ABSTRACT

Safe and reliable operation should be kept during the whole nuclear power plant (NPP) operation. Some of most important means are provided us for this purpose by so called “ageing management programmes” (AMP). Ageing could be considered broadly in principle as time change of service–related characteristics and properties of equipment (mechanical components, structures, electrical and I&C systems), the computer systems (hardware and software), plant specifications and documentation, staff abilities and knowledge and information level. In our paper we will concentrate on problems of NPP mechanical components ageing only. We shall try to describe basic features of research project which have been carried out in Slovakia recently with the aim to develop AMPs for main mechanical components of WWER 440 NPP primary and secondary circuit.

INTRODUCTION

The first stage of our project was concentrated on preparation of AMPs for selected NPP components. International Atomic Energy Agency (IAEA) methodology for the management of ageing of NPP components important to safety was applied for this purpose. The first step included the preliminary selection of safety related mechanical systems and components. After analysis of operational experience from relevant Slovak and foreign NPPs the narrowed component list was defined containing basic pipings, pressure vessels, pumps and valves of primary and secondary circuits. All available aging relevant data for selected components and systems were collected and summarized thoroughly again. The second step consists in the development of AMP proposals for all selected components, which mainly deal with : relevant ageing mechanisms identification, operational ageing risk evaluation, ageing mechanisms understanding and effects description, components critical locations, ageing effects prediction models analysis, replacement methods evaluation, ageing monitoring methods, ageing mitigation methods, AMP data collecting methods, AMP organisational and coordination measures. The structure and content of necessary NPP databases for AMP purpose were defined in this stage too.

The second stage of project consisted in elaboration of proposals of NPP guidelines dealing with initiation and effective application of developed AMPs. It means in fact solution of following practical issues - general AMP organisation measures (NPP AMP department, special NPP staff participation and coordination, special expert teams, external organisation participation, process control etc.), detail operational procedures and methods to ensure continuous and efficient activities in the frame of AMPs, AMP processes documentation, AMP databases and information streams, AMP feedback and effectivity evaluation tools.

PREPARATION OF AMPs

Selection of safety related mechanical componentes and systems (SSC)

Applied steps of AMP elaboration for Slovak NPP mechanical components were following:

1) Preliminary selection based on screening criteria was applied at first. Only safety-related SSCs and these ones which failure could affect NPP safety were chosen. SSCs with existing complex monitoring and maintenance program, short-term living and replaceable items were not included. Following systems were considered:
   - systems monitoring and controlling radioactivity and systems removing heat from the core
   - other systems directly involved in the safe operation of reactor systems ensuring safe NPP shutdown and keeping it in cold conditions
   - safety systems that are used to mitigate reactor accident
   - other systems potentially affecting safe NPP operation after their failure
   - other systems which replacement could be too difficult or too expensive or is not planned

Preliminary selection of parts of selected SSCs was based on similar criteria:
   - component failure could have significant influence on NPP safety and availability
   - component is safety substantial or necessary for safe cool shutdown and keeping in this status
   - component role is specific important regarding NPP operation licensing
component operation or environment conditions are substantially different from design conditions
component maintenance (or replacement) is too difficult or too expensive

2) Final selection of relevant components was based on detail analysis of operation experience, operation history analysis, reliability considerations, existing partial ageing management programs evaluation, economical criteria and regulatory body requirements analyses.

Selected SSCs, their parts and identified ageing mechanisms were:

Development of AMP proposals
AMP proposals were elaborated in two interconnected stages:

1) Analysis of selected SSCs.
   - thorough analysis of selected SCC’s operation conditions dealing with operation loading history, chemistry and environment control, history of maintenance, service inspections etc.
   - relevant ageing mechanisms identification on the basis of operational experience
   - understanding of acting ageing phenomena with respect to applied materials, mechanisms and degradation places
   - ageing risk and failure consequences evaluation in accordance with SCC operation
   - the assessment of predictive models availability and reliability for each possible ageing mechanism
   - ageing mitigation methods availability study concentrated on applicable methods of maintenance, repair, replacement etc.
   - possible ageing monitoring methods study dealing with diagnostics, tests, in service inspection, surveillance program etc.

2) AMP elaboration for selected SSCs according to Deming cycle (Understand-Plan-Do-Check-Act). The AMP is longterm, dynamic, systematic, feedback process working with and coordinating following components for each SSC (Fig.1):
   - equipment basic databasis (geometry, dimensions, material and material properties, design operational limits and conditions, identified ageing mechanisms, criteria definition for nonacceptable SSCs damage status, ageing consequences during normal operation and design basis accident)
   - SSC operation (operational conditions, existing operational measures to prevent ageing phenomena, operational parameters and loading history records including any unexpected transient or accident, corresponding period for data gathering and archiving)
   - monitoring programs (inservice inspections, diagnostics, function tests, special ageing monitoring, data gathering and archiving systems, failure and abnormal status records)
   - ageing mitigation methods (operational rules change, design change, material change, material properties recovery, operating parameters change etc., maintenance and repair data gathering and archiving)
   - all necessary input data gathering, archivation, processing and transfer
   - organization and co-ordination of activities within the AMP
# Table 1  Selected components

