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KEY ELEMENTS OF THE AGEING MANAGEMENT OF THE WWER-440/213 TYPE NUCLEAR POWER PLANTS

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ABSTRACT

The owner's intention of WWER-440/213 units in Central Europe is to keep the plants in operation as long as technically feasible and reasonable from business point of view. The preconditions of the long term operation and license renewal are the safety and good plant condition. The past and recent ageing management practices have to ensure the required condition and performance of the essential structures, systems and components. In the paper an overall picture of the long term operation of WWER-440/213 units is given. The review covers ageing of mechanical equipment, building structures and electrical equipment to. Key elements of the ageing management are identified and described. Basic issues of assessment of ageing of essential structures, systems and components, also the issues related to availability of design basis information and lacking environmental qualification are discussed. Reference examples typical for WWER-440/213 plants long term operation are given from Paks Nuclear Power Plant practice.

Keywords: WWER-440/213, ageing management, long term operation, equipment qualification, design basis.

1. INTRODUCTION

The WWER-440/213 nuclear power plants in Central Europe were designed and constructed at the technical level of late seventies early eighties. Design, operation and maintenance practice of WWER units had been determined in great extent by the Soviet rules and regulations and less by the national regulations of the recipient countries. Beginning from mid eighties identification and elimination of safety deficiencies had been the strategic tasks of the operators of WWER-440/213 NPPs in Central Europe. The comprehensive safety upgrading programmes always resulted in essential achievements, e.g. the core damage frequency has been decreased more than order of magnitude, and the level of safety of these units is comparable today to the safety level of PWR's of same vintage around the world.

Assessment of safety, definition of safety upgrading measures and confirmation of effects of the implemented measures had been carried out either in the frame of periodic safety reviews (PSR) and/or in form of renewal of final safety analyses report (FSAR).

The extensive safety upgrading projects caused a very important side effect: great part of the safety systems had been modified and modernised. Therefore systems or part of safety systems, structures and components are practically not aged. For example at Paks NPP in the frame of seismic upgrading programme steel and reinforced concrete members of the main building complex had been reconstructed and fixed, also the status of anchorages, supports of all safety classified components had been evaluated and reconstructed.

The PSR and renewal of the FSAR resulted at al plants in the recognition of the same issues relevant to the long term operation (LTO) of WWER-440/213 units: necessity of conscious ageing management and maintenance programmes, reconstitution of the design bases, also lacking of environmental qualification.

The owner's intention of WWER-440/213 units in Central Europe is to keep the plants in operation as long as technically feasible and reasonable from business point of view, e.g. to run Paks NPP 20 years behind the planned 30 years of operational lifetime. The preconditions of the long term operation are the safety and good plant condition. The first is ensured by the implemented safety upgrading programmes, commitment of operators and proper regulation. The last depends mainly on the past and recent practice of in-service inspection, maintenance, testing and recording the lifetime relevant data as well as on the knowledge of the design basis of the lifetime limiting structures, systems and components.

The national regulations with respect to LTO are different in countries operating WWER-440/213 units. In some countries, e.g. Czech Republic, where the plants have permanent operational license, PSR might be a tool for the control and approval of the operation for the next PSR period. In Hungary the operational license is limited in time, a formal license renewal required for the extended operational time. However, these differences influence mainly the procedures of the licensees to obtain regulatory approval for LTO and much less the technical content of the tasks to be performed for the LTO.

In the paper an overview is of ageing management programmes is given, which shows the most important tasks and issues related to long term operation of WWER-440/213 type units. The main areas considered are the mechanical, electrical and I&C, also building structures of the plant.

2. BASIC TASKS FOR ENSURING OF SAFE LONG TERM OPERATION

2.1 Main tasks for long term operation

The generic goal of the overall plant-life management (PLiM) is to ensure the cost effective and competitive production under stringent condition of safety. Generally, PLiM covers all systems, structures and components (SSC) of the plant, also the infrastructure necessary for the functioning of the operating organisation.

Within the scope of the PLiM programme, ensuring the intended function of the safety classified SSC has the most important role. Independent form the regulatory framework related to the LTO, the required technical condition of the safety classified items and their intended function has to be ensured by proper ageing management, maintenance practice and reconstructions. For the acceptance of LTO it has to be demonstrated that the effects of aging will be adequately managed so that the intended safety functions will be maintained consistent with the current licensing basis for the period of extended operation.

In case of licence renewal of Paks NPP, the programs and activities for managing the effects of ageing have to be reviewed and their adequacy have to be demonstrated. Also the time-limited aging analyses, e.g. fatigue, pressurized thermal shock (PTS) analysis, also limited in time qualifications have to be reviewed taking into account the operational history and forecast for the period of extended operation. If necessary modifications and additions to the in-service-inspection, maintenance, testing programmes, etc. have to be identified, developed and implemented for the management of aging during the period of extended operation.

