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1 General information

Switzerland is taking part in the Topical Peer Review (TPR) initiated by the Council of the European Union in 2017, focussing on the 'Ageing Management of Nuclear Power Plants'. The European Nuclear Safety Regulators Group (ENSREG) is coordinating the TPR 2017. The objectives of the TPR 2017 include, in particular, ensuring that the participating countries review the provisions put in place so far in the context of the ageing management of operational nuclear facilities, identifying good practices and areas of improvement from them and exchanging operating experience at the European level. As part of this, the Swiss Federal Nuclear Safety Inspectorate (ENSI) is called upon to publish a national assessment report on the current status of the ageing management in Switzerland in phase 1 of the TPR by the end of 2017. Consequently, all Swiss licensees of nuclear facilities with a power of ≥ 1 MW, and those that will also continue operating beyond 2017, are requested, in the form of a directive [1-1], to prepare a plant specific report by the end of 31 August 2017 providing the essential contents for the national assessment report. In creating the plant reports, the requirements of the corresponding specification [1-2], drawn up by the Western Nuclear Regulators Association (WENRA), are to be taken into account.

This document presents the plant report for TPR 2017 for the Mühleberg NPP (KKM) of BKW Energie AG. This document is a translation of the original report AN-MM-2017/086. In case of a discrepancy, the German original will prevail.

2 Requirements on the overall AMP and its implementation

2.1 Description of the overall ageing management programme

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

– The GSKL programme for checking the ageing management actions builds on many years of applied maintenance concepts of the Swiss NPPs, references the legal requirements and forms the basis for the ageing management of the Swiss NPPs. The document describes the physical ageing phenomena occurring in the NPPs in general and presents a procedure for the early detection and control of these phenomena.
– The ageing monitoring is implemented in the individual departments of the Swiss NPPs. In addition, an independent GSKL expert team was set up for each department, making it possible to monitor ageing with the necessary technical competence. In dividing the ageing monitoring over three departments, electrical, civil and mechanical engineering, it was necessary to create a GSKL interface document [2-2] that lists and clearly allocates the interface and liaison points between the individual departments in the ageing management of equipment.
– In terms of the ageing management of civil engineering, the GSKL guide for the creation of fact sheets contains a listing and an assignment of ageing mechanisms relevant for the various construction materials.
– In the ageing management of electrical engineering and I&C, Part 1 of the fact sheets contains a listing of the most important function-impairing and qualification-influencing descriptions for the specified component with a link to the corresponding references. Part 2 of the fact sheets contains possible diagnostics and testing methods, as well as characteristics by which the ageing progress can be identified. This is documented in the corresponding guide for the creation of fact sheets within the scope of the ageing management of electrical engineering components [2-5].
– The GSKL catalogue of ageing mechanisms for mechanical equipment (KATAM) [2-4] identifies, classifies and describes in detail the ageing mechanisms relevant for light water reactors. After revision in 2011, this document was recognised by the regulator as an essential foundation for ageing management in the Swiss NPPs.
– GSKL guides for the creation of fact sheets for civil, electrical and mechanical engineering ([2-3], [2-5], [2-6]) provide guidance for the practical implementation of ageing management and for documenting the results of the assessment of mechanical and electrical components as well as the civil engineering structures.
– Departments in individual plants implemented the AMP in detail based on the specifications of the GSKL working group. The ageing assessments of civil engineering and building structures, systems and/or components are summarised in the plant-specific fact sheets.

2.1.1 Description of the overall ageing management programme

In accordance with Article 35 of the nuclear energy regulation (KEV) [2-21], the licensee must perform systematic ageing management based on the AMP for all equipment and civil engineering structures whose function and integrity are important for safety and security. Ageing management requirements are specified in the guideline ENSI-B01 [2-8].

The scope of the systems, structures and components (SSCs) to be considered within the AMP primarily depends on the classification of the SSCs in accordance with guideline ENSI-G01, (Safety Classification for Existing NPPs) [2-9], and the relevant specifications of guideline ENSI- B01. Mechanical and electrical equipment relevant for safety based on the probabilistic safety analysis (PSA) in accordance with guideline ENSI-A06 [2-10], must be identified and incorporated in the mechanical engineering and electrical engineering AMP. In accordance with guideline ENSI-G01, essential data relating to electrical and mechanical engineering safety classified components are to be periodically recorded in component lists and/or component type lists when plant changes occur. These lists are to be made available to ENSI.

All SSCs are recorded with this relevant metadata in the database of the integrated plant management system (IBFS), which permits automated identification and checks.

Civil engineering

Based on guideline ENSI-B01 [2-8], ageing management is to include all civil engineering structures classified according to guideline ENSI-G01 [2-9]. In line with their significance for nuclear safety and radiation protection, civil engineering structures are assigned to two nuclear structure classifications, BK1 and BK2.

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

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

Electrical engineering

According to guideline ENSI-B01 [2-8], the AMP is valid for all electrical and I&C equipment classified as 1E in guideline ENSI-G01 [2-9] and for all safety-related electrical equipment classified as 0E. According to ENSI-B01, fact sheets must be created for 1E classified components, whereas for 0E classified components ageing dossiers must be created. The '1E electrical engineering component list' and the '0E electrical engineering system list' are used when identifying structures to be included in the AMP.

As established in electrical engineering ageing management, similar components are assessed as component groups. Relevant ageing mechanisms and possible diagnostic methods for identifying the ageing of electrical components (grouped by operational type such as cables, switches, transmitters, motors, etc.) were elaborated in Parts 1 and 2 of the fact sheet by the GSKL electrical engineering ageing management expert team. The generic fact sheets contain manufacturer and plant-independent basic information for the plant-specific AMP Part 3. The plant-specific fact sheets (Part 3) are drawn up in the individual plants. Here, grouping of components (by nature, type, manufacturer or combined) is left to the plants.

Mechanical engineering

The systematic ageing management for all vessels and pipelines assigned to safety classes SK1 to SK3 based on guideline ENSI-G01 [2-9], including their supports and pressurised equipment (pumps, valves, safety valves), must be documented according to ENSI-B01 [2-8]. Exceptions to this include small pipes with nominal pipe sizes DN ≤ 25 for safety class 1 and DN ≤ 50 for SK2 and SK3.

The ageing condition of the mechanical engineering equipment not covered by the systematic ageing management in accordance with ENSI-B01, is tracked as part of the scheduled maintenance so that early action can be taken to prevent possible damage.

Guideline ENSI-B01 and the results of the PSA are taken into account when identifying structures to be included in the AMP. All active[1] and passive components are assessed.

Guideline ENSI-B01 specifies the SSCs which may be grouped together for assessment. Components of safety classes SK1 and SK2 are not grouped. In general, components of the same or similar construction that are exposed to the same or similar conditions and which exhibit a similar ageing behaviour are grouped together. The groupings must be identified in the fact sheet in a transparent manner [2-6].

Other general aspects of methodology and quality assurance

The term 'Ageing Management Programme' (AMP) was introduced in the USA at the national level in 2001 via GALL (NUREG-1801 [2-12]). In line with the development of the AMP a decade earlier in Swiss NPPs, no specific AMPs are used in Switzerland. At the international level, IGALL [2-13] adopts the GALL methodology (and consequently also the AMPs). IGALL came into existence about 20 years later than the Swiss AMP.

As already presented in Section 2.1, the methods and requirements of the AMP have been set out in the interpretive documents of the GSKL. Moreover, the GSKL guides for the creation of fact sheets for civil, electrical and mechanical engineering ([2-3], [2-5], [2-6]) are a guide for the practical implementation of ageing management and for documenting the results of the assessment of mechanical and electrical components as well as of civil engineering structures based on the classification in guideline ENSI-G01 [2-9].

On the basis of the specifications of the GSKL working group in KKM, the AMP was implemented in detail by the departments according to the requirements of the quality management system. The ageing assessments of civil engineering and building structures, systems and/or components are summarised in the plant-specific fact sheets. The ageing mechanisms relevant for particular plant parts are identified by the ageing management. On this basis, existing programmes, especially maintenance, are checked as to whether ageing-induced damage can be avoided or detected at an early stage. Any omissions revealed by the check are closed in a documented fashion. Embedding this in the national and international activities of GSKL's working group 'AMP in Swiss NPPs' ensures that the state-of-the-art of science and technology in the fields of materials and structural ageing as well as their analysis and diagnostic technology will continue to be considered in future.

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

Relevant ageing mechanisms are determined on the basis of internal and external experience, and essential elements are assigned for the components being assessed. All ageing mechanisms relevant for the individual component parts are listed in tabular form in the fact sheets. The AMP relevant test programmes (e.g. in-service inspection programmes, maintenance programmes, etc.) are determined and the significance of the individual programmes are evaluated. Defined actions for rectification of any detected omissions are carried out. All defined actions are specified in the fact sheets in a list of outstanding actions. Periodic checks assess the implementation of these measures, and their completion is recorded in documents (e.g. logs, reports, maintenance reports, etc.) and fact sheets. All AMP relevant reports are recorded in the document management system, which ensures correct archiving of the documents. Test reports and non-conformance reports are saved in a database.

In the KKM management system, the overall AMP is incorporated in the 'Maintenance' process. This process is subdivided into the areas electrical engineering (P-IEI) and mechanical engineering includ-

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[1] Here the term 'active' is used in the sense of the US-American 'Maintenance rule', i.e. active components need not all necessarily be mechanically active for the GSKL ageing management of mechanical engineering components in the sense of guideline ENSI-G11 [2-11].

ing civil engineering (P-IMI). On the one hand the processes define the organisation, responsibilities and workflows and on the other hand they list higher-level and applicable documents (guidelines, procedure instructions and work instructions). The overall ageing management process is subdivided into three main areas/departments (mechanical, electrical and civil engineering). The interfaces between the individual departments are defined in the interface document, the power plant-specific implementation of the GSKL interface document [2-2], so that there are no omissions in the intersections between the departments.

Drawing on suitable trends and findings from maintenance undertaken, the effectiveness of ageing management and the additional measures resulting from it are evaluated annually in accordance with the state-of-the-art of science and technology on the basis of guideline ENSI-B02 [2-14].

Guideline ENSI-B10 [2-7] defines specific requirements for technical and scientific staff in the plants who are involved in ageing management. Persons who are responsible for ageing management must be qualified to degree level in a scientific or technical subject and also have additional knowledge of methods for ageing management and sufficient experience in the relevant subject (electrical, civil or mechanical engineering). The licensee appoints this staff in accordance with ENSI-B10.

2.1.2 Ageing assessment

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

The division of the AMP into the three areas, civil engineering, electrical engineering and mechanical engineering is defined in the GSKL interface document. The GSKL guidelines for the creation of fact sheets for civil, electrical and mechanical engineering ([2-3], [2-5], [2-6]) provide specifications for the practical implementation of ageing management and for documenting the results of the assessment of the civil engineering structures and the mechanical and electrical components. The component or group-specific assessment takes account of all relevant design and manufacturing documents (especially specifications, material lists, material certificates, manufacturing and prototyping testing certificates).

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

The key elements for effective ageing management are listed in the following table. The basis here is the IAEA Safety Guide for Ageing Management [2-16]. The evidence for this is obtained within the framework of the periodic safety review (PSR), which, in accordance with guideline ENSI-A03 [2-15] is updated every ten years and where, in so doing, a position must be adopted on the attributes of the IAEA guide.

No.	Attribute from the IAEA Safety Guide NS-G-2.12 [2-16]
1	Scope of the AMP based on the understanding of ageing
2	Preventive actions to minimize and control ageing degradation
3	Detection of ageing effect
4	Monitoring and trending of ageing effects
5	Mitigating ageing effects
6	Acceptance criteria
7	Corrective actions
8	Operating experience feedback and feedback of research and development results
9	Quality management

Identification of ageing mechanisms

The systematic identification of ageing mechanisms occurs differently in the three departments based on the subject.

