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Inspection fédérale de la sécurité nucléaire IFSN
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TOPICAL PEER REVIEW

SWISS NATIONAL ASSESSMENT REPORT

AGEING MANAGEMENT IN NUCLEAR POWER PLANTS

Swiss National Assessment Report for the

Topical Peer Review

Ageing management in nuclear power plants

December 2017

Executive summary

At the end of 2016 the Swiss Federal Nuclear Safety Inspectorate (ENSI) decided that Switzerland would take part in the first Topical Peer Review (TPR) of the European Union on 'Ageing management in nuclear power plants'. The licensees of the Swiss nuclear power plants were required to submit reports with the information in accordance with the Specification of the Western European Nuclear Regulators Association (WENRA).

Sections 2 to 5 and 7 of the present national assessment report contain the information and statements from the licensee reports as integrated by ENSI with its assessment of each case. Section 9 of the national assessment report draws the conclusions and provides an overall assessment of the ageing management programme implemented in the Swiss nuclear power plants. The licensee reports are to be published together with the national assessment report at the end of 2017.

There is a total of five operating nuclear power plant units on four different sites throughout Switzerland, which are briefly presented in Section 1 of the national assessment report. As Switzerland only operates boiling water reactors and pressurised water reactors, Sections 6 and 8 of the national assessment report, which are intended for additional reactor types (CANDU and AGR), are denoted as not applicable. Switzerland also still operates one zero power research reactor. In line with the requirements of the WENRA Specification, this reactor is not addressed in the national assessment report.

Overall ageing management programme

The ageing management programme (AMP) implemented in the Swiss nuclear power plants is based on a long-standing development process that has been closely followed by ENSI. The licensees of the Swiss nuclear power plants had already been required to introduce an AMP for safety-relevant structures, systems and components (SSCs) by the former Swiss regulatory authority (now ENSI) at the end of 1991. Consequently, the licensees organised in the Group of Swiss nuclear power plant managers (GSKL) started a common project to develop an AMP on the basis of the already existing maintenance programmes. Within the framework of the GSKL project the fundamental documents for the introduction of the AMP in the electrical engineering, civil engineering and mechanical engineering fields were developed. The implementation of the AMP is done by specially-founded ageing management expert teams in each nuclear power plant. From ENSI's point of view, the structure and organisation of ageing management in the Swiss nuclear power plants and its integration into established plant programmes via existing quality and plant management systems has proven its value over time.

In 2004 the obligation of the licensees to implement comprehensive AMPs was introduced in the new Nuclear Energy Ordinance and became legally binding. The particular significance of ageing management was additionally emphasised at the legal level with the enactment of the ordinance of the Federal Department of the Environment, Transport, Energy and Communications (DETEC) in 2008. According to this ordinance, a nuclear power plant must be provisionally shut down, if unacceptable ageing damage is detected in one of the essential physical barriers: reactor pressure vessel, primary circuit, steel containment (primary containment) and reactor building (secondary containment). From ENSI´s perspective, with the specification of explicit ageing criteria in the DETEC ordinance for a provisional shutdown, a high degree of transparency for the application of general acceptance criteria is achieved.

At the same time, the requirements for systematic and comprehensive ageing management were further specified at the guideline level based on experience gained in the implementation and updating of the AMP in Swiss nuclear power plants. In 2004, general and field-specific requirements for ageing management were incorporated in a regulatory guideline for the first time. This guideline related in particular to the basic elements of a systematic AMP and to the scope of the SSCs to be included in ageing management for each field. The aging management guideline was revised in 2012. In the new guideline ENSI-B01 the scope of the safety-relevant SSCs to be included in the AMP has been expanded and, for the first time, concrete requirements for the proof of the resistance of the pressure vessel to brittle fracture as well as for the scope and evaluation of the fatigue monitoring have been included.

Guideline ENSI-B01 is closely related to other guidelines in which the requirements for the maintenance of mechanical and electrical equipment, in-service inspection of mechanical equipment, qualification of non-destructive testing and manufacturing of mechanical components are specified. Furthermore, the experience feedback necessary for systematic ageing management is regulated with other established plant programmes.

The reporting on AMP is regulated in guideline ENSI-B02. It requires a annual reporting on the status of ageing management. With this, ENSI is promptly informed about changes in the AMPs of the Swiss nuclear power plants and the resulting modifications in other inspection programmes. This allows ENSI to conduct targeted inspections on findings and to evaluate the effectiveness of the AMP. From ENSI´s perspective, the annual reporting clearly shows that the AMP in the Swiss nuclear power plants is continuously updated based on new findings from the evaluation of internal and external operating experience as well as by monitoring the state-of-the-art of science and technology.

When the revision of guideline ENSI-A03 came into force in 2014, the overall reporting on the status of ageing management, to be presented within the framework of the periodic safety review, was harmonised with the annual reporting. In addition, based on the experience obtained from the two oldest Swiss nuclear power plants, the safety case to be provided for long-term operation of the Swiss nuclear plants was included. For the extended service life it must be demonstrated among other things, that the reactor pressure vessel including the internals, the primary circuit, the steel containment and the reactor building (concrete containment envelope) are not subject to any limiting ageing mechanisms and the ageing criteria specified in the DETEC ordinance for provisional shutdown are not reached. In its previous safety evaluation reports on the periodic safety reviews and long-term safety assessments of Swiss nuclear power plants, ENSI concluded that, irrespective of identified improvement potentials, the safety-relevant SSCs are being effectively monitored based on the systematic framework of the AMP and the continuous updating of the AMP, and that the safety-relevant SSCs are in good condition.

Component specific ageing management programmes

Electrical cables

According to the basic requirements in guideline ENSI-B01 the ageing mechanisms applicable to the safety-relevant (class 1E) electrical cables must be identified. Moreover, a check must be undertaken to determine whether the existing maintenance programme is suitable for promptly detecting ageing-induced damage. According to guideline ENSI-B14, the findings from ageing management must be incorporated in the maintenance programme for electrical components within one year. Furthermore, specific requirements for the accepted methods for prediction of potential ageing effects and the proof of accident-resistance are specified in guideline ENSI-B01.

In the Swiss nuclear power plants, generic fact sheets have been created for the electrical cables that contain a list of the most important ageing mechanisms (Part 1) and possible diagnostics and testing methods as well as characteristics by which the ageing progress can be identified (Part 2). These generic fact sheets serve as a basis for the plant-specific Part 3 fact sheets which provide a particular record of the cable type, the design specification, type of cable routing, conditions of use, usage time in respect of the maintaining of accident-resistance as well as the type, scope and findings of conducted tests for the cables used in the nuclear power plant.

In ENSI`s point of view, the Swiss nuclear power plants have systematic ageing management processes and programmes for safety-relevant cables that will ensure the functionality of the electrical cables under long-term normal operating conditions and accident conditions. Through the close cooperation of the Swiss nuclear power plants in both the GSKL coordination team and the GSKL electrical engineering expert team in developing and revising the generic fact sheets, as well as in monitoring international operating experience, known ageing phenomena and the latest diagnostic methods are incorporated in the generic fact sheets. Through random checks performed during inspections, ENSI was able to convince itself that plant-specific fact sheets have been created for all cable types used in the Swiss nuclear power plants and that these sheets contain the information required according to guideline ENSI-B01. A wide spectrum of recognised and effective diagnostic methods is used in the Swiss nuclear power plants to identify the relevant ageing mechanisms. In addition to ageing management, a policy of replacing old cables with new ones during the numerous upgrades is consistently followed in the Swiss nuclear power plants.

Existing experience shows that with the AMP implemented in the Swiss nuclear power plants, the occurrence of ageing effects in electrical cables would be promptly detected and preventive measures implemented in a timely manner.

Concealed pipework

In accordance with the requirements in guideline ENSI-B01, fact sheets must be created for pipes of safety classes 1 to 3, in which the materials used, special manufacturing methods and design characteristics, operating conditions, relevant ageing mechanisms and the specific maintenance measures and the results of ageing management are to be recorded. In this context, the relevant ageing mechanisms must also be identified and the effectiveness of the established maintenance and inspection programmes must be checked for safety-classified concealed pipework sections.

Guideline ENSI-B06 defines no specific requirements for concealed pipework sections. However, findings from ageing management can lead to specific requirements for the inspection of concealed pipework.

In consultation with ENSI, the licensees of the Swiss nuclear power plants have investigated their safety related pipework for the presence of concealed sections. Taking into account the design characteristics of the Swiss nuclear power plants they came to the conclusion that the specific monitoring can be limited to of concealed pipework of safety-relevant cooling water systems which are in direct contact with river water.

As preventive remedial actions, pipe sections of such cooling water systems have been replaced or protected with anti-corrosion coating. However, with the exception of one nuclear power plant, in ENSI`s point of view, neither the background nor the effectiveness of already performed preventive and remedial actions on concealed pipework sections is presented in sufficient detail. Therefore, ENSI will extend the focus of its regulatory efforts regarding ageing management in order to make sure that all safety-relevant concealed piping systems are included and are covered by suitable maintenance and inspection programmes.

Reactor pressure vessels

All reactor pressure vessels (RPVs) in the Swiss nuclear power plants are classified as mechanical components of safety class 1 in accordance with guideline ENSI-G01. According to the requirements of guideline ENSI-B01, the RPVs must be treated in detail within the scope of ageing management, which means that the ageing mechanisms must be evaluated for the individual parts of the component.

Each Swiss nuclear power plant has a fact sheet for the RPV, which describes in detail, amongst other things, the materials used and the applied design codes, special design characteristics, the relevant ageing mechanisms and necessary maintenance measures. The ageing mechanisms are based on the GSKL catalogue of relevant ageing mechanisms prepared by the mechanical engineering departments of the Swiss nuclear power plants. From ENSI`s perspective, these fact sheets contain a systematic analysis of the internal and external operating experience with reference to the on-going research projects of ENSI relating to the relevant topics of RPV ageing management. Fatigue, neutron embrittlement and stress corrosion cracking are identified as the most important RPV ageing mechanisms.

In one Swiss nuclear power plant the fatigue usage factors are still determined manually. The other plants use integrated fatigue monitoring programmes with which temperature histories are recorded and evaluated at selected points on the RPVs. The results of the fatigue monitoring in the form of current fatigue usage factors and the corresponding levels extrapolated to 60 years of operation are submitted to ENSI annually. The existing results show that the long-term operation of the Swiss nuclear power plants is not subject to any limitations because of RPV material fatigue.

In the Swiss nuclear power plants, systematic neutron embrittlement monitoring of the RPVs is performed using irradiation surveillance specimens. The surveillance programmes cover at least 60 years of operation. ENSI agrees with the evaluation of the licensees that RPV neutron embrittlement is not a limiting factor for the long-term operation of the Swiss nuclear power plants up to 60 years of operation. The criteria of the DETEC ordinance for the provisional shutdown of nuclear power plants in respect of the minimum Charpy-V impact energy and the brittle fracture transition temperature at ¼ of the wall depth have not been reached.

Stress corrosion cracking is considered by the Swiss licensees to be a key ageing mechanism for inconel welds and austenitic welds in contact with reactor cooling water. In one Swiss nuclear power plant, an indication caused by stress corrosion cracking in a dissimilar metal weld of an RPV feedwater nozzle was identified through the in-service inspection programme. In response to this, the affected nuclear power plant adapted the maintenance programme for dissimilar metal welds and shortened the inspection intervals. As part of the regulatory process, ENSI will closely monitor the implementation of the maintenance programme for dissimilar metal welds.

In view of the above ENSI comes to the conclusion that the licensees of the Swiss nuclear power plants have so far adequately implemented specific measures for preventing or mitigating ageing effects on the RPVs based on ageing management findings.

Concrete structures of the reactor buildings

Based on guideline ENSI-B01, all structures classified according to guideline ENSI-G01 are to be included into the AMP. In line with their significance for nuclear safety and radiation protection, structures are assigned to two structure classes, BK I and BK II. Moreover, in guideline ENSI-B01, the general civil engineering requirements are specified as well as the requirements for the fact sheets related to individual buildings or building parts. Each fact sheet must comprise a general part, a structural component documentation, a description of the relevant component-specific ageing mechanisms and the inspections to be carried out, as well as the assessment of the civil engineering condition derived from the inspections. The general part denominates the substructures and structural components that are considered in the AMP. In particular, the structural component documentation must specify the design principles, properties of the materials used, operating conditions and extraordinary effects as well as the assessment of the underlying target conditions.

ENSI has reviewed and approved the GSKL civil engineering guide, which serves as a basis for the ageing management of the structures in the Swiss nuclear power plants. The guide contains the possible ageing mechanisms for the structures, specifies the type and frequency of inspections and defines the assignment of inspected structural components or materials to condition levels. In ENSI´s perspective, this guide has proven effective so far and fulfils the requirements of the guideline ENSI-B01.

With the introduction of guideline ENSI-B01 in 2011, the ageing management programme was especially expanded to include all safety-classified structures. Additionally, ENSI has initiated an important expansion of the GSKL civil engineering guide. This concerns the monitoring of inaccessible or difficult to access structural components. To date such methods have hardly been used. ENSI has pointed out this monitoring gap to the licensees on a number of occasions, and in its future inspections ENSI will increasingly demand corresponding tests.

From ENSI´s perspective, the fact sheets created for the outer reactor building envelope cover the relevant ageing mechanisms and fully evaluate the condition investigations carried out. The plant walk-downs performed by ENSI confirm the results of the condition investigations. Based on this and in agreement with the assessment of the licensees, ENSI rates the condition of the concrete structures of the outer reactor building envelopes in the Swiss nuclear power plants as good. The structural maintenance and the preventive measures conducted within the scope of the ageing management of the outer reactor building envelope have proven effective.

General conclusions

Overall, ENSI comes to the conclusion that the regulatory framework for a systematic ageing management in Swiss nuclear power plants is adequate and covers the internationally applicable requirements of the IAEA and the WENRA. The particular importance of ageing management for nuclear power plants is emphasised in Switzerland by the fact that there are statutory requirements for a provisional shutdown of a nuclear power plant for reasons related to ageing degradation. From ENSI´s perspective, with the specification of explicit ageing criteria in the DETEC ordinance for the provisional shutdown a high degree of transparency for the application of general acceptance criteria is achieved.

With the annual reporting, ENSI is promptly informed about changes in the AMPs of the Swiss nuclear power plants and based on this it is possible to conduct targeted inspections on findings and to evaluate the effectiveness of the AMP (potential good practice). From ENSI`s perspective, the annual reporting clearly shows that the ageing management programme in Swiss nuclear power plants is continuously updated based on new findings from the evaluation of internal and external operating experience as well as by monitoring the state-of-the-art of science and technology.

From the insights gained through the regulatory process in Switzerland, it can be concluded that the Swiss nuclear power plants have implemented a comprehensive AMP for safety-relevant SSCs which contains the attributes listed in the IAEA Safety Guide NS-G-2.12 for effective ageing management.

By establishing a common project of the GSKL, a standardised document structure has been achieved and a standardised implementation of the AMP in individual nuclear power plants is ensured through the specially-founded expert teams. In ENSI`s point of view, the required specifications for systematic ageing management and the information necessary for monitoring the safety-relevant SSCs are contained in the basic documents developed for implementing ageing management and the safety-relevant SSCs are being effectively monitored based on the systematic framework of the AMP (potential good practice).

In ENSI`s point of view the component-specific ageing management programmes for electrical cables, the reactor pressure vessels and the outer reactor building envelopes are based on a comprehensive recording and analysis of potential ageing mechanisms. A wide spectrum of diagnostic methods is used to identify the relevant ageing mechanisms in the Swiss nuclear power plants. The following should be mentioned in particular (potential good practices):

- The evaluation of experience from accelerated ageing investigations on cable samples, which enable a proactive assessment of cable ageing under extreme ambient conditions;
- The use of integrated fatigue monitoring programmes which record and evaluate temperature time series at selected points on the RPVs;
- The application of the master curve method as a complement to the classical approach for the analysis of the irradiation surveillance specimen used for the systematic neutron embrittlement monitoring of the RPVs, allowing direct determination of fracture toughness.

Existing experience gained from the regulatory process shows that the ageing management programmes implemented for electrical cables, the reactor pressure vessels and the outer reactor building envelope detect the relevant ageing effects in a timely manner and that effective counter-measures are adopted. As a result, these components are in a condition that permits the long-term operation of the Swiss nuclear power plants.

Irrespective of the preceding assessment, ENSI has identified the following areas of improvement within the scope of the Topical Peer Review.

- Further harmonisation of reporting among the Swiss nuclear power plants is necessary. This especially concerns the overview of the updated fact sheets, the evaluation of the international operating experience and the assessment of the effectiveness of the AMP based on trends from maintenance findings.
- ENSI will extend the focus of its regulatory efforts regarding ageing management in order to make sure that all safety-relevant concealed piping systems are included and are covered by suitable maintenance and inspection programmes.
- ENSI has required the monitoring of inaccessible or difficult to access structural components. However, to date such methods have hardly been used. Therefore, there is still no reliable experience for the condition assessment of inaccessible civil engineering structures. ENSI has pointed out this monitoring gap to the licensees on a number of occasions, and in its future inspections ENSI will increasingly demand corresponding tests.

Contents

1 General information

1.1 Nuclear installations identification

There is a total of five operating nuclear power plant units on four different sites throughout Switzerland (see Figure 1.1). They include the Beznau Nuclear Power Plant (KKB), which has two reactor units, and the Gösgen (KKG), Leibstadt (KKL) and Mühleberg (KKM) Nuclear Power Plants, each with just one unit. These plants generate approximately 40% of Switzerland's total electricity. Table 1.1 shows the licensees of the Swiss nuclear power plants.

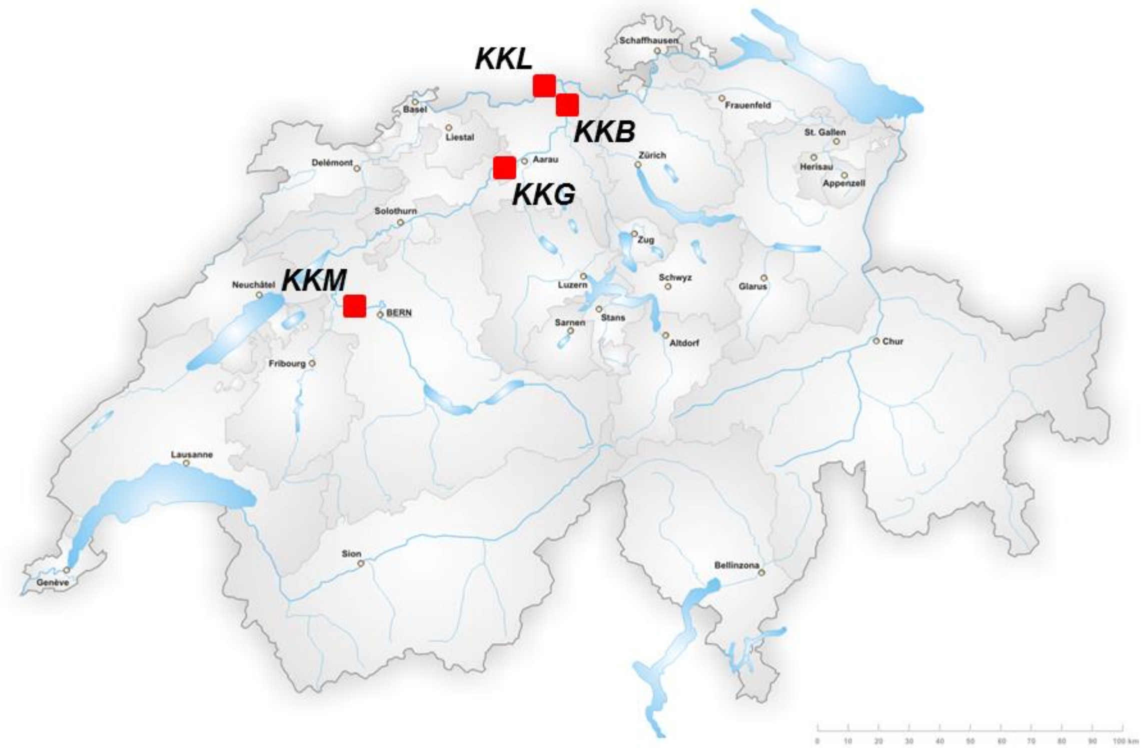

Figure 1.1: Swiss Nuclear Power Plant Sites

Three of the reactors in the Swiss nuclear power plants are pressurised water reactors, including two US designs and one German design. The other two Swiss nuclear power plants are different generations of US boiling water reactors. The reactor units in the Beznau Nuclear Power Plant and the reactor in the Mühleberg Nuclear Power Plant have been operating for over 40 years, while the Gösgen Nuclear Power Plant reactor is approaching 40 years. The Mühleberg Nuclear Power Plant will finally terminate power operation at the end of 2019. Table 1.1 below shows key technical data for these nuclear power plants.

	KKB 1	KKB 2	KKG	KKL	KKM
Thermal output [MW]	1130	1130	3002	3600	1097
Gross electric output [MW]	380	380	1060	1275	390
Net electric output [MW]	365	365	1010	1220	373
Reactor type	Pressurised water	Pressurised water	Pressurised water	Boiling water	Boiling water
Reactor supplier	W	W	KWU	GE	GE
Turbine supplier	BBC	BBC	KWU	BBC	BBC
Generator data [MVA]	2 x 228	2 x 228	1140	1318	2 x 214
Main heat sink	River water	River water	Cooling tower	Cooling tower	River water
Commenced commercial operation	1969	1972	1979	1984	1972
Licensee	Axpo AG	Axpo AG	Kernkraft-werk Gösgen-Däniken AG	Kernkraft-werk Leibstadt AG	BKW FMB Energie AG
Final shutdown date	Not specified	Not specified	Not specified	Not specified	2019

Table 1.1: Key Data for Swiss Nuclear Power Plants

As Switzerland only operates boiling water reactors and pressurised water reactors, Sections 6 and 8 of the present national assessment report, which are intended for additional reactor types (CANDU and AGR) in line with the WENRA Specification /1/, are denoted as not applicable.

Switzerland also still has three research reactors which are currently in various phases of decommissioning. In line with the requirements of the WENRA Specification /1/, these research reactors are not addressed in the national assessment report.

The existing ageing management programmes in all Swiss nuclear power plants are described and assessed in the present national assessment report in accordance with the Specification of the Western European Nuclear Regulators Association (WENRA) /1/.