Independent from the national regulations the long-lived, passive, non replaceable, non renewable SSCs have specific and decisive role in the programmes for long term operation. Ageing of these SSC defines and limits the plant lifetime, therefore the ageing of long-lived, passive non replaceable SSC shall be managed in proper way to ensure the safe operation for long term. In the Hungarian regulation the ageing of long-lived, passive SSC are in the focus of licence renewal. The ageing management of active short-lived components is ensured by proper testing, monitoring, maintenance and replacement practice. In case of Paks NPP the USNRC Maintenance Rule approach has been adapted for monitoring effectiveness of the maintenance activities.

Comparing the practice of different WWER-440/213 operators, the practically the same SSC are in the focus of programmes determining the feasibility of safe LTO.

2.2 Adequacy of the AMP

In the last ten years comprehensive ageing management studies have been performed for the most important safety related SSCs of the WWER-440/213 units in the countries operating this type of units. The reviews of AMP were performed in the frame of PSR in accordance to the guidelines developed on the basis of IAEA Safety Guide 50-SG-O12. The focused ageing studies and ageing management programme (AMP) reviews were based also on the IAEA methodology (e.g. IAEA TRS 338).

Most countries operating WWER-440/213 units developed their own guidelines for ageing management and long term operation. Some countries like Czech Republic, also Slovak Republic mainly follow the IAEA documents while developing own guidelines and procedures. Russia defines its regulation mainly on the basis of own experience and know-how.

Hungary adapted the Licence Renewal Rule and other relevant documents of the US NRC and also the basic recommendations and guidance of the IAEA. The requirements related to the AMP and other relevant activities of the licensee are given in the guidelines. These documents define the regulatory control and the quality assurance in the ageing management too. The SSCs requiring specific attention are identified and listed in the Appendix of Guideline "Regulatory control of the ageing management programmes". For these items the regulation prescribes the aim and content of AMP. The Hungarian regulation takes into account specific features of the WWER-440/213 units, the results of the ageing studies, also the findings of AMP reviews in the PSR. The aging management programmes are part of plant existing operational, maintenance, and in service inspection practice. Ageing management programmes should have the following main attributes:

1. Definition of SSC that are subject to ageing management.
2. Actions capable to prevent or mitigate aging process.
3. Surveillance, monitoring and testing all parameters related to degradation of the function of SSC.
4. Investigation of aging factors that may cause degradation or loss of function of SSC.
5. Trend-analysis to predict degradation process and to perform corrections in time.
6. Acceptance criteria to provide maintaining intended function.
7. Correction measures to prevent or solve problems.
8. Feedback process to ensure that preventive actions are proper.
9. Administrative control of the processes.
10. Obtaining information from operation practice to ensure that ageing management is properly carried out.

3. MECHANICAL EQUIPMENT

3.1 Mechanical systems and components relevant for safe LTO

The scope SSC relevant to the safety of LTO can be divided into two groups: There are selected SSC which requires individual ageing management programmes (sometimes several), like reactor pressure vessel (RPV), steam generator (SG), reactor cooling system (RCS), emergency core cooling system (ECCS), etc. (see Table 1).

Table 1, Selected, important mechanical systems and components

Reactor pressure vessel (RPV)	Pressurizer
Reactor vessel internals	Hydroaccumulators and other SSC of ECCS
Reactor vessel supports	Pumps, valves and connecting piping of safety classes 2 and 3
Control Rod Driving Mechanisms (SDRM)	Emergency diesel-generator
Reactor cooling system	Containment isolation valves
Piping connected to RCS	Feed-water piping, pumps, valves
Steam generator (SG)	Safety related heat exchangers
Main circulating pump (MCP)	Piping and component supports (also part of structures)
Main gate valves (MGV)	Containment ventilation system

There are items, e.g. pipelines, pipe elements (elbows, T-pieces), valves, heat exchangers, which can be grouped into commodity groups according to type, material, working environment. The SSC within a group have the same degradation mechanism and about the same operational and maintenance history. The definition of the commodity groups is performed applying the attributes given in the Table 2 in all reasonable combinations.

Table 2, Attributes for the definition of commodity groups

Safety classification	Type of SSC	Medium	Material
Safety Class 1 Safety Class 2 Safety Class 3 Non-safety class 4, which failure may inhibit intended safety function	Valve body Pump body Pipe and pipe elements Heat exchanger Tank	Borated water Prepared water river water Steam Gas-steam mixture Acid or alkali Oil other	Stainless steel Cast stainless steel Carbon steel

3.2 Degradation mechanisms and AMP in case of mechanical systems and components

The most important mechanical systems and components requiring specific AMP are listed in the table 3. The ageing mechanisms are also identified in the Table 3. The ageing mechanisms were identified on the basis of the results of the ageing studies and findings of AMP reviews in the PSR. The specific features of the WWER-440/213 units are taken into account.

