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Lifetime-Management and Operational Lifetime Extension at Paks Nuclear Power Plant

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ABSTRACT

The design life of the NPP PAKS WWER-440/213 units is 30 years. Formally the design life limits the operational licence. The condition of the equipment after almost 20 years of operation is excellent. The lifetime management activity of the Paks NPP provides a proper basis for the continuation of safe operation. The current Hungarian Nuclear Regulations allow the extension of the operation licence of the NPP Units beyond the design life. To prove the acceptability of continuation of operation the Licensee have to prepare a Licence Renewal Application not later than 5 years before the expiration of the design lifetime. The Licence Renewal process based mainly on USNRC approach taking into account the special features of the WWER-440/213 Units. Summary of the preconditions of the Licence Renewal and the activity for the preparation of the operational lifetime extension are reported in the paper.

KEY WORDS: ageing, stress corrosion cracking, embrittlement, erosion, corrosion, reactor pressure vessel, steam generator, water chemistry, ageing management, operational lifetime, licence reneval, WWER-440/213 units.

FOREWORD

The structure of the Hungarian electric energy system is presently well balanced. The production capacity mix consists of about ≈39% nuclear, ≈37 % oil and gas, ≈25 % coal fired capacities. Before 2010, almost exclusively, gas fired power plants are expected to be constructed, and some coal fired ones are predicted to be closed down. A significant change in the structure of energy-production would occur after 2012, if the Paks units were shut down with the expiry of their operational license limited recently by the design lifetime. Based on the present tendencies and market conditions, the industry is either predicted to cover the lack of electricity and the growth of demand with gas fired power plants that produce energy more expensively compared to the nuclear power plants, or would import the electric energy itself increasing the import-dependency. This way between 2012 and 2019 the import gas consumption of electric energy production, as well as its carbon-dioxide emission would grow dramatically compared to its present values (even in case of an intensive utilization of renewable energy sources). The electric energy import would, in the long run, be an expensive and obviously import-dependence-increasing solution. For the compensation of the production of Paks NPP it is rather difficult to find a green alternative. The strategically unfavourable structural changes can be counterbalanced via upholding the market position of the Paks NPP as well as the power uprating and licence renewal (LR) of the Paks NPP.

In 2000 a comprehensive study demonstrated the technical feasibility of the extension of the operational life of Paks NPP, as well as the economic rationale of the licence renewal project. In 2001 and 2002 the project for the license renewal has been prepared simultaneously with the development of detailed regulation of the LR. The Hungarian Regulatory requirements for the content of the Periodic Safety Report (PSR), Final Safety Analysis Report (FSAR) and LR Application together represent an "upper-bound" of those in the defined in the IAEA and NRC documents. The basic tasks of the preparation of the LR are described in the paper. The specific aspects of extended operation of the WWER-440/213 units at Paks NPP are discussed in details.

PRECONDITIONS FOR THE OPERATIONAL LIFETIME EXTENSION

Extension of the operational life of the Paks NPP is a strategic decision, which takes into account numerous external circumstances as well as factors dependent on the characteristics of the NPP and the practice of the Operating Company.

The future of the Paks NPP depends greatly on the international tendencies. The energy policy of the USA strongly motivates the operational lifetime extension activity in Hungary and some new tendencies in the European Union, e.g. the great progress achieved in Finland are also very encouraging. In Central Europe at least 6 units, similar to the ones in Paks, are expected to be in operation until 2030, so The Paks NPP will not be an isolated, unique phenomenon in the future either.

The strategic decision on the extension of the operational lifetime of Paks NPP is entirely based on the features of WWER/440/213 units; the robustness of the main equipment; on the in-service inspections (ISI), testing and maintenance practice of the Operating Company, as well as on the good condition of the plant maintained via reconstruction and refurbishment during last five years.