Civil engineering

All ageing mechanisms relevant to civil engineering are specified in the guide for civil engineering fact sheets [2-3]. In the case of inspections also defined in the guide, civil engineering structures are inspected at least every ten years for the relevant ageing mechanisms. The inspections may only be carried out by qualified and experienced persons who know how to interpret and evaluate any unexpected anomalies that might occur. When working within the framework of the AMP, the support of a specialist planner/engineer and, if necessary, a special expert is essential when using special diagnostic methods. The results of inspections are recorded in the fact sheets for the individual buildings, and any actions are defined.

Electrical engineering

The GSKL electrical engineering ageing management 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 NPPs. Necessary adjustments and developments are permanently implemented. To ensure that state-of-the-art of science and technology is maintained in the plant-specific fact sheets, including in the years after the fact sheet has been created, the generic fact sheets Part 1 and Part 2 ('basis documentation') are continually checked by the GSKL-AMP electrical engineering team no later than every ten years and updated as necessary.

Mechanical engineering

The GSKL expert team of mechanical engineering ageing management inspects, evaluates and documents the completeness and assessment of known ageing mechanisms taking into consideration the state-of-the-art of science and technology available and world-wide experience in NPPs. This includes, in particular, the 'Catalogue of Ageing Mechanisms of Mechanical Equipment' (KATAM) [2-4], an essential, ENSI-recognised reference for assessing the relevance of ageing mechanisms in the mechanical engineering area.

In creating the system fact sheets, the following aspects are systematically dealt with and documented:

- General information about the system and its components
- Influencing variables (media, operating conditions, material data)
- Identification of relevant ageing mechanisms
- Internal and external operating experience
- Existing monitoring
- Supplementary measures.

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

Acceptance criteria

The implementation of ageing management actions ensures that a structure or a component maintains its integrity and/or functionality under all design conditions.

In Switzerland, there are also overall criteria specified by the Federal Department of the Environment, Transport, Energy and Communications (DETEC) in an ordinance [2-17] for the temporary shutdown of NPPs, which are closely associated with the physical ageing of the NPPs. These relate to the embrittlement of RPVs, reductions in wall thickness and cracks in primary circuits, wall thickness reductions of steel containment structures of the primary containment and cracks and spalling of the containment concrete shell. The licensee is legally obliged to perform corresponding tests or analyses. This enables ENSI to monitor compliance with defined acceptance criteria.

Regularly performed function tests of active components use specific acceptance values or threshold values. When there is a deviation from these values, a fault indication is triggered, which then leads to maintenance and/or repair actions, so that the correct design condition of the component is recreated.

Civil engineering

The GSKL guide specifies condition levels 1 to 5 for the civil engineering fact sheets [2-3]. All components subject to assessment are evaluated according to these condition levels as part of the regularly performed inspections. Level 1 means ‘very good condition’, level 5 ‘poor condition’. For levels 4 and 5 short-notice or immediate repair is necessary.

Electrical engineering

Due to the diversity of electrical and I&C equipment there are no generally valid acceptance criteria. These must be derived from methodically analysed predictions (accelerated ageing tests in a test environment; inspection of removed components with known conditions of use; cable or component storage in the containment under extreme ambient conditions such as increased temperature, humidity, radiation, etc.) and the plant-specific ambient conditions.

Mechanical engineering

The acceptance criteria for passive mechanical components are assembly or component specific. In Section 5, which relates to the reactor pressure vessel (RPV), the defined acceptance criteria for this component are looked at in more detail. Where RPV embrittlement and fatigue monitoring are concerned, precise specifications are defined by ENSI in the revision of the regulatory guideline on ageing management ENSI-B01 [2-8].

Research activities and expansion or preservation of knowledge

Depending on the design, all Swiss nuclear power plants participate, fully or partially, in on-going research and development programmes via the following institutions:

– EPRI Boiling Water Reactor Vessel Internals Program (BWRVIP)
– EPRI Pressurized Water Reactor Materials Reliability Program (MRP)
– VGB Power Tech e.V.
– swissnuclear (sn), Begleitgruppe Material (BGM)
– and Paul Scherrer Institut PSI

KKM is currently monitoring the following research activities:

– EPRI/BWRVIP (Electric Power Research Institute/Boiling Water Reactor Vessel and Internals Program): This is an internationally recognised research project. Based on the results, EPRI is developing inspection projects for the RPV internals of BWRs that can be applied both in Switzerland and in many other countries.
– PLiM (Plant Life Management), Thermo-Mechanical and Multiaxial Fatigue caused by Cyclic Thermal Shocks: This project covers crack formation due to thermal fatigue in components made of austenitic steel. For example, this project analysed a pipe configuration (hot/cold feed) of a Swiss NPP.
– UT guided-wave technology on complex geometries: To make use of the possibilities of non-destructive condition assessment of containment shells encased in concrete, programmes were started in some Swiss NPPs to make it possible to also use UT guided-wave technology on geometries that are more complex than those associated with piping.

In addition, licensees have access to the results of the following regulator-financed projects [2-18]:

– SAFE-II (Safe long term operation in the context of environmental effects on fracture, fatigue and environmental assisted Tracking): The SAFE-II project deals with materials problems, especially with respect to corrosion cracking and fatigue in the structural materials of light-water reactors. This internationally-recognised project supports and promotes the acquisition of know-how in environment-induced crack propagation, an area which is important for the operation of NPPs.
– CODAP database: For ENSI and the Swiss NPPs, this data collection and background information represents a direct and current source of international experience relating to damage cases occurring on classified mechanical equipment, which can be used directly for ageing assessments.

New findings based on external sources and bodies such as EPRI, TÜV, work groups of the VGB, WANO, CODAP, IGALL, suppliers, EQDB etc. or from conferences and seminars as well as new, recognised diagnostic methods and models are discussed and evaluated in the GSKL AMP team and decisions made about their application in the Swiss AMP. A further important source is also experience feedback from the supplier or manufacturer. Operation-induced damage cases occurring in the individual Swiss NPPs are also presented to the GSKL AMP expert teams and then discussed in respect of their relevance for the AMP ('operating experience exchange').

The recording and analysis of operating experience from external sources (e.g. from external NPPs, authorities, plant and component suppliers, etc.) is coordinated in KKM by a specialist department. The aim of this process is to use the targeted evaluation of experience reports and the consistent implementation of findings relevant to KKM to maintain or improve the safety, availability and environmental compatibility of the plant. Additionally, when creating fact sheets, the relevant databases (WANO, IGALL, CODAP and reports of the manufacturer, General Electric) are examined carefully to find ageing-relevant entries for relevant systems.

Civil engineering

New findings such as, in particular, methods or testing techniques for materials used in civil engineering (especially concrete and steel, plastics or coating materials) have been and are being discussed in the GSKL AMP civil engineering group and evaluated in respect of their application in the AMP. Participation in courses and seminars ensures that knowledge of the latest state of the art is kept up to date.

Electrical engineering

New findings from internal and external operating experience are discussed within the framework of the GSKL working group 'Electrical Engineering Ageing Management' and if necessary followed up and integrated in the AMP. In the context of checking and updating of fact sheets and ageing dossiers, the existing sources/references are scrutinized and current, relevant information which could be used to update the fact sheets are identified.

Mechanical engineering

The Catalogue of Ageing Mechanisms of Mechanical Equipment (KATAM) [2-4] represents the current state-of-the-art of science and technology in respect of the ageing mechanisms of light water reactors. Under the aegis of the mechanical engineering expert team within GSKL's ageing management working group, this catalogue is checked regularly to determine whether new findings are available that require the KATAM to be adapted. To do so, relevant publications, conference proceedings, codes and standards are systematically reviewed and evaluated. The results of this review are presented as summary in the annual reports of the individual power plants.

2.1.3 Monitoring, testing, sampling and inspection activities

The essential components of the ageing management actions for monitoring the technical equipment and controlling the relevant ageing mechanisms are:

- Operational monitoring
- Preventive maintenance including the in-service inspection programme
- Repeat tests including functional tests

In accordance with guideline ENSI-B01 [2-8] surveillance programmes to detect embrittlement of the RPV material and fatigue-relevant components of SK1 to SK3 are necessary. These two surveillance programmes are continuously performed so that the condition of the components mentioned can be continuously gauged and an extrapolation made to determine the expected service life.

Furthermore the following programmes have been set up in the individual departments, which the plant-specific AMP accesses:

- Water-chemistry analyses based on internationally valid guidelines and specifications
- Periodic testing of operating resources, such as lubricants, etc.
- Cable removal programmes and inspection programme
- Diagnostic measurements on actuators (MOV)
- Diagnostic measurements on solenoid valves
- Diagnostic measurements of stator windings of motors
- Capacity measurements on emergency power batteries
- Inspection of cranes

In the civil engineering area, special inspections are carried out in addition to the inspection plan. These include the visual inspection or material sampling of various potential 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 civil engineering structures and laboratory analyses are listed in the guide and applied as necessary.

For the mechanical components of safety classes SK1 to SK4 subject to nuclear acceptance testing, in-service inspection programmes are established according to specification NE-14 [2-19] and guideline ENSI-B06 [2-20]. These include non-destructive testing (NDT), system and component walkdowns, pressure tests, function tests on safety valves and snubbers, and pressure tests. Relevant criteria such as the selection of suitable test methods and test parameters as well as classification and finding-dependent test intervals are also specified in NE-14 and guideline ENSI-B06. These programmes are checked and approved by ENSI and/or its technical experts, the Swiss Association for Technical Inspections - Nuclear Inspectorate (SVTI-N).

Periodic tests on safety relevant systems and components are defined in the technical specifications of the plant and include function and leak tests at defined intervals.

In addition, further provisions and routines are established, which provide information about whether ageing-induced damage is present in the SSC of interest:

- Walkdowns
- Abnormalities during function tests (according to repeat tests in the technical specifications)
- Weekday plant meetings with discussion of abnormalities in operating parameters
- Raising the awareness of maintenance personnel so that they monitor the general state of individual parts of the components during maintenance.
- Water-chemistry monitoring (Amongst other things, the change in the chemical parameters implies internal leaks are occurring)
- Temperature monitoring at relevant positions
- Vibration monitoring on a case by case basis
- Special tests if a suspected problem exists

2.1.4 Preventative and remedial actions

The AMP is designed so that the relevant ageing mechanisms and the resulting ageing effects are detected at an early stage. This forms the basis for identifying and implementing any necessary preventive and remedial actions. Implementation takes place in the relevant departments based on various quality management programmes. Examples include:

- Plant modifications
- Maintenance

The implementation of these actions is regulated in corresponding instructions which ensure that all necessary boundary conditions and specifications are adhered to.

ENSI requires a special concept for components subject to the relevant ageing mechanisms and which cannot be inspected or repaired with standard methods (e.g. inaccessible areas of the containment). Here, the specific ageing situations are considered in depth and a holistic concept for maintaining integrity is developed.

A further example are cross-system exchange programmes which are initiated as soon as a systematic defect or a strongly time-limited applicability has been identified within the AMP for a particular group of components.

On the structural side, progressive carbonation is effectively prevented by thermal insulation measures, by sealing and in particular by the application of surface protection systems.

The respective actions are systematically recorded in the fact sheets or the tracking folders of the fact sheets (see Section 2.1.2).

2.2 Review and update of the overall AMP

The cross-plant contribution to checking and updating of ageing management is carried out in the GSKL working group 'Ageing Management in Swiss NPPs (CH-KKW)'. The leaders of the civil, electrical and mechanical engineering expert teams make up the coordination team of the working group. All parties responsible for the AMP in the individual plants are represented in the expert teams.

The coordination team of the working group discusses overriding aspects of ageing, updates the common overriding documents and defines joint measures and procedures in Switzerland. The common subject-specific specifications and principles for carrying out the ageing management are compiled or updated by the expert teams for use in the individual plants. The tasks of the expert teams include the active participation in special events, national and international exchange of experience and the joint monitoring of the state-of-the-art of science and technology, which is documented in joint subject-specific documents and made available to the individual power plants to implement ageing management.