1.2 Process to develop the national assessment report

At the end of 2016 the Swiss Federal Nuclear Safety Inspectorate (ENSI) decided that Switzerland would take part in the first Topical Peer Review (TPR) of the European Union on 'Ageing management in nuclear power plants'. The licensees of the Swiss nuclear power plants were required to submit reports with the information in accordance with the WENRA Specification /1/.

The following aspects were discussed in technical meetings with the Swiss nuclear power plant licensees:

1. Coordinating the TPR and assigning ENSI and licensee contacts;
2. Defining the structure and content of the reports to be submitted by the licensees;
3. Defining the scope of components and structures to be assessed by the licensees;
4. Deadline for submission of the licensee reports to ENSI.

It was agreed that the licensee reports would be published as background information, like the national assessment report.

The Swiss nuclear power plant licensees submitted the required reports to ENSI on time. ENSI has integrated the information and statements from these reports in Sections 2 to 5 and 7 of the national assessment report and provided an assessment in each case. Section 9 of the national assessment report provides an overall assessment of the ageing management programme implemented in Swiss nuclear power plants and draws the conclusions.

The licensee reports /3/, /4/, /5/, /6/ are to be published with the national assessment report at the end of 2017.

2 Overall ageing management programme requirements and implementation

2.1 National regulatory framework

In accordance with Article 35 of the Swiss Nuclear Energy Ordinance (NEO) /7/, the licensee of a nuclear installation must perform systematic ageing monitoring based on the Ageing Management Programme (AMP) for all structures, systems and components (SSCs) whose function and integrity are important for the safety of the plant. The AMP is to be periodically reviewed in respect of the current condition of the plant and any consequential measures have to be implemented. In addition, Articles 32, 33, and 34 of the NEO require that the licensee develops systematic programmes for maintaining safety-relevant equipment and performs systematic safety evaluations of operational experience as well as a comprehensive, periodic safety review. Furthermore, the ordinance on safety-classified vessels and pipework in nuclear installations (VBRK) /8/ also contains specific requirements for the planning, manufacturing installation and commissioning of vessels and pipework. This ensures that proven, demonstrably high-quality manufacturing processes, materials and methods are used in the design, construction and commissioning of nuclear installations, as required in Article 7a of the NEO /7/.

The particular importance of ageing management for nuclear power plants is emphasised in Switzerland by the fact that there are statutory requirements to provisionally shut down a nuclear power plants because of ageing degradation. The criteria for a provisional shutdown are given in the ordinance of the Federal Department of Environment, Transport, Energy and Communications (DETEC) 732.114.5 /9/. A nuclear power plant must be provisionally shut down if any of the following weaknesses are identified: unacceptable extent of embrittlement in the reactor pressure vessel (Article 4), unacceptable cracks in the primary circuit (Article 5), wall thickness of the primary circuit (Article 6) or the steel containment (Article 7) below minimum thickness, unacceptable cracks or damage to the concrete envelope of the reactor building (Article 8). If one of these criteria is evident, this must be reported to ENSI.

The requirements of ageing management for nuclear installations in operation in Switzerland are further specified in guideline ENSI-B01 /10/ and refer exclusively to the aspect of material ageing. The recommendations of the IAEA Safety Guide NS-G-2.12 regarding the fundamental concept of ageing management (Plan-Do-Check-Act) are explicitly referred to as applicable requirements.

On the one hand, guideline ENSI-B01 contains fundamental, interdisciplinary requirements for ageing management. In particular, these relate to the development of catalogues of ageing mechanisms, guides and fact sheets as well as the interaction of ageing management with maintenance, evaluation of operating experience and monitoring of the state-of-the-art in science and technology. On the other hand, it defines specific requirements for the civil, electrical and mechanical engineering areas in respect of the scope, content and documentation of the respective AMP. Where mechanical engineering is concerned, these requirements also relate to the main proofs of the brittle fracture resistance of the reactor pressure vessel (RPV) and the fatigue usage of safety-classified equipment.

Guideline ENSI-B01 is closely related to guidelines ENSI-B06 /11/ and ENSI-B14 /12/ (Maintenance of mechanical and electrical equipment), the SVTI specification NE-14 /13/ (In-service inspection of mechanical components), guideline ENSI-B07 /14/ (Qualification of non-destructive testing) as well as guideline ENSI-G11 /15/ (Planning, manufacturing and installation of mechanical equipment). In the above-mentioned guidelines, the interaction of the respective inspection programmes is defined.

According to the guidelines ENSI-B02 (Periodic reporting) /16/ and ENSI-A03 (Periodic safety review), /17/ the findings from the individual inspection programmes must be periodically evaluated by the licensees of Swiss nuclear power plants and submitted to ENSI. The annual reporting according to guideline ENSI-B02 includes a compilation of the newly created, updated or modified documents on ageing management, presentation of the results of the fatigue monitoring, evaluation of the internal and external operating experience, presentation of new findings regarding the state-of-the-art of science and technology, as well as the evaluation of the effectiveness of the AMP on the basis of failure statistics and findings from maintenance. In the periodic safety review, which according to guideline ENSI-A03, is to be conducted every 10 years, the following must be evaluated: the design specifications for safety-classified plant components, consequential modifications to the maintenance programmes for safety-classified plant components, the effectiveness of the AMP based on the attributes defined in the IAEA Safety Guide NS-G-2.12, the aspect of technological ageing not covered by guideline ENSI-B01, and also equipment critical for long-term operation for which the safety cases are time-limited.

In accordance with guidelines ENSI-G07 (Organisation) /18/ and ENSI-B10 (Training) /19/ qualified personnel with a university or college degree and sufficient experience in one of the areas of electrical, mechanical or civil engineering are to be provided by the licensees for special technical and scientific tasks, which also include the updating and review of the AMP.

2.2 International standards

In Section 2.1 of this report it was shown that at the time of development of guidelines ENSI-B01 and ENSI-A03, the latest requirements from the IAEA Safety Guide NS-G-2.12 /20/ were incorporated in the AMP. In addition, when guideline ENSI-B01 was created, it was explicitly checked whether the requirements of the WENRA Safety Reference Levels for ageing management (Issue I: Ageing Management) /21/ were covered by the regulatory specifications in Switzerland. ENSI showed in the explanatory report on guideline ENSI-B01 /22/ that all of the requirements for Issue I were covered by the statutory and regulatory requirements.

Currently, the IAEA Safety Guide NS-G-2.12 is being revised and shall be replaced by the new IAEA Draft Safety Guide DS485 /23/. Switzerland was directly involved in the preparation of this new IAEA Draft Safety Guide, in which new findings from important changes in IAEA Safety Requirements and from the International Generic Ageing Lessons Learned (IGALL) Programme for nuclear reactors /30/ are taken into consideration. Since guideline ENSI-B01 specifically refers to recommendations in the IAEA Safety Guide NS-G-2.12, guideline ENSI-B01 must be adapted after the publication of the new Safety Guide. A first evaluation by ENSI showed that new or expanded topics in the Draft Safety Guide DS485, such as the interface between ageing management, other plant programmes, and the periodic safety review or the role of ageing management in long-term operation, are to a large extent already covered by the guidelines in Switzerland.

2.3 Description of the overall ageing management programme

Development of the ageing management programme in Switzerland

The licensees of Swiss nuclear power plants had already been required to introduce an AMP for safety-relevant SSCs by the former Swiss regulatory authority (now ENSI) at the end of 1991. Consequently, it was decided by the Group of Swiss nuclear power plant managers (GSKL) to charge a coordination team ‘Ageing Monitoring in Swiss Nuclear Power Plants’ with creating joint documents as a basis for preparing an AMP. This was to ensure that ageing management is performed according to the same requirements and with the same quality in all Swiss nuclear power plants.

The development of the AMP in the Swiss nuclear power plants took place gradually:

- The higher level GSKL document for checking the ageing management /24/ builds on many years of applied maintenance concepts of the Swiss nuclear power plants, references the legal requirements, and forms the basis for the ageing management of all Swiss nuclear power plants. The document describes the physical ageing phenomena occurring in the nuclear power plants in general and presents a procedure for the early detection and control of these phenomena.
- Ageing management is implemented in the individual departments of the Swiss nuclear power plants. For this purpose, a GSKL expert team with the necessary technical competence was established for each department. Ageing management was divided into the electrical, civil and mechanical engineering fields. To clearly assign the technical responsibility, interfaces between the individual departments were defined in an additional GSKL document /25/.
- A GSKL guide was developed for each field /26/, /27/, /28/ which included the specifications for preparing fact sheets. These guides gave assistance for practically implementing and documenting the results of the ageing management.
- The GSKL guide for the civil engineering field /26/ also contains a list and classification of the relevant ageing mechanisms for the various construction materials.
- In the GSKL guide for the electrical engineering field /27/ a distinction is made between the Part 1 and Part 2 fact sheets. The Part 1 fact sheets contain a list of the most important ageing mechanisms affecting function and qualification. Part 2 of the fact sheets contains possible diagnostics and testing methods, as well as characteristics by which the ageing progress can be identified. These generic fact sheets serve as a basis for the Part 3 fact sheets which are created for a specific plant.
- A separate GSKL catalogue of ageing mechanisms for mechanical equipment (KATAM) /29/ was created for the mechanical engineering field. In it, the relevant ageing mechanisms for light water reactors are identified, classified and described in detail. After it was revised in 2011, this document was recognised by ENSI as an essential basis for ageing management in the Swiss nuclear power plants.
- The AMP was implemented by the departments in the Swiss nuclear power plants based on the specifications of the GSKL coordination team. The performed ageing-related assessments of safety-relevant SSCs are summarised in the plant-specific fact sheets.

Integrating the ageing management programme into existing plant programmes

The process of ageing management is integrated into the certified management system of the Swiss nuclear power plants and divided by department. These processes define the responsibilities and procedures for the ageing-related assessment of safety-relevant SSCs as well as whether, with the existing plant programmes, ageing-induced damage can be avoided or detected at an early stage and whether additional measures should be taken. In addition, there is a link to higher level and other applicable documents (guidelines, process instructions, work instructions) based on the previously described specifications of the GSKL coordination team. This ensures that the results from the existing inspection programmes are introduced into the ageing management process and, within the framework of updating the AMP, are regularly evaluated in terms of the necessary adaptation of ageing management.

The information required for ageing management, such as SSC design and manufacturing data including the maintenance history, relevant evaluation reports, inspections performed, maintenance and repairs, operational measurements, is stored in the Swiss nuclear power plants in plant management systems or databases so that this information is fully retraceable.

According to the requirements in guideline ENSI-B10 /19/ only specialist personnel with a high level of qualification and specific experience in the area may be responsible for ageing management in the Swiss nuclear power plants. This specialist personnel must ensure that the GSKL specifications are implemented in the nuclear power plants and also that information is fed back from the GSKL coordination team and the GSKL expert teams.

2.3.1 Scope of the overall ageing management programme

Identification and classification of safety-relevant SSCs

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 /31/ and the relevant specifications of guideline ENSI- B01 /10/.

- In the civil engineering field, all safety-classified structures must be included in ageing management. In line with their significance for nuclear safety and radiation protection, structures are assigned to the structure classes, BK1 and BK2. As part of ageing management, fact sheets are created for either individual buildings or building parts.
- In the electrical engineering field, all safety-classified electrical and I&C components must be included in the ageing management. Fact sheets must be created for 1E-classified components and ageing dossiers for 0E-classified components. Components are grouped in a type-specific manner, where components of similar design and technology are combined into component groups.
- In the mechanical engineering field, all safety-classified vessels and pipelines assigned to safety classes 1 to 3, their supports and pressurised equipment parts (pumps, valves, safety relief valves) must be included in the ageing management. Excepted from this are small pipes. The ageing condition of the mechanical engineering equipment not covered by the systematic ageing management, is monitored as part of the scheduled maintenance so that early action can be taken to prevent possible damage. The fact sheets are created on a component or system basis, where, in accordance with the requirements in guideline ENSI-B01, components of safety class 1 or 2 are not grouped in system-related fact sheets. In general, components of the same or similar construction

in safety class 3 that are exposed to the same or similar conditions and which exhibit a similar ageing behaviour are grouped together. The grouping must be indicated in the fact sheet in a transparent manner.

Mechanical and electrical components which are important for safety based on probabilistic analyses /32/ and are not covered by the criteria mentioned above must be additionally included in the AMP in both fields. The essential data for the safety-classified mechanical and electrical components are included in component lists or component type lists and are reviewed and updated periodically or when there are plant changes.

2.3.2 Ageing assessment

Identification of ageing mechanisms

The systematic identification of ageing mechanisms takes place by field.

- All ageing mechanisms relevant to the civil engineering field are specified in Annex 1 of the guide for civil engineering fact sheets /26/. According to the guide, structures are inspected at least every 10 years for the ageing mechanisms. The inspections are only carried out by qualified and experienced persons who know how to interpret and evaluate any unexpected anomalies that might occur. These are supported by qualified engineers and, in particular, when special diagnostics are used, by specialists. The results of inspections are recorded in the fact sheets for the individual buildings, and any necessary actions defined.
- In the electrical engineering field, the examination, evaluation and documentation of the ageing mechanisms is performed by the GSKL expert team on electrical engineering ageing management. In order to ensure that the state-of-the-art of science and technology is reflected in the plant-specific fact sheets also in the years after they were created, generic fact sheets Part 1 and Part 2 (basis documentation) are continually checked at least every 10 years and updated as necessary.
- In the mechanical engineering field, the examination, evaluation and documentation of the ageing mechanisms is done by the GSKL expert team on ageing management in mechanical engineering. When reviewing the relevance of ageing mechanisms, the catalogue of ageing mechanisms for mechanical equipment (KATAM) /29/ is of particular importance. The following aspects are systematically dealt with and documented when fact sheets are created:
  - General information about the system and its components
  - Influencing factors (media, operating conditions, material data)
  - Identification of relevant ageing mechanisms
  - Internal and external operating experience
  - Existing monitoring systems
  - Supplementary measures

In the following component-specific sections of the present national assessment report, relevant ageing mechanisms are addressed in detail.

Determining acceptance criteria

The acceptance criteria used in the implementation of ageing management measures serve to uphold the functionality and/or integrity of a structure or component under all design conditions. Acceptance criteria are also determined by field.

- For the civil engineering field, five condition levels with defined assignment criteria are specified in the GSKL guide for civil engineering fact sheets /26/. All structures to be monitored 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. The required condition is defined such that, under consideration of the specifically possible ageing of a structural component, the functionality limit will not have been reached by the time of the next major inspection.
- In the electrical engineering field, the applicable criteria are derived from internationally recognised standards and rules or from predictions of potential ageing mechanisms under consideration of the plant-specific ambient conditions. These predictions are based, for example, on accelerated ageing tests in a test environment, inspection on removed components with known conditions of use, or storage of components in the containment under extreme ambient conditions.
- In the mechanical engineering field, the criteria for the passive components are defined on a part-specific or component-specific basis. For fatigue monitoring, the criteria are specifically defined in the guideline ENSI-B01 /10/. For the regularly performed function tests of active components, specific acceptance values or threshold values are applied. When these values are exceeded, a failure notification is triggered, which then leads to maintenance and/or repair actions with the aim to restore the specified design conditions of the component.

The acceptance criteria in the individual fields are addressed in the following component-specific sections of the present national assessment report. In Switzerland, there are also high-level criteria at the statutory level for the provisional shutdown of nuclear power plants in the event of ageing-induced damage to essential physical barriers.

Monitoring of international research programmes

Depending on the design type, Swiss nuclear power plants participate in the on-going research programmes of the Electric Power Research Institute (EPRI), the VGB PowerTech, swissnuclear (sn) and the Paul-Scherrer Institute. In particular, the following programmes are currently being closely followed:

- EPRI Boiling Water Reactor Vessel Internals Program (BWRVIP),
- EPRI Pressurized Water Reactor Materials Reliability Program (MRP),
- EPRI, Non-Destructive Testing (NDE),
- EPRI, Nuclear Maintenance Application Center (NMAC),
- Plant Life Management (PLiM), Thermo-Mechanical and Multiaxial Fatigue caused by Cyclic Thermal Shocks,
- Ultrasonic-Guided Wave Technology in embedded concrete structures.

The contents of these programmes are described in detail in the licensee reports. In addition, Swiss nuclear power plants have access to the results of the following ENSI-financed projects:

- SAFE-II: This project deals with material issues, in particular corrosion cracking and fatigue in structural materials for light-water reactors. This internationally-recognised project supports and promotes the acquisition and preservation of know-how on environmentally assisted crack propagation, an area which is important for the operation of nuclear power plants.
- NORA-II: Noble metal injection is used in both Swiss boiling water reactors (BWRs) to prevent or delay the occurrence of stress corrosion cracking in the reactor pressure vessel internals. This project primarily investigates the platinum coverage of test samples stored in the primary water of Leibstadt Nuclear Power Plant (KKL). The protective effect of platinum-injection in the two Swiss BWRs was improved based on the results of the study.
- CODAP database: For the Swiss nuclear power plants, this data collection and background information represent a direct and current source of international experience with cases of failure or degradation occurring on classified mechanical equipment, which can be used directly for ageing assessments.

Evaluation of internal and external operating experience

The GSKL expert teams check and evaluate new findings from external sources and committees, information from plant suppliers, or from exchange of technical experience with foreign nuclear power plants. The IAEA's IGALL programme /30/ is of particular importance here. On the basis of this evaluation, it is decided whether these findings will be taken into account in the AMP and whether it is necessary to update the specific technical documents (fact sheets, ageing catalogue, ageing dossiers). In addition, operation-induced degradation that has occurred in Swiss nuclear power plants is discussed and evaluated in respect of its relevance for the AMP. The results of this review are presented in summary in the annual reports of Swiss nuclear power plants.

2.3.3 Monitoring, testing, sampling and inspection activities

The programmes implemented in Swiss nuclear power plants primarily comprise test and inspection activities within the framework of operational monitoring and preventive maintenance.

Within the framework of the operational monitoring, field-specific tests are conducted, and the findings used for the plant-specific AMP. These tests comprise, among other things:

- Water-chemistry analyses based on internationally valid guidelines and specifications,
- Regular checking of process medium, such as lubricants,
- Wall thickness measurement programmes ('EROSKO'),
- Cable deposit programmes and cable inspection programmes,
- Diagnostic measurements on actuators (MOV), solenoid valves, motors (stator winding) and wires,
- Periodic capacity measurements on stationary battery systems,
- Accelerated ageing tests on newly qualified components (on-going qualification).

In addition, automatic monitoring equipment is installed and the results are systematically evaluated in respect of possible ageing influences. This includes, for example

- Loose part monitoring system of the reactor pressure vessel,
- Vibration monitoring system of the main coolant pipes and pumps,
- Leak monitoring system.

The preventive maintenance includes, among other things, in-service inspection programmes for mechanical components of safety classes 1 to 4 requiring nuclear inspection and approval, functional tests of electrical and I&C components as well as inspections of civil engineering structures.

- The scope of the in-service inspection programmes is defined in specification NE-14 /13/ and in guideline ENSI-B06 /11/. These include among others non-destructive testing (NDT), system and component walk-downs, pressure tests, function tests of selected mechanical components like safety valves and shock absorbers, leak testing of the containment. Specification NE-14 details inspection methods and inspection parameters, as well as inspection intervals, which are based on classification and condition of the components. Guideline ENSI-B06 also includes general requirements for the inspection personnel, the inspection supervisors and the testing and measuring equipment.
- The requirements for the functional testing of electrical and I&C components are defined in guideline ENSI-B14 /12/. The testing requirements specified by the manufacturer must be taken into account for the functional inspections.
- The requirements for the inspection programme for structures are defined in guideline ENSI-B01 /10/. These include base and intermediate inspections of the general condition as well as special inspections in the event of significant changes in the condition of the structure. Special inspections can include, for example, material samples of damaged areas or measurements of changes in crack width.

The type, scope and frequency of the maintenance programmes must be defined in the plant-specific documents (e.g. technical specifications, component inspection schedules, inspection and test specifications). The maintenance programmes are promptly adapted taking into consideration the findings from the plant-specific AMP.

As further important elements of ageing management, guideline ENSI-B01 /10/ requires programmes for monitoring of embrittlement in the reactor pressure vessel materials and of fatigue-relevant components of safety classes 1 to 3. Both monitoring programmes are continuously performed in the Swiss nuclear power plants so that the condition of these components can be continuously assessed and an extrapolation can be made for the expected service life.

2.3.4 Preventive and remedial actions

The AMP of the Swiss nuclear power plants is designed to ensure the timely detection of the relevant ageing mechanisms and the resulting ageing effects. This programme thus forms an important basis for the identification and implementation of necessary preventive actions (see section 2.3.3) and remedial actions.

The implementation of necessary preventive and remedial actions takes place in the relevant field of the individual nuclear power plants in compliance with the specifications for the quality processes important for maintenance and plant modification. The necessary feedback of information to the AMP is ensured by the routine updating of the AMP (see section 2.4). In this way, the ageing management fact sheets are adjusted after a preventive or remedial action has been implemented. Actual examples of applied preventive and remedial actions are contained in the following component-specific sections of the present national assessment report.

2.4 Review and update of the overall ageing management programme

Generic review and update

The GSKL ageing management coordination team for Swiss nuclear power plants, which also comprises the managers of the GSKL expert teams of civil, electrical and mechanical engineering, is responsible for discussing the generic aspects of ageing. This includes the decision about which collective generic documents for ageing management are to be selected for updating based on the results of the AMP, and which collective measures and procedures should be derived. The principles and requirements for the AMP developed by the coordination team are implemented in the individual nuclear power plants by the GSKL expert teams. Expert team tasks include active participation in technical events, national and international exchange of experience, and joint monitoring of the state-of-the-art of science and technology in the context of research projects in the field of material ageing. The results are documented in joint field-specific documents and thus made available to the individual nuclear power plants for executing the ageing management.

Plant-specific review and update

The review and update of the AMP is subject of the 'ageing management' process incorporated in the Swiss nuclear power plant’s certified management system. This ensures regular internal review and updating of the AMP by the licensees so that unexpected ageing phenomena can also be detected and addressed. An essential review step is the updating of field fact sheets, which is also linked to the review of the effectiveness of the in-service inspection programmes. If the criteria defined in the inspection and test specifications are not met, non-conformance reports are prepared that must be processed by the defined deadlines. This can lead to alternative non-destructive tests or supplemental computational analyses having to be performed or repairs or replacement of the affected components. Another essential review step is the systematic inspection and testing of fatigue-relevant components in order to determine the fatigue usage. Countermeasures will be taken before an overall degree of fatigue, as defined in guideline ENSI-B02 /10/, is reached.

