Ulrich WILKE, Reinhard KORING, EON (Germany)
Ageing Management in German Nuclear Power Plants

Ulrich Wilke, Reinhard Koring, E.ON Kernkraft, Germany

Abstract

Ageing management (AM) programmes have been launched in many countries. In the USA ageing management activities were initiated to demonstrate the long term integrity of nuclear power plants for plant life extension purposes. Also in other countries e.g. Switzerland AM programmes became an important issue. In addition, the International Atomic Energy Agency (IAEA) has published recommendations concerning the physical ageing of safety relevant systems. As a consequence of these international developments, the ageing management aspect was introduced to Germany, too, although plant life extension is definitely not the key subject in the German nuclear industry, today. The situation in Germany concerning long term integrity of safety relevant NPP-systems and components is determined by the requirements stated in regulations and codes. They contain basic requirements for continuous precaution measures according to the current state-of-the-art starting already with the plant commissioning. This included demands for redundant safety and for surveillance measures. A continuous adjustment related to the requirements of the respective state-of-the-art is provided by the German utilities and submitted to the responsible safety authority to demonstrate an appropriate integrity status of the safety relevant systems.

In Germany, no specific programme named ageing management exists. The measures concerning long term integrity of safety relevant components are performed under different names. Nevertheless, the German utilities understand that the subject “Ageing Management” is comprehensively covered by the entirety of the different precaution and maintenance measures and regulations already established. This paper presents the existing German utility integrity concept and its sound application to ageing management issues.

Introduction

Ageing in nuclear power plants (NPP) can be defined as the time dependent quality change of technical, personal and administrative issues. Ageing management (AM) is the quantitative evaluation of the ageing facts correlated to the established requirements to cover the protection against conceptual, technological and physical ageing phenomena.

Conceptual ageing is dealing with changes in the plant design philosophy. In technological ageing relevant changes in the state-of-the-art are considered. The physical/material ageing comprises the operational ageing mechanisms.

The international development of ageing management activities was derived for various reasons. About 20 years ago AM studies for nuclear power plants were initiated in the USA.
The decisive motive for starting the ageing management activities was the specific nuclear power plant situation in the USA. The operational licence of nuclear power plants in the US was limited to a certain time period and the activities to fulfil the premises for plant operation extension beyond this time limit were summarized under the conception of an ageing management programme. Such AM programs were also launched in other countries, e.g. Switzerland, to demonstrate the long-term integrity of the plant and to obtain safety approval for plant life extension, Fig. 1.

![Figure 1: International development in ageing management](image)

The International Atomic Energy Agency (IAEA) is involved in ageing management programmes since 1988 and has published recommendations [1] concerning the physical ageing of safety relevant systems (the Class I-components must be covered completely) for

- mechanical components,
- instrumentation and control components (I&C),
- containment building.

As a consequence of these international developments, the ageing management aspect was also introduced to Germany, although plant life extension is definitely not the key subject in the German nuclear industry, today.
In 1997 a VGB-report was provided by the German utilities containing a comprehensive listing of potential ageing phenomena and showing the technical and administrative handling of these ageing effects [2]. The conclusion of the utilities in this report was, that the ageing phenomena are controlled by the entirety of numerous measures already taken, although no specific ageing management programme has existed.

Due to the fact, that divergent interpretations existed how to handle the technical contents of AM and how to execute the administrative issues the conclusion was drawn that a harmonised understanding and handling is required for German AM activities considering the international practice.

The Gesellschaft für Reaktorsicherheit (GRS) finalized in 2003 the research program SR 2423 [3] with the objective to support the federal nuclear regulators in the definition of requirements for the ageing management of NPPs. In 2004 the Reactor Safety Commission (RSK) published recommendations on the governing of ageing processes in German NPPs. The RSK recommendation addresses technical and non-technical ageing management features [4].

In parallel, the German utilities have installed a VGB-Working Group to clarify the German utilities ageing management approach in order to demonstrate that an ageing management concept already exists and its application by the German utilities is sound. Various presentations on this topic have been published by the utilities nationally and internationally [5], [6]. The following chapters describe the German utilities ageing management concept elements

- requirements established in the German regulations and codes / standards,
- NPP safety relevance, NPP availability concerns,
- safety relevant systems to be considered,
- component ranking concerning safety significance,
- explanation of AM concept elements,
- examples for AM concept application and

the relevant criteria to be considered followed by an application example for the preventive maintenance of mechanical systems.