The ageing of the plant structures, systems and components (SSC), relevant for safety had been assessed during the Periodic Safety Reviews in 1997-1999. The PSR confirmed that the performance and the safety function of the relevant SSC are ensured in spite of the ageing processes. The most important activities related to the ageing management are performed at the plant from the very beginning of the operation, such as surveillance of the embrittlement of reactor pressure vessel (RPV) material, monitoring erosion-corrosion events, etc. These are the starting points to build up a conscious ageing management programme. Already in the course of the PSR the ageing processes of the critical equipment were identified, and the monitoring ageing processes as well as possible correction measures were determined. A systematic status monitoring of structures, equipment and components other than critical is going on at the plant too, hereby ensuring the required performance of the large number of (although replaceable) components.

The conscious approache to the ageing has already grained ground during modifications and replacements performed so far. Replacement of turbine condensers is a good example. The new condensers have stainless steel tubing, which allows introduction of high pH secondary circuit water chemistry. This measure decreases the erosion/corrosion in the feed-water system and eliminates the deposition of corrosion products in the steam generators (SG) affecting local corrosion of the heat exchanging tubes.

Safety of the Paks NPP is a prerequisite of the LR. A comprehensive safety-upgrading programme has been completed recently, as a result of which the safety level of the power plant complies with the requirements for nuclear power plant units of similar age operated in developed countries.

The renewal of the operational licence is addressed and regulated within the frame of the Hungarian nuclear safety regulations. The detailed guidelines relevant to the ageing mangement and LR have been developed recently.

The public acceptance of the Paks NPP is permanently around 70%, which had an important role for the acceptance of the LR.

It was already recognised in 1992 that the favourable characteristics of the plant, the comprehensive safety enhancing programme, the operational and maintenance practice of the operator give an opportunity to extend the operatioan lifetime of the Paks NPP [1]. A complex technical-economical study for the feasibility of lifetime extension was completed in 2000, which fully confirmed this assumption [2].

Main features of the ageing management practice of the Paks NPP and also the findings of the plant status assessment also the specific features of the Paks WWER-440/V213 units are summarized below.

AGING MANAGEMENT OF THE VVER MAIN EQUIPMENT

The systematic lifetime management of the components of nuclear power plant is developed according to the current international practices. The components included in the Ageing Management Programme (AMP) system at the present time are listed below:

1. Reactor vessel
2. Steam generator
3. Pressurizer
4. Primary circulating pipe
5. Branch pipes of the primary circuit
6. Primary circulating pump
7. Primary shut-off gate valve
8. I & C cables
9. Structures within the RPV
10. Reactor control rod-drives
11. Feed water pipes
12. Diesel Generators
13. I & C equipment
14. Reinforced concrete structures around the hermetic zone
15. Emergency Core Cooling System (ECCS) pumps
16. ECCS valves
17. Airtight lead-through points
18. RPV support
19. Reservoirs for cooling water of safety related equipment
20. Quick-action isolation valves of pipe passages in the hermetic zone
21. Other safety valves
22. Hydro-accumulators
23. Air valves in the hermetic zone

The main steps of the systematic aging management are the following:

a) Identification of ageing effects
b) Assigning the parameters of the ageing process for monitoring
c) Adaptation of the current programs (ISI, Test, Maintenance etc.)

d) Determination of acceptance criteria
e) Trend observation, condition monitoring
f) Making and scheduling corrective arrangements, replacements etc.
g) Operational practice (own, other) feedback

As an example figure 1 shows the identified steam-generator (SG) potential critical locations, while Table 1 shows the related ageing processes.

