power Research Institute
EQDB	Equipment Qualification Data Bank
EFQM	Quality management system of the Total Quality Management (TQM) of the European Foundation for Quality Management
EROSKO	Systematic testing programme for monitoring of erosion-corrosion
GSKL	Group of Swiss nuclear power plant managers
IAEA	International Atomic Energy Agency
IBIS	Integrated plant management and maintenance system
I&C	Instrumentation and control
IEEE	Institute of Electrical and Electronics Engineers
IFT	Instrumentation function test
IGALL	International Generic Ageing Lessons Learned (project and programme of the IAEA)
IVVI	In Vessel Visual Inspection
KATAM	Catalogue of ageing mechanisms of mechanical equipment
KEV	Nuclear Energy Ordinance
KKL	Kernkraftwerk Leibstadt AG
LEAP	Life Expectancy Analyses Programme
LIRA	Resonance Analysis method
LOCA	Loss of Coolant Accident
MI	Mineral insulated
MOSI	Daily morning meeting
MS	Medium voltage
NDE	Non-destructive Evaluation Program of EPRI
NORA-II	Project Noble metal deposition behaviour in BWR's

NMAC	Nuclear Maintenance Applications Center of EPRI
NS	Low voltage
OLNC	Hydrogen operating mode with noble metal injection for the prevention of stress corrosion cracking, Online Noble Chem
PLiM	Project Plant Life Management
PSA	Probabilistic Safety Analysis
PSI	Paul Scherrer Institut
RDB	Reactor Pressure Vessel
SAFE-II	Project 'Safe long term operation in the context of environmental effects on fracture, fatigue and environmental assisted cracking'
SFT	System Function Test
SK	Safety Class
SPN	Swiss Pool for insurance of nuclear risks
SSK	Systems, Structures and Components
swissnuclear	Nuclear energy expert group (the former Organisation of Swiss Federation Electricity Companies swisselectric)
SVTI-N	Nuclear Inspectorate in Switzerland
TDR	Time Domain Reflectometry
TQM	Total Quality Management, ISO 9001 certified quality management system in KKL
TÜV	Technical Inspection Agency
NRC	Nuclear Regulatory Commission, USA
VGB	Fachverband für die Strom- und Wärmeerzeugung (Professional association for CHP)
WANO	World Association of Nuclear Operators
WENRA	Western European Nuclear Regulators Association
WHP	In-service inspection programme
WKA	Recurring work
WRTC	Welding & Repair Technology Center of EPRI NDT
NDT	Non-destructive testing

10. References

[1] ENSI, Directive: Participation in the Topical Peer Review 2017 'Ageing Management of Nuclear Power, letter of 14/03/2017

[2] WENRA, Topical Peer Review 2017 Ageing Management Technical Specification for the National Assessment Reports, December 2016, in reference [1] or: http://www.wenra.org/media/filer_public/2017/05/15/2016-12-21_tpr_specification_final.pdf

[3] ENSI, Guideline ENSI-B10, Vocational training, Recurrent Training and Continuing Education of Personnel, current version: 01/10/2010

[4] ENSI, Guideline ENSI-B01, Ageing Management, current version: 01/08/2011

[5] ENSI, Guideline ENSI-G01, Safety Classification for Existing NPPs, current version: 01/01/2011

[6] ENSI, Guideline ENSI-G11, Safety classified vessels and pipes: Planning, production and assembly, current version: 01/06/2013

[7] ENSI, Guideline ENSI-A06, 01/11/2015, Probabilistic Safety Analysis (PSA): Applications, current version: 01/11/2015

[8] US-NRC, Generic Aging Lessons Learned (GALL) Report — Final Report (NUREG-1801, Revision 2), December 2010 (First issued in 2001)

[9] IAEA, Safety Report SRS No. 82, Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned (IGALL), Revision 0, 30/04/2015

[10] ENSI, Guideline ENSI-B02, Periodic Reporting of Nuclear Installations, current version: 30/06/2015

[11] ENSI, Guideline ENSI-A03, Periodic safety review of nuclear power plants, current version: 01/10/2014

[12] IAEA, Safety Guide No. NS-G-2.12, Ageing Management for Nuclear Power Plants, Rev. 0, 31/12/2009

[13] SVTI Specification NE-14, Repeat tests on mechanical components subject to nuclear acceptance testing of safety classes 1 to 4, current version: 01/01/2005

[14] ENSI, Guideline ENSI-A03, Periodic safety review of nuclear power plants, 01/10/2014

[15] IEC/IEEE 62582-3 :2012, Nuclear power plants - Instrumentation and control important to safety - Electrical equipment condition monitoring methods - Part 3: Elongation at break