Specialist departments in each Swiss nuclear power plant evaluate the in-plant and international operating experience according to the specific plant processes. The relevant findings from inspection programmes are forwarded to the responsible departments. In addition, the departments receive information about plant modifications and changes in the operational characteristics in order to be able to review the effects on ageing management.

The results of the regularly performed collective and plant-specific reviews of ageing management as well as the actions derived from them are compiled in an annual safety report and the effectiveness of the existing AMP is evaluated by the Swiss nuclear power plants according to the specifications in guideline ENSI-B02 /16/. This report is submitted to ENSI.

A further significant, comprehensive review of the AMP is carried out within the framework of the periodic safety reviews performed every 10 years. Based on guideline ENSI-A03 /17/ the AMP is reviewed in respect of completeness, topicality and effectiveness. From this, the current state of the AMP and any actions derived from the review are presented and evaluated. Indicators such as annual unplanned non-availability of safety-relevant systems or the number of operational incidents that can be traced back to ageing mechanisms are used for evaluating effectiveness. As part of the new systematic safety assessment to be performed, the analysis is broken down as far as the received event reports. Moreover, it is shown how ageing-induced progression of damage is measured, taking into consideration the inspection techniques applied, and what improvement measures for the identification of degradation are being and have been taken. In this context, the analyses for reviewing the brittle fracture resistance of the reactor pressure vessel are especially important. The results of the periodic safety review are submitted to ENSI.

In addition to the periodically performed inspections, special tests and/or in-depth analyses of the influencing factors, such as evaluation of manufacturing documentation or operational data, are promptly performed when knowledge becomes available of new important safety aspects in other nuclear power plants (e.g. the unexpected findings in the base metal of RPVs in 2012 or cracks outside the heat-affected zones of core shrouds in 2014).

2.5 Licensees experience of application of the overall ageing management programme

The overall AMP, implemented in Swiss nuclear power plants from an early stage, has not fundamentally changed in the view of the licensees. The basic documents drafted by the GSKL coordination team have been proven in practice and are regularly reviewed and updated. The modifications thus far were mostly due to changes in regulatory specifications or further development of the state of the art of science and technology.

With the introduction of guideline ENSI-B01 /10/ in 2011, which replaced guideline HSK-R-51 on ageing management from 2004, and revision 1 of guideline ENSI-B02 /16/, the ageing management process was reviewed and updated in the Swiss nuclear power plants. This included harmonising the procedure for the annual review of ageing management for the civil, electrical and mechanical engineering fields.

The AMP represents an essential, systematic expansion of the existing maintenance programmes in the Swiss nuclear power plants and is continually updated. In particular, the ageing mechanisms for safety-relevant SSCs are identified by ageing management. Based on this, existing inspection and test programmes, especially preventative maintenance, are reviewed to determine whether ageing-induced degradation can be avoided or detected at an early stage. Any gaps revealed by the review can be closed in an accountable manner. Embedding the AMP in the national and international activities of GSKL's coordination team ensures that the state-of-the-art of science and technology in materials and structural ageing as well as analysis and diagnostic technology will continue to be considered in the future. In addition, potential for improvement in the ageing management of Swiss nuclear power plants was identified through the periodic reviews performed by the WANO and IAEA.

In general, the licensees consider the AMP well-established and proven in Swiss nuclear power plants.

2.6 Regulatory oversight process

The regulatory framework conditions described in section 2.1 of the present national assessment report show that ageing management is an integral part of the oversight process in Swiss nuclear power plants and is closely monitored by ENSI. Thus, in 2011, the requirements for a comprehensive and systematic ageing management were updated in the then newly published guideline ENSI-B01 /10/, which was based on the experience gathered by implementing ageing management up until that time. Furthermore, the feedback of experience from other inspection programmes, particularly from the plant-specific maintenance programmes, that is necessary for effective ageing management is regulated in several guidelines. The scope of these inspection programmes requires the approval of ENSI and qualification is confirmed by an accredited testing organisation. The planning, manufacturing and assembly of the SSCs included in the AMP, as well as modifications to them, are subject to approval by ENSI. Therewith, ENSI is directly involved in processes that have a significant impact on ageing management. In addition, other regulatory guidelines ensure that only experienced and specially qualified operating personnel are involved in the process of ageing management in Swiss nuclear power plants.

The licensees of Swiss nuclear power plants are obliged to notify ENSI periodically about modifications and extensions of the existing AMP which are derived from evaluations of plant-specific and external operating experience as well as analysis of the state-of-the-art of science and technology. Thus, based on the 2012 revision of guideline ENSI-B02 /16/, each licensee must present the state of the ageing management in the civil, electrical and mechanical engineering fields, as well as the condition of fatigue-relevant components as part of the annual safety report. Whenever the documents on ageing management, including the field-specific guides, plant-specific fact sheets, ageing dossiers and structural inspection programmes, are changed, these also must be submitted to ENSI. ENSI reviews this information, approves the field-specific guides for further use and informs the licensees within the framework of the annual meeting between ENSI and the GSKL coordination team of the review results in respect of the other documents. ENSI also performs targeted inspections based on the information it received.

Within the framework of guideline ENSI-A03 /17/ safety reviews must be carried out by the licensees every 10 years, under consideration of the annually evaluated information, of the plant-specific AMP for completeness and topicality as well as for other long-term topics, such as design specifications for safety-classified components, changes in the maintenance programme, technological ageing and time-limited verification of critical equipment. ENSI ultimately forms an opinion of the licensee’s evaluations and, if necessary, derives additional requirements for ageing management.

2.7 Regulators assessment of the overall ageing management programme and conclusions

The AMP implemented in Swiss nuclear power plants is based on a long-standing development process that has been closely followed by ENSI. The structure and organisation of the ageing management and its integration into the established plant programmes via the existing quality and plant management systems has proven its value over time. Thus, with the establishment of an overall cross-plant GSKL coordination team by the licensees, a standardised document structure and joint monitoring of plant-specific and international operating experience and new findings from research and development have been achieved.

In addition, a standardised implementation of the AMP in individual nuclear power plants is ensured through the cross-plant GSKL expert teams which consist of specially qualified operating personnel. From ENSI`s perspective, the documents developed by the licensees for implementing ageing management contain the required specifications for systematic ageing management and the information necessary for monitoring the safety-classified SSCs: the field-specific GSKL guides, the GSKL interface document, the GSKL catalogue of ageing mechanisms, and the plant-specific fact sheets for the safety-classified SSCs.

The licensees obligation to perform systematic and comprehensive ageing monitoring and the requirement to provisionally shut down the nuclear power plant if the essential physical barriers are impacted by unacceptable ageing-induced damage, both established on a statutory level, should be pointed out. At the same time, the requirements for a systematic ageing management were amended at the guideline level based on experience in the implementation and updating of the AMP in Swiss nuclear power plants. Proven elements from the original guideline, such as the type and scope of the GSKL documents and the civil engineering inspections to be performed, were taken over when guideline ENSI-B01 /10/ came into force. In addition,

- in the civil and electrical engineering fields, the scope of ageing management was expanded to all safety-classified buildings and electrical components,
- in the mechanical engineering field, the scope of the safety-class 2 and 3 components was expanded and specific requirements for the proof of brittle fracture resistance for the reactor pressure vessel as well as the scope and evaluation of fatigue monitoring were included,
- a graded approach for the documentation depth in the fact sheets was included in all fields dependent on the safety classification of the SSCs.

When the revision of guideline ENSI-B02 /16/ came into force in 2012, a new annual report on the state of the ageing management was introduced. The goal is to keep ENSI informed about the updating of the AMP in Swiss nuclear power plants and the resulting modifications in other plant programmes. This allows ENSI to conduct targeted inspections in the case of findings, and to evaluate the effectiveness of the AMP. The annual reporting clearly shows that the AMP in Swiss nuclear power plants is continuously updated based on new findings from the evaluation of internal and external operating experiences as well as by monitoring the state-of-the-art of science and technology. These updates particularly concern the revision of the existing fact sheets for safety-classified SSCs as well as the expansion of existing inspection, surveillance and maintenance programmes. From ENSI’s point of view, the annual reporting has proven its worth. However, further harmonisation of reporting among the Swiss nuclear power plants is necessary. This especially concerns the overview of the updated fact sheets, the evaluation of the international operating experience and the assessment of the effectiveness of the AMP based on trends from maintenance findings (area of improvement).

When the revision of guideline ENSI-A03 /17/ came into force in 2014, the required periodic safety review reporting was harmonised with the annual reporting. The safety assessments needed for long-term operation were explicitly included so that the time-limited ageing analyses of large components were extended to cover longer operating periods than originally assumed. These additional requirements for long-term operation closed an existing gap in the ENSI guidelines. In the process, experience from the safety assessments of the two oldest Swiss nuclear power plants was included. In its previous safety evaluation reports on the periodic safety reviews and long-term safety assessments of Swiss nuclear power plants, ENSI concluded that, irrespective of identified improvement potentials, the safety-relevant SSCs are being effectively monitored based on the systematic framework of the AMP, the continuous updating of the AMP and the large number of fact sheets, and that the safety-relevant SSCs are in good condition. In the initial phase of the implementation of the AMP improvement potentials to achieve a sound basis for ageing management were identified. These improvements primarily were related to the preparation of missing fact sheets in the civil, mechanical and electrical engineering fields, performance of the required inspection programmes in the civil engineering field, and the expansion of fatigue monitoring. In the current phase of updating the existing AMP, the focus is on a standardised evaluation of findings from operating experience and the state-of-the-art of science and technology, the inclusion of inaccessible or difficult to access structural parts (see section 7), as well as special inspections to prove the integrity of the reactor pressure vessel (see section 5) and the steel containment with respect to the age of the Swiss nuclear power plants.

From ENSI's perspective, the ageing management process implemented in Swiss nuclear power plants contains the attributes listed in the IAEA Safety Guide NS-G-2.12 /20/ for effective ageing management. Based on the design and operating conditions for the supervised safety-relevant SSCs, ageing effects identified as relevant are listed in the fact sheets. Recognised testing techniques are used to identify these ageing effects, necessary remedial actions are introduced, and new findings from operating experience and research are monitored so that existing plant programmes which are essential to ageing management can be promptly adapted.

Conclusion

In general, from ENSI's point of view, the regulatory framework for a systematic ageing management in Swiss nuclear power plants is adequate and covers the internationally applicable requirements of the IAEA and the WENRA. From the findings regarding the regulatory process in Switzerland, it can be concluded that the Swiss nuclear power plants have implemented an effective and comprehensive AMP for safety-relevant SSCs.

3 Electrical cables

3.1 Description of ageing management programmes for electrical cables

3.1.1 Scope of ageing management programmes for electrical cables

The basis for the ageing management of electrical components in the Swiss nuclear power plants is guideline ENSI-B01 /10/. Hence, for all components classified 1E according to guideline ENSI-G01 /32/, type and manufacturer-specific fact sheets must be created. This includes electrical cables that are necessary for ensuring that safety functions are fulfilled. Each fact sheet comprises three parts: Parts 1 and 2 have been jointly created for all Swiss nuclear power plants, while part 3 is plant-specific because of the use of different cable types.

Fact sheet Part 1 contains all potential ageing mechanisms in respect of the relevant cable types obtained from the monitoring of the technical literature. Fact sheet Part 2 contains possible diagnostics methods, with which the potential ageing mechanisms can be detected. Plant-specific fact sheet Part 3 describes the applicable diagnostics methods that are used in the plant-specific maintenance programme and in the procedures for the periodic testing of cables. This closes the circle from ageing management to maintenance. The fact sheets are revised every 5 to 10 years (at the latest). New findings from science and technology, from internal and external operating experience are thus regularly incorporated in the AMP and the maintenance programme. If plant changes affect fact sheet Part 3, then the fact sheets are adapted.

In general, the fact sheets for electrical cables do not contain any penetrations, terminal boxes or terminals. These component types are dealt with in separate fact sheets.

The AMP for electrical cables was developed by the licensees of the Swiss nuclear power plants within the GSKL electrical engineering expert team. Plant-specific fact sheets for the class 1E electrical cables are divided into the following groups:

Group 1: Fact sheet for medium voltage power cables (≥ 1kV)

Group 2: Fact sheet low voltage power cables (50V – 1kV)

Group 3: Fact sheet for instrumentation cables (< 50V)

Group 4: Fact sheet for special mineral insulated cables (MI cable)

This grouping roughly corresponds to the grouping suggested in the WENRA specification /1/. Here the explicitly mentioned neutron flux cables belong to group 4.

Beznau Nuclear Power Plant (KKB)

As part of the AMP for electrical engineering and I&C safety classified components, ageing-induced damage mechanisms, which could lead to faults or impairment of safety-relevant systems are identified and monitored. In doing so, electrical cables are classified as particularly important individual components. The scope of the electrical cables included in AMP is recorded using internal, integrated management system processes. The aim of the established AMP for electrical cables is to ensure functionality under both operating and accident conditions. The systematic ageing management of electrical cables identifies gaps in preventive and condition-based maintenance and diagnostics. The findings obtained are incorporated directly into the maintenance and in-service inspection programmes, which are then correspondingly adapted.

In KKB, electrical cable fact sheets have been created for medium voltage cables, thermoplastic insulated cables and their connections, and mineral insulated cables, which are grouped as follows:

Group 1: Medium voltage power cables (6kV) class 1E of type GKG (Kabelwerke AG), NoFlamm (Cossonay), type GKN (Kabelwerke AG) and type XDME-Mono (Leoni-Studer);

Group 2: Low voltage power cables (0.4kV) class 1E and accident-resistant (1E-LOCA) of type Noflamm (Cossonay), type Radox (Huber+Suhner), type Pyrofil (Dätwyler), type Comp. 702 GG-82 (Studer) and type NU-EHXHX (Eupen);

Group 3: Instrumentation cables class 1E and accident-resistant (1E-LOCA) of type Noflamm (Cossonay), type Radox (Huber+Suhner), type Pyrofil (Dätwyler), type Comp. 702 GG-82 (Studer), NU-THXCHX (Eupen);

Group 4: Special cables for class 1E neutron flux and accident-resistant (1E-LOCA) mineral insulated cables (Combustion Engineering) with magnesium, aluminium or silicon oxide-based insulation material.

The cable insulation material comprises ethylene polyethylene diene monomer rubber (EPDM) and ethylene propylene rubber (EPR).

Gösgen Nuclear Power Plant (KKG)

Group 1 of the medium voltage cable component group includes the thermoplastic insulated cables and their connections in a voltage range from 1kV up to 30kV. Ageing management includes not just the cables themselves but also the cable fittings (sleeves, terminations). The medium voltage cables are subdivided in the fact sheet into ageing relevant component parts. In KKG there are two medium voltage levels, 10kV for the standard network and 6kV for the emergency network. Since 2011 when the replacement of the medium voltage cables was completed, both networks have used halogen-free, flame-retardant cross-linked polyethylene cables.

Groups 2 and 3 of the low voltage and instrumentation cables include the thermoplastic insulated cables with voltages up to 1kV(AC) or 1.5kV(DC) and their connections in the extra-low and low voltage range. This also includes ageing relevant device-internal wiring. There are specific fact sheets for the following cable categories:

- Accident-resistant cables routed in the containment: Both the classified cables and the cables that are not classified as accident-resistant are fully recorded in the AMP. Between 2003 and 2008, Halar-insulated cables of this cable category were systematically replaced.
- Non-accident-resistant cable routed in the containment: On the one hand, these are ageing relevant, classified special cables for the radiation detectors and, on the other hand, thermally and radiologically highly loaded class 1E power and instrumentation cables.
- Non-accident-resistant cable outside the containment: Both classified and unclassified cables for which an ageing relevance exists, are recorded in the AMP. This includes amongst other things, special cables for radiation detectors fitted outside the containment, signal cables for actuation criteria for cooling water protection logic, miscellaneous connecting cables for components in the steam- and feedwater valve

chamber plus the connecting cables for inductive linear position transducers that are part of the accident instrumentation.

Group 4 includes mineral insulated cables, which are, among other things, used for neutron flux measurement. In KKG, two cable types are part of the neutron flux measurement circuit: The first cable is a mineral-insulated cable, which runs from the detector to an accident-resistant sub-distribution board on the circular platform. The signal goes from the sub-distribution board via another cable to the measuring cabinets. The cable is inaccessible. To prevent electromagnetic interference, the cable is routed continuously through insulated copper tube and consequently also largely protected against mechanical effects.

Leibstadt Nuclear Power Plant (KKL)

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. Documents for the ageing management of electrical cables are created according to the specifications of the GSKL electrical engineering expert team. KKL is responsible for the implementation of ageing management measures and their adaptation. Electrical cables are grouped based on their functions and requirements as follows:

Group 1: Medium voltage cables class 1E

Groups 2, 3: Low voltage power and I&C cables, class 1E and accident-resistant (1E-LOCA) up to 1kV

Groups 2, 3: Low voltage power and I&C cables, class 1E up to 1 kV

Group 4: Special cables for neutron flux instrumentation, mineral insulated

Mühleberg Nuclear Power Plant (KKM)

The AMP for electric cables is an integral part of electrical maintenance in KKM. The aim of ageing management is the timely, preventive definition of retrofitting and replacement measures to prevent ageing-induced failures.

The group 1 medium voltage cables include the power cables of the emergency power supplies from the Mühleberg Hydro Power Plant.

Groups 2 and 3 of the low voltage and instrumentation cables include the thermoplastic insulated cables for voltages up to 1kV(AC) or 1.5kV(DC). This includes the following power and I&C cables:

- Class 1E cable in the reactor building including the drywell;
- Class 1E cable outside the reactor building;
- Class 1E cables, which have been replaced within backfitting projects.

The group 4 special cables include the mineral-insulated cables and coaxial cables for neutron flux measurements in both wide range (WRNM) and power range (PRNMS) and are subdivided into the following fact sheets Part 3:

WRNM: Motor cables and control cables, signal cables in protective tube and system cables

PRNMS: Coaxial cables (cable between the neutron flux measurement system and penetration) and mineral insulated cable (cable between the penetration and detector)

3.1.2 Ageing assessment of electrical cables

In the Swiss nuclear power plants, cables used are primarily plastic or mineral insulated with copper or aluminium conductors. Based on operating experience, the following cable components in particular are subject to various ageing effects: jacket insulation, wire shielding, wrapping, conductors and conductor insulation as well as connectors. The following ageing mechanisms are of particular importance:

- Embrittlement or cracking of the cable jacket by oxidation;
- Dielectric changes to the conductor insulation;
- Embrittlement or discolouration of cable wrapping;
- Corrosion of conductors, wire screen and cable connectors;
- Loosening of conductor and cable connectors.

The type and scope of the diagnostic methods applied for monitoring these ageing mechanisms are described below.

Beznau Nuclear Power Plant (KKB)

In the course of their service life in the radiation field and under high room temperatures, electrical cables, in particular their plastic insulation material, experience changes to the strength values due to oxygen diffusion. In KKB, suitable tests on batch samples from the cable pre-ageing area enable changes in strength value properties to be checked as part of the operation accompanying AMP.

The relevant ageing mechanisms and their diagnostic methods applied in KKB for electrical cables are presented in tabular form, subdivided by cable parts for the 4 cable groups, in the licensee report /6/. The diagnostic methods used include in particular, visual inspection of the cables, infrared measurements for medium voltage cables, analysis of samples from the cable pre-ageing area, capacitance and insulation resistance measurements, tan delta measurement, Isothermal Relaxation Current (IRC) analysis and Time Domain Reflectometry (TDR).

Section 3.1.3 of the present national assessment report describes the use of these methods in KKB for the individual cable groups in detail.

Gösgen Nuclear Power Plant (KKG)

The relevant ageing mechanisms and their diagnostic methods applied in KKG for electrical cables are presented in tabular form, subdivided by component parts for the 4 cable groups, in the licensee report /3/.

- No infrared measurements for the detection of embrittlement are carried out for medium voltage cables (group 1) in KKG. Instead, during the periodic walk-downs the cables are visually checked and manually qualitatively checked by touch to test for heat formation and brittleness. Since the safety-relevant medium voltage cables are laid dry, corrosion of the wire/tape screen is not important as an ageing effect. KKG participates in the VGB programme ‘Operational demonstration of cable ageing of medium voltage cables’. Partial discharge measurements and loss factor measurements are not comprehensively carried out in KKG. However, these cables were systematically replaced (project completion 2011) so that now they are virtually new. The cable manufacturer indicates a service life of at least 40 years. Nevertheless, a loss factor measurement is periodically performed on a random sample. These measurements were also carried out for new cable (baseline for comparison measurements).

- The low voltage and instrumentation cables (groups 2 and 3) are only checked on demand using a voltage probe or magnetic pulse method for dielectric changes. However, a random sample of about 50 highly loaded cables is periodically measured using the Line Resonance analysis (LIRA) method, and the ageing progress in respect of the change in the electrical parameters is assessed. KKG does not currently manage its own cable pre-ageing area. Instead, use is made of the findings from the central high stress test area for cable pre-ageing as part of the VGB programme 'Operational verification of the LOCA-resistance of electrical engineering and I&C components'.
- The MI cables of the neutron flux external instrumentation (group 4) are not accessible. The insulation resistance values, the saturation characteristics of the ionisation chambers and the signal transmission behaviour of the measuring circuits are checked within the scope of the periodic tests recommended by the manufacturer and continually improved upon over the years. Ageing-induced errors are detected based on these integral tests.
- The special cables of the radiation measuring points (group 4) carry currents with a maximum value of 0.1 A. There is practically no heat development, even with covered contact resistances. For this reason, various diagnostics methods which are relevant for power cables are not applicable for the special cables of radiation measuring points. Ageing-induced changes are detected within the scope of the periodically performed integral function tests. Amongst other things, function checks include measurement of the insulation resistance, checks of limits and signalling. High-quality connections are used, junction boxes (sub-distribution boards) are not used.

Section 3.1.3 of the present national assessment report describes some of the diagnostic methods applied in KKG in detail.

Leibstadt Nuclear Power Plant (KKL)

Particular attention is paid by KKL to the electrical loading of cables under different accident scenarios and loads arising as a result of changes to the ambient conditions resulting from the accident. In KKL, only electrical cables with plastic insulation are used for safety-relevant cables. The main insulating materials used are XLPE (cross-linked polyethylene), EPR (ethylene propylene rubber, primarily for medium voltage cables) and EPDM (ethylene polyethylene diene monomer rubber).