Table 3, List of important mechanical systems and components and the ageing mechanisms

	Fatigue	Thermal fatigue	Radiation embrittlement	wear	Stress corrosion	Corrosion in boric acid environment	Erosion	Crevice corrosion	General corrosion	Embrittlement	Loosening	Change of properties	Stratification
RPV	x	x	x	x	x	x							
In-vessel structure	x	x	x	x	x					x	x	x	
Reactor supports	x		x						x				
CRDM	x	x		x					x	x	x		
Pressurizer	x			x	x	x	x						
Steam generator	x	x		x	x		x	x	x	x	x	x	
MGV and MCP	x	x		x	x		x				x	x	
RCS main circulating pipes	x	x			x		x						x
Pipes connected to RCS	x	x			x		x						x
Hydroaccumulators					x				x				
ECCS quick closing valves	x			x			x		x		x	x	
ECCS pumps	x			x		x	x					x	
Low-pressure ECCS pumps	x						x		x			x	
Sprinkler pumps	x						x		x			x	
High-pressure boron pumps	x			x			x					x	
Pumps of make-up system	x			x			x					x	
Tank of essential service water	x								x				
Essential service water pumps	x			x			x					x	
Air-trap valves									x			x	
Containment quick-closing valves	x			x			x						
Normal + emergency feed-water pipes	x	x					x		x				x
Normal + emergency feed-water pumps	x						x		x				
Safety classified piping and piping elements	x			x			x		x				

3.3 Issues of ageing management of mechanical systems and components

3.3.1 Reactor Pressure Vessel

The reactor vessels at WWER-440/213 units were shipped with complex surveillance specimen sets. Implementation of the surveillance programme was obligatory. The recording of the operational history and control of the ageing of RPV is generally properly established at these units. National and international research programmes were and are carried out for the investigation the ageing phenomena of these RPV.

In case of WWER-440/213 RPV at Paks NPP the original surveillance sets were irradiated in the first four campaigns. Because of the relatively high lead factors, by the end, they were through a “pre-ageing” process equivalent to the planned extended life cycle of the reactors. To ensure continuous monitoring of the vessel wall condition new supplementary surveillance chains were placed in the vessel after taking out the original ones.

Although the vessel wall and the next to the core circumferential weld have good embrittlement properties, low leakage core configurations are used according to the life time management program. This resulted in 30% decreasing of the fast neutron flux to the RPV wall and welded joint No 5/6.

Considering the feasibility of LTO it was found, that the RPV at the units 3-4 reactor vessels do not require extra measures even at 50 years of lifetime. At unit 2 the water in the ECCS tanks has to be heated up in order to decrease stress levels caused by pressurized thermal shock (PTS) transients. At unit 1, in case of the 50-year lifetime, in addition to the ECC heating-up, the annealing of the welded joint No. 5/6 close to the core has to be considered with 50% probability in the business assessment.

There are two issues requiring further development in case of Hungary:

According to present knowledge, PTS is the lifetime limiting process of the RPV. Methodology of the PTS evaluation has to be established in the Hungarian regulation, which will take into account the applicable best practices, features of RPV and the thermo-hydraulic peculiarities of the WWER-440/213.

Annealing of the critical weld of the RPV is a well developed technology. In case if annealing will be applied, the re-emrittlement process has to be understood.

3.3.2 Pressurizer and surge line aging management

In the case of the pressurizer, fatigue is supposed to be the major life limiting degradation mechanisms for the location of water injection nozzle and the surge nozzle with the surge line. In the case of the injection nozzle, partial cycle counting, based on partial water injection temperature differences is implemented. Sample type fatigue monitoring has been used by processing surface temperature measurement results for AMP of the surge line. Other possible degradation mechanisms are managed mainly by in-service inspection (ISI) programs conducted every 4 years.

3.3.3 Steam generator aging management

The status of the steam generators determines the plant economically competitive life. The life time limiting ageing mechanism of the SG is the Outer Diameter Stress Corrosion Cracking (ODSCC) of the austenitic heat-exchange tubes. The ODSCC indications appear typically (80%) at the grid structure supporting the tube bundle, where the secondary circle corrosion products with concentrated corrosive agents are absorbed. A 100% Eddy-current inspection programme is implemented for monitoring of the tubes. Samples were cut out from the plugged tubes for the investigation of the phenomena.

The ODSCC was essentially slowed down by series of modifications:

- Replacement of the condensers, the new condensers have austenitic tubes
- Removal of copper from the secondary circuit
- Replacement of the feed-water distributor (the old was manufactured from carbon steel)
- Cleaning the heat exchanging surface of the SG
- Introducing a high pH secondary water regime.

The high-pressure pre-heaters will be replaced. The new pre-heaters will have erosion-corrosion and erosion resistant tubes.

These measures completely change the conditions and the rate of ODSCC in the SG. Consequently, a better plugging trend is experienced, which can be expected in long-term, too. The reserve in heat exchange surface of the SG is more then 15%. Considering the past experience and the recent plugging trend of the heat exchange tubes, none of the SG would exceed 10% by the end of 50 year of operation.