[16] EPRI, Report 1020804, Plant Support Engineering: Aging Management Program Development Guidance for AC and DC Low-Voltage Power Cable Systems for Nuclear Power Plants, 02/06/2010

[17] EPRI, Report 1020805, Plant Support Engineering: Aging Management Program Guidance for Medium-Voltage Cable Systems for Nuclear Power Plants, 03/06/2010

[18] IEEE Std. 400.2, IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF)

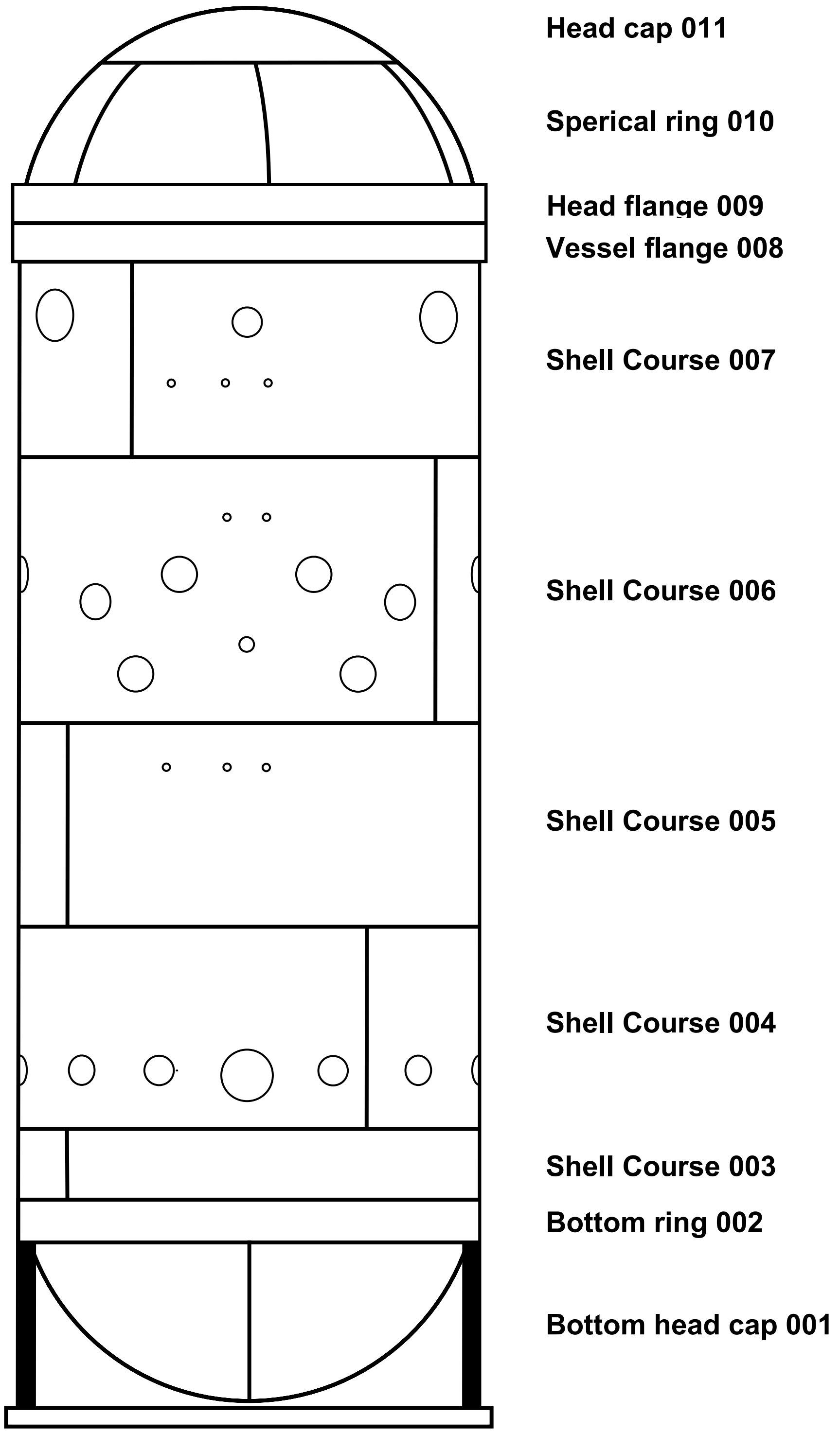
[19] EPRI, Report 3002002623, BWRVIP-190 Revision 1: BWR Vessel and Internals Project, Volume 1: BWR Water Chemistry Guidelines - Mandatory, Needed, and Good Practice Guidance and Volume 2: BWR Water Chemistry Guidelines – Technical Basis, 24/04/2014