When AMP fact sheets are revised, the in-service inspection programme is checked in respect of its effectiveness, adapted as necessary and in rare cases special tests are scheduled. In implementing the tests, if the criteria defined in the test instruction are not adhered to, non-conformance reports are prepared. The anomalies must be dealt with inside a defined period, where NE-14 [2-19] governs the scope and the involvement of ENSI and its technical experts, the Swiss Association for Technical Inspections (SVTI). The treatment of the non-conformance reports can be implemented in the form of alternative NDT tests, computational analyses and surveys, maintenance work or component replacement. The completion of these activities is documented in the integrated plant management system and the AMP tracking folder of the SSC in question, so that this information can be considered in the next revision of the fact sheets.

Deviations and areas for improvement in the AMP process detected in audits, inspections and reviews (e.g. by ENSI, WANO, IAEA) are documented in the final report of the tests in question.

Unless specified by the supervising entity, the responsible organisation units shall derive an action plan with clear tasks, responsibilities and deadlines. With audits and reviews, follow-ups are normally performed a few months later in which the auditors check the effectiveness of the implemented actions.

Specialist departments are established in the plants for operational evaluation, which continuously carry out systematic screening of external events and forward the potentially relevant messages to the relevant maintenance and AMP organisational units. In addition, all plants receive prompt AMP-relevant messages from international operating experience via memberships and contacts in a wide range of organisations and working groups (see Section 2.1.2).

In general, these messages are analysed promptly in respect of the transferability and relevance for KKM and documented, e.g. in the form of an 'external event evaluation'. In accordance with guideline ENSI-B02 [2-14], the 'Ageing management annual overview' of the 'Safety Annual Report' provides ENSI with information for each power plant, providing details on which external events have been evaluated and on the respective result.

Likewise, when revising AMP fact sheets, all external messages from the previous year are collected, evaluated and clearly documented for all of the SSCs being assessed.

Since 2011 no fundamental changes have taken place in any of the plants (e.g. an increase in power output or a significant change in the primary water chemistry) with relevance for overall ageing management. An exception is KKM which, prior to 2019, had already started to prepare a ageing management concept for the post shut-down phase from 2020. However the focus of TPR 2017, is not on the ageing management of NPPs which have been finally shut down and therefore this is not discussed further at this point.

The influence of smaller changes (e.g. changing of the type or material of individual components or system sections) on the AMP is (if actually relevant) addressed in the approval process with ENSI.

The effectiveness of ageing management can only be indirectly and inaccurately quantified. A concise key performance indicator (KPI) which is largely, but not exclusively, dependent on ageing management, is 'unplanned unavailability' per year. This is expressed as a percent and broken down in all Swiss plants in more or less detail from the entire plant to individual systems or system groups (e.g. emergency cooling systems or emergency power systems). A further indicator, which is also to some extent dependent on ageing management induced influencing values, is the number of scrams per year.

The systematic approach to creation of AMP fact sheets ensures that ageing mechanisms which result in a time-limited deployment of SSCs (e.g. embrittlement, fatigue, reduction in wall thickness) do not remain unconsidered. Corresponding programmes are initiated for the fatigue and embrittlement of key components (see Section 2.1.3). If necessary, measurement programmes are extended so that trends can be defined.

The ageing management guideline ENSI-B01 [2-8], which came into force in 2011, involved a revision of the ageing management in the areas of civil, electrical and mechanical engineering in all Swiss NPPs.

ENSI granted a five-year transitional period for the full implementation of the AMP in accordance with the new guideline. ENSI continuously monitors the changes and measures in the AMP area and evaluates the overall ageing management at least every ten years in its PSR statement.

The requirement for additional research is discussed and, if necessary, initiated several times a year within the scope of the GSKL AMP expert team meetings, swissnuclear's support team 'Material' and in various bodies with the VGB, EPRI and other institutions.

The cycle of no more than 10 years defined in ENSI-A03 [2-15] between PSRs defines a reasonable upper threshold for reviewing ageing management. In addition, all plants undertake that they will undergo repeating reviews more frequently than every 10 years (e.g. WANO, OSART) in the area of AMP, so that basic areas for improvement are reliably detected and quickly acted upon.

In accordance with guideline ENSI-B02 [2-14], ENSI is informed annually in the section 'Ageing management annual overview' about essential activities and events in the AMP of each plant. This is used as an additional tool for closely checking the implementation of ageing management.

Unexpected ageing mechanisms or new ageing-relevant aspects can be incorporated in the AMP in various ways. In the event of findings or damage within KKM, the non-conformance reports process (see Section 2.2) ensures that not only do short-term measures take place, but also that the results of these are transferred into the AMP.

External operating experience and findings from research and development continually flow into the AMP of the potentially affected SSCs via the following channels:

- Feedback of experience from working groups, conferences and participating research programmes (see Section 2.1.2)
- Annual review and maintenance of the KATAM (see Section 2.1.2)
- Periodic processing of the external experience with each update of the AMP fact sheets
- Sorting of all new external event reports by the corresponding specialist department in KKM

New aspects that are safety-relevant are always treated very quickly by means of special tests and/or in-depth analyses of the influencing variables (manufacturer documentation, operational measurement data). These topics (e.g. unexpected findings in the RPV base material [Doel 2012] or cracks outside the heat affected zones in core shrouds [Hatch 2014]) are always closely followed and monitored by ENSI.

Since the new ageing management guideline ENSI-B01 [2-8] came into force in 2011, findings of monitoring, testing and inspection programmes have confirmed the effectiveness of the overall ageing management. No significant omissions have been identified in the methodology that would have made an adaptation of the ageing management necessary. This confirms the good and close monitoring of the implementation of ageing management in Switzerland as an accompanying measure to the defence in depth safety concept.

2.3 Licensee's experience of application of the overall AMP

The ageing management guideline ENSI-B01 [2-8], which came into force in 2011, involved a revision of the ageing management in the areas of civil, electrical and mechanical engineering in all Swiss NPPs. The close interaction between the plants and ENSI led, within just a few years to a comprehensive, effective and yet still practical implementation of ageing management according to the new guideline.

With the introduction of the new ENSI-B01 guideline [2-8], personnel requirements in the plants have increased significantly. Given the broad level of expertise required, it is somewhat difficult to recruit suitable personnel.

The continual exchange of experience and the systematic processing of external events are essential instruments for the effective optimisation and/or expansion of individual AMPs and for the competent staff to develop their know-how. Adaptations and improvements in ageing management were not triggered by this. In this respect, the periodic reviews performed by WANO and the IAEA also prove effective measures for identifying systematic improvement potential in ageing management.

3 Electrical cables

3.1 Description of ageing management programmes for electrical cables

The AMP in Mühleberg Nuclear Power Plant (KKM) is an integral part of electrical maintenance and based on guideline ENSI-B01 [2-8]. The aim of ageing management is the timely, proactive definition of reinforcing and replacement actions to prevent ageing-induced failures.

Together, the Swiss nuclear facilities have defined the ageing management methodology in the overriding GSKL Working Group Electrical Engineering Ageing Management Expert Team. In doing so, the expert team sets out the basis for plant-specific implementations of the AMP, based on generic fact sheets parts 1 and 2. These two parts contain information on ageing mechanisms, framework conditions and possible diagnostic methods for identifying ageing. Here the fact sheets are divided into component families. The fact sheets parts 1 and 2 contain the national and international status of the relevant ageing mechanisms and form the basis for the type and manufacturer implementation in the individual plants. The electrical cables are combined in the 'cable' component family.

The subdivision of the electrical cables in the WENRA specification [1-2] differs from the subdivision that has proven itself in the Swiss NPPs. The following table shows a comparison of the two subdivisions

Group	Definition Swiss plants	WENRA TPR 2017
G1	Medium voltage power cable › 1 kV (DC › 1.5 kV)	High Voltage Cables › 3 kV
G2	Low voltage power cables 50 V - 1 kV	Medium Voltage Cables 380V to 3 kV
G3	Instrumentation cables ‹ 50 V	-
G4	Special cables (e.g. mineral insulated, coaxial, etc.)	Neutron flux instrumentation cables

3.1.1 Scope of ageing management for electrical cables

The following description of the ageing management of electrical cables includes the 1E and 1E-LOCA cables of the above mentioned groups. The cable products used are described in fact sheets that comprise three parts.

Part 1 deals generically with the cable ageing mechanisms. It lists all factors applicable to cables affecting the ageing process. These ageing mechanisms were compiled from the technical literature and articles. Their maintenance to the state-of-the-art of science and technology is ensured by monitoring the corresponding literature.

In turn, Part 2 describes generic diagnostic methods with which the corresponding ageing mechanisms can be detected and evaluated. The diagnostic methods were also compiled from the technical literature and articles and their maintenance to the state-of-the-art is ensured by monitoring the corresponding literature.

Part 3 contains the plant-specific implementation. The relevant ageing mechanisms and diagnostic methods for the respective cable types are assessed in it. Deviations are treated as omissions and evaluated as actions, so that the findings are incorporated into maintenance.

The fact sheets are revised at least every 10 years. This ensures that new findings from science and technology as well as from internal operating experience flow into the AMP. Since a few years, whenever plant modifications are made, the affected cables are replaced as a preventive maintenance measure.

The affected fact sheets are adapted accordingly.

Within KKM, the component group medium voltage power cable (G1) comprises the cables of the emergency power supplies C1 and C2, which are fed by the generators of the Mühleberg hydroelectric power plants.

In KKM, the component groups low-voltage power cables (G2) and instrumentation cables (G3) comprise the thermoplastic insulated cables for voltages up to 1000 VAC and 1500 VDC. This include the following power and I&C cables of 1E classified electrical components that are recorded within the framework of the AMP:

a) 1E classified cables in the reactor building including drywell
b) 1E classified cables outside the reactor building
c) 1E classified cables under project SUSAN which have been fitted or removed in association with the project

In KKM, the component group special cables (G4) includes the mineral-insulated cables (MI-cables) and coaxial cables for neutron flux measurements in the wide-range (WRNM) and power range (PRNMS). Within the scope of the AMP they are subdivided into following groups in the fact sheet part 3:

a) WRNM: Motor cables and control cables, signal cables in the protective tube and system cables
b) 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

Medium voltage power cable (G1)

The medium voltage power cables (G1) for the emergency power supplies C1 and C2 from the HEPP are three-conductor cables with mass-impregnated non-draining insulation, lead jacket and flat wire shielding (16 kV cable impregnated insulation cable 3 x 95 mm2). These cables are part of the original equipment and were not evaluated in a fact sheet, rather were surveyed in 2015 in cooperation with the BKW business unit Grid/High-voltage Department and documented in a report.

Low voltage power cables (G2) and instrumentation cables (G3)

The low voltage power cable (G2) and the instrumentation cable (G3) were evaluated as part of the AMP and based on the specifications from the fact sheet part 1 and 2, are documented in the fact sheets part 3.

The following table provides an overview of the ageing mechanisms and diagnostics methods for various component parts of the low voltage power cables and instrumentation cables

Component parts	Ageing mechanisms Fact sheet Part 1	Diagnostics methods Fact sheet Part 2	Diagnostics present in KKM
Jacket insulation	Oxidation	Visual inspection	Yes
	Embrittlement	Visual inspection	Yes
	Discolouration	Visual inspection	Yes
	Dielectric change	Cable sample / ageing store	Yes[1)]
	Cracking	Visual inspection	Yes
	Abrasion	Visual inspection	Yes
	Blistering	Visual inspection	Yes
Harness wrapping	Embrittlement	Cable sample/ageing store	No[2)]
	Discolouration	Cable sample/ageing store	No[2)]
Conductor insulation	Embrittlement	Cable sample/ageing store	Yes[1)]
	Discolouration	Cable sample/ageing store	Yes[1)]
	Dielectric change	Voltage test	No[3)]
		Capacitance measurement	No[3)]
		Insulation resistance	Yes
	Cracking	Cable sample/ageing store	Yes[1)]
Conductor and connection	Corrosion	Magnetic pulse	No[3)]
		Visual inspection	Yes
		IR measurement	No[4)]
	Loosening of the connection	Visual inspection	Yes
		Magnetic pulse	No[3)]
Protective coating on electrical connections	Corrosion of the underlying metal	Visual inspection	Yes
Junction box	Corrosion	Visual inspection	Yes

1) Cable pre-ageing area (high stress test area for cable pre-ageing) is only valid for accident-proof cables inside the drywell (primary containment). As part of ageing management, individual cable sections from the cable pre-ageing area-containment were analysed using elongation at break tests.