Two issues have to be mentioned in relation of SG ageing:

The ODSCC on the heat exchanging tube surface is slowed down by the measures implemented. The gaps between the tubes and support grid are still the critical places because the remaining corrosion products. It is difficult to forecast the ODSCC rate in the gaps, therefore the ageing process has to be well monitored in the future.

Under new condition sludge may be accumulated at the bottom area of the SG. An effective draining of the sludge has to be solved.

3.4 Changing of the periodicity of the ISI programmes

The ISI programmes delivered partly by the supplier or developed by Hungarian institutes follow basically the ex-Soviet regulation. Recent review and overall updating of the ISI programmes should adopt the state-of-the-art techniques and methodologies (e.g. the ASME Section XI, Inservice Inspection). Extensive studies are going on to provide a solid basis for changing the rules and techniques of ISI. One practical question is the periodicity of the ISI programmes, which is 4 years at Paks NPP, in accordance to the ex-Soviet regulation. Because of practical reason the new ISI period should be 8 years. In the same time the scope and depth of ISI programmes have to be upgraded, too.

4. BUILDING STRUCTURES

4.1 Structures and structural components relevant for safe LTO

The civil engineering structures and structural components are drawn into the scope of LTO are the structures and structural elements rated into the Safety Classes 2, and 3 (Safety Class 1 structures do not exist), and from non-safety structures and structural elements those that endanger performing of any safety function if damaged (interactions). Also the structures and structural elements rated into the Seismic Classes 1 and 2 are included into the scope. The list covers the following structures:

1. Containment (load bearing structure and the liner)
2. Structures inside the containment pressure boundary (boxes, etc.)
3. Other safety classified buildings (e.g. Diesel)
4. Auxiliary building
5. Spent fuel pool (as a part of main reactor building)
6. Cooling water intake and outlet structures
7. Foundation systems (turbine, others), embedment
8. Stacks
9. Buried pipelines (with direct interface with the soil), support (channels) and protection structures for the underground pipelines.
10. Cranes (the supporting structures)
11. Pipe whip restraints
12. Structural components embedded into concrete.
13. Decontaminable painting, coating, fire proof coating, etc.

Item No 12 above covers also the following structural components:

- Interfaces/anchoring of HVAC ducts (embedded in concrete or not)
- Concrete embedded part of the electrical and mechanical penetrations
- Equipment hatches and hermetic doors, small hatches and other doors (including fire protection doors)

4.2 Degradation mechanisms and AMP in case of building structures

The structures and structural components requiring focused ageing management programmes are listed in the Appendix of Hungarian Regulatory Guideline "Regulatory inspection of the ageing management programmes". For these items the regulation gives the ageing mechanisms to be considered. Example of this is given in the Table 4. It is also shown in the Table 4, what ageing consequences are subject of regulatory control.

Table 4, Ageing mechanisms of lifetime limiting structures and structural components

item	place of the degradation	degradation mechanism	consequences	Reg. contr.
Containment: reinforced concrete structures of the hermetic part of the main building	Reinforced concrete	corrosion change of the material properties due to heat or irradiation fatigue settlement	cracks cracks cracks cracks declining the reactor axis from vertical, limit for CRDM	no no no no yes
	support plates in the concrete	corrosion	leakage	yes
	liner	corrosion	leakage	yes
RPV support	Support grid, support plate	fatigue corrosion embrittlement	declining the reactor axis from vertical, limit for CRDM	yes yes yes

In case of reinforced concrete structures the chemical (e.g. boric acid) attack, leaching and settlement are the relevant ageing phenomena. Ambient vibration is relevant phenomena in case of some support structures. Corrosion is the dominant ageing mechanism of the steel structures and structural components.

The particular ageing monitoring programmes developed by the NPP Paks are listed in the Table 5. The programmes comply with the Hungarian guideline, which regulates the ISI of civil structures. The programmes include essential elements of ASME XI Subsections IWL and IWE.

Table 5, Existing ageing monitoring programmes of structures and structural components