The ageing resistance of the electrical cables is primarily defined by the insulation material of the cable conductors and the cable itself. Changes or corrosion to the metallic cable conductors is only relevant for interfaces. To identify and evaluate the relevant ageing phenomena, the ageing-relevant loads and their effects are assessed. In general, these loads are considered as early at the cable design stage and when selecting cable types, taking account of the materials used and the cable design. The following loads are considered for cable ageing management in KKL:

- Thermal load (inherent heating of the cable resulting from the current load, cable routing in trays, pipes, conduits, etc., cable heating due to the ambient temperature)
- Radiation exposure (radiation-induced degradation of the plastics used)

- Electrical load (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 dielectric load in instrumentation/coaxial cables)
- Mechanical load due to field forces
- Water influences/moisture
- Media contact (for example oil mist)

In ageing management, the relevant design, manufacturing and operating documents are used and are listed in detail in the fact sheets in Part 3. Moreover, international requirements from relevant international standards and rules are used, which are listed in detail in the licensee's report /4/. In particular, KKL makes use of DIN standards and KTA-rules from Germany as well as IEEE standards, EPRI reports and NUREG reports from the U.S. NRC.

When planning, implementing and adapting the AMP, the evaluation of internal and external experience feedback is also very important. In KKL, the following information sources are used in particular for this purpose:

- Results from internal monitoring, testing and maintenance programmes
- Internal fault/defect reports
- Internal and external reportable events
- Findings from international research projects (e.g. research projects on the application of LIRA diagnostic methods and EPRI-projects on cable-ageing)
- Findings from the power plant manufacturer's evaluation of experience

Regular feedback from experience is particularly important for identifying unexpected damage to electrical cables.

The insulation resistance (conductor-conductor and conductor to earth), current load capacity and conductivity as well as the signal transmission behaviour are crucial for the evaluation of the function of electrical cables. The effects of ageing-induced changes on these function-defining properties are evaluated in Section 3.1.3 of the present national assessment report.

Mühleberg Nuclear Power Plant (KKM)

The relevant ageing mechanisms and their diagnostic methods applied in KKM for electrical cables are presented in tabular form, subdivided by component parts for the 4 cable groups, in the licensee report /3/. The diagnostic methods used include in particular, visual inspection of the cables, infrared measurements for medium voltage cables where there are special cases of concern, analysis of samples from the cable pre-ageing area, capacitance and insulation resistance measurements, tan delta measurement, Isothermal Relaxation Current (IRC) analysis and Time Domain Reflectometry (TDR).

- The medium voltage power cables for the emergency power supplies (group 1) from the hydro power plant belonging to KKM, are three-conductor cables with mass-impregnated non-draining insulation, lead jacket and flat wire shielding. These cables are not incorporated directly in the AMP, rather are checked separately.
- If low voltage and instrumentation cables (groups 2 and 3) are routed inside the drywell, visual checks are performed, the insulating resistance measured and samples from the cable pre-ageing area are evaluated to demonstrate their accident resistance.

- No insulating resistance measurements are performed for group 4 special cables, including mineral-insulated cables and coaxial cables for wide-range and power range neutron flux measurements. Instead, TDR measurements are carried out based on internal test instructions to highlight any ageing-induced change in cable properties.

Section 3.1.3 of this report describes in detail a few of the diagnostics methods used in KKM.

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

Beznau Nuclear Power Plant (KKB)

In KKB, electrical cables are generally monitored by periodic visual inspections and diagnostic measurements to detect any ageing.

The visual inspections form part of various operational walk-downs and take place according to the periodic testing programmes. During, for example, periodic inspections of cable supporting structure, visual checking of the outer condition (discolouration, cracking, mechanical damage, etc.) of the cable supported on the structure is performed simultaneously and the results recorded in check-lists. Likewise, visual checks of connecting cables are made as part of component tests (e.g. for motors).

Diagnostic measurements of installed cables are performed using non-destructive methods.

- Specific test programmes exist for medium voltage cables (group 1). Measurements of the dielectric loss factor have proven effective and yield authoritative results on the ageing condition. Measurements are repeated every 10 years on selected cables. The proven tan delta (TD) measurement method with sinusoidal 0.1 Hz very low frequency AC voltage is used. Additional TDR measurements are performed at the cable nominal voltage and then at twice the nominal voltage. Then the measured values are compared with the baseline measurement (mainly the commissioning measurement) and the cable condition is correspondingly assessed (new, significantly aged or defective). Depending on the completed assessment, necessary maintenance measures in respect of repair or replacement can be promptly planned.
- The test programmes for low voltage and instrumentation cables (groups 2 and 3) include impedance and insulation resistance measurements. TDR measurements have also proven useful for determining the ageing condition of low voltage cables. These measurements are repeated every 12 years on selected cables. Since 1996, spare cables and pre-fabricated sample pieces have been specifically exposed over long periods in a location behind a steam generator to an environment with high room temperature and high radiation to determine the exact significant influence of radiation and temperature on ageing. As part of the procurement of qualified cables from a new supplier in 1999, the cable pre-ageing area was supplemented with spare cables and prefabricated sample pieces from this supplier. With periodic evaluations every 5 years and further tests, the plant-specific service time of the cables installed in KKB can be realistically determined in advance. Actual measurements and evaluations are included in the relevant cable fact sheets and are continuously updated. The first evaluations of samples were performed in 1998 and 2003, and then further evaluations in 2008, 2009, 2011 and 2016. Comparing the baseline measurement and the current measurement, it is apparent that the residual elongation at break is still above the required 50%. If there are significant changes in test values, the test intervals are correspondingly shortened.

- The materials of the special mineral-insulated, neutron flux measurement cables (group 4) are not subject to any ageing-relevant material changes under the ambient conditions specified in KKB. The existing test programmes (visual inspection, insulation measurements) have proven effective.

Gösgen Nuclear Power Plant (KKG)

In KKG, electrical cables routed in the plant are always monitored by periodic visual inspections and diagnostic measurements to detect any ageing.

Operational ageing management for cables is an extension of the originally performed qualification tests and is based on the monitoring of the change in the elongation at break of cable sample materials. VGB operates a high stress test area for cable pre-ageing in the German nuclear power plant at Neckarwestheim in which samples of the accident-resistant cable types used in KKG are also stored. Ambient conditions prevailing in the high stress test area for cable pre-ageing (temperature, radiation) are measured. Periodic elongation at break tests are performed, specifically before and after a LOCA test. These investigations make it possible to determine service life curves for the stored cable types. The service life curve indicates the possible service life for a cable dependent on the local dose rate, up to which no further recurring verifications of the accident resistance are necessary.

For special long-term accident-resistant cables, a remaining service life calculation is performed in the fact sheet. The basis for this are data from the original qualification test. By considering the prevailing ambient conditions at the place of installation under both normal operation and accident states, thermal and radiological cable ageing, which both limit the service life, can be determined. The type of ageing which restricts the remaining service life defines when the cable must be replaced.

Line Resonance Analysis (LIRA) is used in KKG as a supplement to operational ageing management for I&C and low voltage power cables. With the aid of this method, it is not only possible to make generic statements, but also through non-destructive measurements, to make statements about the status of individual cables fitted in KKG. However, the evaluation of such cable degradation points requires a lot of experience in using the measurement method and can only be performed by experts. For a more meaningful evaluation of the general ageing condition of a cable, a reference measurement of the cable must be available or at least a series of measurements over a long time period so that a trend can be derived. As no such reference measurements exist for cables older than 35 years, an appropriate measuring cycle must be set up to be able to assess the general ageing condition. In KKG, some 50 highly loaded cables are included in the LIRA measurement programme. The first 10 cables were measured in 2012. Each additional year a further 10 cables were measured and in 2017 the cables measured in 2012 could be re-analysed for the first time. Hence, for the first time it was possible to determine the change in cable parameters over 5 years.

As part of ageing management, the preventive, systematic replacement of all medium voltage cables was decided upon and this was completed by 2011. The decision was based, on the one hand, on experience in other nuclear power plants and, on the other hand, on investigations into the ageing condition of the cables commissioned by KKG from the cable supplier. After the replacement, measurements of the loss factor were performed for the first time for representative new medium voltage cables, which will serve as reference values for future measurements. In terms of the ageing management and condition monitoring of the medium voltage cable, new loss factor measurements are to be made approximately every 6 to 8 years. The measurements are performed by external specialists and the measurement intervals can be shortened in case of suspected changes.

The cables concerned are included in nearly all periodic tests of systems and subsystems. With certain periodic tests, detailed measurements are performed which allow direct conclusions to be drawn about the cable quality. In the neutron flux measurement circuits, for example, insulation resistance and signal transmission behaviour are periodically measured.

In KKG, systematic visual cable inspections during fixed, periodic walkdowns through all buildings, rooms and channels were performed. Attention is primarily paid to the general state of the cables, but also to the ambient conditions (moisture, water ingress, leaks, etc.).

Leibstadt Nuclear Power Plant (KKL)

The effects of ageing-induced changes on electrical cables are monitored and evaluated with the diagnostics methods described below:

- On the one hand, insulation resistance measurements are performed to prove compliance with the specified maximum leakage currents when operating the cable under normal conditions in compliance with the existing conventional technical standards (e.g. codes of practice). On the other hand, this type of cable measurement is established as a test method to identify any ageing effects acting on the cables 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 of the obtained measurement results, allows the ageing behaviour of the cable insulation materials to be evaluated.
- In general, contact resistance measurements are coordinated with insulation resistance measurements on electrical 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 forms part of the measurements. The permissible limits are specified in the relevant KKL maintenance procedures.
- Measurements using the Line Resonance Analysis (LIRA) method are performed as additional random tests on selected cable runs. If cable damage exists, this method allows any necessary actions to be planned in advance. The method can be used with many types of cable insulating materials. The compliance with permitted limits must be determined by specially trained experts who evaluate the measurements that have been carried out.
- Time Domain Reflectometry (TDR) is applied to the neutron flux instrumentation cables. 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 procedures.
- The tan delta test allows insulation damage in both plastic and paper/pulp insulated cables to be located without degrading the quality of the surrounding insulation material. Loss factor diagnostics provide a differentiated statement on the ageing condition of EPR medium voltage cables used in KKL. The short duration of the test means the cable is only loaded for a minimal period.
- 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. Where there are deviations in measuring results from expected values, the individual links of the measuring chain are investigated in respect of their influence. Hence, changes to the cables involved can be detected and appropriate

measures derived. The permissible limit patterns are specified in the relevant KKL maintenance procedures.

- The cables are subject to visual tests during routine walkdowns and also specifically in the form of special visual inspections during the course of inspection and maintenance actions. Changes to the visible parts of the cable (e.g. local discolouration of the jacket surface) are evaluated and, depending on the result, further measures initiated. Only fault-free cable jackets are permitted (no cracks or changes to the structure and surface).
- Thermography results can 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.
- 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 by use of elongation at break tests. In general, in these tests, the relative elongation at break is used as a reference value for the ageing of the cable plastics. Here, the current elongation at break value of (aged) samples is compared with that for samples of the same material without ageing loading. If the value of the reduced stretching ability falls below a fixed limit, 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.

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 loss of coolant accident (LOCA) conditions (steam atmosphere with high temperature and pressure). Periodic measurements are carried out on defined test samples from the high stress test area for cable pre-ageing. The results obtained in this way can be applied, with the corresponding requirements, to the cable used in KKL.

Since electrical cables are simple and rugged components for which there is already extensive operating experience, including from the non-nuclear area, it is not necessary to apply the diagnostic methods described above comprehensively. The appropriate diagnostics, the test triggers and test intervals are selected according to safety requirements, availability requirements and the cable technology of the cable under consideration. In doing so, the following approach is adopted in KKL:

- Insulation resistance measurements on representative cables used with rated voltages > 1kV within the context of periodic and special tests.
- In general, performance of visual inspections to assess the state of the cable used, expanded if necessary by thermography measurements.
- Performance and evaluation of diagnostic measurements of the dielectric loss factor in accordance with IEEE 400.2 /42/ for medium voltage cables at different voltages to assess the ageing condition of the insulation used.
- Periodic Line Resonance Analysis (LIRA) on selected cable runs for condition-oriented assessment of the insulation strength where deterioration is caused by temperature, radiation, moisture or mechanical damage.

- Periodic Time Domain Reflectometry (TDR) measurements on mineral insulated neutron flux instrumentation cables to determine the condition and assess the strength of the insulation.
- Inspection and maintenance accompanying checks on cables are performed as part of work on electrical consumers or I&C facilities.
- The ageing condition is assessed using the high stress test area for cable pre-ageing to provide evidence of the maintaining of LOCA resistance.

Mühleberg Nuclear Power Plant (KKM)

In KKM, the visual and measurement-based testing of 1E class cables as part of the AMP, is performed according to a test instruction during the annual plant revision. In doing so, the condition and change in condition of defined random cable samples are measured. Both cable ends are inspected as part of the visual check. Where possible and clearly identifiable, the jacket insulation is also subject to random checks. The visual checking includes inspection for discolouration, embrittlement, cracking, abrasion, blistering, corrosion and loosening. The metrological testing involves measuring the insulation, in which the insulation resistance of the cables is measured using different voltages.

The wide range and power range neutron flux measurement cables are largely inaccessible, as, on the one hand, they are largely routed in protective tubes or cable trays that are difficult to access and, on the other hand, are routed in areas with high radiation exposure levels. To be able to assess the condition of the cables, Time Domain Reflectometry (TDR) is used. This method makes it possible to identify fault points in the cable and cable transitions such as plugs, crimp connections, etc. These measurements are carried out annually as part of ageing management and then compared with the measurements of the previous year. This means that changes in the cable can be detected at an early stage and preventive actions can be initiated in time. For the wide-range measurement cabling, the reflection measurements are performed from the pre-amplifier. This ensures that the condition of the signal cable including the drywell penetration and connector box at the transition to the detector is checked. For the power range neutron flux measurement, the measurement signal is coupled in directly at the neutron flux measurement system. In this way, the entire measurement path is analysed.

As part of the ageing monitoring process, it was determined in 2012 that there was no design documentation available for the cables of some safety-relevant systems that have been in operation since the KKM was commissioned. As a result, ENSI required the replacement of the affected cables within the reactor building by the end of 2014 and the replacement or re-qualification of the remaining safety-relevant cables outside the reactor building by 2018. All affected class 1E cables within the reactor building were replaced on time.

For the remaining safety-relevant cables outside the reactor building, a material investigation was commissioned by KKM as a basis for decision-making about whether they must be replaced or re-qualified. The investigations of the cable insulation materials were carried out in cooperation with an accredited testing laboratory to estimate the remaining life of the cables. To do so, an operationally aged cable piece was investigated in detail in respect of its resistance to fire and ageing condition. Additionally, the composition of 15 small cut samples of cable insulation material from different locations was analysed. These material investigations were to provide evidence of the comparability of the cables used relative to the test cable. The material analyses showed that two different insulation materials are in use in

KKM. To determine the ageing condition of the second cable type, a further operationally aged cable of this type was analysed. The material investigation confirmed that the cables could be used for at least another 8 years in KKM. Based on these results, it was decided that the remaining safety-relevant cables outside the reactor building, for which there is no design documentation, will not be replaced. In view of the decision to permanently shut KKM down in 2019 and the results from the material investigations, these cables can be used for at least another 8 years in compliance with their design requirements. The re-qualified cables will continue to be monitored within the AMP in order to maintain safe operation of the still required safety systems beyond the establishment of post operation.

In KKM, various cable samples have been stored in the drywell since 1996 so that these cables age in the most unfavourable hostile conditions prevailing in the plant. In 2015, three qualified cables were removed from the cable pre-ageing area and analysed. An accredited test laboratory then investigated the elongation at break by tensile testing. The results of the investigations showed that the insulation of the cables had an elongation at break significantly higher than the required minimum elongation at break of 50 %. Even after additional artificial ageing of 12 weeks at 90°C all elongation at break values were greater than the required minimum elongation at break. To determine the residual lifetime of the cables, the n-degree rule was applied. For the three materials investigated, an ageing behaviour was assumed where for plastics a 10°C lower operating temperature results in a doubling of the wear margin (service life). Based on the results, it can be assumed that the cables tested have an adequate wear margin up to the decommissioning of the respective safety systems.

3.1.4 Preventive and remedial actions for electrical cables

Beznau Nuclear Power Plant (KKB)

Ageing tests were performed for KKB halogen-free medium voltage cables (group 1) in an approved testing laboratory. These tests showed that the medium voltage cable used in KKB is free from faults. Additionally, diagnostic measurements were performed by an external company on various medium voltage cables. The results were evaluated and maintenance measures, in the form of additional, periodic tan delta (TD) measurements, were specified in the plant-specific medium voltage fact sheet.

During the course of their service life in the radiation field, the low voltage and instrumentation cables (groups 2 and 3), in particular their plastic insulation material, suffer changes to the mechanical strength values due to oxygen diffusion (time and temperature dependent). In KKB, suitable tests on batch samples from the cable pre-ageing area enable monitoring of changes in strength values. The results of the evaluations demonstrate that the specified scope and the interval of 5 years for the removal of test samples is suitable for monitoring the cable ageing process in advance. In the 1980s, all partially accident-resistant or non-accident-resistant cables inside the containment were replaced with accident-resistant cables.

Where the special, neutron flux measurement cables (group 4) are concerned, the materials are not subject to any ageing-relevant material changes under the ambient conditions specified in KKB.

As part of miscellaneous backfitting projects, such as the replacement of the original safeguard system, the uninterruptible AC supply and the emergency power supply, group 1 to 3 cables have been replaced as a preventive measure.

Gösgen Nuclear Power Plant (KKG)

For a number of years, cables have been consistently renewed during any plant modifications in KKG. Old cables are not left on the supporting structures. This approach prevents ageing effects, reduces the load on the cable supports, reduces the fire loads where necessary and reduces the risk of increased temperatures along the cable runs.

From 2009 to 2011, all 6 kV cables of the emergency power supply and all 10 kV cables were replaced. Therefore, no ageing effects are to be expected for these cables over the next 40 years. If, in spite of this, there are any findings as a result of the periodic testing of medium voltage cables, the cables are replaced.

Between 2003 and 2008 cables with Halar coating, which must be accident-resistant, were systematically renewed as part of a replacement programme. Mechanically damaged cables are found during the course of walkdowns and are replaced or repaired as necessary. In the coming years, the cable supports will be replaced in trains 1 and 3 of the safety systems. In this connection, identified cable damage is either repaired or the cables are likewise replaced.

Brittle cables were discovered during the course of modifications to the control panels in the control room. Consequently, cables were checked at similar locations. This led similarly to a replacement of I&C cables.

Leibstadt Nuclear Power Plant (KKL)

In KKL the qualified service life of electrical cables is systematically checked. The service life evaluations take into consideration the actual operating and ambient conditions during operation, and assessment results are incorporated in the maintenance planning. Thus, for example, on the basis of notifications concerning damaged cables in other nuclear power plants in 2005, extensive investigations were performed on halogen-free medium voltage cables (10/6kV) with EPR insulation in a qualified laboratory. The results obtained were compared with the applicable qualification requirements and confirmed the fault-free condition of the medium voltages cables used in KKL, so that no remedial actions were necessary.

The measurements of the cable samples stored in the high stress test area for cable pre-ageing represent a further important preventive measure for monitoring the ageing behaviour of cables. The results of the evaluations of the samples demonstrate that the specified scope and the interval for the removal of test samples from the test area are suitable for continually monitoring the ageing process of the cable samples. In addition to the measurement of test samples from the test area, supplementary measurements on class 1E accident-resistant cables were performed by a test institute using the Line Resonance analysis (LIRA) method. The evaluation of these measurements confirms that these cables are in a good condition.

An evaluation of the results of the diagnostic measurements of the medium voltage cables > 3kV made in accordance with IEEE 400.2 /42/ over a period of 5 years (2010 to 2014) in KKL yielded evidence of very good dielectric values. There is a very wide safety margin relative to the limits defined according to EPRI. The results also indicate a very wide margin relative to the generally specified limits of certified testing institutes, who have available a very large database.

Mühleberg Nuclear Power Plant (KKM)

In KKM, numerous class 1E cables have been replaced over the last 26 years within the context of plant improvements. These improvements concerned the following systems which are in operation since the commissioning of KKM:

- The reactor protection system (1991/92),
- Wide range neutron flux monitoring instrumentation and the emergency diesel generator (1993),
- N_2-inerting of the primary containment (1995),
- The emergency air control, the ventilation insulation in the reactor building, the drywell and torus depressurisation system and the drywell recirculation air cooling (1999),
- Drives of the recirculation pumps and feedwater pumps (2009 to 2012).

Preventive cable replacement was also carried out within the context of replacement projects for 0E class and unclassified components and systems.

In KKM, the class 1E cables of some safety systems in the reactor building were replaced during a two-year period (see Section 3.1.3). The majority of the identified cables were already installed before the 2013 annual revision and then connected during the revision. In this way, the old cables could be completely removed during and after the 2013 annual revision. The remaining cables were installed during the 2014 annual revision. In doing so, the cables outside the reactor building up to the next connection point were also replaced. Where present, the local control boxes in the reactor building were also replaced together with the corresponding cables. The cables were routed in the existing cable runs.

The examination of the medium voltage cables of the emergency power supply, which are not directly incorporated in the AMP, showed that the cables including their insulation are in a good working condition. Nevertheless, the emergency power cable connections were replaced as a preventive measure.

3.2 Licensees experience of the application of ageing management programmes for electrical cables

Beznau Nuclear Power Plant (KKB)

In KKB, the electrical engineering expert team 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 nuclear power plants. Necessary adjustments and developments are continuously implemented. To ensure that the state-of-the-art of science and technology is taken into consideration in the plant-specific fact sheets, the generic basic documents for ageing management (fact sheets Part 1 and Part 2) are continually checked, but in any event no later than every ten years, and updated as necessary. Based on these evaluations, the plant-specific documents for cables (fact sheets Part 3 and corresponding maintenance documents) are also adapted as necessary. The following findings can be derived from the ageing management of the electrical cables in KKB:

- Where the medium voltage cables (group 1) are concerned, no new ageing relevant findings are known that must be taken into account. The existing maintenance concept (periodic inspection, testing and measurements) has proven its worth.
- Amongst the low voltage and instrumentation cables (groups 2 and 3) there are likewise no new ageing relevant findings to be taken into account. Therefore, here too, the existing ageing concept is also found to have proven its worth.
- Where the special mineral-insulated, neutron flux measurement cables (group 4) are concerned, the materials in KKB are not subject to any ageing-relevant changes under the ambient conditions specified in KKB.