2) No cable harness winding is used.

3) No voltage test, capacitance measurement or magnetic pulse measurement is performed.

4) No infrared measurements are carried out. However in special cases where damage is suspected, infrared measurement can be requested.

Visual inspection and measurement of the insulation resistance were introduced from 2016. To do so, selected cables were tested based on the test instruction during the annual overhaul and the insulation resistance was measured. The main focus of the visual inspection is laid on the cable ends.

Special cables (G4)

The special cables (G4) including the mineral insulated cables (MI cables) and coaxial cables for wide-range neutron flux measurements (WRNM) and power range measurements (PRNMS), have been evaluated within the framework of the AMP and documented in the fact sheet part 3.

Special cables for wide range neutron flux measurements (WRNM):

Component parts	**Ageing mechanisms Fact sheet Part 1**	**Diagnostics methods Fact sheet Part 2**	**Diagnostics present in KKM**
Jacket insulation	Oxidation	Visual inspection	Yes
	Embrittlement	Visual inspection	Yes
	Discolouration	Visual inspection	Yes
	Dielectric change	Cable sample/ageing store	Yes[1)]
	Cracking	Visual inspection	Yes
	Abrasion	Visual inspection	Yes
	Blistering	Visual inspection	Yes
Harness wrapping	Embrittlement	Cable sample/ageing store	No[2)]
	Discolouration	Cable sample/ageing store	No[2)]
Conductor insulation	Embrittlement	Cable sample/ageing store	Yes[1)]
	Discolouration	Cable sample/ageing store	Yes[1)]
	Dielectric change	Voltage test	No
		Capacitance measurement	No
		Insulation resistance	No
	Cracking	Cable sample/ageing store	Yes[1)]
Conductor and connection	Corrosion	Magnetic pulse	No[3)]
		Visual inspection	Yes
		IR measurement	No[3)]
	Loosening of the connection	Visual inspection	Yes
		Magnetic pulse	No[3)]
Protective coating on electrical connections	Corrosion of the underlying metal	Visual inspection	Yes
Junction box	Corrosion	Corrosion	Yes

1) Cable pre-ageing area (high stress test area for cable pre-ageing) is only valid for accident-proof cables inside the drywell and relates only to signal cables.

2) No cable harness winding is used.

3) No voltage test, capacitance measurement or magnetic pulse measurement or infrared measurement is performed. A test instruction is used to carry out the reflection measurements, which would indicate time-induced change.

Coaxial cables for power range neutron flux measurements (PRNMS):

Component parts	**Ageing mechanisms Fact sheet Part 1**	**Diagnostics methods Fact sheet Part 2**	**Diagnostics present in KKM**
Jacket insulation	Oxidation	Visual inspection	Yes[1)]
	Embrittlement	Visual inspection	Yes[1)]
	Discolouration	Visual inspection	Yes[1)]
	Dielectric change	Cable sample/ageing store	No[2)]
	Cracking	Visual inspection	Yes[1)]
	Friction	Visual inspection	Yes[1)]
	Blistering	Visual inspection	Yes[1)]
Harness wrapping	Embrittlement	Cable sample/ageing store Cable	No[3)]
	Discolouration	sample/ageing store	No[3)]
Conductor insulation	Embrittlement	Cable sample/ageing store	No[2)]
	Discolouration	Cable sample/ageing store	No[2)]
	Dielectric change	Voltage test	No[4)]
		Capacitance measurement	No[4)]
		Insulation resistance	No[4)]
	Cracking	Cable sample/ageing store	No[2)]
Conductor + connection	Corrosion	Magnetic pulse	No[4)]
		Visual inspection	Yes[1)]
		IR measurement	No[4)]
		Visual inspection	Yes[1)]
	Loosening of the connection	Magnetic pulse	No[2)]
Protective coating on electrical connections	Corrosion of the underlying metals	Visual inspection	Yes[1)]
Junction Box	Corrosion	Visual inspection	Yes[1)]

[1)] Because of accessibility, visual inspections can only be carried out on the connection side of the measuring system (see also comment [4)] reflection measurements).

[2)] Cable pre-ageing area (high stress test area for cable pre-ageing) is only valid for accident-proof cables inside the drywell.

[3)] No cable harness winding is used.

[4)] No voltage test, capacitance measurement or magnetic pulse measurement or infrared measurement is performed. A test instruction is used to carry out the reflection measurements, which would indicate time-induced change.

Mineral insulated power range neutron flux measurements (PRNMS):

Component parts	**Ageing mechanisms Fact sheet Part 1**	**Diagnostics methods Fact sheet Part 2**	**Diagnostics present in KKM**
Outer tube	Corrosion Cracking	Visual inspection	No[1)]
Conductor	Corrosion	Visual inspection	No[1)]
Insulation	Leakage current increase Change in insulation	Insulation measurement	No[2)]
Termination – Fitting – Spacer – Potting compound	 Cracking Corrosion Leakage Cracking Cracking Embrittlement Leakage	Visual inspection	No[1)]
Electrical connection	Cracking Corrosion Loosening	Visual inspection TDR method (reflection method)	Yes

[1)] The mineral insulated cable is laid in the drywell in protective conduit from the penetration to below the reactor vessel. Access is difficult because of building and radiation safety constraints. A visual inspection would be unreasonable and not necessary because of the mechanically robust cable jacket.

[2)] Insulation measurement: Insulation measurements were carried out at the time of installation during the annual outage in 1997. For a periodic insulation measurement, cable connections must be removed from the side of the detector. Due to the environmental conditions and proneness to errors during manual manipulation of the cable connections ("Lemo plug"), an insulation measurement is omitted and instead a reflection measurement is performed. As a result, time dependent changes are identified at an early stage.

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

Visual and measurement-based testing of 1E cable

The visual and measurement-based testing of 1E cable as part of the AMP, is performed according to a test instruction during the annual overhaul. In doing so, the condition and change in condition of defined samples of 1E cables are measured.

Both cable ends are inspected as part of the visual check. Where possible and clearly identifiable, spot checks are performed on the jacket insulation over the path of the cable.

The visual inspection includes the following criteria:

– Checking of the jacket insulation for discolouration, embrittlement, cracking, abrasion and blistering

– Checking of the conductor insulation for discolouration, embrittlement and cracking

– Checking of the conductor connection for looseness and corrosion

– Checking of the protective coating on electrical connections (conductor end sleeves or cable terminals) for corrosion of the underlying metal

– Checking of the junction box for corrosion

The measurement-based inspection includes measuring of the insulation. In doing so, the insulation resistance between N (+) and PE (-), between L_1 (+) and PE (-), and L_n (+) and L_n (-) is measured at different voltages.

Procedure:

– Ensure that the live conductors and neutral conductor of the cable under test are disconnected at both ends from the system but that the PE conductor remains connected.

– Carry out insulation measurement (250VDC N-PE if OK 500VDC N-PE, if OK Measurement with 500VDC L_1-PE, if OK Measurement with 500VDC L_n-L_n)

TDR (time domain reflectometry)

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 difficult to access cable trays and, on the other hand, routed in areas with high radiation exposure. To be able to assess the condition of the cables, time domain reflectometry (TDR) measurements are 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 the AMP 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 initiated.

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. This means that the entire measurement path is analysed.

Analysis and re-qualification of the PVC cables outside the reactor building for which no design documentation is available

In view of the final shut-down of KKM in 2019 (EELB 2019), ENSI required the replacement of safety-relevant cables in the reactor building by the end of 2014 and the replacement or re-qualification of other cables by 2018.

Within the context of AMP, it was established in 2012 that no design documentation was available for various cables in safety-relevant systems.

Consequently, all affected 1E cables within the reactor building were replaced by the end of 2014. For the remaining safety-relevant cables for these systems outside the reactor building, a material investigation was commissioned as a basis for decision-making about the replacement or re-qualification. The investigations of the cable insulation materials (jacket, conductors) were carried out in cooperation with an accredited testing laboratory. The aim of the investigations was to obtain an estimation of the remaining service life. 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. To determine the ageing condition of the second cable type, a further operationally aged cable of this type was analysed.

Based on the results of the investigations into the cable insulation materials (jacket, conductors), it was decided that the remaining safety-relevant cables outside the reactor building, for which there is no design documentation available, need not be replaced. Both cable types have a remaining lifetime of at least 8 years where the ageing condition is concerned.

In view of the decision to finally shut KKM down in 2019 and the results from the material investigations, which conservatively demonstrate the safe use of the cables for at least a further 8 years, the design compliant use of this cable is proven.

The re-qualified cables will continue to be monitored within the scope of the AMP and also considered in the preparations to establish the technical post-operation. This ensures that the design-appropriate functioning of the systems mentioned can be evidenced at any time.

Analysis of cable sections from the containment high stress test area for cable pre-ageing

The cable jacket and cable insulation materials age during operation in KKM due to various influencing factors (e.g. ambient temperature, oxygen diffusion, radiation). Depending on the cable material, period of use and overall loading, the ageing of the insulation materials (jacket, conductors) may have progressed to different levels.

In KKM, various cable samples have been inserted in the drywell since 1996 (containment high stress test area for cable pre-ageing) so that these cables are left to age in the 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 investigated the elongation at break by tensile testing after the cable was further aged for 12 weeks at 90°C.

The results of the investigations showed that the insulation of all three supplied cables in the latest state (after their operation in KKM) have an elongation at break, that is 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 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 tested cables have an adequate wear margin up to the final shut-down of the respective systems.

3.1.4 Preventive and remedial actions for electrical cables

Cable replacement on the occasion of previous projects

Over the last 26 years 1E cables were replaced within the scope of projects for the following safety-relevant systems:

a) Reactor protection: 1991/92
b) Wide range neutron flux monitoring instrumentation (WRNMS): 1993
c) Emergency diesel generator: 1993
d) Replacement emergency exhaust control, RB ventilation isolation, drywell and torus pressure reduction and drywell circulation air cooling: 1999

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

Cable replacement in the reactor building 2013/2014

KKM was required by ENSI to replace all 1E cables of the safety system in the reactor building, for which there was no design documentation, by 31 December 2014. For the remaining safety-relevant cables for which there was no design documentation, a replacement plan was to be submitted to ENSI by 30 June 2013.

KKM fulfilled the requirement and replaced the relevant 1E cables of the safety systems in the reactor building, for which there was no design documentation. Affected by this were the safety systems 'shut-down and torus cooling system including pressure increasing pumps', 'standby liquid control system', 'hilltop reservoir feed', 'core spray system', 'spent fuel pool cooling and cleaning system' and 'sampling system'.

The majority of the identified cables were laid before the 2013 annual overhaul and enclosed during the overhaul. In this way, the old cables could be completely dismantled and removed during the 2013 annual overhaul. The remaining residual quantity was similarly removed during the 2014 annual overhaul. In doing so, not only were the relevant cables inside the reactor building replaced, but also the cables outside the reactor building up to the next connection point. Where present, the local control boxes in the reactor building were replaced alongside the corresponding cables.

The cables were routed along the existing cable runs. Qualified cable material was used.

Where the primary system containment is concerned, it should be noted that KKM has investigated the relevant cables of the Nitrogen-inerting system. The system was converted in 1995 and all cables replaced in accordance with the 'SUSAN standard'. Consequently cable replacement was not necessary.

The second part of the ENSI requirement concerned the replacement planning of the remaining safety-relevant cables, for which no design documentation is available.