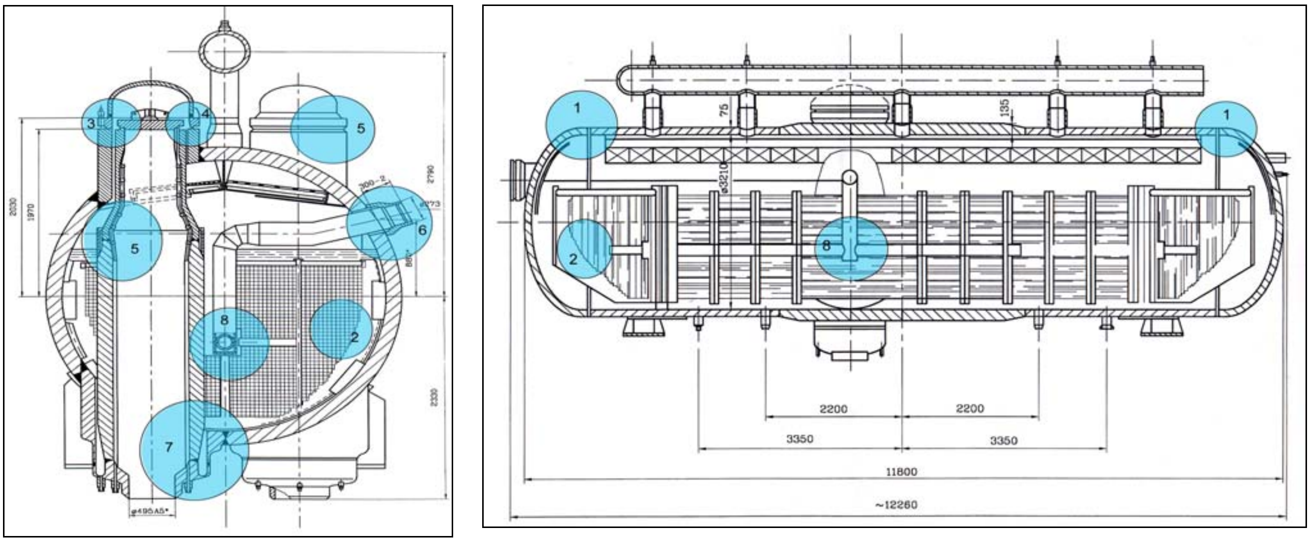

Fig. 1 Potential critical locations in the steam generator

Table 1. Steam-generator ageing processes

Areas susceptible to degradation	Wear	Corrosion/SCC	Fatigue	Embrittlement	Stress relaxation	Erosion/ corrosion
Steam generator wall		+	+	+		
Heat exchanger tubes		+				
Sealing	+	+	+		+	
Flange points		+	+		+	
Primary collectors		+		+		
Feed water nozzle		+	+			
Nozzles of the primary circuit		+	+			+
Feed-water distribution collectors						+

The systematic condition monitoring is focusing on the component locations identified as critical. The maintenance activities can be scheduled according to the monitoring results and the acceptance criteria. The periodic review of the component specific ageing management measures is being performed by a systematic feedback of the operational practice (own experience, experience of other WWER plants and also PWR experience). It is a strong confidence that the ageing management system of the plant with certain development and modification will ensure the safe operation.

A complex technical-economical study for the feasibility of lifetime extension was completed in 2000, which fully confirmed this expectations [2]. The feasibility study was based on the assessment of the plant status, which has been carried out on a representative set (~ 500 items) of SSC. This analysis covered the lifetime-perspectives of SSC, the maintenance, ISI, testing, monitoring practice of the plant, as well as the data related to ageing and degradation processes. It has been found that there is no technical or safety limitation to the 50 years of operation of the Paks NPP.

Findings related to the reactor vessels and steam generators should be dealt with great attention because of their increased significance for extension of the operational lifetime.

REACTOR PRESSURE VESSELS' AGEING MANAGEMENT

As for the reactor vessels of WWER/440/213 at Paks NPP the dominant ageing process is caused by embrittlement of the material due to fast neutron irradiation.

The WWER-440/213 reactor pressure vessels at Paks manufactured by SKODA (Czechoslovakia) represent the second generation of the Soviet designed vessels. Hard efforts were already made during the fabrication to decrease the quantity of the contaminant materials (Cu, P) that basically determines the embrittlement of the wall components. The vessels were made by assembling forged rings using only circumferential weldments. Unlike the earlier Soviet made vessels, the RPV fro Paks NPP were shipped with complex surveillance sets (Crack Opening Displacement COD, CVN Charpy V-notch, tensile, Ne indicators, temperature indicators). The original surveillance sets were irradiated in the first four campaigns, and 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 state new supplementary surveillance chains were placed in the vessel after taking out the original ones. The vessels neutron flux (>0.5 MeV) is calculated using neutron-transport code, validated by measured on site dosimeter results.