In report /6/, KKB checked the effectiveness of the cable AMP based on the 9 attributes from table 2 of the IAEA Safety Guides NS-G-2.12 /20/, by presenting measures implemented in the AMP for each attribute. Hence, the AMP implemented in KKB contains all the attributes of an effective ageing management system.

Gösgen Nuclear Power Plant (KKG)

KKG plans a long-term operating period of 60 years. The most appropriate measure for the avoidance of ageing damage to electrical cables is the systematic preventive replacement of cables within the scope of plant modifications.

The participation in the VGB research project with regular evaluation of cables that are subject to accelerated ageing in a store is a worthwhile diagnostics method for the early identification of cable ageing effects. Also, Line Resonance Analysis (LIRA) measurement programmes have proven successful in KKG. In June 2017, cables were measured for the first time that had already been tested 5 years previously. No ageing-induced findings were identified as a result.

KKG consequently concludes that the ageing behaviour of electrical cables is satisfactory monitored in the plant-specific AMP.

Leibstadt Nuclear Power Plant (KKL)

Based on the preventive measures taken within the plant specific AMP and the findings and forecasts obtained as a result, KKL comes to the conclusion that the condition of the safety-relevant cables is very good. The selection and specification of the cable materials and cable types used within the framework of the plant design and corresponding qualification of the cables has proven successful. The tests specified via the maintenance programme, represent a suitable sample size. In KKL, it has not so far been necessary to take any actions to delay the further advance of cable ageing nor to prevent it.

Based on current knowledge, the relevant ageing mechanisms for all parts of the safety-relevant cables are identified in the KKL AMP. The occurrence of the ageing effects caused by the ageing mechanisms can be promptly detected based on the implemented monitoring actions and as a result necessary counter-measures can be initiated. Moreover, experience and findings in other plants are continuously monitored so that, if necessary, the AMP for cables in KKL can be adapted as necessary.

Mühleberg Nuclear Power Plant (KKM)

KKM will finally terminate power operation at the end of 2019. Some safety systems, including the corresponding class 1 cables will continue in operation beyond this point in time. This condition has been taken into account in the KKM AMP, as the evaluation and the measures derived from it consider the safe operation of the still required safety systems beyond permanent shutdown.

As over many years, KKM has replaced electrical cables as a matter of course whenever plant modifications have occurred, there is now only a very limited amount of the original cabling remaining. The ageing of these cables is assessed by periodic testing and condition checks of individual cables within the scope of the AMP and, where necessary, preventive measures implemented.

3.3 Regulators assessment and conclusions on ageing management programmes of electrical cables

According to the basic requirements in guideline ENSI-B01 /10/ the ageing mechanisms applicable to the safety-relevant (class 1E) electrical cables must be identified. Moreover, a check must be undertaken to determine whether the existing maintenance programme is suitable for promptly detecting ageing-induced damage. According to guideline ENSI-B14 /12/, the findings from ageing management must be incorporated in the maintenance programme within one year.

Moreover, the documents created for cable ageing management, must be checked regularly to ensure they correspond to the latest state of knowledge. For this purpose, manufacturer information and findings from operating experience from Swiss plants and other comparable plants, and from monitoring of the state-of-the-art of science and technology must be considered. Changes made in the electrical cables AMP must be reported annually to ENSI /16/.

Beyond the basic requirements referred to, guideline ENSI-B01 includes more specific requirements in respect of the ageing management of electrical components. These relate in particular to the accepted methods for prediction of potential ageing effects, the proof of accident-resistance and the information contained in the plant-specific fact sheets. The cable type, the design specification, type of cable routing, conditions of use, usage time in respect of the maintaining of accident-resistance as well as the type, scope and findings of conducted tests are in particular to be recorded in the fact sheets for electrical cables.

Alongside guideline ENSI-B01, ENSI refers in particular to IAEA documents /43/, /44/ and /45/ in assessing the ageing management of electrical cables.

From ENSI's point of view, the Swiss nuclear power plants have effective ageing management processes and programmes for safety-relevant cables that will ensure the functionality of the electrical cables under long-term normal operating conditions and accident conditions. Through the close cooperation of the Swiss nuclear power plants in both the GSKL coordination team and the GSKL electrical engineering expert team in developing and revising the generic fact sheets, as well as in monitoring international operating experience, known ageing phenomena and the latest diagnostic methods are incorporated in the generic fact sheets. Based on random checks performed during inspections, ENSI was able to convince itself that plant-specific fact sheets have been created for all cable types used in the Swiss nuclear power plants and that these sheets contain the information required according to guideline ENSI-B01.

A wide spectrum of recognised and effective diagnostic methods is used in the Swiss nuclear power plants to identify the relevant ageing mechanisms. In particular, in ENSI`s point of view, all Swiss nuclear power plants evaluate experience from accelerated ageing tests, which enable a proactive assessment of cable ageing under extreme ambient conditions. Beyond that, targeted, condition-orientated assessment of the insulation resistance of selected cable types is performed using the advanced measuring methods of Line Resonance Analysis (LIRA) and Time Domain Reflectometry (TDR). In addition to ageing management, a policy of replacing old cables with new ones during the numerous upgrades is consistently followed in the Swiss nuclear power plants.

In contrast to the other Swiss nuclear power plants, in Mühleberg Nuclear Power Plant (KKM), due to the ending of power operation in 2019, no method will be applied anymore for identifying a cable ageing trend. In view of the predicted residual running times of safety-relevant systems, visual inspections and insulation resistance measurements on the cables are primarily carried out. A deficiency relating to the design documentation of some safety-relevant cables identified in 2012 has, in ENSI`s point of view, been consistently rectified by replacement or requalification of the cables concerned. The cables concerned were exclusively cables used since the start of power operation which had not yet been replaced. The results of the investigations showed that it could be retroactively demonstrated that visual checks and test measurements on the cables carried out up until that time had been effective. Based on focused visual checks within the scope of inspections (general condition, fastening, rubbing points, brittle and cracked points, hardening, kinks or sharp direction modifications, penetration of moisture) ENSI was able to convince itself, that the cables are in a good working condition. In ENSI`s point of view, the planned approach to electrical cable ageing management for the remaining life of KKM is appropriate.

Furthermore, after checking the available fact sheets of the other Swiss nuclear power plants, ENSI came to the conclusion that the findings in KKM could not be transferred to the other Swiss nuclear power plants.

Based on the periodic reporting specified in guidelines ENSI-B02 /16/ and ENSI-A03 /17/, ENSI comes to the conclusion that new findings from both internal operating experience and experience from other plants, as well as from monitoring of the state-of-the-art of science and technology are being incorporated in the AMP for cable and the corresponding maintenance programmes. Existing experience shows that with the AMP implemented in the Swiss nuclear power plants, the occurrence of ageing effects in cables would be promptly detected and preventive measures implemented in a timely manner. The test results in respect of the recorded ageing resistance of the mineral insulated cables used in the Swiss nuclear power plants, in particular their resistance to radiation, is also confirmed by international operating experience.

Conclusion

The AMP implemented in the Swiss nuclear power plants for electrical cables fulfils the essential national and international regulations and, in ENSI`s point of view, includes the elements (attributes) referred to in the IAEA Safety Guide, of effective ageing management. The effectiveness of the ageing management is demonstrated by the fact that safety-relevant cables are in a good condition and that until now there have only been very limited findings in connection with cable ageing problems in the Swiss nuclear power plants.

4 Concealed pipework

4.1 Description of ageing management programmes for concealed pipework

4.1.1 Scope of ageing management programmes for concealed pipework

The licensees of the Swiss nuclear power plants have checked which of the pipes contained within the AMP can be regarded as concealed pipework. The checks focused on underground pipes of safety classes 1 to 3 that cannot be monitored with the usual inspection methods. To identify these pipes specific plant documents were used and partially additional plant walkdowns were carried out.

The so-called zone concept that applies to the Swiss nuclear power plants, according to which all radioactive releases to the environment must occur in a controlled manner, ensures that all concealed pipes do not carry any radioactivity.

Concrete-embedded classified piping sections, especially in the area of building penetrations, are not given further consideration here because the inaccessible sections are very short and the external surfaces are not subject to relevant ageing mechanisms. In the plant-specific AMP, these pipe sections are not handled any differently from the accessible pipe sections of the respective systems. The checks also revealed that no safety-relevant oil, fuel or compressed air lines are routed such that they are inaccessible.

The focus of the investigations was on those pipes contained in the fact sheets of essential service water and emergency cooling water systems, including the corresponding inlet structures. The construction design of these pipe systems differs in the Swiss nuclear power plants. Service water systems, for example, are routed either in accessible pipe ducts or in inaccessible concrete ducts.

The licensee of Leibstadt Nuclear Power Plant (KKL) comes to the conclusion /4/ that there are no inaccessible, safety-relevant pipes in its plant and therefore did not carry out any further assessment.

4.1.2 Ageing assessment of concealed pipework

Beznau Nuclear Power Plant (KKB)

KKB only identified a few short, concealed pipework sections in the essential service water system. These pipe sections, which are only a few metres long, are made of stainless steel and are under dry atmospheric conditions in the turbine building inside hollow concrete-embedded pipes. The licensee therefore excludes any relevant ageing mechanisms.

Mühleberg Nuclear Power Plant (KKM)

KKM has identified concealed pipework in the emergency cooling water system and in the essential service water system.

The concealed pipework sections of the emergency cooling water system are plastic pipes inside a reinforced concrete pipe. The annular gap between the reinforced concrete and the plastic pipe is filled with a bentonite suspension. The wall of the inner pipe is made of a thermosetting polymer composite material. Corrosive ageing damage can be excluded for plastic pipes. However, over longer periods of use, the material properties can deteriorate. Based on the inspection programme presented in the following section, the licensee comes to the conclusion that the concealed pipework sections of the emergency cooling water system are in good condition.

According to the licensee, the buried ferritic pipes of the service water system are subject to the ordinary corrosion mechanisms of metallic pipes. The ferritic pipes are wrapped on the outside and run in a sand bed. The inside of the pipes is covered with a tar epoxy coating. Based on the inspection programme presented in the next section, the licensee comes to the conclusion that the inaccessible ferritic pipes of the service water system are in good condition.

Gösgen Nuclear Power Plant (KKG)

KKG has identified concealed pipework sections in the secondary and the primary service water systems. These are buried or located in inaccessible ducts. Based on the results of the inspections performed, the licensee comes to the conclusion that the operating experience for the concealed pipework of both service water systems is positive.

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

Mühleberg Nuclear Power Plant (KKM)

Only KKM has presented the implemented monitoring, test and inspection activities for the identified concealed pipework. These activities are specified in the fact sheets of the emergency cooling water system and the service water system. According to the fact sheets, the river water that flows through both systems is periodically analysed in respect of its corrosive properties. Where these properties are concerned, the river water is equivalent to drinking water.

For the plastic pipes of the emergency cooling water system, compliance with the required material properties is checked annually using retained samples from the manufacturing batch which were stored in the river water. It is therefore possible to detect ageing-induced changes in the material properties in a timely manner. For instance, over recent years the decrease in strength of the plastic pipe material is slowing down. Based on the determined regression curve, the minimum permissible value will not be reached within the planned period of system operation.

Periodic inspections of the inner surface of the accessible, ferritic pipe sections of the service water system within the turbine building are performed. Extensive ultrasonic wall thickness measurements reveal only a few positions with slight reductions in wall thickness. The measured wall thicknesses are significantly above the calculated required wall thicknesses, so that the structural integrity of the service water system is ensured up to the time the system will be put out of operation. According to the licensee, this result also applies to the concealed pipework sections of the service water system, because these sections are of identical design and are exposed to the same conditions as the accessible pipe sections.

Regarding the condition of the outer surface coatings of the concealed pipework sections of the service water system, the licensee refers to experience from sample drilling on the main cooling water pipe, which is of the same design and runs in parallel to the service water pipe in the ground. Here the outer wrappings were still largely intact after 40 years and there was no relevant corrosion damage on the outer pipe surface.

4.1.4 Preventive and remedial actions for concealed pipework

Mühleberg Nuclear Power Plant (KKM)

Based on existing operating experience, KKM comes to the conclusion that for the concealed pipework area of the emergency cooling water system and the service water system no preventive measures or repairs are required up to the time the systems will be put out of operation.

Gösgen Nuclear Power Plant (KKG)

KKG refers to the already performed replacement of ferritic pipe sections with austenitic stainless steel where pipes are buried. Moreover, for selected, originally uncoated pipes, the inner surface has been protected by a Polyethylene (PE) liner or an epoxy resin coating.

4.2 Licensees experience of the application of ageing management programmes for concealed pipework

The licensees of the Swiss nuclear power plants refer to the fact that concealed pipework sections are only present in a few safety-relevant systems. Based on positive operating experience, no special ageing management measures are necessary for the short, concealed pipework sections of building penetrations.

KKM judges the monitoring and tests of concealed pipework sections in the emergency cooling water system and the service water system carried out as part of ageing management to be effective and sufficient.

4.3 Regulators assessment and conclusions on ageing management programmes of concealed pipework

Based on the specifications in the guideline ENSI-B01 /10/ the results of ageing management for pipes of safety classes 1 to 3 are to be recorded in the form of fact sheets. In this context, the requirement to identify the relevant ageing mechanisms and to evaluate the effectiveness of the established maintenance and inspection programmes also applies to these safety-classified concealed pipework sections. Identified gaps must be documented and suitable supplementary measures taken. Identified gaps must be documented and suitable supplementary measures taken.

In guideline ENSI-B06 /11/ no specific requirements for the inspection of concealed pipework are defined. However, findings from ageing management can lead to specific requirements for the inspection of concealed pipework.

In consultation with ENSI, the licensees of the Swiss nuclear power plants have investigated safety-classified systems that are part of the AMP according to guideline ENSI-B01 for the presence of concealed pipe sections.

With the exception of KKM, the licensees of the other Swiss nuclear power plants in which concealed pipework sections have been identified do not made any specific statements about the relevant corrosion-induced ageing mechanisms or the inspections carried out (e.g. internal inspections using camera pigs). Moreover, neither the background nor the effectiveness of already performed preventive and remedial actions on concealed pipework sections is presented in sufficient detail.

Therefore, ENSI will extend the focus of its regulatory efforts regarding ageing management in order to make sure that all safety-relevant concealed piping systems are included and are covered by suitable maintenance and inspection programmes (area of improvement).

Conclusion

According to the investigations performed by the licensees, there are only a few areas in which there are safety-relevant concealed pipework. In individual cases, preventive measures have been implemented in these areas. Irrespective of this, from ENSI´s point of view it is important to check whether concealed pipework areas are systematically included in the existing plant programmes for ageing management.

5 Reactor pressure vessels

5.1 Description of ageing management programmes for RPVs

5.1.1 Scope of ageing management programmes for RPVs

According to guideline ENSI-G01 /31/, all reactor pressure vessels (RPVs) in the Swiss nuclear power plants are classified as safety class 1. The design code used is ASME BPVC, Section III, Subsection NB /33/ or a corresponding earlier version. According to guideline ENSI-B01 /10/, the RPVs are assigned to category A. It follows that the RPVs must be treated in detail within the scope of ageing management, which means that the ageing mechanisms must be evaluated for the individual parts of the component. The RPVs are made from low alloy ferritic steel with austenitic cladding on the inside. Further construction and design characteristics of the RPVs can be found in the published licensee reports /3/, /4/, /5/ and /6/.

Included in the scope of RPV ageing management are the RPV with the cylindrical part, head flange with bolt fastenings, vessel head and bottom, cladding, nozzles including the safe-end welds, and the internal welding. Also included are the penetrations for the control rods and core instrumentation nozzles as well as all welds. The RPV internals and the control rod mechanisms are considered separately.

5.1.2 Ageing assessment of RPVs

Ageing assessment of RPVs is performed based on a large number of specifications and documents, internal and external operating experience and monitoring of the state-of-the-art of science and technology.

Of particular importance for the ageing management of the RPVs are the following documents:

- Regulatory guideline ENSI-B01 /10/,
- GSKL guide for the preparation of fact sheets for mechanical components /28/,
- GSKL catalogue of relevant ageing mechanisms (KATAM) for mechanical components /29/,
- Component-specific fact-sheets,
- DETEC ordinance /9/ on the criteria for provisional shutdown.

The guideline ENSI-B01 and the GSKL guide specify the requirements for the preparation of fact sheets for the RPVs. For each Swiss nuclear power plant, there is a corresponding RPV fact sheet. Based on the catalogue of ageing mechanisms for mechanical equipment (KATAM), the relevant ageing mechanisms and necessary maintenance measures are described in detail in these fact sheets. The DETEC ordinance defines acceptance criteria for the embrittlement of the RPV materials, which if infringed would result in provisional shutdown of the nuclear power plant.

Further documents used for RPV ageing management are the ENSI guidelines and the specifications of the Swiss Association for Technical Inspections (SVTI) as well as the design codes ASME BPVC, Sections III /33/ and Section XI /34/. Also referred to are the IAEA-Safety Guide NS-G-2.12 /20/, regulatory guides (e.g. RG 1.99 /35/, RG 1.207 /36/), NUREG reports (e.g. NUREG/CR-6909 /37//305/) of the U.S.-NRC, as well as the ASTM standards (ASTM E 1820 /38/, ASTM E 1921 /39/).

Manufacturing documents, such as drawings, manufacturing test certificates, construction supervision reports and expert statements of the responsible authorised experts, repair reports and non-conformance reports are used to identify possible RPV ageing effects. Relevant ageing mechanisms include in particular thermo-mechanical fatigue, neutron embrittlement and stress corrosion cracking. Fatigue primarily results as a consequence of temperature transients or partially as a result of thermal stratification. Particularly affected are RPV nozzles and RPV bolts. Embrittlement because of neutron irradiation affects the ferritic base metal and the circumferential welds in the reactor core area. Stress corrosion cracking is primarily relevant for dissimilar metal welds on the nozzles or penetrations and for austenitic materials. Moreover, further ageing mechanisms, such as surface corrosion, abrasive sliding wear and adhesive wear, thermal embrittlement and acid corrosion are considered for the RPVs of pressurised water reactors.

The licensees of the Swiss nuclear power plants continuously monitor the state-of-the-art of science and technology. Accordingly, the research projects INTEGER, NORA, PISA, SAFE, PROBAB of the Paul Scherrer Institute (PSI) and BWRVIP are supported. The PSI NORA research project is investigating material behaviour associated with optimisation of water chemistry by injection of hydrogen and catalytic noble metals. The research project SAFE deals with questions relating to stress corrosion cracking and fatigue under environmental influence. PROBAB is a research project on the application of probability methods in the integrity assessment of RPVs, especially associated with PTS analyses and leak before break (LBB) behaviour. BWRVIP is an extensive and internationally recognised research project of EPRI on the most important issues concerning the component integrity of boiling water plants.

Also of great importance for the ageing management of RPVs is the evaluation of internal and external operational experience. Sources for internal operating experience are, amongst others, non-conformance reports, maintenance reports and logs of important operating parameters such as temperatures at selected positions on the RPVs or water chemistry parameters. Findings or indications detected in periodical in-service inspections are followed by measures for further clarification. If necessary, replacement, repair or shortened inspection intervals are the outcome. External operating experience comes primarily from the reports of the plant manufacturers, WANO, from the CODAP database of OECD/NEA and the IGALL database of the IAEA. Other sources are, for example, reports from EPRI, U.S.-NRC, VGB, GRS or direct exchange with other licensees.

After the findings in the Belgian Nuclear Power Plants, Doel 3 and Tihange 2, all Swiss nuclear power plants conducted investigations into the RPV base metal. In 2013, in particular, the manufacturing documents were analysed. The licensees came to the conclusion that the manufacturing-induced formation of hydrogen flakes can be considered highly unlikely for the Swiss RPVs. Additionally, in 2015, ultrasonic measurements were carried out on the RPV base metal, which likewise revealed no evidence of hydrogen flakes. However, in the RPV of unit 1 of Beznau Nuclear Power Plant (KKB), indications were detected that can probably be traced back to non-metallic inclusions from manufacture. The RPV integrity assessment, taking into consideration the ultrasonic testing indications, is not yet complete. KKB unit 1 has been shut down since the discovery of the indications.

5.1.3 Monitoring, testing, sampling and inspection activities for RPVs

The RPVs in the Swiss nuclear power plants are subject to the monitoring and tests described below:

In-service inspection programme

Maintenance includes an in-service inspection programme with numerous inspections carried out on the RPV. Here, particular use is made of the standard NDT methods for surface and volumetric inspection. In addition, regular system and component walkdowns are performed. The pressure boundary of the primary system, including the RPV, is subjected to a pressure test at the design pressure every 10 years in accordance with the SVTI Specification NE-14 /13/ and Guideline ENSI-B06 /11/.

The in-service inspection programme includes ultrasonic testing (UT) and eddy current testing (ET) of the RPV circumferential welds and, where present, also the vertical welds of the cylindrical shell and on the head and bottom, the nozzle welds, dissimilar metal welds and welds of the 'safe ends'. The base metal in the immediate vicinity of the welds is included in the testing. A large proportion of the tests is carried out using automated scanning and data collection. In addition, various sections of the RPV are also inspected using visual (VT), dye penetrant (PT) or magnetic particle (MT) testing.

Other typical inspection areas are the head or flange bolts, threaded blind holes, and nuts and washers (ET and VT). The penetrations in the head and bottom for control rod drive and in-core monitoring housings are inspected using visual tests. Moreover, internal supports for the RPV internals and selected areas of the RPV cladding are inspected.

In most cases, the inspection interval is 10 years. Shorter intervals are specified for certain areas. For example, in Leibstadt Nuclear Power Plant (KKL) some dissimilar metal welds made from the weld metal alloy 82/182 are examined every three years.

Before every restart of the Swiss nuclear power plants, the RPV is subject to a leakage test, which includes a visual inspection for leaks and other anomalies. If indications are detected, it must be checked whether they are subject to registration or evaluation. Indications subject to evaluation, require further assessment in respect of their acceptability, as well as potential follow-up measures such as shortened inspection intervals, repair or replacement, and a clarification as to their cause.

Fatigue monitoring

Components susceptible to fatigue are equipped with temperature sensors. In particular, the RPV nozzles for the main reactor coolant lines are monitored. In addition, the fatigue governing transients are recorded.

In Mühleberg Nuclear Power Plant (KKM), the fatigue usage is manually evaluated and, since guideline ENSI-B01 /10/ was published, compiled in an annual report on component fatigue. The basis for this is Annex 6 of guideline ENSI-B01. Amongst other things, the current fatigue usage factors and the extrapolated fatigue usage factors for 60 years of operation must be recorded for all fatigue-relevant components. For KKM, this period is limited to 47 operating years due to its final shutdown in 2019.