Building or part of the building	structure	aim of the monitoring	measurements	evaluation and criteria
turbine building: turbine foundation	reinforced concrete structure	vibration monitoring	fixed measuring points;	ExpertAlert system; evaluation of bending
technological and fire water pumping house; 12 bar fire water pumping house; auxiliary building	all structural members; joints	overall condition of building	walk-down and visual control according to checklist	expert judgment
cooling water outlet	reinforced concrete structural members	concrete cracking and overall condition	walk down and visual control; NDE of concrete	expert judgment
main building complex: all buildings, including reactor and auxiliary buildings, stacks, diesel-building and other structures	reference points	building movements; settlement; control of stability of cracks caused by movements	fixed geodetical measuring points;	3D evaluation of building movements; correlation with ground-water table; Allowable declination of vertical axis of reactor pressure vessel defined by functioning of CRDM
reactor building: floor slabs and walls	heavy reinforced concrete	interaction with boric acid media	investigation of samples; inspection of check-holes	control of mechanical and chemical properties and comparison with reference values
reactor building, turbine building; intermediate building and galleries: floor slabs and walls	reinforced concrete	control of possible leakages and consequent leaching	investigation of samples; inspection of check-holes	control of mechanical and chemical properties and comparison with reference values
reactor building: walls, members	reinforced concrete	control of stability of cracks	measuring of crack sizes	control of mechanical condition of concrete, comparison of parameters with reference values
reactor building floor slabs and walls	carbon steel liner	control of corrosion rate, identification of possible leakages	US measuring of liner wall thickness at the identified places	control of corrosion rate and thickness; focused investigation if the overall leak-tightness is less than the reference value for the given unit (comparison with allowable leak rate)
reactor building and auxiliary building: floor slabs and walls	decontaminable coating and painting	control of condition of coating and painting	walk down and visual control according to checklist	expert judgment
main building complex: all building parts	hatches, gates, penetrations fire protection doors;	control of condition of doors	walk down and visual control according to checklist, fluorescent test	expert judgment

4.3 Issues of ageing management of building structures

Monitoring and ISI programmes, maintenance and reconstruction practice of the Paks NPP are the main tools for managing the ageing of the structures and structural components. This system seems to be effective for ensuring the required condition of structures for the extended period of operation, too.

4.3.1 Non-uniform settlement

Geodetic control of the settlement was started during the construction. The control of settlement is periodically performed 4 times per year. The measured results have to be evaluated and reported yearly. Basic findings are as follows:

- Uneven settlement in NW-N direction is observed at unit No 4. The non-uniformity of settlement did not result in non-allowed tilting of the RPV vertical axis, which would cause problems for CRDM.
- The non-uniform settlement at the unit 4 and especially the relative settlement between the containment and attached gallery building cause cracks in the non-structural masonry walls in the gallery building.
- Except of the main building of unit 4, settlement is consolidated at all buildings.
- Stacks are consolidating after their recent reconstruction.

Further assessment of settlement is planned to clarify whether the settlement of the Unit 4 is

4.3.2 Leak-tightness of the containment

Containment leakage has a complex origin. Investigations carried out practically from the time of start up tests shows that the containment leakage is mainly caused by the sealing of doors and hatches. It means that the leakage itself is a maintenance problem rather than ageing issue.

Table 6 below, which is taken from the last updated Final Safety Analysis Report, shows the details about the contributors of the leakage. The allowable value of the leakage at WWER-440/213 containment is high; it equals to 14.7%/day at the post large-break loss-of-coolant accident, when the design internal containment pressure equals to 2.4 MPa. Although the containments at Paks NPP have much better characteristics, the leak tightness of the containment remains the basic issue of ageing management and maintenance.

Table 6, Contributors to the containment leak rate

component of the containment	contribution to the leakage, [%]
sealing of the doors	20,53
sealing of the hatches at the service floors	77,33
welding of the liner	0,28
Isolating valves	0,82
Electrical penetrations	1,04
total	100,00

4.3.3 Need of studies

The structures and structural components at Paks NPP were designed in general for the lifetime 50 years, i.e. for the time interval of the planned LTO. The design limits of the lifetime shall be reviewed and the validity of the time-limiting ageing analyses has to be demonstrated for the licence renewal.

In the near future, more detailed examinations are planned e.g. in the following areas:

- Detailed analyses in connection with the subsidence monitoring of structures;
- Corrosion of concrete reinforcement steel and inserted steel elements in concrete;
- Examination containment steel structures and reinforced concrete structures supporting some specific equipment that are exposed to higher temperature
- Examination of penetrations;
- Examination of machine foundations;
- Review of carbon steel structures.

4.3.4 Examples of the already implemented measures

Essential structures and structural components have been reinforced or reconstructed in the frame of Safety Upgrading Program of Paks NPP (more than 2000 tons of seismic structural upgrades of steel construction, upgrades of the supports, fire protection upgrades, etc.). Consequently, essential part of the building structures and structural components are renewed, practically not aged.

A progressive degradation (cracking, etc.) of the reinforced concrete ventilation stacks has been observed due to pure construction quality. An overall reconstruction has been implemented using injection technique and adding reinforced concrete inner and outer shells.

Repair of some specific parts of carbon steel liner and claddings and decontaminable coatings had been accomplished or is in progress. Improvement of the leak-tightness improving has been performed on the basis of local leakage examinations. Concrete grouting was implemented and cladding jointing nods were repaired. These measures have been resulted a significant enhancement in compactness of the containment.

Concrete ageing in boric environment was observed in the region of pools. Periodic control of the reinforced concrete behaviour subjected to the effects of boric acid environment was implemented: specimens taken, laboratory testing, slight increase of porosity of the concrete and the pH-value. Essential improvement was reached by reconstruction of liner in the pools.

Severe biological corrosion observed in service water systems piping. The monitoring, inspection, destructive examination, etc. was implemented. An overall reconstruction of the system is going on. The experience gained with respect of ageing has been taken into account while designing the reconstruction.