**AM requirements in German safety regulation and codes**

For the operation of German NPPs requirements for continuous precaution measures according to the state-of-the-art are stated in the following regulations:

- German Atomic Law,
- German Safety Criteria for NPPs,
- Reactor Safety Commission (RSK) guidelines and the German basic safety concept for fabrication and design,
- RSK recommendations and GRS generic letters,
- Plant specific requirements imposed by the responsible safety authority.
These regulations including demands for surveillance and redundant safety measures concerning the integrity of safety relevant systems have been considered from the beginning of the plant commissioning. The practical implementation of these requirements is accomplished in codes and standards or plants specific regulations. For instance for mechanical Class I components of the primary circuit the rules assembled in Tab. 1 apply [7-10].

**Table 1: KTA 3201 standard for mechanical class I components in the primary circuit [7-10]**

<table>
<thead>
<tr>
<th>Standard</th>
<th>Part</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>KTA 3201.1</td>
<td>Part 1: Materials and Product Forms</td>
<td>design</td>
</tr>
<tr>
<td>KTA 3201.2</td>
<td>Part 2: Design and Analysis</td>
<td>design and operation</td>
</tr>
<tr>
<td>KTA 3201.3</td>
<td>Part 3: Manufacture</td>
<td>design</td>
</tr>
<tr>
<td>KTA 3201.4</td>
<td>Part 4: Inservice Inspections and Operational Monitoring</td>
<td>operation</td>
</tr>
</tbody>
</table>

These rules are comparable with the American ASME code Section III for design and ASME Section XI for operation [11, 12]. For ageing management issues the basic criteria from KTA 3201.4 and ASME XI can be applied for mechanical components and adjusted also for instrumentation and control components as well as for the reactor building.

The KTA 3201.4, released in June 1999, [10] contains an overall concept for safeguarding of component integrity during plant operation, **Fig. 2**. The basic idea of this concept is to demonstrate the quality status of the component.

The first step is to demonstrate that the currently existing component/system quality status meets the current quality requirements. This current component quality status is determined by the originally established basic component/system quality by design and manufacturing. Degradation mechanisms from the past plant operation may have had an impact on this basic component quality as well as relevant general changes in the state-of-the-art.

The second step focuses on the safeguarding of the quality requirements during the future operation of the plant using proactive and reactive measures. Proactive measures are applied by means of the monitoring of root causes of potential operational degradation mechanisms, e.g. operational loadings, water chemistry. The reactive surveillance of consequences of potential operational degradation mechanisms deals with degradation effects after they have had occurred and been detected, e.g. by non-destructing testing (NDT) measures.
Figure 2: Mechanical components Group M1, integrity concept, KTA 3201.4 [10]
These both basic criteria may be summarized as follows:

1. determination of actual component quality and
2. safeguarding of component quality during plant operation.

This procedure can be applied for all general and specific ageing management approaches by the following steps:

- Definition of safety/availability relevant systems/components (mechanical components, I&C components; building)
- Determination of the currently existing system/component quality status and related safeguarding measures:
  - Was the quality originally provided by design and application affected by any relevant effects during the operation so far?
  - Are the root causes of operational degradation mechanisms known from operational monitoring?
  - Have resulting impacts of the component integrity been evaluated and conclusion been drawn?
  - Are redundant inservice inspection (ISI)/surveillance-measures of potential consequences of operational degradation mechanisms still appropriate?
  - Have relevant changes of the state-of-the-art been considered?

In addition to the handling of the technical issues, administrative procedures have to be established for transparent documentation and delivery of results.

**German utility management approach**

In general, ageing in NPPs is governed by the time-dependent change of characteristic properties of the technique, personnel, plant specific regulation, documentation and data processing systems. According to the requirements stated in German safety regulations and codes, the German utility ageing management approach may be separated into the

- lifetime management,
- ageing management and
- long-term integrity assessment.