KKM defined the affected systems and cables as follows:

- All cables extending beyond the first connection point outside the reactor building of the relevant 1E systems according to Part 1 of the ENSI requirement
- Recirculation pump system including drives
- Feedwater system including drives

KKM arranged for an accredited test laboratory to determine the residual life expectancy of the above-mentioned cables. In doing so, two removed, operationally-aged cables were pre-aged according to the ‘n-degree rule for pre-ageing’ according to GSKL rules, with the aim of obtaining a quality demonstration record for these cables, indicating their safety for continued operation over the coming years.

Moreover, 15 samples were investigated for comparability with the test specimens. This ensured that the tested cables are equivalent to the cables fitted in KKM.

The results showed that the tested cables had a sufficient wear margin for continued operation.

In respect of the system ‘recirculating pump systems including drives’, it should be noted that the cables of the recirculating pump system do not come within the area of the remaining safety-relevant cables and are thus not associated with the 1E cable replacement in the RB.

However, the recirculating pump system was converted in 2010 and consequently all related cables were replaced. The design documentation for the cables is available. Consequently, no further cable replacement is necessary.

In respect of the system ‘feedwater system including drives’, it should be noted that the cables of the feedwater system do not come within the area of the remaining safety-relevant cables and are thus not associated with the 1E cable replacement in the reactor building.

The drives of the feedwater system were converted in 2009 and 2012 and consequently all related cables were replaced. The design documentation for the cables is available. Consequently, no further cable replacement is necessary.

3.2 Licensee’s experience of the application of AMPs for electrical cables

KKM will finally shut down at the end of 2019. Some systems and thus also the appropriate cabling will continue in operation beyond this point in time. This will be taken into account in the AMP, i.e. the evaluation and the derived actions consider the operation up to final shut-down of the corresponding system or partial system.

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

In the opinion of KKM, this means that safe operation can be ensured beyond final shut-down.

4 Concealed pipework

4.1 Description of ageing management programmes for concealed pipework

4.1.1 Scope of ageing management for concealed pipework

The scope of concealed pipework on the KKM site that is subject to the AMP in accordance with guideline ENSI-B01 [2-8] is determined as follows: In KKM, a general drawing of the plant pipes is kept up-to-date, in which all underground pipes on the site and the adjoining areas are recorded.

Here, a differentiation is made between:

– Different pipe types
  (e.g. cooling water, metrology, sewage water, compressed air, electrical cable duct)
– Components/facilities
  (e.g. control shafts, hydrants, gate valves, vents, pump stations, sumps)
– Materials
  (material information and positions of all possible materials and/or material changes)

Detailed drawings exist for each trade. These drawings are updated by building activity. Based on the general drawing, classified (safety-relevant) concealed pipework can be identified beyond doubt in comparison with the respective system schematic in which the safety classification can be seen.

There are no concealed oil or fuel pipes in KKM.

The concealed compressed air lines in KKM are not safety relevant.

Classified pipe sections embedded in concrete are not considered here separately because the inaccessible areas are very short (e.g. building penetrations) and the outer surfaces are not subject to any relevant ageing mechanisms. In the AMP, they are not handled differently to accessible areas of the respective systems.

In KKM, concealed pipework is grouped as follows:

– Safety class 3 (SK3)
  The SK3 group only includes the inlet and outlet pipes of the SUSAN cooling water system CWS ('HOBAS pipes'). The SUSAN system is a special independent system for the removal of decay heat that was built in the 1980s to improve safety in respect of design accidents. Its cooling water system is an open circuit from and to the Aare river, which removes the heat from various coolers.
– Safety class 4 (SK4)
  The group of SK4 pipes includes the buried sections of the auxiliary cooling water system. These run from the pump station to the turbine hall and also convey Aare river water to the various coolers of the KKM.
– Unclassified pipes, not relevant for safety
  Other concealed pipework is not considered within the framework of the Topical Peer Review 2017.

The so-called zone concept ensures that all radioactive releases to the environment are controlled. Adherence to this concept ensures that concealed pipework does not convey any radioactive substances. The zone concept is checked periodically, especially in connection with expansion actions. All actions or results of these checks are to be mentioned:

- The SUSAN-CWS transport inactive river water for the cooling of various coolers. The pressure difference in the coolers ensures that any internal leaks that might occur cannot escape via the SUSAN-CWS into the environment. As an additional measure to prevent environmental releases into the environment, the SUSAN-CWS is continually radiologically monitored.
- The intermediate store is designed with a double bottom with radiologically monitored collection shafts for any waste water.
- Any radioactively contaminated fire extinguishing water is already captured in the respective building sumps.

4.1.2 Assessment of concealed pipework

SK3

HOBAS pipes are GUP pipes, that is they comprise glass fibre (G) reinforced, unsaturated (U) polyester resin (P) and fillers. The result is a thermoset composite material. HOBAS pipes are produced in the centrifugal casting process with a layered structure of the pipe wall (sandwich pipes). The supporting fibre layers are arranged on both sides of the neutral axis of the pipe wall at a fixed distance. The intermediate spaces is filled with a binder-resin mixture. This design means that the pipe wall acts like an I-beam
under bending load.

Schematic representation of the wall layers of HOBAS pipes:

1 Outer protective layer
2 Outer reinforced layer (glass fibres, thermoset plastic)
3 Transition layer (glass fibres, thermoset plastic, sand)
4 Reinforcement layer (sand, thermoset plastic, glass fibres)
5 Transition layer
6 Inner reinforced layer
7 Barrier layer
8 Inner pure resin layer

The ageing condition of the concealed SUSAN-CWS line (HOBAS PIPES) is evaluated by defining a target condition level for use in annual testing of the bending tensile strength of retained samples. Over recent years, the decrease in strength of the plastic pipes has slowed. The minimum permissible value will not be reached based on the determined regression curve within the planned service life. Moreover, the bending tensile strength is tested annually and the regression curve updated according to the test results. The SUSAN-CWS pipe is in good condition and will remain fully functional beyond its planned operational period (2024).

SK4

No documentation in the form of AMP fact sheets is necessary according to guideline ENSI-B01 [2-8]. However, the guideline requires an AMP, for which the criteria have not been defined by the regulator. Here it is the responsibility of the licensee to develop suitable strategies and measures to identify relevant ageing mechanisms and rectify ageing-induced damage at an early stage to ensure that it does not cause safety-relevant degradation of the nuclear plant parts. Here, the ageing management is primarily based on the findings from the internal maintenance programme as well as evaluation of external experience and events.

In KKM, the SK4 section of the auxiliary cooling water inlet is treated in the AMP fact sheet of the system. The pipes are readily accessible along the further path of the system in the turbine hall and reactor building. The outlet takes place via the reactor cooling water outlet. Here the pipe diameters are so large that these areas are periodically accessible from the inside for inspection and maintenance work. The relevant ageing mechanisms of the inaccessible areas in the auxiliary cooling water inlet circuit are limited to the usual corrosion mechanisms acting on metal pipes. Special research and development programmes are not put in place for the SK4 class buried pipes in KKM because there is already sufficient experience both for nuclear and non-nuclear applications.

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

SK3

The activities for condition monitoring are explained in the fact sheet for concealed SUSAN cooling water pipes. The following table summarises the activities.

Component	Type of test / Inspection	Method	Time Interval
SUSAN -CWS (HOBAS pipes)	Bending tensile strength test of test specimens stored in Aare river water	Bending tensile strength according to DIN 53452 Since then, 3-point bending tensile test according to ISO 178 or SN EN 11296-4	Annually since 1988 (3-5 specimens per year)
SUSAN-CWS (whole pipe)	Pipe internal video inspection	Visual inspections	10-yearly and after special events since 1989

SK4

The first section of the auxiliary cooling water system transports river water in partially buried pipes from the pump house to the turbine hall. The further course of the system does not include any concealed areas. In the buried, inaccessible section, the ferritic pipes are of diameter DN 600, wrapped on the outside and run in a sand bed. The inside of the pipes is coated with tar epoxy coating. All inspection and monitoring activities on the auxiliary cooling water system are recorded in the AMP fact sheet. The river water is periodically analysed and, in respect of its corrosive properties, has a quality corresponding to that of drinking water.

Extensive ultrasonic wall thickness measurements were carried out on the auxiliary cooling water system in 2011. Even after about 40 years' operation, these wall thickness measurements revealed that the pipes were in a very good condition with only slight wall thickness losses at a few locations. These are in line with expectations. The local calculated minimum required wall thicknesses are in all cases significantly below the measured wall thicknesses, so that there is no need for maintenance prior to decommissioning of the system (provisionally 2024). The acceptance criteria for the wall thickness measurements are based on the latest structural mechanics calculations for the pipeline. These results are representative for the condition assessment of the inner surfaces of the inaccessible areas, which are of identical design and exposed to the same conditions as the investigated pipe sections in the turbine hall.

The condition assessment of the outer surface in the inaccessible section can be carried out by analogy to the similarly manufactured, wrapped and routed reactor cooling water line which runs parallel to the auxiliary cooling water line. Within the scope of a probe excavation, a section of the inaccessible reactor cooling water line was uncovered. Even after more than 40 years, no significant degradation of the outer surface including the wrapping could be detected.

4.1.4 Preventive and remedial actions for concealed pipework

SK3

In the event of an inadmissible reduction in the bending tensile strength by 2030, a pre-study on the replacement or relining of the buried SUSAN-CWS line was prepared by way of precaution. The results of the study confirm that until the end of the anticipated period of use up to 2024, no preventive measures and repairs will be necessary.

SK4

Due to very good operating experience, no preventive actions or maintenance are required or planned in the inaccessible areas of the auxiliary cooling water lines before the end of the provisionally planned period of use.

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

SK3

Within the framework of the AMP for concealed pipework, it was possible, based on the performed and further planned monitoring actions, to answer open questions posed by the regulator such as:

- Why do the HOBAS pipes age?
- Does this correspond to the expected ageing?
- What are the critical, defining effects or ageing mechanisms?
- Is the definition of the target condition level sufficient in respect of the bending tensile strength?

Several other questions were further raised during a technical discussion with ENSI. The answers were summarised in a memorandum. In its assessment of the document, ENSI came to the conclusion that actions still planned within the scope of the AMP sufficiently cover the ageing process of the buried SUSAN-CWS pipes and that their integrity and functionality are ensured.

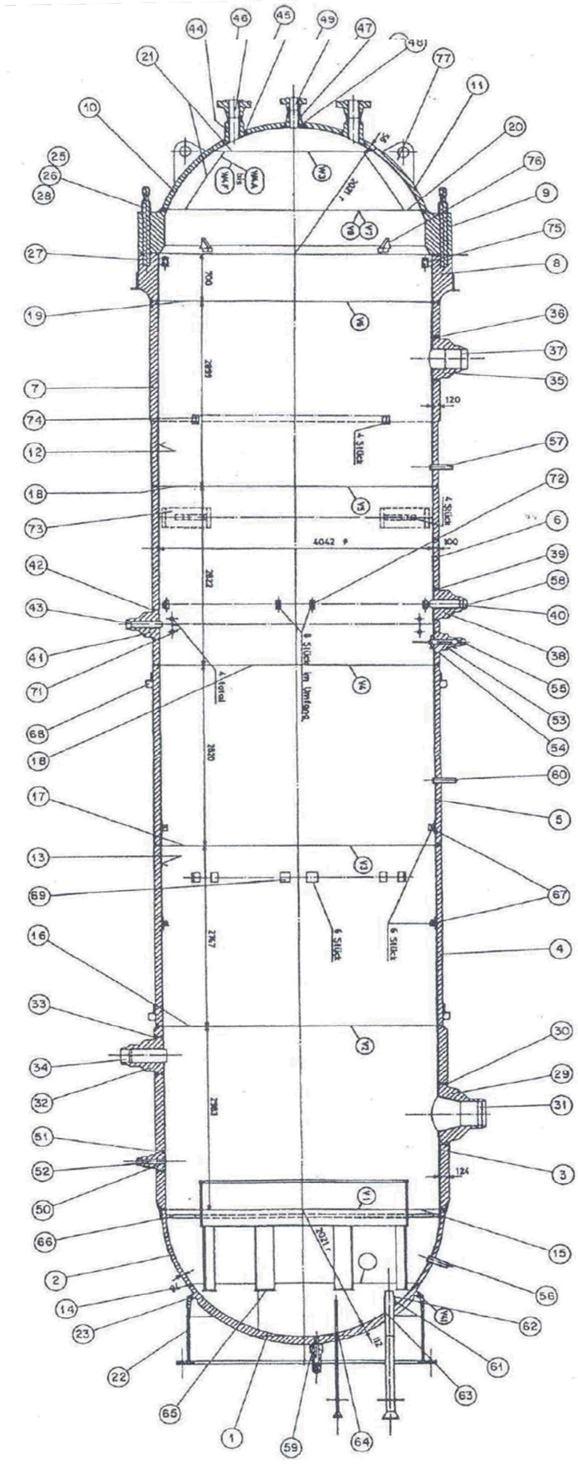
SK4

The experience of KKM in respect of the inaccessible areas of the auxiliary cooling water lines confirms the effectiveness of the SK4 concealed pipework AMP. Based on well-founded analogous considerations and well planned tests on accessible system sections, the condition of inaccessible areas can be estimated with sufficient reliability and the functionality of the pipeline in question is guaranteed.