Although the vessel wall and the weld have good embrittlement properties, because of their relatively low contaminant material quantity, low-low leakage core configurations are used according to the life time management program, and like this the fast neutron flux could be decreased with more than 30 percents.

The significantly decreased irradiation load not only makes a good base for the operational lifetime extension for 50 years of the vessels, it allows also the reactors' power uprating (~8%) without further impairment of the vessels.

As an example figure 2 shows the trend of the unit No 2 reactor vessel weld transition temperature, marking the temperatures T_k where intervention is needed according to the conservative PTS calculations.

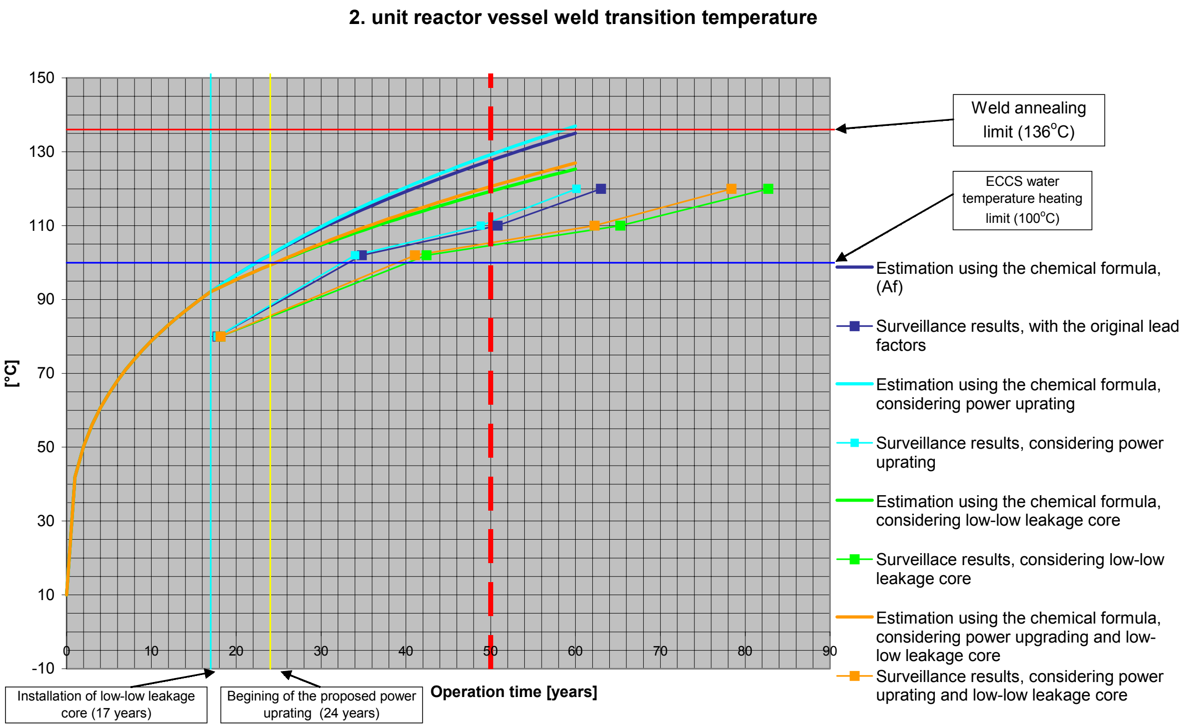

Fig. 2 Unit No 2 RPV transition temperatures

As the figure 2 shows both lifetime extension and power uprating requires only ECCS water temperature heating at the unit No 2 vessel, because the T_k temperature in the extended life time does not expected to exceed the 136°C limit where e.g. the No 1 vessel of the Loviisa NPP was annealed.

The reactor vessels at Paks NPP are different per units and extending their operational lifetime can be realized under different conditions. The reactor vessels at units 3 and 4 do not require extra measures even for the 50 years of operation. At unit 2 the water in the emergency core cooling (ECC) tanks has to be heated up in order to decrease stress levels caused by pressurized thermal shock (PTS) transients. For this purpose cost-effective technical solutions are available. 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. Annealing is no longer a cost-critical measure and it has been successfully applied at WWER plants (e.g. Finland and Slovakia).