The other Swiss nuclear power plants are now using an integrated system for fatigue monitoring. Since 2002, Beznau Nuclear Power Plant (KKB) has used the WESTEMS system provided by the plant manufacturer, Westinghouse. Gösgen Nuclear Power Plant (KKG) uses AREVA's FAMOSi system, which is widely used in German nuclear power plants, while Leibstadt Nuclear Power Plant (KKL) uses the system FATIGUE PRO developed by EPRI and Structural Integrity. Prior to the introduction of these systems, fatigue was evaluated on the basis of conservative assumptions in a conventional transient recording system. The counted transients were compared with the transients specified in the design and from this, a fatigue usage factor was determined. Guideline ENSI-B01 specifies the cases in which the influence of the reactor coolant must be considered according to NUREG/CR-6909 /37/.

In summary, the licensees of the Swiss nuclear power plants come to the conclusion that the computed 60-year extrapolation value of the fatigue usage of the RPVs are all well below 100%.

Embrittlement monitoring

For RPVs, radiation-induced material embrittlement is the most important ageing mechanism. The neutron irradiation causes structural changes in the material, which is reflected in a decreasing ductility. In particular, the radiation-induced shift of the ductile-to-brittle transition temperature causes a decrease in fracture toughness.

The Swiss nuclear power plants apply the programmes prescribed in the nuclear regulations for the monitoring of radiation-induced material embrittlement which specify the use of material surveillance specimens positioned close to the reactor core so that they are exposed to an increased neutron flux. The irradiated surveillance specimens are removed at specified times and evaluated using destructive testing. A trend curve for the adjusted reference temperature (ART) can be obtained in combination with the measured values for non-irradiated material samples. The ART reference temperature characterises the transition between brittle and ductile material behaviour. The basis for determining the ART reference temperature is the U.S.-NRC Regulatory Guide 1.99 Rev. 2 /35/. Alternatively, the reference temperature T0 can be determined according to the master curve concept of ASTM E 1921 /39/ and converted to a reference temperature RT_{ref} that is equivalent to the ART reference temperature in accordance with the specifications of Annex 5 of guideline ENSI-B01 /10/. It must be demonstrated that the Charpy-V upper shelf energy is at least 68 J, while the reference temperature ART must not fall below a value of 93°C at a depth equal to ¼ of the overall wall thickness. Otherwise, an immediate provisional shutdown of the power plant is required in accordance with the DETEC ordinance /9/.

In addition, in order to exclude brittle fracture, a fracture mechanics analysis must be performed for the main transients using deterministic methods. In pressurised water reactors, this approach is referred to as PTS analysis. The Swiss regulations and standards do not include any specific specifications on the methodology of PTS analyses. They must be carried out in accordance with the current state-of-the-art of science and technology, e.g. based on IAEA-TECDOC-1627 /40/ or KTA 3201.2 /41/. For boiling water reactors, no PTS load cases are specified for technical reasons. Analogous brittle fracture analyses must be carried out for the main transients, but in comparison with pressurised water reactors, they are much less severe.

The results of the RPV brittle fracture safety analyses of the Swiss nuclear power plants are presented next.

Beznau Nuclear Power Plant (KKB)

Six capsules of irradiated specimens have been removed from the RPV in unit 1 and five of six sets of specimens from unit 2. For both units, the removed sets of irradiated specimens cover an operating period of more than 60 years. The embrittlement of the RPV in unit 1 is much higher than in unit 2. The last irradiation capsule from the unit 1 RPV was evaluated according to the master curve method of ASTM 1921 /39/ and Annex 5 of guideline ENSI-B01 /10/. The PTS analyses for units 1 and 2 have been updated as of 2016 and exhibit adequate safety for 60 operating years. The shutdown criteria specified in /9/ are not reached.

In 2015, ultrasonic indications were detected in the base metal of some forged rings of the RPV of unit 1. These are probably from aluminium oxide inclusions resulting from the production process. Possible effects on the integrity assessment of the RPV are the subject of ongoing investigations.

Gösgen Nuclear Power Plant (KKG)

Three sets of irradiated specimens were placed in the KKG RPV, all of which have been removed and evaluated. The last sample covers an operating period of well over 60 years. The minimum Charpy-V impact energy was determined as 118 J. The brittle fracture transition temperature is 33°C based on conventional methods and -16°C according to the master curve method. In an updated PTS analysis based on the state-of-the-art of science and technology, it was demonstrated that large margins exist relative to the acceptable brittle fracture transition temperature.

Leibstadt Nuclear Power Plant (KKL)

Six sets of surveillance specimens were placed in the KKL RPV. In the meantime, two of them have been removed for evaluations after 14 years and 24 years of operation. The Charpy-V upper shelf energy is at least 130 J. Extrapolation to 60 years of operation shows only a minimal shift of the ART reference temperature of 4 K. Therefore, there are large margins relative to the criteria of the DETEC ordinance /9/. The evaluation was carried out according to the U.S.-NRC Regulatory Guide 1.99 Rev. 2 /35/.

Mühleberg Nuclear Power Plant (KKM)

Three capsules with irradiation specimens were removed from the RPV and then evaluated, in total covering an operating period of 78 years. The KKM RPV has a peculiarity in the form a circumferential weld with increased copper content, which increases the susceptibility to neutron embrittlement. Therefore, the embrittlement of the RPV is higher than for comparable boiling water reactors. Nevertheless, extrapolated to 60 years of operation, it is still well within the acceptable range.

Other monitoring measures

In the Swiss nuclear power plants, the water chemistry conditions are continuously monitored and documented because changes in the chemical parameters could provide evidence of previously undetected ageing effects. In particular, chlorides, sulphates, conductivity and hydrogen redox potential are recorded. In the boiling water reactors, monitoring of the water chemistry also is used to assess the effectiveness of hydrogen and noble metal injection for the prevention of intergranular stress corrosion cracking.

The Swiss nuclear power plants have different systems for leakage monitoring of the RPV. Supplementary measures are temperature, humidity and pressure monitoring systems and periodic visual inspections during walkdowns in the primary containment. KKG also has a primary circuit vibration monitoring system.

5.1.4 Preventive and remedial actions for RPVs

The following section describes the measures carried out in the Swiss nuclear power plants for the prevention and remedying of ageing effects acting on the RPV.

Beznau Nuclear Power Plant (KKB)

In 2015, the heads of both units were replaced. Alongside a series of small improvements, the material Inconel 600 which is susceptible to stress corrosion cracking was replaced by Inconel 690 and by Inconel 52 for the head penetrations.

Gösgen Nuclear Power Plant (KKG)

Preventive measures of KKG are based on the evaluation of internal and external operating experience as well the current state-of-the-art of science and technology. Consideration of the ageing behaviour of the materials used in the design and manufacture of the RPV, the material selection, and the quality assurance measures are considered by the licensee to be adequate precautionary measures for the planned service life of the plant.

Leibstadt Nuclear Power Plant (KKL)

In KKL, the OLNC (On-line NobleChem) process is used with the injection of hydrogen and noble metals. Its effectiveness is determined by the measurement of the electrochemical potential based on EPRI specifications. The lowering of the electrochemical potential achieved with the process, reduces the initiation of and/or the propagation speed of stress corrosion cracking.

On the basis of external operating experience a repair concept was prepared for the potential occurrence of leaks in the bottom penetrations of the control rode drive housings. The essential foundations for the qualification and implementation of the roll repair procedure are ASME-Code Case N-730, N-769-1, N-769-1 /33/ and guideline ENSI-G11 /15/.

After detection of stress corrosion cracking at a feed water nozzle of the RPV, a repair was undertaken with a ‘full structural weld overlay’ using the corrosion-resistant nickel alloy Inconel 52M. The qualification and implementation took place according to the requirements of design code ASME III, Subsection NB /33/ as well as ASME Code Case N-740-2 and guideline ENSI-G11 /15/. As part of the evaluation of the indications on the feedwater nozzle, a revised maintenance and ageing management concept for the pipe connection welds of all RPV nozzles was prepared and submitted to ENSI. This essentially comprises shortened inspection intervals and special remedial actions (MSIP, Mechanical Stress Improvement Process). Currently, an application for approval of the technical specification for the process is being prepared based on ASME III, Subsection NB, ASME Code Case N-770-1 /33/ and guideline ENSI-G11 /15/.

Since 1985, single loop operation has been introduced to reduce thermal fatigue during low-load operation. This avoids the occurrence of thermal stratification as a result of return flow of the reactor water into the feedwater nozzles.

Mühleberg Nuclear Power Plant (KKM)

From 1995 to 1996, the RPV head bolts were replaced, with the replacement bolts having rolled threads and optimised thread geometry.

Because of a modification of the control rod drive system, there was no injection of cold feed water via the return line into the RPV anymore. Therefore, a blind flange could be fixed on RPV nozzle N9 in 2004.This modification largely eliminated fatigue loadings on this nozzle.

Since 2000, in order to minimise stress corrosion cracking on internals, cladding and internal RPV welds, a switch to hydrogen water chemistry control (HWC) took place, which since 2005 has been supplemented by noble metal injection with platinum (OLNC™ process - Online Noble Chem).

Beginning in the mid-1980s, various RPV temperature monitoring systems have been backfitted. In 1997, based on results from these monitoring measures, the RPV nozzles were modified by the installation of double thermosleeves. Since 1996 improved temperature sensors have been used in the bottom region.

5.2 Licensees experience of the application of ageing management programmes for RPVs

As a preventive measure, both Swiss boiling water reactors are operated with optimised water chemistry, in that a hydrogen operating mode with additional noble metal injection is applied. Consequently, the susceptibility to stress corrosion cracking of components made of austenitic steels and nickel based alloys is reduced. Both KKM and KKL consider the use of the hydrogen operating mode as effective.

Moreover, in all Swiss nuclear power plants, the condition of the RPV and its components are checked regularly through comprehensive in-service inspection programmes, and an estimate of the fatigue usage level of the RPV is obtained via fatigue monitoring programmes. The evaluations show that an operating life of 60 years is not limited by RPV fatigue.

The monitoring and evaluation of the neutron embrittlement of the RPV is provided in all Swiss nuclear power plants by the use of surveillance specimens. The RPVs of KKL and KKB unit 2 still contain sets of test samples that have not yet been evaluated. The licensees of the Swiss nuclear power plants have reached the conclusion that there is a sufficient safety margin in respect of the safety against brittle fracture of the RPVs to permit long-term operation. The criteria of the DETEC ordinance /9/ for the provisional shutdown of a nuclear power plant have not been reached. In addition, the integrity of the RPVs is also confirmed by computational analyses of the resistance to brittle fracture.

Based on the evaluation of external operating experience, KKL has expanded the AMP for the RPV bottom penetrations by subjecting the bottom penetrations to an annual visual inspection for leakage. Moreover, a repair procedure has been qualified as a pre-emptive measure. For the dissimilar metal welds on the RPV nozzles that are susceptible to stress corrosion cracking, a maintenance concept was prepared, which is based on shorter inspection intervals and special mitigative actions.

In KKB, the RPV head was replaced in both units with an optimised design and improved material selection. Consequently, the risk of ageing-induced damage due to stress corrosion cracking is significantly reduced. Due to the findings in the RPV base metal, unit 1 of KKB has been out of operation since March 2015. The safety case, taking into account the detected ultrasonic indications, is being currently verified by ENSI.

In summary, all Swiss nuclear power plants conclude, that within the AMP all relevant ageing mechanisms for the RPV components are identified and evaluated according to the current state-of-the-art of science and technology. Based on results of the extensive inspection programmes, specific corrective actions have been taken for identified ageing-related damage and degradation. With the existing AMP for the RPVs, safe long-term operation for an operating period of 60 years, or for KKM until the final shutdown in 2019, is ensured.

5.3 Regulators assessment and conclusions on ageing management programmes of RPVs

General aspects

The Swiss nuclear power plants have created fact sheets for RPV ageing management in accordance with the specifications of guideline ENSI-B01 /10/ and submitted them to ENSI. From ENSI`s perspective, these fact sheets contain a systematic analysis of the external operating experience with reference to the on-going ENSI research projects concerning the relevant topics of RPV ageing management. The relevant ageing mechanisms of the RPVs listed below are included in the fact sheets and the suitability of the monitoring and maintenance programmes used for the identification of ageing effects is evaluated. Based on the ageing management findings, specific measures for the prevention or mitigation of ageing effects have been implemented.

Cladding anomalies were not mentioned in the licensee reports, however such anomalies were identified in the RPVs in Gösgen and Beznau Nuclear Power Plant (KKG and KKB).

KKG carried out an investigation by replica technique in such an area of interest using a qualified procedure. The replica confirms the findings of the visual inspections - no cracking was detected. Moreover, because the form and shape of the cladding anomaly are unchanged, there is no evidence of an active degradation process. At present, the investigations carried out in KKB have not yet been fully evaluated.

Fatigue

The Swiss nuclear power plants have fatigue monitoring programs implemented with which temperature histories are recorded and evaluated at selected points on the RPVs. With the exception of Mühleberg Nuclear Power Plant (KKM), the evaluation is performed using an integrated fatigue monitoring system. The results of the fatigue monitoring in the form of current fatigue usage factors and the corresponding levels extrapolated to 60 years of operation are submitted to ENSI in an annual report. The existing results show that the long-term operation of the Swiss nuclear power plants is not subject to any limitations as a result of RPV material fatigue.

ENSI concludes that fatigue monitoring procedures in the Swiss nuclear power plants correspond to the specification of guideline ENSI-B01 /10/ and reflect the international state of the art. The absence of an integrated monitoring system at KKM is acceptable, in view of the final shutdown in 2019 and the projected degree of fatigue of no more than 55% at that time.

Neutron embrittlement

In the Swiss nuclear power plants, systematic neutron embrittlement monitoring of the RPVs is performed using irradiation surveillance specimens. The surveillance programmes cover at least 60 years of operation. With the exception of Leibstadt Nuclear Power Plant (KKL), the vast majority of the irradiation specimens have been removed and evaluated.

ENSI generally agrees with the evaluation of the licensees that RPV neutron embrittlement is not a limiting factor for the long-term operation of up to 60 years of operation. The criteria of the DETEC ordinance /9/ for the provisional shutdown of a nuclear power plant in respect of the minimum Charpy-V impact energy and the brittle fracture transition temperature at ¼ of the wall depth have not been reached. Beznau Nuclear Power Plant (KKB) and Gösgen Nuclear Power Plant (KKG), both pressurised water reactors, have provided numerical computations of brittle fracture safety with updated PTS analyses. Similarly, Leibstadt Nuclear Power Plant (KKL) and Mühleberg Nuclear Power Plant (KKM), both are boiling water reactors, have adequate proof that brittle fracture of the RPV can be excluded.

Neutron fluences are continuously monitored. With the early introduction of nuclear fuel loading according to the 'low leakage' principle, the neutron fluences at the structural materials of the RPV could be significantly reduced. The projected fluences for 60 operating years are consequently lower than those originally specified for 40 operating years.

So far in KKL two of a total of six sets of test samples, which cover 24 years of operation, have been tested. ENSI assumes that, with the remaining four sets, it will be possible to cover the long-term operation of up to 60 operating years. Currently a very small shift in the brittle fracture temperature of 4 K has been detected, which lies within the typical range of the evaluation accuracy. Therefore, it can be assumed that the neutron embrittlement of the RPV materials does not represent a limitation for the long-term operation of KKL.

In KKM, all three sets of irradiation test samples have been evaluated and cover a fluence that would correspond to 78 operating years. One peculiarity is the circumferential weld V2 in the RPV, which has an increased copper content. Therefore, weld V2 has the highest level of neutron embrittlement. The evaluation based on the conservative procedure of the U.S.-NRC Regulatory Guide 1.99 /35/) shows a large margin against the criteria of the DETEC ordinance /9/. Here too, ENSI comes to the conclusion, that the neutron embrittlement of the RPV materials does not limit the KKM operating period up to 2019.

The KKG surveillance samples likewise cover fluences that correspond to an operating period of much greater than 60 operating years. KKG too, still has considerable margins against the criteria of the DETEC ordinance /9/. Similarly, the PTS analyses indicate considerable safety reserves of more than 30 K for 60 operating years, even with conservative evaluation of the surveillance specimen in accordance with U.S.-NRC Regulatory Guide 1.99 /35/ and without including the supporting WPS (warm pre-stress) effect. Therefore, neutron embrittlement of the RPV materials can also be excluded as a limiting factor for KKG.

Of all the Swiss nuclear power plants, the unit 1 RPV of KKB exhibits the highest neutron embrittlement. Although both units are almost identical in construction and have similar neutron fluences, the embrittlement in the RPV of unit 2 is considerably less because of the different chemical composition of the RPV materials. Therefore, the analyses for the unit 1 RPV also cover the unit 2 RPV. In unit 1, all six surveillance specimens have been removed and evaluated while in unit 2, there is still one set of surveillance specimens left. The last set of irradiation test samples from unit 1 was also evaluated according to the master curve method. The margins against the criteria of the DETEC ordinance /9/ and in respect of exclusion of brittle fracture according to the updated PTS analysis of 2015 are currently assessed by ENSI as adequate. For unit 2, the margins in respect of exclusion of brittle fracture and the DETEC criteria /9/ are considerably higher, so that the neutron embrittlement of the RPV material is not a limiting factor in respect of long-term operation.

Stress corrosion cracking

Within the scope of the ageing management of the RPVs, the fact sheets of the Swiss nuclear power plants list stress corrosion cracking as a key ageing mechanism for Inconel welds and austenitic welds in contact with reactor cooling water. The susceptibility of primary water-exposed Inconel dissimilar metal welds to IDSCC (Inter Dendritic Stress Corrosion Cracking) and/or PWSCC (Primary Water Stress Corrosion Cracking) is internationally known.

From ENSI`s perspective, stress corrosion cracking of the dissimilar metal welds of the RPV nozzles, is, especially for Leibstadt Nuclear Power Plant (KKL), a significant ageing mechanism that must be closely monitored, because an indication caused by stress corrosion cracking was identified on an RPV feedwater nozzle. With the adaptation of the maintenance program for dissimilar metal welds and the shortening of the inspection intervals, in ENSI`s point of view, adequate counter measures have been taken in KKL. In order to define adequate inspection intervals, both the performance of the applied non-destructive testing techniques and also the crack propagation rates for the postulated cracks must be taken into consideration. In addition, ENSI has also requested measures for reducing the susceptibility to stress corrosion cracking. Amongst these are the planned application of MSIP (Mechanical Stress Improvement Process) technology for the affected welds. This method induces residual compressive stress at the inner (medium-exposed) surface to prevent the initiation of stress corrosion cracking. ENSI has accepted the concept submitted by KKL concerning this approach. Moreover, as part of the regulatory process, ENSI will closely monitor the implementation of the maintenance programme for the dissimilar metal welds.

Periodic inspections

SVTI as the authorised expert of ENSI, verifies the licensee in-service inspection programmes for the RPVs and the adherence to the defined inspection intervals and monitors the correct implementation of non-destructive testing. All non-destructive inspections on the RPVs must be qualified in accordance with guideline ENSI-B07 /14/. Additionally, during the annual outages, ENSI carries out specific inspections of selected non-destructive tests in order to independently verify the correct implementation of the test programmes directly on site.

Conclusion

From ENSI`s perspective, a comprehensive and effective ageing management is implemented for the RPVs in the Swiss nuclear power plants, with which relevant ageing effects are detected at an early stage and effective corrective actions are initiated. As a result, the RPVs are in a state that fulfil the prerequisites for long-term operation of the Swiss nuclear power plants. In particular, the indications detected in the RPVs in Beznau Nuclear Power Plant (KKB) and Leibstadt Nuclear Power Plant (KKL) will be closely monitored by ENSI.

6 Calandria/pressure tubes CANDU

not applicable

7 Concrete containment structures

7.1 Description of ageing management programmes for concrete structures

7.1.1 Scope of ageing management programmes for concrete structures

Based on guideline ENSI-B01 /10/, all structures classified according to guideline ENSI-G01 /31/ are to be included into the AMP. In line with their significance for nuclear safety and radiation protection, structures are assigned to two structure classes, BK I and BK II. Structures and substructures are complete buildings or large parts of buildings. Each classified building is assessed separately within the scope of ageing management. The civil engineering fact sheets concern individual buildings or parts thereof.

The description of the ageing monitoring of the concrete structures of the reactor building was carried out in coordination between the licensees and ENSI using the example of the outer reactor building envelope, which forms the secondary containment. The outer reactor building envelope comprises the foundation slab, the outer reinforced concrete wall in the ground, the cylindrical part of the above ground outer reinforced concrete wall and the reinforced concrete roof dome, each with the corresponding steel liners, seals, coatings and anchoring structures. The outer reactor building envelopes of the Swiss nuclear power plants have different designs. The structures of the reactor buildings are depicted in the published licensees reports /3/, /4/, /5/ and /6/.

The civil engineering AMP ensures that the buildings are operational and fulfil the specified requirements at all times. Therefore, the characteristic values of the construction materials used must be checked and knowledge of the design is required to focus the inspection on the relevant points.

Requirements on the structures of the outer reactor building envelope

The outer reactor building envelope is used to protect the inner structures against external effects such as airplane crashes, earthquakes, snow and wind loads while also providing radiation shielding. In addition, the structural components and construction materials must fulfil the following functional requirements:

Foundation slab

- Absorbing the loads of building and system components in accordance with the load plan
- Transfer these loads into the foundation soil
- Resistance against external water pressure
- Tightness against groundwater
- Air tightness (slight internal vacuum under operation)
- Absorbing internal accidental overpressure
- Retention of radioactive materials

Outer concrete wall in the ground

- Absorption of the loads of the above-ground reinforced concrete shell
- Absorbing the support forces of the fastenings
- Transfer of these loads onto the foundation slab
- Resistance against external water pressure and earth pressure
- Tightness against groundwater
- Air tightness (slight internal vacuum under operation)
- Absorbing internal accidental overpressure

- Retention of radioactive materials

Above-ground outer concrete wall (outer cylinder)

- Absorbing the loads of the roof dome and the floor slabs
- Absorbing the support forces of the fastenings
- Air tightness (slight internal vacuum under operation)
- Absorbing internal accidental overpressure
- Retention of radioactive materials
- Weather protection
- Penetration protection against impact

Dome

- Air tightness (slight internal vacuum under operation)
- Absorbing internal accidental overpressure
- Retention of radioactive materials
- Weather protection

Materials of the outer reactor building envelope

The concrete structures of the outer reactor building envelope comprise, almost exclusively, untensioned steel reinforced concrete, which was implemented on-site. The material properties of the concrete and reinforcement steel comply with the standards of the Swiss Society of Engineers and Architects (SIA) applicable at the time of construction.