In case of decontaminable coating 15% of the surface should be repaired.

5. ELECTRICAL EQUIPMENT

5.1 Electrical and I&C relevant for safe LTO

Table 7 shows examples for electrical components required ageing management programmes. Examples are taken from the Appendix to the Hungarian Regulatory Guide "Regulatory control of ageing management". The regulation defines the minimum scope of ageing management. The dominating degradation mechanisms are also indicated. The scope of licence renewal includes a relatively small part of the electrical and I&C items. These are the passive components (cables) and those safety classified, which have limited in time qualification. Full scope of electrical and I&C systems and components is subject of the PLiM programme.

Table 7, Examples of the high priority electrical and I&C items and their ageing mechanisms

Item	Place of the degradation	Mechanism of the degradation	Worst consequences
XLPE I&C cables in harsh environment	Cover and core isolation	Thermal aging; Change of the material properties due to heat or irradiation	Crack / Loss of function under loss-of-coolant condition
6 kV PVC power cables in channel /humidity environment/	Metal structure of cables	Humidity penetration Corrosion of metal structure	Decrease isolation resistance /loss of function/
Cable connection in harsh environment	Corrosion of metal structure	Humidity/chemical Corrosion of joints	Increase transit resistance of connectors

5.2 Degradation mechanisms and AMP in case of electrical and I&C at Paks NPP

Full scope ageing studies had been prepared between years 1995-2001 for the Paks NPP for the following electrical, and I & C items:

1. Equipment of electric power generation and transmission systems:
   - Bus cabinets
   - Overhead-line towers, medium and high voltage insulators
   - LV and HV cables of power supply systems
   - Cables for containment electrical penetration
   - Cable joints and assemblies
   - Enclosed electrical equipment
   - Battery packs
2. Equipment of the technological systems:
   - Fixtures for Transmitters
   - Impulse pipes and assemblies
   - Operation monitors
   - Relay boards
   - Cables for E, I&C equipment
   - Cables of containment electrical penetration for E, I&C
   - Cable joints and assemblies
   - Terminal boxes

Under operating and loss-of-coolant conditions the following factors were identified as important for the degradation:

- Temperature: In case of organic materials, commonly used as insulation and/or sealing parts of components high temperature is the main factor of aging effect.

- Radiation: Inside the containment, mainly the γ-rays shall be taken into account. At Paks NPP, the more sensitive material is the PVC and the less sensitive is the XLPE. Therefore, PVC insulated cables are not used for safety-related function inside the containment. Neutron radiation shall be considered only for copper parts that are located next to the reactor, where these parts may be activated.
- Pressure changes: Extreme pressure changes may occur in loss-of-coolant (LOCA) conditions and may endanger the proper operation of systems and components affecting the sealing materials of various equipments.
- Humidity: Humidity of the containment may change from several reasons, e.g. leakage or break of pipes, unintended operation of fire extinguisher appliances, LOCA. Penetrating humidity may result in malfunction of electrical and I&C equipment.
- Steam: In LOCA conditions, steam may condense on the surface of equipment causing quick temperature-rise and it may penetrate into the equipment.
- Chemicals: The applied chemicals (boric acid, hydrazine, etc.) may penetrate into sealing of electrical equipment, reducing dielectric strength, and causing corrosion.
- Seismic events: Seismic effects and vibration may degrade the functionality of certain E, I&C equipment (relays, transmitters, motors, etc.). For seismic effect on equipment, the response function of that particular equipment is the most important factor, which depends on the frequency and amplitude of the excitation, as well as the damping of the coupling elements between the fixture and the equipment. In case of Paks NPP, the SSE (SL-2) is 0.25g horizontal acceleration measured on flat ground surface. For the OBE (SL-1) is 50% of SSE was applied.

5.3 Ageing monitoring and mitigation measures applied for electrical and I&C

5.3.1 Testing and Monitoring Practices for passive Components

<u>Monitoring parameters of cables in operational environment:</u> The actual operational environment of cables is determined by monitoring the temperature and the radiation of the harsh environment of the containment during one operation cycle. A multi-channel data logger measures temperature, while radiation is measured by an aluminium-oxide ceramic thermo-luminescent detector. Result obtained during this monitoring may be used also for the qualification tests of active electrical and I&C components.