STEAM GENERATORS' LIFE TIME MANAGEMENT

The state of the 24 horizontal steam generators belonging to the four units at Paks, play serious part in the plants' economically feasible lifetime extension. Considering the steam generators' austenitic heat-exchange tubes' the lifetime limiting ageing mechanism is the Outer Diameter Stress Corrosion Cracking (ODSCC). Regarding the experience of the WWER power plants the Primary Water Stress Corrosion Cracking (PWSCC) like failures of the tubes were not yet detected. The current state of the steam generators can be characterized by the plugging rate given in the Table 2 below.

Table 2. Plugged tubes in the steam generators (2002)

Unit	1. SG	2. SG	3. SG	4. SG	5. SG	6. SG
1. (20. campaign)	24	34	2	8	3	0
2. (19. campaign)	56	154	181	162	68	104
3. (17. campaign)	60	42	42	36	90(	15
4. (14. campaign)	10	21	28	29	44	10

According to the designers preliminary analysis the WWER steam generators have more than 15% heat exchange capacity reserves. Assuming the recent plugging trend of the tubes will remain constant, none of the steam generators would exceed the 15% plugging limit of the tubes (it will be <10%) by the end of its 50-year lifetime. Although not all circumstances affecting ODSCC are known, it is evident, that better plugging trend can be expected in the future. The arguments for this are as follows:

- The Ni content of the austenitic SG tubes varies in the range of 9-12% as per manufacturing standard. According to the recent researches results, if the Ni content of the austenitic steel tube is more than 10.5%, the tube is practically not susceptible to ODSCC. Contrary, if the Ni content is less than 10%, the susceptibility is much higher. The ~5600 heat exchange tubes doe not have evenly distributed chemical composition. From the distribution of the Ni content (see figure 3) one can see, that more then 50% of the SG generators tubes are protected from ODSCC by its own Ni content.

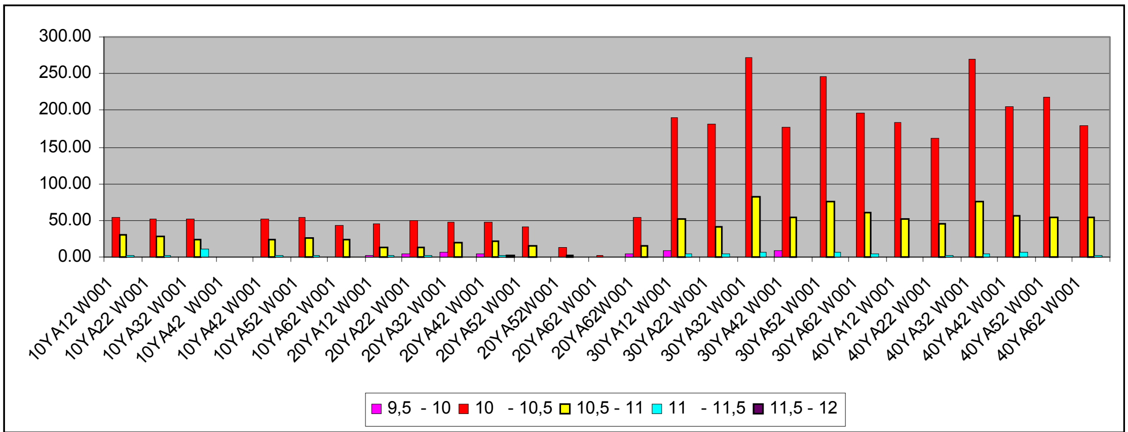

Fig. 3 Distribution of the Ni content of the heat exchanger tubes in the steam generators

- Modification of the secondary circuit water chemistry (increasing feed water pH) and the material composition of the secondary system achieved due to different measures (Cu removed, austenitic condenser tubes, austenitic high pressure pre-heater tubes, other erosion proof modifications, etc.) provide reasonable chance that the ODSCC will slow down in the following operating periods.