[20] ENSI, Guideline ENSI-B06, Safety classified vessels and pipes: Maintenance, 01/06/2013

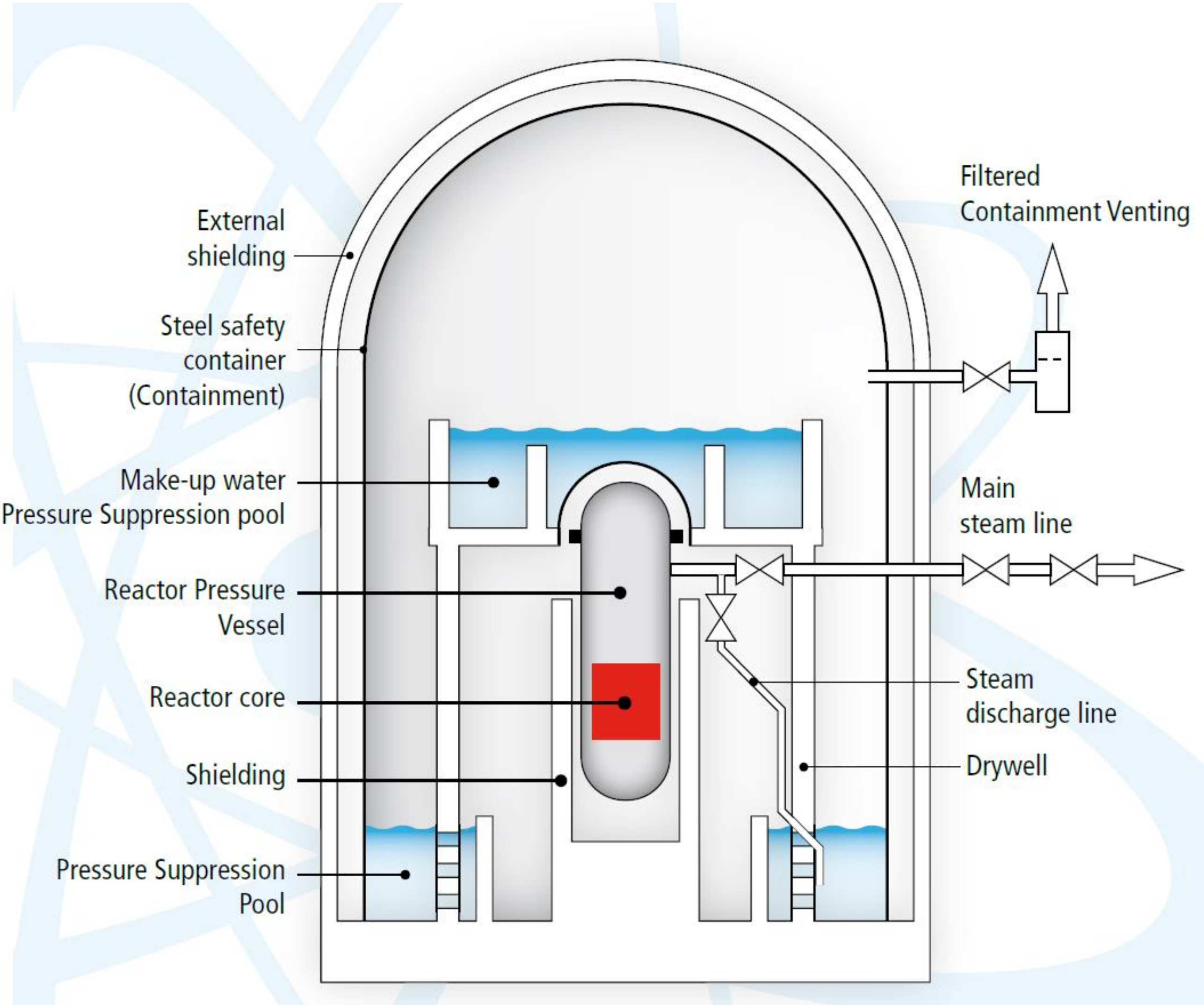
[21] US-NRC, Regulatory Guide 1.99: Radiation Embrittlement of Reactor Vessel Materials, Mai 1988