<u>Diagnostic tests on the insulation of 6 kV cables:</u> If cables operate in humid environment (e.g. in ground or in cable channels), corrosion may occur in its steel and aluminium parts. Moisture causes treeing of the insulation material, and it leads to breakdown and loss of operability of the cable. The aim of the diagnostic methods is monitoring of the condition of the cable and prevention of malfunctions. The applied diagnostic methods are as follows:

- Insulation resistance measurement
- Dielectric test
- Partial discharge (PD) measurement
- Location of fault by oscillating wave test (OWTS)

<u>Accelerated aging tests on 0.6/1 kV I&C cables:</u> During the test, the cables, which aged under known, normal operating conditions, are exposed to an accelerated thermal and radiation aging test in the depot, located in the containment. The simulated lifetime is determined by the acceleration factor of the depot. Before placing the cables into the depot, an initial breaking test is performed to determine the elongation to break value (E/E_0). After the simulation of the required lifetime in the depot, the cable samples are subjected to a simplified steam test that simulates line break conditions. This test does not include the radiation test of LOCA condition. After the simplified steam test, further breaking tests are performed on the cable insulating material. International experience shows that the cables keep their operability under LOCA condition if the elongation to break value measured after the aging remains higher than 50 % of the initial value. If it is lower than 50 % of the initial value, aging condition of the cable shall be determined by a full LOCA test (which includes LOCA radiation). This method can be applied in case of newly installed cables where the initial elongation to break value is known. If this value is unknown, the method cannot be applied.

<u>Operability test of safety related 0.6/1 kV I&C cables:</u> In cases when the initial elongation to break value is not available, an accelerated aging and LOCA test is performed in laboratory to determine the condition of the cables. The safety related cables are exposed to an accelerated thermal and radiation aging according to the operational parameters of the environment where the cables are installed. This aging is followed by a LOCA test according to the LOCA parameters of the installation environment. The acceptance criterion is the operability of the cables.

5.3.2 Component function tests

The functional tests are carried out periodically to justify that the active systems and components are capable to maintain the functions they are designed for. Beside the justification of the functional availability, these tests are used to reveal potential deviations, before these deviations could lead to an inappropriate operation of the SSCs.

Separate sets of tests are conducted prior to unit shutdown to justify that the conditions of SSC required for RCS cool-down and depressurisation comply with the corresponding requirements. By means of successful execution of the on power functional tests, it can be proved that the SSCs fully match the requirements of power operation mode.

The on-power tests are executed according to a yearly schedule taking the corresponding prescriptions of the Technical Specification into account.

5.3.3 Applied diagnostics and testing

Test of 6 kV cables: For the safe operation, the most important property of cable insulation is the dielectric strength. Because it cannot be measured on cables in service, non-destructive tests are carried out to gain information on the present condition of the cable insulation. The non-destructive tests are based on the fact that operating conditions modify the dielectric parameters, like the insulation resistance, which can be measured. The non-destructive tests are performed every four years after shutdown of the unit. In case of fault or short-circuit to earth of the ungrounded system, the tests are carried out immediately when it is possible in service conditions. The regular diagnostics of 6 kV cables are listed in the Table 8.

Table 8, Regular diagnostics of the 6 kV cables

Measurement	Reason	Acceptance criteria
Insulation resistance measurement:	Resistance measurement provides information on the ageing and performance of the cable. Cables are disconnected and the cable ends are cleaned before the measurement.	Acceptance criteria are described in the maintenance rules of the given cable type.
High voltage test	This test is intended to decide that the cable can be switched onto the power source without the risk of breakdown. Cables are disconnected and a test voltage is applied for a time interval specified in the maintenance rules of the given cable type.	The cable passed the test if neither breakdown nor flashover occurs and the leakage current remains constant or decreases during the test.
HV test of the outer cover of the cable	Discontinuities of the cable cover results in water penetration that may increase treeing. As its consequence, partial discharges occur that may lead to breakdown. During the test the cables are disconnected and an AC test voltage is applied between cable shielding and ground. This test gives information only for the present condition of the cable.	Test voltage and test time are described in the maintenance rules of the given cable type.
Partial discharge test with OWTS	Oscillating wave test makes possible the accurate location of insulation faults on longer cables and determination the type a fault. It makes possible also the measurement of further parameters, such as the dielectric loss and cable capacitance. (Introduced recently at Paks NPP).	

Test of Containment Electrical Penetrations: Performed annually or in every four years at shutdown of the unit, depending on type. Test includes insulation resistance measurement and the test of tightness. Test parameters and acceptance criteria are given in the Maintenance Procedures of Paks NPP.

Chemical regimes monitoring: Rechargeable batteries of the safety uninterrupted power supply systems are checked weekly by visual inspection (general condition, leakage of acid, etc.). In every three months, temperature, the cell voltages and the density of electrolyte are measured. Full maintenance is performed annually.

Destructive tests and material research carried out during NPP operation: At Paks NPP, destructive test applied for monitoring cable insulation performance is the elongation to break method. As the cable ages, its insulation material becomes more rigid, therefore the elongation to break value decreases. The samples are tested in a tensile stress machine. The elongation is measured from initial state to break. At Paks NPP, this method cannot be applied for the originally installed cables.

Besides the mentioned above diagnostics, also the main generators and high-voltage transformers are monitored on-power and during maintenance.

5.3.4 Issues of ageing management of electrical and I&C

In the harsh environment of the containment, the relatively high temperature basically determines the aging of the organic materials. At certain places of the containment of the Paks NPP, the temperature exceeds the specified values, even in normal operating conditions. This high temperature accelerates the aging of insulating materials, especially that of cables. This problem has to be solved in the near future by an enhanced ventilation system.