In addition to the ageing management for safety relevant systems and components the German utilities provide a lifetime management for those availability relevant systems and components which are in the liability of the utility only, **Fig. 3**. The lifetime management measures usually correspond to the ageing management measures for safety relevant components, e.g. for valves which are installed in the same quality in safety and availability relevant systems. Due to the lifetime management an additional comprehensive base of knowledge on ageing phenomena is available.
Basically, the handling of ageing phenomena can be divided into

- the technical and administrative ageing management of safety relevant systems/components and of safety relevant actions, e.g. PSA-Probabilistic Safety Analysis, which is supervised by the responsible safety authority and
- the technical and administrative lifetime management of the remaining system/components and of quality assurance actions and maintenance activities to be performed mainly on the utilities responsibility.

According to the international scope and the RSK recommendation [4], ageing management for safety relevant systems can be focused on Class I-systems and systems required for safe plant shut down. Within the safety relevant systems the following safety categorization of components is introduced:

**Group 1: High safety relevance**

- **Surveillance of root cause and consequence of operational degradation mechanisms**
- “Guarantee” required component quality

Group 1 components are the reactor pressure vessel (RPV), systems with leak-before-break (LBB) requirements and other components classified in Group 1 due to specific safety or plant availability reasons.

**Group 2: Medium safety relevance**

- **Preventive maintenance**
- “Preserve” required component quality

Group 2 components are mainly redundant components as valves, pumps, I&C-components, the reactor building and other components with specific safety or availability requirements. For components existing redundantly, a single case failure is no safety problem as long as no common cause failure occurs.
Group 3: Low / none safety relevance
Failure oriented maintenance
“Replacement” of component after failure

Group 3 components are small components or redundant I&C-components. A single case failure is no safety problem as long as no common cause failure occurs.

The assignment of components to the Groups 1 - 3 is directly related to their safety relevance and the associated proactive and reactive measures to maintain the required quality status. Consequently, the ageing management approach varies according to the safety categorization of the components.

The proactive approach tries to avoid/minimise premature degradation effects. The reactive ageing management approach deals with degradation effects after they have occurred and been detected. Following the system qualification (safety relevant) and the component ranking (high, medium, lower safety significance) the ageing management starts with the evaluation of the current component/system quality status because degradation mechanisms from operation so far may have had an impact on the original component quality. Also the considering of relevant changes in the state-of-the-art may have an impact on the evaluation of the actual component quality status. With the proactive approach the surveillance and monitoring of root causes of potential operational degradation mechanisms in terms of actual loads is required. The result of the load monitoring shows whether the original design loads are still enveloping or if new loadings have occurred. In case of new loads plant operation procedures may be changed to avoid premature degradation effects due to these new loads. Based on loads actually occurring, integrity evaluations are performed in terms of stress and fatigue analyses to determine the actual integrity status of the component. Finally, the evaluation results may lead to additional surveillance measures: determination of stress/fatigue relevant locations, implementing additional monitoring, optimising ISI/NDE measures.

For Group 1 components with high safety requirements in addition to the precaution measures the redundant surveillance of consequences of potential operational degradation mechanisms is required, Fig. 2.

For Group 2 components, e.g. mechanical components, with medium safety relevance the reactive approach is appropriate, Fig. 4. As the first step the current component quality status has to be determined considering the original design and the impacts from plant operation so far and from potential changes in the state-of-the-art. For redundant components, e.g. valves, the failure of a single component is not a safety problem as long as no common root cause for the failure occurs. Safeguarding measures can than be limited to reactive surveillance of consequences of potential operation degradation mechanisms which have already occurred and which have been detected.
This approach is covered by the common preventive maintenance measures performed in nuclear power plants, e.g. for valves. Maintenance is performed either as visual inspection, maintenance issues, repair or replacement. Whereas these measures applied are either time-orientated or based on the actual component condition. Time-orientated maintenance means that the corresponding components, e.g. valves, will be inspected in fixed time intervals, e.g. four years or eight years according to the safety classification. If the maintenance is based on the existing component condition the time period for inspections will be chosen individually. It is known from experience that maintenance activities performed too frequently may lead to additional ageing effects.