<table>
<thead>
<tr>
<th>SSC</th>
<th>Part</th>
<th>Relevant ageing mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor pressure vessel (RPV)</td>
<td>Weld and base metal near to core</td>
<td>Irradiation embrittlement</td>
</tr>
<tr>
<td></td>
<td>RPV closure head nozzles</td>
<td>Stress corrosion cracking (SCC)</td>
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<td></td>
<td>RPV closure head sealing surfaces</td>
<td>SCC, corrosion, wear</td>
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<td></td>
<td>Main coolant piping (MCP) nozzles</td>
<td>Fatigue</td>
</tr>
<tr>
<td>RPV inner components</td>
<td>Core barrel</td>
<td>Wear, intergranular SCC (IGSCC), irradiation accelerated SCC (IASCC), fatigue, irradiation embrittlement</td>
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<tr>
<td></td>
<td>Core basket</td>
<td></td>
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<td></td>
<td>Block of guide tubes</td>
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<tr>
<td>Main circulation pump</td>
<td>Pressure part</td>
<td>Fatigue</td>
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<tr>
<td></td>
<td>Wheel</td>
<td>Fatigue, cavitation</td>
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<tr>
<td></td>
<td>Flange sealing surfaces</td>
<td>Fatigue, corrosion, wear</td>
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<tr>
<td></td>
<td>Supports</td>
<td>Fatigue, corrosion</td>
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<tr>
<td>Main primary valve</td>
<td>Pressure part</td>
<td>Fatigue</td>
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<tr>
<td></td>
<td>Flange sealing surfaces</td>
<td>Fatigue, corrosion, wear</td>
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<tr>
<td></td>
<td>Supports</td>
<td>Fatigue, corrosion</td>
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<tr>
<td>Steam generator</td>
<td>Vessel</td>
<td>Fatigue</td>
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<tr>
<td></td>
<td>MCP nozzles</td>
<td>Fatigue</td>
</tr>
<tr>
<td></td>
<td>Primary collectors</td>
<td>IGSCC, corrosion</td>
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<tr>
<td></td>
<td>Heat exchange pipings</td>
<td>IGSCC, corrosion</td>
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<td></td>
<td>Feed water nozzles</td>
<td>Fatigue</td>
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<tr>
<td></td>
<td>Feed water inner piping</td>
<td>IGSCC, corrosion</td>
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<td></td>
<td>Steam collector</td>
<td>Corrosion, erosion-corrosion</td>
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<tr>
<td></td>
<td>Steam piping nozzles</td>
<td>Corrosion, erosion-corrosion</td>
</tr>
<tr>
<td></td>
<td>Supports</td>
<td>Fatigue, corrosion</td>
</tr>
<tr>
<td>Main primary piping</td>
<td>Welds, elbows, T-joints</td>
<td>Fatigue</td>
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<tr>
<td>Pressurizer</td>
<td>Vessel</td>
<td>Fatigue, corrosion, thermal ageing</td>
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<td></td>
<td>MCP nozzles</td>
<td>Fatigue</td>
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<td></td>
<td>Spray piping nozzles</td>
<td>Fatigue</td>
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<td></td>
<td>Steam piping nozzles</td>
<td>Fatigue</td>
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<td></td>
<td>Electric heaters nozzles</td>
<td>Fatigue</td>
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<td></td>
<td>Hatch (including sealing surfaces)</td>
<td>Fatigue, corrosion, thermal ageing</td>
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<tr>
<td></td>
<td>Supports</td>
<td>Fatigue, corrosion</td>
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<tr>
<td>Pressurizer surge piping</td>
<td>Welds, elbows, T-joints</td>
<td>Fatigue</td>
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<tr>
<td>Pressurizer spray piping</td>
<td>Welds, elbows, T-joints</td>
<td>Fatigue</td>
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<tr>
<td>Feed water piping</td>
<td>Welds, elbows, T-joints</td>
<td>Errosion-corrosion</td>
</tr>
<tr>
<td>Main steam piping</td>
<td>Welds, elbows, T-joints</td>
<td>Errosion-corrosion</td>
</tr>
</tbody>
</table>
2. AMP co-ordination
- Documentation of the requirements of regulatory body and significant safety criteria
- Documentation of significant activities and programs within AMP
- Description of AMP organization and co-ordination mechanisms
- AMP optimization based on current knowledge and periodic re-evaluation

Improvement of AMP efficiency

Minimization of expected degradation

5. Mitigation of ageing effects
- Repairs
- Replacements
- Use of improved materials
- Construction modification
- Strategy for repairs, replacements, and control of spare parts
- Modification of operational parameters
- Regeneration of properties
- Maintenance history

1. Mechanism understanding
- Materials and material properties
- Operation loads
- Ageing mechanisms
- Degradation points
- Indication of degradation degrees
- Effects of ageing degradation and consequential failures at NOC, DBE

1. Operation and usage
- Operation according to operational principles
- Prevention from damage by accepting additional measures
- Following operational history including the records from operation transients