Further method to mitigation of aging is finding and elimination hot spots. This is achieved mainly by maintenance of thermal isolation of pipes.

In high-humidity places another source of problems is that water may penetrate into sealing of electrical equipment. If chemicals are present, the penetrated humidity causes corrosion of terminal blocks, contacts of switches, etc. It may result in malfunction of E, I&C equipment.

Lack of environmental qualification was recognised during the first PSR at all WWER-440/213 plants. It is a typical electrical and I&C issue. Because of the generic feature of the issue, it will be discussed in the chapter 6.

6. KEY ISSUES OF LONG TERM OPERATION OF WWER-440/213

6.1 Design base reconstitution

Lack of design base (DB) information is a generic issue of the WWER-440/213 type units.

The availability of design base information is a current licensing basis requirement. In the same time knowledge of DB is absolutely unavoidable for the preparation of long-term operation and licence renewal, especially for the review of time-limited ageing analyses and for the review of the environmental qualification limited in time.

Operators of WWER-440/213 units have to perform specific project for the DB reconstitution. The design base reconstitution covers the identification of DB functions, DB values and bounding conditions according to the licensing basis.

For the DB reconstitution two basic problems have to be solved:

- Collect and review the original design information. Main problem is that neither the codes and standards nor the safety analyses are properly described in the documents supplied with WWER-440/213 reactors and equipment.
- The licensing basis has been changed since the design and issuance of the operational licence, therefore the design base have to be newly created taking into account all essential changes in the licensing basis. (For example in case of Paks NPP seismic loads were not considered in the design. Recent DB includes safe shutdown earthquake, which has 0.25g horizontal acceleration.)

The DB reconstitution for Paks NPP has been performed. The results have been documented in the FSAR.

The collection and review of supplied documentation provided some understanding of the design. The design base functions could be identified. Further work needed for the proper definition of design base values and conditions. They could not be reconstructed from the existing documentation, because essential part of supporting design documentation is missing, which includes the design inputs, design analyses, and design output results. Very often the final results of the design analyses are known only. In some cases the analyses are obviously obsolete.

For the completion of the design base information the original documentations are not sufficient even if they would be available.

Taking into account the second problem mentioned above, design input loads and conditions have to be newly defined for the most important SSC. Information sources for this work are:

- the existing design information
- results of the reviews
- current licensing basis compliance check
- analyses performed for the FSAR (chapter 15)
- operation history.

The necessary analyses (stress calculations, PTS, fatigue, etc.) have to be performed by state of the art methods for the scope of licence renewal. It means that for the most important SSC complete re-design has to be performed which will be the basis of the time-limited ageing analyses too.

6.2 Equipment qualification issue

When the Paks NPP was built, certain part of the originally installed E, I&C equipment did not have initial qualification. It is also a generic issue of WWER-440/213 plants. The issue was recognised already in the first PSR. The qualification of such equipment was started after the first PSR and is still in progress. The safety related equipment purchased later because of safety or other reason, was installed with proper qualification as required by the Hungarian regulations.

The qualification of equipment delivered without proper first qualification can be performed by testing, data evaluation, evaluation and assessment of experience gained in operation and by combination of the mentioned methods. Whenever possible, testing is preferred especially for the qualification for harsh environmental conditions. Methods are given in industrial standards. Acceptance criteria shall follow the changes in the operating or environmental conditions. These changes may arise due to modifications of the NPP, or measures to improve safety. In the case of old equipment the conservatism of qualification might be minimised. The qualification of components without initial qualification consists of the following steps:

- Definition of environmental parameters, characteristic to the place of installation
- In case of safety equipment, definition of environmental parameters characteristic to the place of installation under loss-of-coolant condition
- Definition of accelerated thermal and radiation aging test parameters
- Performing laboratory test with above parameters (accelerated thermal and radiation aging, radiation exposure with LOCA condition, and simulation of LOCA)
- Performance checks on tested sample to verify conformity with acceptance criteria.

The regulation requires also the preservation of their qualified state. For the approval of LTO the environmental qualification limited in time has to be reviewed and the operability of the equipment has to be demonstrated.

It is important to mention that in case of original components conservatism cannot be reduced during renewal of qualifications, because the re-qualifications are made with the minimal required conservatism.

7. CONCLUSIONS

A complex picture of the ageing and ageing management of WWER-440/213 units of Paks NPP is given in the paper. Significant for safe long-term operation structures, systems and components are identified. Proper level of understanding of the ageing phenomena is reached and adequate ageing management programmes were developed for ensuring the required status and intended function for long-term. Ageing management programmes of essential mechanical, electrical and I&C systems and components and building structures cover all important aspects of ageing. It is shown that the recent practice and solution of identified ageing management issues will ensure the safety of long-term operation these types of units.