5 Reactor pressure vessel

5.1 Description of ageing management programmes for the RPV

5.1.1 Scope of ageing management for the RPV



General view of the KKM RPV with all items considered in the AMP.

The following table summarises the essential key data of the KKM reactor pressure vessel (RPV).

System	**Nuclear steam generator**
Plant identifier (MKZ)	002A 0001
Reactor type	BWR 4 of the manufacturer General Electric
Thermal rated power at commissioning 1972	997 MW
Thermal rated power Since power increase 1991	1097 MW
Material	ASTM A-50B Cl. 2 according to Code Case 1332 for forged cylindrical parts; ASTM A-533 Gr. B, Cl. 1 according to Code Case 1339 for bottom and head
Safety class (SK)	1
Seismic class (EK)	I
As built design spec.	ASME B&PV Code Section III, Class A
Current design spec.	ASME B&PV Code Section III, NB
Supplier	Sulzer AG (CH) / RDM (8)
Operating / design temperature	285 °C / 302 °C
Operating pressure / design pressure	72 bar (69 bar before the power increase) / 86 bar
Medium	Deionised water
Internal height	19,000 mm
Internal diameter	4,034 mm
Wall thickness (without cladding)	100 mm (120 mm in a few areas)
RT_{NDT}-Initial temperature of the base metal	max. 4.4°C
Plating material	Strip weld cladding from austenitic steel welded with an E308 electrode
Cladding thickness	4 mm
Commercial commissioning	1972

The validity range of ageing management as defined in the in-service inspection programme encompasses the reactor pressure vessel as such, including the nozzle-safe-end welds, plus the welds on the inside of the RPV and the RPV cladding.

RPV internals and the control rod drive mechanism are given special consideration within the framework of the AMP.

In accordance with guideline ENSI-G01 [2-9], the RPV is a safety-classified vessel of safety class 1, as are all components of the pressure boundary of the reactor cooling system up to and including the second connection valve. Consequently it belongs to category A according to the guideline ENSI-B01 and must be treated in detail [2-8].

In accordance with Section 2.1.2, the Mechanical Engineering Department carries out the procedure for identifying the relevant ageing mechanisms.

5.1.2 Ageing assessment of the RPV

The components are subject to ageing management based on their function in respect of pressure containment. Each component is assessed for ageing due to damage that has occurred based on the materials used in manufacture, the operating conditions and the contact medium. All components in the scope of consideration have been evaluated taking into account operating parameters acting on them, the medium in contact with them and their sensitivity to potential damage mechanisms in accordance with the Catalogue of Ageing Mechanisms of Mechanical Equipment (KATAM) [2-4]. In this respect, the following relevant ageing mechanisms have been identified:

- Intergranular corrosion
- Stress corrosion cracking
- Fatigue as a result of operating transients
- Embrittlement due to neutron irradiation
- Thermal embrittlement of welds

The basic acceptance criteria for the RPV have already been explained in Section 2.1.2. Moreover in Switzerland, criteria for the temporary shut-down of NPPs are defined by DETEC (SR 732.114.5, 'DETEC ordinance on the methodology and boundary conditions for checking the criteria for the temporary shut-down of NPPs' [2-17]).

The licensee must immediately temporarily shut down the NPP if:

a) the current adjusted brittle fracture reference temperature of the inner wall at a depth of one quarter of the wall thickness reaches 93°C;

or

b) the actual upper shelf energy from the Charpy impact test falls below 68 J.

No leaks must occur. If through-wall cracks appear in the primary circuit then, with the exception of piping with a nominal diameter ND ≤ 25 mm, the licensee must immediately provisionally shut the NPP down. If the wall thickness falls below the calculated minimum wall thickness of the primary circuit, with the exception of piping with ND ≤ 25 mm for the design pressure, the licensee must likewise immediately provisionally shut the NPP down.

For ultrasonic crack testing of the welds, permissible crack sizes for the welds are determined by computation. The relevant influencing factors for these calculations are the local embrittlement condition and the local stress condition under design conditions. The calculations were carried out in accordance with ASME XI IWB 3600 using linear elastic fracture mechanics. In addition, checks are carried out for ductile fracture according to ASME XI Division 1 C-5322 and C-5410. These specific acceptance criteria were checked and approved by ENSI and its expert body. From these, permissible defect sizes at various positions were determined for the non-destructive tests and documented in a calculation report.

In line with the standards, KKM has access to the following documents, which are used in the ageing assessment of the RPV:

- Manufacturing drawings for all components
- Manufacturing documentation (material certificates, heat treatment records)
- Manufacturing test results
- Summary report on the manufacture and installation
- Reports on the periodic assessment of the level of fatigue usage

Research and development programmes

The following research and development programmes are monitored by KKM:

- Since 2000, KKM has participated in a close cooperation with EPRI and PSI (NORA projects I to III) in research activities to optimise the water chemistry.
- Work is under way on the INTEGER research project in the Nuclear Materials Laboratory of the Nuclear Energy and Safety Research Department at the Paul Scherrer Institute (PSI). This research project, jointly financed by the regulator ENSI and swissnuclear is subdivided into three subprojects:
  - Materials ageing: characterisation and mechanisms: environmentally assisted cracking, thermal fatigue, embrittlement due to neutron irradiation
  - Structural integrity: modelling and evaluation: RPV integrity and safety, thermal fatigue
  - Diagnostics: early detection, monitoring: embrittlement due to neutron irradiation, stress corrosion cracking

Project SAFE-II (Safe Long-Term Operation in the Context of Environmental Effects on Fracture, Fatigue and Environmentally Assisted Cracking), financially supported by the regulator ENSI, concerning RPV embrittlement:

- Investigations into the influence of hydrogen on the fracture behaviour of low alloy RPV steels show that the hydrogen content in the reactor water does not present a risk for hardening of the RPV steel or embrittlement of the base metal or even the heat affected zone.
- In addition, the influence of high-temperature water on the fracture behaviour of low alloy RPV steels was investigated. Under the operating conditions in KKM, there is no reduction in the initial ductility or the tearing resistance of the RPV metal.

The PROBAB (Probabilistic Component Integrity Analysis) project, financially supported by the regulator ENSI:

- In this project probabilistic and deterministic fracture mechanics analyses of the RPV are evaluated, taking into consideration the neutron embrittlement and material inhomogeneities under pressurised thermal shock (PTS) loading and during start-up and shut-down transients. Probabilistic fracture mechanics analyses of nozzles and pipes under consideration of active damage mechanisms such as fatigue, corrosion, stress corrosion cracking, etc. are investigated.

Internal operating experience

During the first 30 years of operation, numerous actions were implemented to minimise RPV thermal fatigue. On the one hand these actions relate to a more preservative mode of operation during start-ups and shut-downs and in respect of operation of the circulating pumps in the reactor recirculation loops. This ensures that cold water transients can be effectively avoided or reduced. In addition to the operative actions, hardware measures were also implemented. By installing thermal sleeves in some nozzles, the potential for thermal fatigue could be greatly reduced in these positions. The effectiveness of the implemented actions is demonstrated particularly by repeat tests which are free from any findings.

Due to the findings detected in 2012 in the RPV base metal of two Belgian RPVs, which were manufactured in the same forge, a representative circumference of the KKM RPV was ultrasonically inspected in the same year. This test confirmed that the RPV base metal was fault-free.

External operating experience

The evaluation of external events is carried out as described in Section 2.1.1. Although KKM is a BWR, events in PWRs are also analysed in respect of their applicability to KKM. An increased global incidence of damage due to the mechanisms ECSCC (external chloride stress corrosion cracking), PWSCC (primary water stress corrosion cracking) and TGSCC (transgranular stress corrosion cracking), which were identified in the AMP fact sheets as not relevant for the KKM RPV, require detailed consideration. Here it is apparent that all the damage is associated with PWRs, which have a different design and are operated with a different water chemistry.

The following sources of external operating experience are available:

- Reports from the manufacturer GEH
- Reports from WANO (World Association of Nuclear Operators)
- Entries in the CODAP (Component Operational Experience, Degradation and Ageing Programme] database of the Nuclear Energy Agency
- IGALL database of the IAEA (International Generic Ageing Lessons Learned)

The reports are briefly analysed to determine whether they are relevant for KKM. If yes, the reports are evaluated in detail. The following results are possible: the message is informative for KKM or is relevant for design, connecting/joint technology, material selection, operating conditions or special, premature ageing. The following actions can result: increase in the testing effort (method, shorter intervals), adaptation of the in-service inspection programme and the relevant test instructions, repair, replacement of a component, possibly associated with design improvements, material replacement.

5.1.3 Monitoring, testing, sampling and inspection activities for the RPV

Maintenance programmes, repair and service

No special maintenance programmes exist for the RPV because, in general, its key components are not subject to any ageing or wear that would make periodic maintenance necessary over the planned operating period. The RPV maintenance programme essentially comprises the in-service inspection programme. If maintenance or repair becomes necessary as a result of the in-service inspection programme, this would be planned and implemented based on the findings.

General monitoring actions

- Temperature recordings
  To monitor the mode of control or temperature gradients, the RPV is equipped with thermocouples (see also guideline ENSI-B01 [2-8]).
- Irradiation specimens
  The analysis of the specimen sets for monitoring of RPV material embrittlement reveals no limitation of the service life of at least 60 operating years (54 years of full power operation). Based on the coverage of the analyses, no further evaluation of specimen sets is envisaged before the final shut-down.

In-service inspection programme

Repeat tests take place over the entire service life of the RPV. Essentially they include the following listed areas which, based on guideline ENSI-B07 [5-1], must be performed by qualified, volumetric and visual tests according to a defined in-service inspection programme.

- All accessible horizontal welds by ultrasonic testing
- All accessible vertical welds (there are no vertical welds in the cylindrical area of the RPV) by ultrasonic testing
- All accessible nozzles and safe-ends by ultrasonic and surface crack testing
- Visual inspection of all instrumentation nozzles for cracks
- RPV flange bolts by eddy current testing
- RPV flange threaded blind holes by eddy current testing
- Visual inspection of the nuts and washers
- Leak test on every restart
- Pressure tests
  Periodic pressure tests are required for the RPV. They are carried out according to the SVTI

specification NE-14 [2-19] or guideline ENSI-B06 [2-20] at the required 10-year intervals. No further pressure test is necessary before 2019 because of the final ending of power operation.
- Visual inspections during leak and pressure tests

The requirements for qualification of the testing systems used are specified in guideline ENSI-B07 [5-1].

Reportable indications required more detailed clarification as to whether they are permissible or whether the component concerned must be repaired to ensure structural integrity is maintained. If the findings have suddenly worsened and exhibit unforeseeable accelerated ageing, an increase in inspection intensity can be initiated and/or the intervals between inspections shortened down to a minimum of one year. Where possible other test methods are used so that the identified wear can be more precisely estimated. If testing activity is to be expanded or the frequency increased as a long-term measure, the corresponding in-service inspection programme will be adjusted. The necessity to modify the in-service inspection programme has not arisen for the KKM RPV.