Reactor Pressure Vessel:
Component Information and general outline

System	Nuclear Steam Supply System
Component	Reactor Pressure Vessel
Reactor type	Boiling Water Reactor
Plant identifier	YC00B001
Safety class	1
Seismic category	I
Medium	Reactor water
Operating / design temperature	288 / 300 °C
Operating pressure / design pressure	72 / 80 bara
Material of the strakes and plates	SA-533 Grade B Class 1
Flange material	SA-508 Class 2
Nozzle material	SA-508 Class 2
Cladding material	RPV inner side: SAW-ER309L Vessel flange SAW-ER309L Head flange SAW-ER308L Inside N5-nozzle E308L-16(E)


Head cap 011
Sperical ring 010
Head flange 009
Vessel flange 008
Shell Course 007
Shell Course 006
Shell Course 005
Shell Course 004
Shell Course 003
Bottom ring 002
Bottom head cap 001

Containment: Cross-section view



Excerpts from the guide of the GSKL AMP civil engineering expert team

Ageing mechanisms for concrete and reinforced concrete

Influence and phenomena	Ageing mechanism	Consequences
Temperature	Constraint stresses and deformation in the presence of temperature differences, which promote crack formation.	Cracks and spalling due to excess stresses E.g. if expansion joints are incorrectly configured. Deformations are reversible.
Moisture, water	Moisture plays an important role in all physical effects	On its own, moisture does not cause any damage
Frost	This effect is the underlying cause of complex microscopic and macroscopic interactions. The pore fluid of concrete contains a large number of dissociated ions, which reduces the freezing point. Moreover the freezing point of the pore water falls even further, the smaller the pores	The phase transition from water to ice is associated with a 9 % increase in volume, which results in a hydraulic pressure in the concrete structure. The consequence is spalling of components due to volume expansion.
Thawing agent	Both carbon dioxide and chloride react with the calcium hydroxide of the cement stone, chloride however primarily with the aluminate phases to form Friedel's salt. Through the stable binding of calcium hydroxide in calcite and aragonite, carbonation reduces the chloride binding capacity of the concrete. Additionally the carbonation of the concrete destroys the protective passive layer on the steel surfaces so that even very low concentrations of chloride attack the steel. Therefore for carbonated concrete, the corrosion triggering chloride content must lie below the limits specified for the non-carbonated concrete.	Criteria for corrosion risk are carbonation, chloride loading and the relative pore humidity of the concrete.

Influence and phenomena	Ageing mechanism	Consequences
Shrinkage, swelling	Cement based materials are deformed by changes in the moisture content in the pores. Drying out is referred to as early shrinkage or also, in the absence of after-treatment, as plastic shrinkage and the supply of moisture as swelling. The change in moisture content can take place as a result of capillary water transport or diffusion.	Cracks, deformation, partially reversible with moisture changes
Load, static	The overall change in shape of concrete under external load can be subdivided into immediately occurring (elastic) and delayed (elastic and plastic) parts. The sum of the changes in shape is referred to as elastic if it is reversible, and largely as plastic when it is irreversible. Concrete only behaves in an approximately elastic manner. If the load is removed after just a short application, there will still be permanent strain	Deformation and/or crack formation, decrease in Young's modulus
Load, dynamic	Material fatigue, promoting of cracking	Reduced high load bearing capacity and cracking possible
Settlement	Deformations and load shifting	Cracking, local overloading
Carbon dioxide (CO_2)	Carbonation refers to the chemical reaction of alkaline components of the cement with carbon dioxide to form carbonates. The reactions only take place in the presence of sufficient moisture. The pH value of the concrete pore water falls from an original value of > 12.5 to values between 6 and 9 (depending on the CO_2 content). As a result the corrosion protection of the reinforcement is lost.	These reactions change the structure and essential properties of the concrete. Particular hazard locations for the carbonate induced reinforcement corrosion are corners, edges, water courses, dripping areas of components and severe cracking but also components of small size and components with a high level of reinforcement.
Fouling	Moisture penetration and root penetration in porous areas and cracks.	Scaling possible.

Ageing mechanisms for reinforced steel and prestressed steel

Influence and phenomena	Ageing mechanism	Consequences
Oxygen corrosion	Approximately neutral, conducting and oxygen-containing water (electrolyte) acts on the metal The rate of corrosion is dependent on the oxygen supply.	Loss of load bearing capacity
Pitting/seam corrosion	Dry periods: oxide layer formation Damp periods: oxygen corrosion	Corrosion in pits
Contact corrosion (electrochemical series)	Different metals connected in a conducting manner in the same electrolyte form an electro-chemical element if potential differences are at least 250 mV.	The more noble metal is protected against corrosion, the least noble is dissolved.
Load, dynamic Load change	Fatigue and high actual load proportion relative to the total load has an unfavourable effect on steel. Fatigue strength decreases.	Fatigue fracture at areas of peak stress and changes in the material geometry (screw holes, welded seams)