No pre-stressed concrete components were used in the outer reactor building envelope. The sole exceptions are the outer reactor building envelopes of units I and II of Beznau Nuclear Power Plant (KKB). Here the reinforced concrete ring between the dome and the outer cylinder was pre-stressed. The tendons and the anchor heads are set in concrete and thus are inaccessible for non-destructive testing.

Nearly all the inner surfaces of the outer reactor building envelope structures in the Swiss nuclear power plants are coated. The coating is for operational reasons (ease of decontamination) and does not serve as protection for the function of the structural components. The underground part of the outer reactor building envelope is protected by a groundwater seal to prevent water ingress.

7.1.2 Ageing assessment of concrete structures

The implementation of ageing management actions ensures that a concrete structure maintains its integrity and/or functionality under all design conditions. In Switzerland there are higher-level civil engineering criteria for the provisional shutdown of a nuclear power plant that are defined in statutory regulations. A nuclear power plant must be provisionally shut down, if unacceptable cracks and spalling are detected on the concrete envelope of the reactor building. The licensees are obliged to perform appropriate tests or analyses.

All ageing mechanisms relevant to civil engineering are specified in the GSKL civil engineering guide /26/. Through inspections structures are inspected at least every ten years for the relevant ageing mechanisms. For those inspections the assistance of an expert engineer and, in some cases, a specialist in diagnostic methods is required. The results of inspections are recorded in the fact sheets for the individual structures and any actions are defined.

Based on the operating conditions known from the long operating period, the construction materials used and the design, the component-specific ageing mechanisms were selected from the comprehensive catalogue in the GSKL civil engineering guide and listed in a component-specific manner in the civil engineering fact sheets. Based on the design, the following ageing mechanisms are of greatest importance (Table 7.1):

Effect	Mechanism	Consequences
Reinforced concrete		
Temperature changes	Expansion, contraction, constraint stresses	Opening and closing of cracks, local overstraining, deformation
Humidity, water	Initiation of chemical processes	Chemical changes
Shrinking	Cracking due to restraints	Cracks, deformation
Load, static	Creep, promotion of cracking	Cracks, deformation
Carbon dioxide	Carbonation	No damage to concrete. Reinforcement corrosion when in the carbonated area.
Steel, reinforcement steel		
Oxygen corrosion	Corrosion depending on the micro-climate (Moisture, oxygen supply)	Increase in volume leads to spalling, loss of load bearing capacity if there is a reduction of cross-section
Contact corrosion	Formation of electro-chemical elements	The less noble metal is dissolved

Table 7.1: Ageing mechanisms of reinforced concrete structures

Thus far, the following ageing mechanisms of the outer reactor building envelope have proven to be the most important:

- <u>Frost</u>
  On porous outer surfaces and on areas re-profiled during maintenance or mended areas, damage can occur due to penetrating and freezing water. This damage is highly localised. The possibly affected structures are monitored and can be repaired with a minimum of effort and cost.

- <u>Carbonation</u>
  The loss of alkalinity and the resultant possible loss of corrosion protection of the reinforcement is probably the most important ageing mechanism. The possibly affected structures are monitored. If action is taken promptly, the effects of carbonation can be overcome without any risk of corrosion damage to the reinforcement.

- <u>Alkali-Aggregate-Reaction (AAR)</u>
  Damage caused by AAR does not often occur in concretes with aggregates from the Swiss plateau and it therefore plays a relatively minor role in comparison with other damage mechanisms. Nevertheless, the occurrence of AAR on weathered concrete components in the presence of potentially reactive aggregates cannot be excluded. The risk for the building structure is low because the occurrence can be quickly detected and if necessary a repair is easily implemented.

- Corrosion of reinforcement steel/pre-stressing steel
  Oxygen corrosion and shallow pit corrosion can occur in carbonated outer areas, because there is a loss of passivity and a high moisture level. If action is taken promptly, the danger to the building structure is low, because the corrosion is superficial.

- Embrittlement of sealing membranes
  Seals, e.g. the dome seal, can consist of a loosely positioned plastic membrane. Over time, direct sunlight leads to a loss of plasticiser and ultimately to embrittlement of the seal. The risk that underlying concrete structure will be impacted is low because leaks can be quickly detected and rainwater is low in pollutants. However soft water that ingresses can leach out calcium hydroxide.

Depending on the significance for nuclear safety, on the assignment criteria for the condition levels, on the component-specific ageing and on the shutdown criteria /9/, target condition levels are defined in each fact sheet for all structural components of the outer reactor building envelope. The current conditions identified during inspections are assigned to the condition levels listed in Table 7.2.

Assessment	Description
1: Very good condition	The defect / damage has no influence on the durability, structural safety and nuclear safety of the component / civil engineering structure. No measures are needed for repair.
2: Good condition	The defect/damage may prejudice the durability and/or the structural safety of the component in the long-term. Nuclear safety is ensured. Repairs are required in the long-term.
3: Adequate condition	The defect/damage prejudices the durability and/or the structural safety of the civil engineering structure/component, the nuclear safety may be prejudiced. Repairs are required in the medium-term, may also be needed in the short-term to prevent the spread of damage.
4: Inadequate condition	The defect/damage will prejudice the durability and the structural safety 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 in the short-term.
5: Poor condition	The defect/damage will considerably prejudice the structural safety 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.

Table 7.2: Condition levels of construction materials according to the GSKL civil engineering guide /26/

Current conditions determined in the basic and main inspections of the outer reactor building envelope structures were always found to be the same or better than the specified target condition levels, so that in all fact sheets of the outer reactor building envelope it could be stated that the corresponding structural components were in a good condition and, based on the construction material quality, are fully operational up to the next planned inspection. A service life of 80 years could be achieved with continued monitoring and good maintenance.

Alongside this overall condition assessment, the condition of the individual construction materials is additionally described in each fact sheet and findings from inspections are recorded in a list. Most of the recorded findings for the outer reactor building envelope relate to small localised damage that has no effect on the integrity of the structure in question. Many findings were remedied within the ongoing maintenance programme and were marked as completed. Others could be classified as unimportant so that no actions are necessary.

New findings on ageing mechanisms are discussed in the GSKL expert group for civil engineering and their relevance to ageing management will be evaluated. Participation in courses and seminars ensures that knowledge of the latest state of the art is kept up to date. At this point, there are no new significant findings from science and research for the assessment of the outer reactor building envelope.

Internal and external operating experience, events and changes in the state of the art, as well as journals papers dealing with ageing problems are collected by the licensees and are assessed in the GSKL expert group for their relevance. New important findings are recorded and included in the AMP. Moreover, a summary of the evaluated operating experience is given in the annual safety report of the Swiss nuclear power plants.

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

In the area of civil engineering, the inspection programmes comprise main and intermediate inspections, which are carried out in accordance with the inspection plan for each safety-classified structure and consequently also for the outer reactor building envelope. Special inspections are performed in addition to the inspection plan. These include the visual inspection or material sampling of identified areas of damage which can contribute to the ageing degradation of structures. In addition, electronic measurements of the relative air humidity and temperature as well as electronic and manual measurements of changes in crack width are performed. Further materials tests on structures and laboratory investigations are listed in the GSKL civil engineering guide and are applied as necessary.

The general inspection plan for structures is defined in the GSKL civil engineering guide. The inspection plan for the individual structural components is described in the plant-specific fact sheets. The base inspection is the first main inspection and takes place at the beginning of a structure inspection programme. Intermediate and main inspections take place alternately at 10-year intervals. A special 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 structures and structural components. The aim of the examinations is to determine the current state in respect of nuclear safety and serviceability and to allow a comparison with the target state and the results from earlier inspections (trending).

Possible testing methods for the different materials are described in the GSKL civil engineering guide together with the aims of the investigations. The selection of the method is dependent on the type, scope and aim of the inspection and is defined by qualified expert personnel. The following procedures are used for the assessment of the reinforced concrete of the outer reactor building envelope:

- The inspections are primarily focused on a visual check of the concrete structure. This check is performed to see whether cracks, spalling, inhomogeneous surfaces, efflorescence or discolouration are present. Crack widths are determined using a crack width comparison standard. The position of the findings is recorded in drawings and summarised in tables in the findings inventory. The prominent positions are photographed and documented.

- In order 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 the microstructure quality based on microsections.
- In cases of suspected deficiencies and for identification of active reinforcement corrosion, electrical potential measurements and electrical potential field measurements must be performed on the reinforcement.

The target condition level is specified in a way that the operational limit of a structural component will not be reached before the next main inspection, taking into account the specific ageing mechanisms. For example, for concrete structures with typical exposure, the corresponding acceptance criterion is target condition level 2 (see Table 7.2), ensuring nuclear safety.

Beznau Nuclear Power Plant (KKB)

In units I and II of KKB, samples are cut out of the plastic membrane of the dome seals of the outer reactor building envelope. Tensile and folding endurance tests are carried out on these in the laboratory and the content of plasticisers is determined. This allows the expected remaining service life to be determined. As a result of the replacement of the steam generators in 1993 and 1999, as well as the replacement of the RPV heads in 2015, the outer reactor building envelope and the steel liner were broken over large areas. As part of such interventions, information is always collected and included into the AMP, for example information about the condition of the concrete, reinforcement and the steel liner and its anchoring.

As part of maintenance measures, the condition of the pre-stressing of the annular girder between the dome and the outer cylinder of the outer reactor building envelope building was assessed based on special inspections using drilled cores, tapering of the anchor heads and potential field measurements.

Mühleberg Nuclear Power Plant (KKM)

In the KKM reactor building the drywell concrete encasement is firmly attached to the outer cylinder via the floor slabs. Due to the temperature changes, primarily due to seasonal changes at the outer cylinder, constraint forces are generated that have led to superficial cracks in the floor slabs. They have been monitored for over 20 years at several places using fixed permanent crack measurement systems. The regularly logged data shows that the crack widths change according to an annual cycle. Viewed over the long-term, the crack widths remain the same, within narrow limits for the time being and are therefore acceptable.

7.1.4 Preventive and remedial actions for concrete structures

Findings thus far on the outer reactor building envelopes are generally acceptable in respect of their specified target condition level. They are assessed by the civil engineering department and included in the maintenance plan, if it is to be assumed that they could lead to a worse condition than the permitted target condition level within an inspection interval due to degradation. Minor damages such as local concrete spalling, efflorescence, and corrosion spots are frequently repaired on an ongoing basis because, in general, the degradation increases exponentially and delaying repair would not be economical.

In all Swiss nuclear power plants preventive surface coatings have been applied to the outer reactor building envelope. The plant-specific measures are briefly described below.

Beznau Nuclear Power Plant (KKB)

As a preventive measure, a protective coating was applied to the shadow gaps of the outer reactor building envelope of both KKB units. This measure has prevented the ingress of water, humidity and carbon dioxide into the shadow gap area to reduce the advance of carbonation and the risk of corrosion of the reinforcement. As a type of preventive measure, a concept was applied to all safety classified structures in 2016 that identified measures with which corrosion of the reinforcement can be prevented in the long-term, in particular in the shadow gap area.

Gösgen Nuclear Power Plant (KKG)

In the coming years, the surface coating of the reactor building dome will be renewed as a preventive measure. In this way, water and moisture will be consistently and permanently deflected from the surface and penetration into the support structure prevented. This will significantly extend the service life of the structure.

Leibstadt Nuclear Power Plant (KKL)

A water-repellent treatment has been applied to the outer surface of the outer reactor building envelope as a preventive action. This action retards the ingress of water, humidity and carbon dioxide so that the progression of carbonation and the risk of reinforcement corrosion are reduced.

Mühleberg Nuclear Power Plant (KKM)

Even before the introduction of AMP, cracks were found in the area of the foot ring of the dome which threatened the leak-tightness of the outer reactor building envelope. Due to the building design, with its tensile ring with untensioned reinforcement, the origin of the cracks could be fully clarified. The load bearing capacity was not an issue, but measures were required to ensure the serviceability and leak-tightness. After the application of a vapour barrier as a seal, the dome was thermally insulated to reduce the variations in temperature and provided with an outer plastic sealing sheet. The measures carried out in 1989 have proven effective thus far.

On the outer cylinder of the outer reactor building envelope it was found that the carbonation depth would reach the level of the reinforcement before the end of the desired service life in various areas because the planned value of the reinforcement covering was not adhered to in all areas. KKM decided to apply a crack-bridging coating as a preventive measure. The surface protection system applied in 2000/2001 has proven effective thus far.

On the inclined wall of the outer reactor building envelope wet areas were detected with local efflorescence at the level of the water surface of the outer torus. After renewing the coating in the outer torus in 1991, no more wet areas could be detected.

In the interior of the outer reactor building envelope, practically all coatings were replaced. They were repaired for operational reasons (to simplify decontamination) but are not necessary for the functional capability of the building structure. Nevertheless, the coatings were assessed within the scope of the AMP inspections.

7.2 Licensees experience of the application of ageing management programmes for concrete structures

The ageing management guideline ENSI-B01 /10/, which was published in 2011, required a revision of the ageing management in the civil engineering field in all Swiss nuclear power plants. The close interaction with ENSI led, within just a few years, to a comprehensive, effective and yet still practical implementation of ageing management in the civil engineering field.

The continual exchange of experience and the systematic assessment of external events are essential for effective optimisation and/or expansion of the AMP and for increasing the knowledge of the responsible staff. Generic adjustments and improvements to ageing management have not been triggered in the civil engineering department as a result of this exchange of experience. The periodic reviews performed by WANO and the IAEA have proven to be effective measures for systematically improving ageing management.

With the introduction of the AMP, systematic monitoring of the structures and a uniform documentation of the inspections, conditions and actions were ensured. The inspection programmes were continuously adapted and expanded in accordance with the obtained knowledge and findings. However, the approach did not need to be fundamentally modified or adapted.

The exchange of experience in the regular meetings of the GSKL expert team is valuable. The jointly-prepared guide for civil engineering fact sheets /26/ has proven its value, and the uniform basis it provides for the AMP simplifies the exchange of experience. The back flow of experience from ageing management activities is ensured by the reporting system and the documentation.

New findings from science and technology, e.g. in respect of chemical influences such as ettringite formation or alkali-aggregate reactions have led to an extension in the description of ageing mechanisms and their consequences in the civil engineering guide, and ensured an increase in awareness of such ageing effects in subsequent inspections. In accordance with the analyses of the aggregates from the Swiss plateau, no damage resulting from the effects of these refining processes is to be expected in the Swiss nuclear power plants. Thus far, no evidence for this mechanism has been identified.

The results of trend monitoring in the civil engineering inspection reports show that the preventive actions were adequate and effective. The requirements for the specified target condition levels have been met. The AMP of the outer reactor building envelope concrete structures has been shown to be successful and it ensures that the load bearing capacity and the serviceability of the reactor building are ensured at all times.

As part of the collaborative work in the GSKL civil engineering expert group, experience in respect of ageing management, ageing mechanisms and investigation methods and knowledge about the state of the art is exchanged. The exchange through this platform likewise confirms that the applied methodology is successful. So far, no unexpected ageing effects have occurred on the civil engineering structures in the Swiss nuclear power plants.

The inspections carried out confirm that all building structures achieve target condition level 2. In a few cases, condition level 3 has been achieved locally, which has triggered repairs. The good to very good quality of the structures and structural components is a result of the good design and construction of the Swiss nuclear power plants, but also of the appropriate and effective ageing management as an important accompanying measure in the defence in depth safety concept.

From the point of view of the Swiss nuclear power plant licensees, no significant changes in the condition of the structures are to be expected if the civil engineering AMP and the maintenance programmes are preserved.

7.3 Regulators assessment and conclusions on ageing management programmes for concrete structures

As part of structural maintenance, the licensees of the Swiss nuclear power plants have monitored the condition of the structures since their commissioning in the period between 1968 and 1985 and, where necessary, have carried out repairs. With the introduction of the AMP requested by ENSI in the 1990s, the monitoring of the structures was systematised and the results of the investigations continuously documented in the civil engineering fact sheets.

Guideline ENSI-B01 /10/ specifies requirements for the civil engineering guides and the civil engineering fact sheets to be prepared for individual buildings or parts of buildings. Each fact sheet must comprise a general part, structural component documentation, a description of the relevant component-specific ageing mechanisms and the inspections to be carried out, as well as the assessment of the structural condition derived from the inspections. In the general part the substructures and structural components shall be described. The structural component documentation must in particular specify the design principles, properties of the construction materials used, operating conditions and accidental impacts as well as the assessment of the underlying target conditions.

ENSI has reviewed and approved the GSKL civil engineering guide /26/, which serves as a basis for the ageing management of the structures in the Swiss nuclear power plants. The guide contains the possible ageing mechanisms for the structures, specifies the type and frequency of inspections and defines the assignment of inspected components or materials to condition states. In ENSI´s perspective, this guide has proven effective so far and fulfils the requirements of the guideline ENSI-B01.

Alongside the expansion of the AMP to all safety-classified structures through the introduction of the guideline ENSI-B01 /10/ as presented in section 2.7, ENSI has initiated an important expansion of the GSKL civil engineering guide. This concerns the monitoring of inaccessible or difficult to access structural components, as for example the outer surfaces of earth-covered components, groundwater seals or concrete-encased tendons. Since the introduction of guideline ENSI-B01, the licensees have added Annex 4 to the GSKL civil engineering guide. Based on five application examples, the guide illustrates, how condition information can be collected for inaccessible components using indirect investigation methods. However, to date such methods have hardly been used. Therefore, there is still no reliable experience for the condition assessment of inaccessible civil engineering structures. ENSI has pointed out this monitoring gap to the licensees on a number of occasions, and in its future inspections ENSI will increasingly demand corresponding tests.

ENSI thoroughly reviews the fact sheets of all structures of classes BK I and BK II in line with the 10-year interval of the main inspections. If necessary, it also reviews the results of special inspections. As part of the review, a plant walkdown is generally also performed. Within the walkdown, those structures or structural components are inspected for which findings of particular interest are documented in the fact sheets. The documentation of the civil engineering structure inspections, which are only referred to in the fact sheets with their final findings and the reference information, are also looked at.

From ENSI´s perspective, the fact sheets created for the outer reactor building envelope record the relevant ageing mechanisms and fully evaluate the condition investigations carried out. The plant walkdowns performed by ENSI confirm the results of the condition investigations. Based on this and in agreement with the assessment of the licensees, ENSI rates the condition of the concrete structures of the outer reactor building envelopes in the Swiss nuclear power plants as good. Up until now, only one special test on an inaccessible structural component of the outer reactor building envelope in Beznau Nuclear Power Plant (KKB) has been performed, in which it was confirmed that the pre-stressing in the annular girder between the dome and the outer cylinder of the outer reactor building envelope is sufficient.

From ENSI´s perspective, the structural maintenance and the preventive measures conducted within the scope of the ageing management of the outer reactor building envelopes have proven effective. All of the applied or planned surface coatings on all reactor buildings help to ensure that the carbonation front in the weather-exposed concrete surfaces does not reach the reinforcement steels and that consequently these remain protected against corrosion.

Conclusion

From ENSI´s perspective, a comprehensive and effective AMP has been implemented for the outer reactor building envelopes in the Swiss nuclear power plants, through which relevant ageing effects are detected in a timely manner and effective countermeasures are taken. The reinforced concrete outer reactor building envelopes of the Swiss nuclear power plants fulfil the requirements defined for them. With unchanged maintenance and consistent implementation of the AMP, this should remain the case for the foreseeable future. Also from ENSI´s perspective, the service life of the Swiss nuclear power plants will not be limited by ageing effects on concrete structures.

8 Pre-stressed concrete pressure vessels AGR

not applicable

9 Overall assessment and conclusions

In the previous chapters of the national assessment report, ENSI has used the reports submitted by the Swiss licensees to assess the implementation and updating of the overall ageing management programme and the component-specific ageing management programmes in the Swiss nuclear power plants which are to be addressed in the Topical Peer Review. In the sections below, these assessments of the individual ageing management programmes are summarised and general conclusions are drawn from them.

Overall ageing management programme

The ageing management programme (AMP) implemented in the Swiss nuclear power plants is based on a long-standing development process that has been closely followed by the Swiss Federal Nuclear Safety Inspectorate (ENSI). The licensees of the Swiss nuclear power plants had already been required to introduce an ageing management programme (AMP) for safety-relevant structures, systems and components (SSCs) by the former Swiss regulatory authority (now ENSI) at the end of 1991. Consequently, the licensees organised in the Group of Swiss nuclear power plant managers (GSKL) started a common project to develop an AMP on the basis of the already existing maintenance programmes. Within the framework of the GSKL project the fundamental documents for the introduction of the AMP in the electrical engineering, civil engineering and mechanical engineering fields were developed. The implementation of the AMP is done by specially-founded ageing management expert teams in each nuclear power plant.

From ENSI's point of view, the structure and organisation of ageing management in the Swiss nuclear power plants and its integration into established plant programmes via existing quality and plant management systems has proven its value over time. Thus, by establishing a GSKL coordination project, a standardised document structure and the joint monitoring of plant-specific and international operating experience and new findings from research and development have been achieved. In addition, a standardised implementation of the AMP in individual nuclear power plants is ensured through the ageing management expert teams which consist of specially qualified operating personnel. In ENSI`s point of view, the required specifications for systematic ageing management and the information necessary for monitoring the SSCs are contained in the basic documents developed for implementing ageing management: the field-specific GSKL guides, the GSKL interface document, the GSKL catalogue of ageing mechanisms and the plant-specific fact sheets for the safety-classified SSCs. The close cooperation of the Swiss nuclear power plants in the development and updating of the basic documents promotes a common basic understanding of the potential ageing mechanisms that must be considered in the ageing management and of the diagnostic methods that can be used to identify these ageing mechanisms.

In 2004 the obligation of the licensees to implement comprehensive AMPs was introduced in the new Nuclear Energy Ordinance /7/ and became legally binding. The particular significance of ageing management was additionally emphasised at the legal level with the enactment of the ordinance of the Federal Department of the Environment, Transport, Energy and Communications (DETEC) /9/ in 2008. According to this ordinance, a nuclear power plant must be provisionally shut down, if unacceptable ageing damage is detected in one of the essential physical barriers: reactor pressure vessel, primary circuit, steel containment (primary containment) and reactor building (secondary containment). From ENSI´s perspective, with the specification of explicit ageing criteria in the DETEC ordinance for a provisional shutdown, a high degree of transparency for the application of general acceptance criteria is achieved.