The following list indicates the components which in combination define the testing scope in accordance with the in-service inspection programme:

Component group	Type of material	Relevant ageing mechanism	Testing method
Cylindrical part of the pressure vessel			
Base metal in the irradiated area	Low alloy steel	Embrittlement due to neutron irradiation	UT (approx. 50 mm on either side of the weld)
Cladding	Austenitic steel	Intergranular corrosion Thermal embrittlement of welds Embrittlement due to neutron irradiation (in the irradiated area)	VT (IVVI)
RPV circumferential welds in the irradiated area	Low alloy steel	Embrittlement due to neutron irradiation	UT
Flange bolts, nuts, tapped blind holes	Low alloy steel	Fatigue as a result of operating transients	ET / VT
Feedwater nozzles	Low alloy steel	Fatigue as a result of operating transients	SKB
Welds of safe ends at the feedwater nozzles	Mixed metal welds of low alloy and austenitic steels	Stress corrosion cracking Fatigue as a result of operating transients	UT
Welds of safe ends and thermal sleeves on various nozzles	Mixed metal welds of low alloy and austenitic steels	Intergranular corrosion Partially stress corrosion cracking Partially thermal embrittlement of welds	SKB UT / ET PT
Internal attachments	Austenitic steel	Intergranular corrosion Stress corrosion cracking Partially fatigue as a result of operating transients	VT / IVVI
Internal attachments	Low alloy steel	Stress corrosion cracking	VT / IVVI
RPV head and bottom head			
N10 nozzle with local weld	Austenitic steel	Intergranular corrosion Thermal embrittlement of welds	VT
Welds on bottom penetrations of the control rod drive housings and neutron flux monitors	Austenitic steel	Intergranular corrosion Stress corrosion cracking Thermal embrittlement of welds	SKB (outer) VT / IVVI UT / ET

Assignment of the relevant damage mechanisms and their testing to the age monitored component groups dependent on their material type.

SKB	System and component walkdowns	VT	Visual Testing
IVVI	In Vessel Visual Inspection	ET	Eddy Current Testing
PT	Penetrant Testing	UT	Ultrasonic Testing

Time-dependent aspects

Alongside the in-service inspection programmes, there are the programmes for monitoring the time-dependent ageing mechanisms fatigue and embrittlement:

- Fatigue monitoring of the primary circuit
- RPV irradiation samples programme

RPV fatigue monitoring is necessary where significant temperature differences can occur cyclically and because constrained heat expansion can result in cyclic stresses in component areas (generally near to nozzles). The fatigue monitoring of the primary circuit includes 30 positions on the RPV, where, based on count lists of defining transients (in particular start-up/shut-down, scram) or based on the evaluation of continuous temperature measurements of the respective contribution of the transients to the overall fatigue level of components, periodic investigations are performed. The overall fatigue level for all monitored positions is, based on extrapolation up to the final cessation of power operation at the end of 2019, less than 55%, where the highest values occur at positions that are very conservatively evaluated. Here, based on refined analyses and actual temperature measurements, the very conservatively assessed usage factors could be reduced considerably. Nevertheless, because of the remaining short operating period of the RPV, such measures are not required.

The most important damage mechanism from the point of view of the service life and safety of light water reactors is neutron embrittlement of the pressure bearing wall and its welds in the area close to the core. To enable monitoring of the RPV, irradiation samples of the relevant materials were inserted during construction so that they could subsequently be removed and tested for embrittlement. These samples were exposed to a higher neutron flux and hence a higher fluence than the RPV wall material, because they were positioned closer to the core. The results of the evaluation of the three sets of prematurely aged samples show that the RPV could be operated beyond 2035 (corresponding to 54 full power years). At a time when it was assumed that KKM would have a long-term operation of at least 50 years, a device for holding the fourth set of irradiation samples was installed in the RPV in 2004.

As a result of the decision to finally shut down the KKM in 2019, and because of the already adequate coverage of the existing analyses from the first three sample sets, no further evaluation of the irradiation samples is planned.

Although for BWRs, the fluences are relatively low, in KKM one automatic weld with increased copper content is subject to special consideration, even though it experiences lower neutron radiation than other welds. Even at a moderate fluence, the increased copper content causes a significant shift in the ductile to brittle transition temperature. However, based on the uncritical results obtained from the extrapolation beyond 60 operating years, no further evaluation is planned before the final shutdown even for this weld with its elevated copper content.

Commissioning	1972	-	-
Removal capsule I	1978	6 calendar years after commissioning	Evidence for 18 years
Removal capsule II	1986	14 calendar years after commissioning	Evidence for 39 years
Removal capsule III	1999	27 calendar years after commissioning	Evidence for 78 years

Further activities for condition monitoring of the RPV

The following actions provide additional help in the timely detection of any degradation:

- Water-chemistry monitoring: changes in the chemical parameters can indicate unexpected degradation or operating conditions that could accelerate the degradation
- Discussions, as part of the daily operating meetings, of any anomalies in respect of the monitored operating parameters
- Sump level monitoring in the drywell below the RPV
- Temperature, moisture and pressure monitoring in the drywell
- Leakage monitoring of the double head flange seal

5.1.4 Preventive and remedial actions for the RPV

- RPV head bolt replacement:
  In 1995 and 1996, the RPV head bolts were replaced. An optimised thread geometry and rolled instead of cut threads were used to minimise the fatigue influences.
- Blind flange N9 nozzle:
  With the CRD system modification that took place in the 2004 annual overhaul, the injection of cold water through the CRD return line was stopped and consequently the main contributor to material fatigue at the associated RPV nozzles was eliminated. During the 2006 outage, the associated nozzle of the CRD return line was repaired. In the course of this work, the thermal protection sleeve and the feed line were removed and the nozzle was provided with a closure cap.
- Water chemistry:
  For primary protection of the reactor internals against stress corrosion cracking, hydrogen water chemistry control (HWC) has been implemented in the primary circuit since 2000. Since 2005 this has been replaced by the OLNC™ (OnLine Noble Chem) process. Here, in addition to the continuous injection of hydrogen, the targeted addition of the precious metal, platinum, also takes place over long time periods during an operating cycle. Finely distributed platinum deposits within the RPV have a catalytic effect, which increases the effectiveness of the addition of hydrogen in inhibiting the corrosion mechanisms. This not only has a positive effect on the reactor internals, but also on the cladding and inner welds of the RPV.
  KKM works closely with EPRI and PSI (NORA projects I to III) on the optimisation of water chemistry.
- Temperature monitoring
  To monitor the temperature differences responsible for the generation of stresses during transient operations, a number of areas (e.g. the head flange) of the RPV are inspected in respect of their temperature. Already in the mid-1980s, three of the four feedwater nozzles were equipped with a range of thermocouples to detect thermal fatigue. The diagnostics resulted in design modifications to the nozzles using double 'thermosleeves' in 1997. Additionally, temperature sensors of an improved design have been installed in the RPV bottom area since 1996. The RPV will continue to be monitored with temperature sensors. Measured values have been recorded every second since 2008.

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

The good condition of the reactor pressure vessel is ensured thanks to established, preventive in-service inspections within the scope of the maintenance programme as well as the implemented monitoring of fatigue and embrittlement. In addition, the optimised water chemistry is effective in inhibiting stress corrosion cracking of the cladding and the inner welds. This is confirmed by the results of the performed in-service inspections.

The latest results of the RPV embrittlement and fatigue monitoring as well as the general evaluation of the AMP confirm that the implemented measures are worthwhile and that sufficient safety margins exist up until the final shutdown at the end of 2019.

6 Calandria / pressure tubes (CANDU)

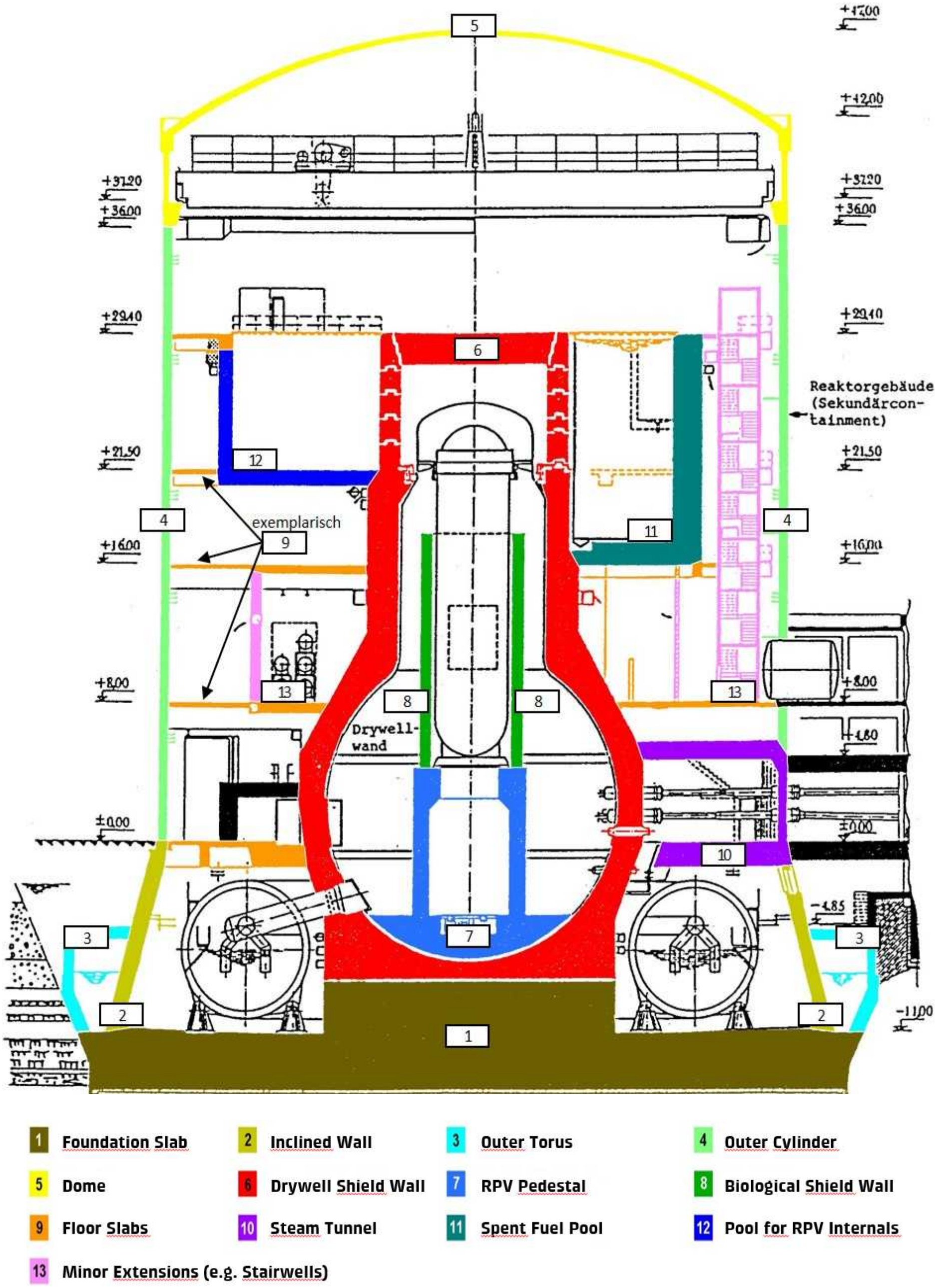
The subject of pressure tubes in CANDU reactors is not relevant for Swiss reactors and therefore requires no further elaboration (see [1-1]).

7 Concrete containment structures

7.1 Description of ageing management programmes for concrete containment structures (outer building shell - secondary containment)

7.1.1 Scope of ageing management for concrete containment structures

The following figure shows all the building structures of the KKM reactor building highlighted in colour.