4. Inservice inspections, monitoring, diagnostics and damage prediction
- Inservice inspections
- Surveillance specimen program
- Monitoring of parameters
- Diagnostics
- Function tests
- Damage prediction
- Record archiving

Correction of unacceptable degradation

Control of degradation

Fig. 1 General AMP function scheme
GUIDELINES FOR EFFECTIVE APPLICATION OF AMPS

AMP organization should (Fig. 2) reflect:

- safety criteria and demands laid on SSC’s by regulatory body to achieve AMP aims
- description of participating organisations
- description of coordination and relations within AMP
- description of AMP actualisation and optimisation mechanisms

AMP realization generates activities which, on one hand, according to the current knowledge state can help to indicate and consequently influence an equipment damage degree and, on the other hand, they cause a growth of operational expenses. These impacts, which seem to be on contrary at the first glance, have to be optimized so that they could globally provide a financial profit to the operator together with an increased level of operational safety. In order to reach such a state there is an AMP implementation strategy at the individual units. The single process steps include:

- Definition of required inputs, information resources, and connections
- Information flows - technology
- Organizational securing of the process
- Process documentation
- Efficiency evaluation

EXAMPLE OF AMP

Basic WWER 440 V213 RPV ageing management procedure referring to irradiation embrittlement is described on Fig. 3. WWER 440 NPP V213 type RPV is manufactured from 15Ch2MFA ferritic steel, welds are Sv10ChMFT type. Dominant ageing mechanism is caused by fast neutrons (E>0.5 MeV) affecting preferably RPV beltline region.

In accordance with recommended guidelines [7] the resistance against nonductile (brittle) fracture of WWER 440 RPV is secured when all postulated defects, virtually located in any RPV location, are stable and not critical during the whole NPP operation, i.e following condition is fulfilled:

\[ K_I (\sigma, T, a, c) < K_{IC} (T, F_n) \]  \hspace{1cm} (1)

where \( \sigma \) denotes the acting stress symbolically, \( T \) is local temperature, \( a \) and \( c \) are postulated crack dimensions and \( F_n \) is actual fluence, \( K_{IC} \) is fracture toughness and \( K_I \) is stress intensity factor. Similar procedure should be used in case of defects revealed during in-service inspection of RPV too.

Postulated cracks are defined by following requirements:

- dimensions are defined on the basis of defects reliably detectable during ISI
- postulation locations shall be in all critical RPV areas
- surface, underclad or embedded cracks shall be considered
- both orientation of cracks shall be introduced - axial, circumferential
- shape of cracks shall be semielliptic or elliptic

Equation (1) can be replaced by similar condition coming from \( T_K \):

\[ T_K < T_{ka} \]  \hspace{1cm} (2)

where \( T_{ka} \) is allowable value of time dependant (mainly fluence dependant) material property \( T_K \). \( T_{ka} \) has to be calculated by complicated procedure analyzing the whole set of possible pressurized thermal shock events (PTS).

CONCLUSIONS

The main issue of research project to develop all necessary tools enabling effective application of AMPs for main mechanical components and systems of primary and secondary circuit of Slovak WWER 440 NPPs has been achieved.
actual state of matters in this area should be followed by activities targeting practical use of complex AMPs on Slovak NPPs in near future.

REFERENCES

7. Guidelines on PTS Analysis for WWER Nuclear Power Plants, IAEA-EBP-WWER-08, IAEA, Revision 1, January 2006
**NPP management**  
Helps AMP realization  
- Defines responsibilities and competences within AMP – creation of a control team  
- Provides the required sources  
- Monitors AMP effectiveness  
- Approves actions recommended by the AMP control team

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**External organizations**  
Provide services within AMP  
- (research organizations, manufacturers, design organizations, NPPs, regulatory body, standardization organisations)  
- Analysis of information from NPP on ageing effects  
- Realization of research works generated by the AMP  
- Development of ageing management methods  
- Proposal of norms, standards, requirements, and measures

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**AMP control team**  
Co-ordinates, evaluates, and optimizes AMP  
- Approval and update of AMP methodic procedures  
- Organization and control of AMP specialized teams  
- Co-ordination of activities within the AMP  
- Evaluation of effectiveness indicators – AMP optimization  
- Information exchange with other organizations including other NPPs and analysis of their usability  
- SSC selection update for AMP  
- Periodical reports for NPP management

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**AMP specialized teams**  
Perform ageing evaluation  
- Ageing evaluation  
- Definition of effectiveness of NPP AMP programs  
- Identification of appropriate actions for AM and appropriate indicators of AMP effectiveness considering the operational economy  
- Identification of a need of research and development activities  
- Analysis of new ageing mechanisms and resulting recommendations  
- Proposals for SSC selection update within the AMP

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**Specialized departments of NPP operation**  
Implement AMP actions in NPP operation  
- Evaluation of recommended actions within the AMP regarding their practical feasibility and operational economy  
- Recommendation of main AMP activities for approval by NPP management  
- Implementation of the approved AMP activities in NPP operation  
- Provision of operational experience of AMP control team including the AMP effectiveness indicators

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Fig. 2 Basic AMP organization and co-ordination mechanisms
Fig. 3 WWER 440 V213 RPV ageing management procedure