At the same time, the requirements for systematic and comprehensive ageing management were further specified at the guideline level based on experience gained in the implementation and updating of the AMP in the Swiss nuclear power plants. In 2004, general and field-specific requirements for ageing management were incorporated in a regulatory guideline for the first time. This guideline related in particular to the basic elements of a systematic AMP and to the scope of the SSCs to be included in ageing management for each field. The aging management guideline was revised in 2012. In the new guideline ENSI-B01 /10/ the scope of the safety-relevant SSCs to be included in the AMP has been expanded and, for the first time, concrete requirements for the proof of the resistance of the pressure vessel to brittle fracture as well as for the scope and evaluation of the fatigue monitoring have been included. With the expansion of the scope of ageing management, in ENSI`s point of view, all safety-relevant SSCs in the Swiss nuclear power plants are covered by the AMP. Concerning the mechanical engineering field, it is the responsibility of the licensee to also incorporate components classified as safety-related (safety class 4) in the AMP.

Guideline ENSI-B01 is closely related to other guidelines in which the requirements for the maintenance of mechanical and electrical equipment, in-service inspection of mechanical equipment, qualification of non-destructive testing and manufacturing of mechanical components are specified. Furthermore, the experience feedback necessary for systematic ageing management is regulated with other established plant programmes.

The reporting on AMP is regulated in guideline ENSI-B02 /16/. It requires an annual reporting on the status of ageing management. With this, ENSI is promptly informed about changes in the AMPs of the Swiss nuclear power plants and the resulting modifications in other inspection programmes. This allows ENSI to conduct targeted inspections on findings and to evaluate the effectiveness of the AMP.

In ENSI`s point of view, the annual reporting clearly shows that the AMP in the Swiss nuclear power plants is continuously updated based on new findings from the evaluation of internal and external operating experience as well as by monitoring the state-of-the-art of science and technology. These updates particularly concern the revision of the existing fact sheets for safety-classified SSCs as well as the expansion of existing testing and inspection programmes. From ENSI's point of view, the annual reporting has proven its worth. However, further harmonisation of reporting among the Swiss nuclear power plants is necessary. This especially concerns the overview of the updated fact sheets, the evaluation of the international operating experience and the assessment of the effectiveness of the AMP based on trends from maintenance findings (area of improvement).

When the revision of guideline ENSI-A03 /17/ came into force in 2014, the overall reporting on the status of ageing management, to be presented within the framework of the periodic safety review, was harmonised with the annual reporting. In addition, based on the experience obtained from the two oldest Swiss nuclear power plants, the safety case to be provided for long-term operation of the Swiss nuclear plants was included. For the extended service life it must be demonstrated among other things, that the reactor pressure vessel including the internals, the primary circuit, the steel containment and the reactor building (concrete containment envelope) are not subject to any limiting ageing mechanisms and the ageing criteria specified in the DETEC ordinance for provisional shutdown /9/ are not reached.

In its previous safety evaluation reports on the periodic safety reviews and long-term safety assessments of the Swiss nuclear power plants, ENSI concluded that, irrespective of identified improvement potentials, the safety-relevant SSCs are being effectively monitored based on the systematic framework of the AMP and the continuous updating of the AMP, and that the safety-relevant SSCs are in good condition. During the implementation phase of the AMP, the improvement potentials included in particular the preparation of still missing fact sheets in the civil, mechanical and electrical engineering fields, completion of the required inspection programmes in the civil engineering field, and the expansion of fatigue monitoring of mechanical components in the AMP in order to achieve a sound basis for ageing management. In the current phase of updating the existing AMP, the focus is on a standardised evaluation of findings from the operating experience and the state-of-the-art of science and technology, the inclusion of inaccessible or difficult to access structural components as well as special inspections to prove the integrity of the reactor pressure vessel and the steel containment with respect to the age of the Swiss nuclear power plant.

All in all, the ageing management process implemented in the Swiss nuclear power plants contains the basic elements (attributes) listed in the IAEA Safety Guide NS-G-2.12 /20/ for effective ageing management. Based on the design and operating conditions for the supervised safety-relevant equipment, ageing effects identified as relevant are listed in the fact sheets. Approved testing and inspection techniques are used to identify these ageing effects, necessary remedial actions are introduced, and new findings from operating experience and research are monitored so that existing plant programmes which are essential to ageing management can be promptly adapted.

Ageing management programme for electrical cables

According to the basic requirements in guideline ENSI-B01 /10/ the ageing mechanisms applicable to the safety-relevant (class 1E) electrical cables must be identified. Moreover, a check must be undertaken to determine whether the existing maintenance programme is suitable for promptly detecting ageing-induced damage. According to guideline ENSI-B14 /12/, the findings from ageing management must be incorporated in the maintenance programme for electrical components within one year. Furthermore, specific requirements for the accepted methods for prediction of potential ageing effects and the proof of accident-resistance are specified in guideline ENSI-B01.

In the Swiss nuclear power plants, generic fact sheets have been created for the electrical cables that contain a list of the most important ageing mechanisms (Part 1) and possible diagnostics and testing methods as well as characteristics by which the ageing progress can be identified (Part 2). These generic fact sheets serve as a basis for the plant-specific Part 3 fact sheets which provide a particular record of the cable type, the design specification, type of cable routing, conditions of use, usage time in respect of the maintaining of accident-resistance as well as the type, scope and findings of conducted tests for the cables used in the nuclear power plant.

In ENSI`s point of view, the Swiss nuclear power plants have implemented systematic ageing management processes and programmes for safety-relevant cables that will ensure the functionality of the electrical cables under long-term normal operating conditions and accident conditions. Through the close cooperation of the Swiss nuclear power plants in both the GSKL coordination team and the GSKL electrical engineering expert team in developing and revising the generic fact sheets, as well as in monitoring international operating experience, known ageing phenomena and the latest diagnostic methods are incorporated in the generic fact sheets. Through random checks performed during inspections, ENSI was able to convince itself that plant-specific fact sheets have been created for all cable types used in the Swiss nuclear power plants and that these sheets contain the information required according to guideline ENSI-B01.

A wide spectrum of recognised and effective diagnostic methods is used in the Swiss nuclear power plants to identify the relevant ageing mechanisms. In particular, ENSI emphasises that all Swiss nuclear power plants evaluate experience from accelerated ageing tests, which enable a proactive assessment of cable ageing under extreme ambient conditions. Beyond that, targeted, condition-oriented assessment of the insulation resistance of selected cable types is performed using the advanced measuring methods of Line Resonance Analysis (LIRA) and Time Domain Reflectometry (TDR). In addition to ageing management, a policy of replacing old cables with new ones during the numerous upgrades is consistently followed in the Swiss nuclear power plants.

Based on the periodic reporting specified in ENSI-B02 /16/ and ENSI-A03 /17/, ENSI comes to the conclusion that new findings from both internal operating experience and experience from other plants, as well as from monitoring of the state-of-the-art of science and technology are being incorporated in the cable AMP and the corresponding maintenance programmes. Existing experience shows that with the AMP implemented in the Swiss nuclear power plants, the occurrence of ageing effects in electrical cables would be promptly detected and preventive measures implemented in a timely manner.

Ageing management programme for concealed pipework

In accordance with the requirements in guideline ENSI-B01 /10/, fact sheets must be created for pipes of safety classes 1 to 3, in which the materials used, special manufacturing methods and design characteristics, operating conditions, relevant ageing mechanisms and the specific maintenance measures and the results of ageing management are to be recorded. In this context, the relevant ageing mechanisms must also be identified and the effectiveness of the established maintenance and inspection programmes must be checked for safety-classified concealed pipework sections.

Guideline ENSI-B06 /11/ defines no specific requirements for concealed pipework sections. However, findings from ageing management can lead to specific requirements for the inspection of concealed pipework.

In consultation with ENSI, the licensees of the Swiss nuclear power plants have investigated their safety related pipework for the presence of concealed sections. Taking into account the design characteristics of the Swiss nuclear power plants they came to the conclusion that the specific monitoring can be limited to of concealed pipework of safety-relevant cooling water systems which are in direct contact with river water.

With the exception of Mühleberg Nuclear Power Plant (KKM), the licensees of the other Swiss nuclear power plants in which concealed pipework sections have been identified have not made any specific statements about the relevant corrosion-induced ageing mechanisms derived from operating experience or the inspections carried out (e.g. internal inspections using camera pigs). In KKM, retained samples from the manufacturing batch, which were stored in the river water, are used to check the required material properties. In conjunction with extensive ultrasonic wall thickness measurements in accessible pipework areas, conclusions were drawn about the inner surface properties in the inaccessible concealed pipework areas. Moreover, the coating of the outside surface in concealed pipework areas was checked using sample drilling. In ENSI`s point of view, these are practical methods for ageing management of concealed pipework areas.

In the other Swiss nuclear power plants, as preventive remedial actions, pipe sections in the cooling water system have been replaced or protected with anti-corrosion coating. However, in ENSI`s point of view, neither the background nor the effectiveness of already performed preventive and remedial actions on concealed pipework sections is presented in sufficient detail. Therefore, ENSI will extend the focus of its regulatory efforts regarding ageing management in order to make sure that all safety-relevant concealed piping systems are included and are covered by suitable maintenance and inspection programmes (area of improvement).

Ageing management programme for reactor pressure vessels

All reactor pressure vessels (RPVs) in the Swiss nuclear power plants are classified as mechanical components of safety class 1 in accordance with guideline ENSI-G01 /31/. According to the requirements of guideline ENSI-B01 /10/, the RPVs must be treated in detail within the scope of ageing management, which means that the ageing mechanisms must be evaluated for the individual parts of the component.

Included in the scope of RPV ageing management are the RPV with the cylindrical part, head flange with bolt fastenings, vessel head and bottom, cladding, nozzles including the safe-end welds, and the internal welding. Also included are the penetrations for the control rods and core instrumentation nozzles as well as all welds. The RPV internals and the control rod mechanisms are considered separately.

Each Swiss nuclear power plant has a fact sheet for the RPV, which describes in detail, amongst other things, the materials used and the applied design codes, special design characteristics and the relevant ageing mechanisms and necessary maintenance measures. The ageing mechanisms are based on the GSKL catalogue of relevant ageing mechanisms (KATAM) prepared by the mechanical engineering departments of the Swiss nuclear power plants.

From ENSI`s perspective, these fact sheets contain a systematic analysis of the internal and external operating experience with reference to the on-going research projects of ENSI relating to the relevant topics of RPV ageing management. Fatigue, neutron embrittlement and stress corrosion cracking are identified as the most important RPV ageing mechanisms.

In Mühleberg Nuclear Power Plant (KKM) the fatigue usage factors are still determined manually. The other Swiss nuclear power plants use integrated fatigue monitoring programmes with which temperature histories are recorded and evaluated at selected points on the RPVs. The results of the fatigue monitoring in the form of current fatigue usage factors and the corresponding levels extrapolated to 60 years of operation are submitted to ENSI in an annual report. The existing results show that the long-term operation of the Swiss nuclear power plants is not subject to any limitations because of RPV material fatigue. The absence of an integrated monitoring system at KKM is acceptable, in view of the final shutdown in 2019 and the projected degree of fatigue of no more than 55% at that time.

In the Swiss nuclear power plants, systematic neutron embrittlement monitoring of the RPVs is performed using irradiation surveillance specimens. The surveillance programmes cover at least 60 years of operation. ENSI agrees with the evaluation of the licensees that RPV neutron embrittlement is not a limiting factor for the long-term operation of the Swiss nuclear power plants up to 60 years of operation. The criteria of the DETEC ordinance /9/ for the provisional shutdown of nuclear power plants in respect of the minimum Charpy-V impact energy and the brittle fracture transition temperature at ¼ of the wall depth have not been reached. The RPV of unit 1 of Beznau Nuclear Power Plant (KKB) exhibits the highest neutron embrittlement of all Swiss nuclear power plants. Although both KKB units are almost identical in construction and have similar neutron fluences, the embrittlement in the RPV of unit 2 is considerably less because of the different chemical composition of the RPV materials.

Stress corrosion cracking is considered by the Swiss licensees to be a key ageing mechanism for Inconel welds and austenitic welds in contact with reactor cooling water. The susceptibility of primary water-exposed Inconel dissimilar metal welds to IDSCC (Inter Dentritic Stress Corrosion Cracking) or PWSCC (Primary Water Stress Corrosion Cracking) is internationally known. In Leibstadt Nuclear Power Plant (KKL), an indication caused by stress corrosion cracking in a dissimilar metal weld of an RPV feedwater nozzle was identified through the in-service inspection programme. In response to this, KKL adapted the maintenance programme for dissimilar metal welds and shortened the inspection intervals, which, in ENSI`s point of view, are adequate counter measures. In order to define adequate inspection intervals, both the performance of the applied non-destructive testing techniques and also the crack propagation rates for the postulated cracks must be taken into consideration. In addition, ENSI has also requested measures to reduce susceptibility to stress corrosion cracking. Amongst these are the planned application of MSIP (Mechanical Stress Improvement Process) technology for the affected welds. This method induces residual compressive stress at the inner (medium-exposed) surface to prevent the initiation of stress corrosion cracking. ENSI has accepted the concept submitted by KKL concerning this approach. Moreover, as part of the regulatory process, ENSI will closely monitor the implementation of the maintenance programme for dissimilar metal welds.

The Swiss Association for Technical Inspections (SVTI) verifies the in-service inspection programmes for RPVs and the adherence to the inspection intervals defined in the test specifications. Moreover, SVTI supervises the correct implementation of non-destructive inspections, which must be qualified prior to use in accordance with guideline ENSI-B07 /14/. Additionally, during the annual outages, ENSI carries out specific inspections of selected non-destructive tests in order to independently verify the correct implementation of the test programmes directly on site. In view of the above ENSI comes to the conclusion that the licensees of the Swiss nuclear power plants have so far adequately implemented specific measures for preventing or mitigating ageing effects on the RPVs based on ageing management findings.

Ageing management programme for concrete structures of the reactor buildings

Based on guideline ENSI-B01 /10/, all structures classified according to guideline ENSI-G01 /31/ are to be included into the AMP. In line with their significance for nuclear safety and radiation protection, structures are assigned to two structure classes, BK I and BK II.

Moreover, in guideline ENSI-B01 /10/, requirements are specified for a civil engineering guide and for fact sheets for the individual buildings or building parts. Each fact sheet must comprise a general part, a structural component documentation, a description of the relevant component-specific ageing mechanisms and the inspections to be carried out, as well as the assessment of the civil engineering condition derived from the inspections. The general part denominates the substructures and structural components that are considered in the AMP. In particular, the structural component documentation must specify the design principles, properties of the materials used, operating conditions and extraordinary effects as well as the assessment of the underlying target conditions.

ENSI has reviewed and approved the GSKL civil engineering guide /26/, which serves as a basis for the ageing management of the structures in the Swiss nuclear power plants. The guide contains the possible ageing mechanisms for the structures, specifies the type and frequency of inspections and defines the assignment of inspected structural components or materials to condition levels. In ENSI´s perspective, this guide has proven effective so far and fulfils the requirements of the guideline ENSI-B01.

With the introduction of guideline ENSI-B01 /10/ in 2011, the ageing management programme was especially expanded to include all safety-classified structures. Additionally, ENSI has initiated an important expansion of the GSKL civil engineering guide. This concerns the monitoring of inaccessible or difficult to access structural components. Based on application examples, the guide illustrates, how condition information can be collected for inaccessible components using indirect investigation methods. However, to date such methods have hardly been used. Therefore, there is still no reliable experience for the condition assessment of inaccessible civil engineering structures. ENSI has pointed out this monitoring gap to the licensees on a number of occasions, and in its future inspections ENSI will increasingly demand corresponding tests.

ENSI thoroughly reviews the fact sheets of all structures of classes BK I and BK II in line with the 10-year interval of the main inspections. If necessary, it also reviews the results of special inspections. As part of the review, a plant walkdown is generally also performed. Within the walkdown, those structures or structural components are inspected for which findings of particular interest are documented in the fact sheets. The documentation of the civil engineering structure inspections, which are only referred to in the fact sheets with their final findings and the reference information, are also looked at.

From ENSI´s perspective, the fact sheets created for the outer reactor building envelope cover the relevant ageing mechanisms and fully evaluate the condition investigations carried out. The plant walkdowns performed by ENSI confirm the results of the condition investigations. Based on this and in agreement with the assessment of the licensees, ENSI rates the condition of the concrete structures of the outer reactor building envelopes in the Swiss nuclear power plants as good. Up until now, only one special test on an inaccessible structural component of the outer reactor building envelope of the Beznau Nuclear Power Plant (KKB) has been performed, in which it was confirmed that the pre-stressing in the annular girder between the dome and the outer cylinder of the outer reactor building envelope is sufficient.

From ENSI´s perspective, the structural maintenance and the preventive measures conducted within the scope of the ageing management of the outer reactor building envelopes have proven effective. All of the applied or planned surface coatings on all reactor buildings help to ensure that the carbonation front in the weather-exposed concrete surfaces does not reach the reinforcement steels and that consequently these remain protected against corrosion.

General conclusions

Overall, ENSI comes to the conclusion that the regulatory framework for a systematic ageing management in the Swiss nuclear power plants is adequate and covers the internationally applicable requirements of the IAEA and the WENRA. The particular importance of ageing management for nuclear power plants is emphasised in Switzerland by the fact that there are statutory requirements for a provisional shutdown of a nuclear power plant for reasons related to ageing degradation. From ENSI´s perspective, with the specification of explicit ageing criteria in the DETEC ordinance for the provisional shutdown a high degree of transparency for the application of general acceptance criteria is achieved.

With the annual reporting, ENSI is promptly informed about changes in the AMPs of the Swiss nuclear power plants and based on this it is possible to conduct targeted inspections on findings and to evaluate the effectiveness of the AMP (potential good practice). From ENSI`s perspective, the annual reporting clearly shows that the ageing management programme in the Swiss nuclear power plants is continuously updated based on new findings from the evaluation of internal and external operating experience as well as by monitoring the state-of-the-art of science and technology.

From the insights gained through the regulatory process in Switzerland, it can be concluded that the Swiss nuclear power plants have implemented a comprehensive AMP for safety-relevant SSCs which contains the attributes listed in the IAEA Safety Guide NS-G-2.12 /20/ for effective ageing management.

By establishing a common project of the GSKL, a standardised document structure has been achieved and a standardised implementation of the AMP in individual nuclear power plants is ensured through the specially-founded expert teams. In ENSI`s point of view, the required specifications for systematic ageing management and the information necessary for monitoring the safety-relevant SSCs are contained in the basic documents developed for implementing ageing management and the safety-relevant SSCs are being effectively monitored based on the systematic framework of the AMP (potential good practice).

In ENSI`s point of view, the component-specific ageing management programmes for electrical cables, the reactor pressure vessels and the outer reactor building envelopes are based on a comprehensive recording and analysis of potential ageing mechanisms. A wide spectrum of diagnostic methods is used to identify the relevant ageing mechanisms in the Swiss nuclear power plants.

The following should be mentioned in particular (potential good practices):

- The evaluation of experience from accelerated ageing investigations on cable samples, which enable a proactive assessment of cable ageing under extreme ambient conditions;
- The use of integrated fatigue monitoring programmes which record and evaluate temperature time series at selected points on the RPVs;
- The application of the master curve method as a complement to the classical approach for the analysis of the irradiation surveillance specimen used for the systematic neutron embrittlement monitoring of the RPVs, allowing direct determination of fracture toughness.

Existing experience gained from the regulatory process shows that the ageing management programmes implemented for electrical cables, the reactor pressure vessels and the outer reactor building envelope buildings detect the relevant ageing effects in a timely manner and that effective counter-measures are adopted. As a result, these components are in a condition that permits the long-term operation of the Swiss nuclear power plants.

Irrespective of the preceding assessment, ENSI has identified the following areas of improvement within the scope of the Topical Peer Review.

- Further harmonisation of reporting among the Swiss nuclear power plants is necessary. This especially concerns the overview of the updated fact sheets, the evaluation of the international operating experience and the assessment of the effectiveness of the AMP based on trends from maintenance findings.
- ENSI will extend the focus of its regulatory efforts regarding ageing management in order to make sure that all safety-relevant concealed piping systems are included and are covered by suitable maintenance and inspection programmes.
- ENSI has required the monitoring of inaccessible or difficult to access structural components. However, to date such methods have hardly been used. Therefore, there is still no reliable experience for the condition assessment of inaccessible civil engineering structures. ENSI has pointed out this monitoring gap to the licensees on a number of occasions, and in its future inspections ENSI will increasingly demand corresponding tests.

10 Abbreviations

ASTM: American Society for Testing and Materials

AMP: Ageing Management Programme

DIN: German institute for standardization

PWR: Pressurised Water Reactor

ENSI: Swiss Federal Nuclear Safety Inspectorate

EPRI: Electric Power Research Institute

GRS: Gesellschaft für Anlagen- und Reaktorsicherheit (Germany)

GSKL: Group of Swiss NPP Managers

IAEA: International Atomic Energy Agency

I&C: Instrumentation & Control

IEEE: Institute of Electrical and Electronics Engineers

KEV: Nuclear Energy Regulation

KKB: Beznau Nuclear Power Plant

KKG: Gösgen Nuclear Power Plant

KKL: Leibstadt Nuclear Power Plant

KKM: Mühleberg Nuclear Power Plant

KTA: Nuclear Safety Standards Commission (Germany)

NDT: Non-Destructive Testing

OECD/NEA: Organisation for Economic Co-operation and Development/Nuclear Energy Agency

PSI: Paul Scherrer Institute (Switzerland)

PTS: Pressurized Thermal Shock.

RPV: Reactor Pressure Vessel

SSC: Structures, Systems and Components

SVTI: Swiss Association for Technical Inspections

BWR: Boiling Water Reactor

TPR: Topical Peer Review

DETEC: Federal Department of the Environment, Transport, Energy and Communications

U.S.-NRC: United States Nuclear Regulatory Commission

VBRK: Ordinance on safety classified vessels and pipework in nuclear installations

VGB: VGB PowerTech (Germany)

WANO: World Association of Nuclear Operators

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Swiss Federal Nuclear Safety Inspectorate ENSI

Issued by
Swiss Federal Nuclear Safety Inspectorate ENSI
Industriestrasse 19
CH-5200 Brugg
Phone +41 (0)56 460 84 00
Fax +41 (0)56 460 84 99
info@ensi.ch
www.ensi.ch

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