It can be expected that the SG at the Paks NPP can be operated during extended lifetime without replacement any of them and also have reasonable reserve for the planned power uprating. However, the ODSCC shall be monitored even in case of high pH secondary water chemistry. Entering of erosion products into the steam generator shall be minimized, for example by means of correct selection of the structural materials during replacement of high-pressure feed-water pre-heaters.

BUSINNESS ASSESSMENT

The business model of the operational lifetime extension includes incomes from electricity generation and sales, direct operational, maintenance costs, and the financing of plant operational lifetime extension programme. The business assessment shows that construction of a Combined Cycle Gas-turbine Plant (CCGTP) to replace the NPP Paks could be reasonable, if during the extended operating time the real electricity price level of the CCGT generation will be below the value of 4.52[1] HUF/kWh. Compared to CCGTP installation the operational lifetime extension of the NPP requires lower investment expenses, and the direct operational costs are also low at nuclear power plants. This result would not be altered by an increase of nuclear fuel prices. On the basis of the net present value criterion, the lifetime extension is reasonable if the electricity price is above of 5.85 HUF/kWh. The project is doubtlessly more economical if the 20-year life extension is considered. The payback of the project is shown in Table 3.

Table 3. Business attributes of the lifetime extension project, 20 years of extension

20-year-lifetime extension	if electricity price, Ft/kWh			
	5,85	6,50	7,50	8,50
Project payback %	8,5	17	20	28

Power uprating is not taken into account in the tables.

REQUIREMENTS FOR LICENCE RENEWAL

In order to keep the units of Paks NPP in operation for a further 20 years over their design lifetime, their operational licence has to be renewed. The first step is to obtain the principal approval for the LR until 2007, then to renew the operational licence in 2012 (taking Unit 1 as example).

The tasks of the licensee can be derived from the main safety requirements for extended operation.

- the conditions of the current operational licence (Current Licensing Basis – CLB) should always be met in compliance with the valid provisions of law, regulations and rules
- good technical status and performance of the SSC with safety functions should be maintained before and after the expiry of the designed lifetime, the activities, programmes for maintaining the required plant status should be initiated and implemented during the designed lifetime, their effectiveness should be systematically reviewed and evaluated
- during the operation (within or over the designed lifetime) there is no possibility to utilize the safety margins of the SSC by referring to the coming end of the licensed lifetime.

The system of requirements can be met the following way:

(1) maintenance of the required plant status

(2) ageing management of the safety relevant long lived passive SSC's

(3) final resolution of environmental qualification issues and maintenance of the qualified status of equipment

(4) renewal of the FSAR including design base reconstitution and annual updating of FSR.

It is clear that these tasks exist also during the design lifetime under the conditions of the current operational licence. They are requirements formulated in the Nuclear Safety Regulations, ordered and scheduled in authority decrees relating to the PSR and FSAR.

Precondition of licence renewal is that the licensee should demonstrate the compliance with the requirements (1)-(4) already during the licensed operational lifetime. LR affects only the time horizon of the tasks under the points (1)-(4) and gives high priority to the issues related to ageing management in compliance with valid regulations.

The recent updating of the FSAR of Paks NPP has two targets: to comply with state of the art regulation (adaptation of the US NRC Reg. Guide 1.70) and to reconstruct the design basis. Obviously, the reconstitution and documentation of the design basis is unavoidable information for equipment Time Limited Ageing Analysis (TLAA) evaluations. The annual updating of the FSAR is a proper tool for demonstrating the plant safety “as it is”.

[1] 245 Ft ≈ 1€

Licence renewal procedure is focusing on ageing and functionality of passive long-lived SSC. The performance and function of other than passive long-lived SSC can be ensured by proper inspection, testing, monitoring practice, maintenance, reconstruction and replacement. These activities can be optimized via monitoring program. All this is hardly applicable to the long-lived, usually non-replaceable (or replaceable at irrational costs) passive components that can be a real obstacle to operation over designed lifetime.

Partial lack of environmental qualification (EQ) of the electrical and I&C equipment has been identified as a specific WWER issue. After first PSR a programme was launched for re-qualifying the electrical and I&C equipment. Resolution of the EQ issue and maintenance of the qualified status of the equipment are the conditions of CLB. This is a precondition of the extended operation too.