For Group 3 components, e.g. mechanical components, with lower safety relevance the reactive ageing management is sufficient based on the original component/system quality established by design and manufacturing. Potential degradation effects due to the past plant operation may be controlled by inspection measures. Impacts of relevant changes in state of the art may help to modify the inspection measures. Due to the fact that a Group 3 component failure is not safety relevant the ageing management may be performed by replacement strategies. If for specific safety or for plant availability reasons the component failure may not be acceptable an upgrade from Group 3 into Group 2 with defined inspection measures is necessary.
The assignment of components to Groups M1-3, E2.1-E2.2, C2.1-C2.2 in the technical faculties is carried out by means of the plant specific documentation:

- Mechanical engineering:
  
  \[
  \begin{align*}
  &M1 \quad \text{e.g. fatigue manual}, \\
  &M2 \quad \text{e.g. operation manual for preventive maintenance}, \\
  &M3 \quad \text{e.g. operation manual for failure oriented maintenance},
  \end{align*}
  \]

- Instrumentation and control engineering:
  
  \[
  \begin{align*}
  &I2.1 \quad \text{Components with required functionality in an accident}, \\
  &I2.2 \quad \text{Components without a required functionality in an accident},
  \end{align*}
  \]

- Civil engineering:
  
  \[
  \begin{align*}
  &C2.1 \quad \text{Structures according to KTA 2201.1 (earthquake requirements)} [13], \\
  &C2.2 \quad \text{Remaining structures}.
  \end{align*}
  \]

An overview of the safety categorization of systems and components in groups for the individual technical fields is presented in Tab. 2.

<table>
<thead>
<tr>
<th>Technical field</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical engineering</td>
<td>M1</td>
<td>M2</td>
<td>M3</td>
</tr>
<tr>
<td>Electrical and instrumentation</td>
<td></td>
<td>I2.1 / I2.2</td>
<td></td>
</tr>
<tr>
<td>control engineering</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Civil engineering</td>
<td></td>
<td>C2.1 / C2.2</td>
<td>-</td>
</tr>
</tbody>
</table>

In general, in Group 1 only components of the mechanical engineering are present. These are for instance components and systems of the primary circuit, systems which are mandatory for the shut-down, leak-before-break system, systems for the residual heat removal and systems of the reactor protection. In Group 2 for all technical fields valves, pumps, auxiliary equipment, I&C systems and the buildings e.g. containment or cooling tower are assigned. In a typical pressure water reactor (PWR) approximately 18.000 valves are installed. From these approximately 3.400 valves are included in the Group M2 maintenance concept, whereas approximately 380 are safety relevant. In Group 3 all remaining systems and components are categorized for which a failure is not safety relevant and, thus, a replacement may take place.

Preventive maintenance for mechanical Group2 components

In a NPP approximately 380 safety relevant valves are represented in the mechanical Group M2. The main requirements on these components are the safety and the operational availability during the entire lifetime of the plant. In order to fulfill these requirements a corresponding concept has been developed consisting of the two basic elements
• analysis and 
• evaluation of the construction
accompanied by a enveloping maintenance concept. These measures also lead to an
appropriate ageing management of these components, Fig. 5.

![Diagram of Operability and Operability](image)

**Figure 5: Preventive maintenance**

The basic operability will be assured by a proof analysis and an evaluation of constructive
features by means of the definition of the nominal conditions to provide the operational
availability. During the operation of the plant the operability has to be ensured by a covering
maintenance concept to keep or to recover the nominal condition and the functionality.

Safety relevant valves are completely maintained preventively. The corresponding
maintenance periods are fixed within a maintenance concept or by check lists which are part
of the operational plant manual. The detailed amount of the maintenance measures is
described in individual valve-type specific procedures for the periodic inspections based on
the requirements and recommendations of the manufacturer including measures as e.g.
• complete dismantling,
• special aspects of visual inspection,
• measuring of functional geometrical dimensions,
• non-destructural examination of seat surfaces or
• reassembly and
and the operational experience.
The maintenance procedures are attended by secondary technical instructions e.g. for the
installation of packings, supervision of bolts torques etc ensuring the definite nominal
condition after reassembly.
The maintenance results will be reported and documented. In this way all predictable aspects of mechanical wear and other influences of e.g. the liquid media as well as the service life of sealings is controlled.

Therefore, the intensity of the practiced preventive maintenance in German NPP leads to the reliable identification of failures mechanisms and new ageing effects. The maintenance results are evaluated and if required modifications of the maintenance procedures are initiated immediately including the secondary technical instructions if affected.