While it can generally be said that one fact sheet was created per building for all other KKM buildings, because of its importance for nuclear safety, the reactor building (RB) has been subdivided into 13 components, with a fact sheet being created for each of them.

An extra fact sheet 'General RB' covers the points that apply to the whole building.

The KKM primary containment corresponds to the GE Mark I design, comprising a drywell and the torus (wetwell). The drywell and torus comprise a self-supporting steel structure and will not be considered further. The lowest part of the drywell is embedded in concrete. Here, the concrete acts as protection and also absorbs the loads. This area is part of the 'foundation slab' component.

Within the scope of TPR2017, the foundation slab, inclined wall, outer torus, outer cylinder and dome form the secondary containment and enclose the primary containment.

The civil engineering AMP ensures that the components are operational and fulfil the specified requirements at all times. In addition, the characteristic values of the building materials used must be checked. Knowledge of the design is required to focus the inspection on the correct points.

Therefore, the most important functional requirements of the components, building materials and construction techniques are listed below.

Component requirements

Foundation slab requirements

- Bearing of the building load (inclined wall, drywell foundation), torus and system components in accordance with the load plan
- Transfer these loads to the foundation soil
- Resistance against external water pressure (up to + 8.00 m)
- Sealing against groundwater
- Air tightness (slight internal vacuum during operation)
- Resistance against internal excess pressure of 35 kPa (0.35 bar) in the event of an accident
- Retaining radioactive materials

Inclined wall

- Bearing of the loads of the outer cylinder and the head +/- 0.00 m
- Bearing supporting forces of fastenings
- Transfer of these loads to the foundation slab
- Resistance against external water pressure (up to + 8.00 m)
- Sealing against groundwater
- Air tightness (slight internal vacuum during operation)
- Resistance against internal excess pressure of 35 kPa (0.35 bar) in the event of an accident
- Retaining radioactive materials
- Resistance against external pressures (earth + water)

Outer torus

- Water-tightness against both internal and external effects
- Resistance against external pressures
  (earth pressure, superimposed load + water up to + 8.00 m)

Outer cylinder

- Bearing of the loads of the dome and the floors
- Bearing supporting forces of the fastenings
- Transfer of these loads to the inclined wall
- Air tightness (slight internal vacuum under operation)

- Resistance against internal excess pressure of 35 kPa (0.35 bar) in the event of an accident
- Retaining radioactive materials
- Weather protection
- Penetration protection

Dome

- Air tightness (slight internal vacuum under operation)
- resistance against internal excess pressure of 35 kPa (0.35 bar) in the event of an accident
- Retaining radioactive materials
- Weather protection

Construction materials

During the construction of KKM, concrete complying with the standard of the time SIA 162/1956 or 1968 was used almost throughout. This required a cube compressive strength after 28 days of 35 N/mm2. According to the concrete compressive strength tests carried out at the time of construction, this condition was satisfied and the values achieved were partially significantly higher, i.e. around 45 N/mm2.

The reinforcement was construction steel complying with the requirements of standard SIA 162/1956 or SIA162/1968. Carbon steel and Roll-S steel from the Von Roll AG, Gerlafingen Plant in Switzerland were used exclusively. With a few minor differences, the steel corresponds to the current reinforcement steel, B500B.

There are no pre-stressed concrete components in the RB.

Nearly all inner component surfaces are coated. However, the coating is present for operational reasons (ease of decontamination) and has no function as a protective system for the functioning of the components.

Below -0.50 m, the building is provided with a groundwater seal on its outer surface (several layers of bituminous membranes) and a protective sump. The groundwater level is at a depth of about 4.00 m.

Construction

Foundation slab

The foundation slab comprises of strongly reinforced concrete and is 3.00 m thick throughout. Below the drywell it forms a 7.70 to 9.80 m thick component in conjunction with the drywell foundation. For concreting, the foundation slab was subdivided into 3 overlapping height stages and surface sectors of about 150 m2.

Inclined wall

In its lower part, the reinforced concrete inclined wall forms the inside wall of the outer torus, above it, the building outer wall against the ground. In the area in contact with the ground, it is sealed against groundwater while in the outer torus it is provided with a coating. Overflow pipes are positioned every 7.5° in the inclined wall (that is a total of 48 pipes), which lead through a water trap of the RB into the outer torus.

Outer torus

The outer torus is a reinforced concrete structure which is attached to the inclined wall and covered in earth. The bottom part of the outer wall is inclined at 25° to the outside. Pre-fabricated concrete elements were used for the ceiling boarding.

Outer cylinder

The outer cylinder is a cylindrical reinforced concrete structure made of site concrete. During construction, a specially developed climbing formwork was used. The concrete was poured in steps of 2 m height and sectors of 45°.

To ensure air-tightness, a corrugated sheet was inserted in the horizontal joints and a waterstop embedded in the vertical joints.

Dome

The reinforced concrete dome was fabricated from site concrete using an empty framework without countering formwork. The dome is designed as a pressure shell (Isler shell). The reinforcement is designed to absorb the loading conditions arising from internal pressure and temperature differences. The foot ring is formed as a tensile ring with untensioned reinforcement.

The dome and foot ring area were externally insulated in 1989 to reduce temperature variations and additionally sealed with a plastic film to provide a water isolating layer.

7.1.2 Ageing assessment of concrete containment structures

Based on the operating conditions known from the long operating period, the building materials used and the design, the component-specific ageing mechanisms were selected from the comprehensive catalogue in the guide and listed in a component-specific manner in the fact sheets.

Based on the design, the following ageing mechanisms are of greatest importance:

Effect	**Mechanism**	**Consequences**
Reinforced concrete		
Temperature changes	Expansion, contraction, constraint stresses	Opening and closing of cracks, local overstraining
Humidity, water	Initiation of chemical processes	Chemical changes
Swelling	Cracking due to limited deformation	Cracks, deformation
Load, static	Creep, promotion of cracking	Cracks, deformation
Carbon dioxide	Carbonation	No damage to concrete. Reinforcement corrosion when this is 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 cross-section reduction
Contact corrosion	Formation of electro-chemical elements	The less noble metal is dissolved

Depending on the significance for nuclear safety, assignment criteria for the condition levels [2-3] and shut-down criteria [2-17], target condition levels were defined in each fact sheet for all components.

Current condition levels were always found to be the same or better than specified condition levels. For all fact sheets it was found that the component is of a good material quality and 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 materials was additionally described in each fact sheet and findings recorded in a findings list.

Most recorded findings relate to small localised damage areas that have no effect on the integrity of the component. Many findings were repaired within the framework of the ongoing maintenance programme and were marked as completed. Others could be classified as unimportant so that no actions were necessary.

New findings in respect of ageing mechanisms were discussed in the GSKL AMP civil engineering group and evaluated in respect of the consideration they were to be given in the ageing management. Participation in courses and seminars ensures that knowledge of the latest state of the art is kept up to date.

No new significant findings are available for the secondary containment assessment.

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

A civil engineering inspection of the dome was carried out in 1987, prior to the start of the official civil engineering AMP.

The baseline inspection in accordance with the AMP was performed for all components in 1994. Thereafter, an intermediate inspection was performed every 5 years (1999, 2008) and a main inspection every 10 years (2003, 2013).

The main activity in the inspections is a full visual inspection of the civil engineering structures. Indirect evidence is evaluated for inaccessible components. If for example a wall in the ground is within the groundwater depth but remains dry on the inside or in a trial bore, it can be assumed that the groundwater sealing is intact.

To assess the concrete quality, bore cores were taken and examined in respect of compressive strength, microstructure, density and leak-tightness. Here, it was often possible to rely on interventions in the concrete structure when modification projects took place, so that it was not often necessary to create many bores solely for the purposes of AMP. More recently, the drilled core samples were further reduced because a good concrete quality has been consistently demonstrated with strengths well beyond the required values.

The average concrete strengths are approximately twice the value required for the new-built structures.

Swelling and temperature changes can result in cracking in reinforced concrete. In the construction type under consideration here with untensioned reinforced concrete, the presence of cracks with limited crack width is normal. The mapping and assessment of the cracks is an important part of the inspection activity.

In the RB 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 a number of sites in KKM using fixed installed permanent crack measurement systems. The regularly logged data show that the crack widths change according to an annual cycle (average annual hydrograph) but that the crack widths, viewed over a long period, remain the same, keeping within narrow tolerances and are therefore acceptable.

The carbonation leads to a layer of dense, but no longer alkaline concrete on all unprotected concrete surfaces. To demonstrate the corrosion resistance of the reinforcement, a further important part of the inspections is to determine the carbonation depth and the effective reinforcement covering present.

Inspection walkdowns are performed by KKM employees together with employees from the certified building inspection companies. The technical installations for the crack and moisture measurements are the responsibility of these companies, who also carry out all building material tests, primarily concrete investigations, in their certified testing laboratories.

Corresponding inspection and test reports are available for all activities.

7.1.4 Preventive and remedial actions for concrete containment structures

Even before the introduction of the AMP, cracks were found in the area of the foot ring of the dome which threatened the leak-tightness of the containment. Thanks 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 fitness for purpose 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 protective system fitted in 1989 has proven effective to date.

On the outer cylinder it was found that at various areas the carbonation depth reached the level of the reinforcement before the end of the desired service life 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 remains effective even today. In 2000 in KKM, long-term operation was still the target. Had it been known that final shut-down would occur in 2019, it would have been possible to forego this measure.

On the inclined wall, damp areas were detected with local efflorescence at the height of the water filling of the outer torus. After renewing the coating in the outer torus in 1991, no more damp areas could be detected.

In the interior, practically all coatings were replaced. They were maintained 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 and their condition recorded.

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

Even before the introduction of AMP in its currently valid scope, deviations were detected and the necessary measures implemented at an early stage in KKM.

With the introduction of the AMP, systematic monitoring of the civil engineering 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 AMP civil engineering expert team of the Swiss Nuclear Power Plant Licensees (GSKL) is valuable. The jointly-prepared guide for civil engineering fact sheets [2-3] has proven to be successful and the uniform basis for the AMP simplifies the exchange of experience.

The flow back 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 GSKL guide [2-3] with the associated increase in awareness in the subsequent inspections. In accordance with the analyses of the additives from the Swiss plateau (Mittelland), no damage resulting from the effects of these refining processes is to be expected. In KKM, no indication of this has been identified until now.

The results of trend monitoring in the inspection reports show that the preventive actions were constructive and the specified target condition levels have been adhered to.

The AMP of the reactor building concrete structures has been shown to be successful and it ensures that the load bearing capacity and the fitness for purpose of the building are ensured at all times.

8 Pre-stressed concrete pressure vessels (AGR)

The subject of pre-stressed concrete pressure vessels is not relevant for Swiss reactors and therefore requires no further elaboration (see [1-1]).

9 Overall assessment and general conclusions

Within the scope of the Topical Peer Review 2017 on ageing management in nuclear facilities, the current status in respect of the following key points for Mühleberg Nuclear Power Plant (KKM) have been presented in this report:

- Requirements on the overall AMP and its implementation
- Electrical cables
- Concealed pipework
- Reactor pressure vessel
- Concrete containment structures

The overall AMP has been developed over the last thirty years in all the main areas in cooperation with the other Swiss plants by the GSKL AMP Working Group under ENSI supervision. This way, it was ensured that the requirements of the national regulatory framework and international (in particular standards specified by the IAEA and WENRA) standards were considered. These include the scope of consideration and the methods involved in ageing management, preventive measures and maintenance, the implementation, testing and updating of the corresponding process content in the KKM management system, as well as the operating experience with the processes applied as part of ageing management.

For the four example areas drawn from electrical, civil and mechanical engineering ageing management that are relevant for KKM, the above-named aspects were presented in depth and the actual implementation was described. Two other systems and structures (pressure tubes and pre-stressed concrete pressure vessels) monitored within the context of the overall TPR 2017 are not present in KKM and were therefore not considered.

Overall, it can be stated that the implementation of the AMP in KKM meets very high international standards and in this respect no known procedural omissions or defects have been found for all considered aspects.

10 References

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