Regarding assurance of required plant status the efficiency of maintenance activities should be assessed in accordance with safety and performance criteria as well. This assessment has to demonstrate the performance and function of safety related active equipment. This allows limiting the scope of LR to the long-lived passive SSC. Such an interpretation of the Regulatory control of the efficiency of the maintenance is a new element in the Hungarian Regulation.

Consequently, for maintaining the proper plant status Paks NPP must have a lifetime management programme consisting of an ISI/S/T system, status-monitoring practice, maintenance, and reconstruction programme, including the ageing-management program as well as the program for maintenance of qualified status. The lifetime management program has to be optimized in respect of the technical content, schedule and expenses in accordance with the status of the plant.

The described methodology based mainly on USNRC practice connected to the "Licence Renewal Rule" and to the implementation of the "Maintenance Rule".

In the system outlined above the PSR has a specific scope and function. This is not a tool for licence renewal, but a licensee self-assessment and reporting obligation. The PSR contains the assessment of the long-term processes and changes in plant status, the changes of the site hazards, assessment of the new scientific results affecting the safety, refreshment of the safety analysis techniques, compliance-check with the modern international requirements, new tendencies in the development of the industry, feedback of experience. The PSR is the source for the identification of the safety upgrading measures.

The PSR, FSAR and the LR requirements together with the special preconditions (issues) determine a "tailor-made" regulation that is easy to use for the Paks NPP WWER Units and harmonise with the existing Hungarian and International Law-system

TASKS OF THE LICENCE RENEWAL PREPARATION PROJECT

NPP Paks launched a Project for the preparation of the LR of the units. Between 2003 and 2006 the LR Project has to develop the documents necessary for the application for in-principle approval of the extended operation over designed lifetime. The preparation, establishment and licensing of the extended operation is a complex task that can be resolved by co-operation with Hungarian technical supporting institutions and with consideration of foreign experiences. From technical and licensing point of view the project tasks are interrelated with the power uprating project and with FSAR renewal.

The main tasks of the Project are to

- identify the scope of the SSC, which are essential for safe operation of the units over designed lifetime,
- determine the ageing processes which should be managed in relation to safe operation over designed lifetime,
- estimate the status of the systems, structures and components within the scope of the licence renewal,
- evaluate ageing management programs and, if necessary, modify them, or develop and initiate new programs,
- determine the scope of time limited safety and ageing analyses which are adequate for licence renewal
- evaluate validity of existing safety and ageing analyses for the extended operation

The LR has to be aproved by the Environmental Protection Authority and also by the authority for protection of water resources too. These approvals have to be attached to the application for the in-principle approval of the extended operation. In the implementation of the LR Project the critical element is the environmental licensing. It defines the critical path. The environmental impact study to be performed will be based on the site evaluation program, already in process. Very important and politically sensitive step of the environmental licensing is the public hearing.

Besides the core tasks the LR Project has to provide support e.g. for the implementation of the new rules related to monitoring maintenance efficiency. The Project provides information for the development of the plant life management program. An important element of this is the Programme for Development and Investment of 2003-2007. The LR Project involves with the sections of the Company responsible for human resources management, training and PR activities so that they consider the preconditions and expectations of the 30+20 years of operation. The LR Project maintains close coordination with the Power Uprating Project and the FSAR Renewal Projects.

The International Atomic Energy Agency supports the Hungarian program of LR with a Technical Cooperation Project. It is important to involve the IAEA and other international forums for the international acknowledgement of the Paks NPP’s goals and results.

CONCLUSIONS

For the extension of operation time over the designed lifetime at Paks NPP the performance and function of the equipment and components for the extended lifetime must be verified. A Project has been launched to prepare the Licence Renewal. This Project will demonstrate and verify, in a way transparent for the Hungarian and international public opinion, that the Nuclear Power Plant Paks, can be operated at least up to 50 years in accordance with the nuclear safety and environmental regulations and the international standards. Nuclear Power Plant Paks will stay a safe and clear source of the electricity generation.

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