A further important element to demonstrate the operational availability is the check of the functionality by periodic testing which may be carried out during the maintenance or the operation. Functional testing and/or free movement testing supports the preventive maintenance as such testings recur within short periods (monthly – yearly). The recurring testings are monitored by means of diagnostic systems which allow the prediction of safety margins and is useful for trending of characteristic data.

The presented maintenance measures ensure an appropriate ageing management of mechanical Group 2 components with the ability to detect and reflect ageing effects if occurring.

**Documentation of ageing management activities**

All safety relevant long term integrity or ageing management activities are documented in reports etc. Although there is no specific ageing management documentation fixed in Germany, there are numerous reports being submitted to the safety authority demonstrating reliability of the ageing management actions even though being performed under different names:

- Monthly plant operation report,
- Annual plant operation report (including cycle counting for fatigue relevant components),
- Annual report about meeting the state-of-the-art requirements,
- Plant specific assessments concerning incidents from other plants,
- Plant specific periodic safety analysis,
- etc.

The current activities of the German utilities focus on the optimization of the description of the measures in a so-called plant specific basic report on ageing management and on the data acquisition. This basic report covers the technical as well as the non-technical aspects of ageing management. In addition, periodic status reports are being prepared showing if new ageing effects have been occurred and what remedial actions have been taken, **Figs. 6 and 7.**
Base Report „Ageing Management“

- Main features
- Requirements
- Overall concepts
- Implementation of measures
- Faculty related description

Periodic report

- Mechanics
- Instrumentation and control
- Structures
- Others
  e.g. non-technical

Figure 6: Example for the documentation structure of ageing management

- Operation management system
- Documentation systems
- Plant specific databases

Ageing management data acquisition

Figure 7: Ageing management data acquisition

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Ageing management in German nuclear power plants
Summary and conclusions

In this paper, the German utilities ageing management concept for NPPs has been presented. Due to safety regulation requirements ageing management activities have been performed since the plant commissioning. Although no specific program named ageing management exists, the German utilities understand that the relevant ageing mechanisms are technically and administratively covered by the entirety of measures already taken. Nevertheless, the German utilities intend to demonstrate how and where the ageing management actions have been carried out in terms of technical and administrative issues based on an overall ageing management concept.

Aspects of technological and conceptual ageing are long-term ageing mechanisms which are treated separately, e.g. in periodic safety reports. The essential issue in ageing management for the technical faculties mechanical engineering, I&C engineering and civil engineering is the physical ageing. For these the key measures in technical ageing management are the maintenance, the operational surveillance and the periodic testing for which distinct procedures exist in the NPP based on the present nuclear standards and regulations. For components with high safety relevance, proactive and reactive measures are applied in parallel, i.e. root causes and consequences of failure mechanisms are monitored, e.g. load determination for fatigue relevant components. For components with medium or low safety relevance reactive measures are initiated, i.e. preventive maintenance or failure oriented maintenance. All these measures are entirely described in the plant specific regulations for safety and/or availability reasons. The detailed application of ageing management is generally derived from the procedure provided by nuclear standard KTA 3201.4 for the components of the primary circuit and modified based on the safety relevance of the system or component. In this evaluation scheme the consideration of an updated state-of-the-art is already an integral part.

The current activities of the German utilities focus on the optimization of the description of the measures in a so-called plant specific base report on ageing management. This base report covers the technical as well as the non-technical aspects of ageing management. In addition, periodic status reports are being prepared showing if new ageing effects have been occurred and what remedial actions have been taken to demonstrate adequate lifetime and ageing management in a more systematic way. The presented approach in ageing management demonstrates a systematic procedure based on present regulations in German NPPs starting from the plant commissioning which also ensures a valuable return of experience.
References

[8] KTA 3201.2: Components of the Reactor Coolant Pressure Boundary of Light Water Reactor; Part 2: Design and Analysis. Rel. 6/96, Salzgitter, Germany
[10] KTA 3201.4: Components of the Reactor Coolant Pressure Boundary of Light Water Reactor; Part 4: Inservice Inspections and Operational Monitoring. Rel. 6/99, Salzgitter, Germany