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SAFETY IMPROVEMENT OF PAKS NUCLEAR POWER PLANT

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1. Origin and history of the safety upgrading measures

The first ideas about safety upgrading of Paks NPP were born in the very early years of operation. The supplier of the VVER reactors made several suggestions in 1985 and 1987 to improve the design safety of the plant. The lessons learned from the Chernobyl accident were related more to the operational safety area.

An important source of upgrading ideas was the operational experience coming from foreign nuclear plants (IAEA event reporting, information from the VVER-440 Club). Paks-specific suggestions were defined during the numerous independent reviews of the plant (see table 1), both in operational and design safety area. The comprehensive analytical review of the Greifswald units performed by GRS was also a valuable source of information. Naturally there was a need to correct the unsuitable design solutions recognised during the operation of our own units.

As result of this input the first safety upgrading measures were completed in the early 90s:

- replacement of steam generator safety valves and level control valves;
- reliability improvement of the electrical supply system;
- modification of protection logic: trip of both turbines and subsequent reactor trip after loss of all feed-water pumps;
- enhancement of the fire protection;
- construction of full scope Training Simulator.

2. Prioritisation of the safety upgrading measures

In the early years of the safety upgrading program there was no real prioritisation among the different measures. New ideas were added to the list of safety upgrading items, and the completed measures were deleted. The safety upgrading activity was a voluntary exercise of the plant operator.

As the list of safety upgrading items expanded in the early 90s and the need for funding was growing, it became obvious that prioritisation among the different items is inevitable. The first effort in this direction was the Advanced General New Evaluation of Safety (AGNES) project, launched by the Hungarian Atomic Energy Commission in 1991. The project had to evaluate to which extent Paks NPP satisfied the current international safety requirements and had to help in determining the priorities for safety upgrading measures. The project was completed in 1994 with the conclusion that though Paks NPP basically satisfied the international safety expectations, several safety upgrading measures should be performed to reach a fully acceptable safety level. The AGNES report defined priorities for the different safety upgrades based on probabilistic safety assessment. [1]

The safety upgrading program of the Paks NPP became legally binding, when the Hungarian nuclear legislation introduced the idea of periodic overall safety re-assessment of the nuclear units. The systematic safety re-assessment has to be performed in ten year intervals. The review has to incorporate the assessment of the actual physical condition of the plant, equipment qualification, safety analysis, ageing and residual lifetime assessment, safety performance and reliability indicators, back-fitting of experiences from other NPPs and research findings, human factors, plant procedures, organisation and administration. The safety review has to make a conclusion in each of the above areas, whether the situation of the plant fulfils the requirements defined by the Hungarian Nuclear Safety Inspectorate (NSI) or not. In case of non-conformance a corrective action has to be proposed along with deadline of implementation. The final report concerning unit 1 and 2 of Paks NPP was submitted to NSI in 1997, containing 84 corrective actions. NSI added an other 14 corrective actions, and granted operating licence to unit 1 and 2 until 2008. The timely implementation of the most important 23 corrective actions serves as condition for validity of the operating licence, so now the upgrading program has a mandatory schedule. [3]

3. Design safety upgrading measures executed in recent years

The event sequences addressed by measures 3.1-3.5 had been the most important contributors to core damage. As a result of implementing these measures in 1996-1998 with overall cost of 15 million USD on all four units, the core damage frequency decreased from 5×10^{-4} to 4×10^{-5} 1/year. As an other result, the core damage frequency has no more such dominant event sequences, so the future safety improvements will be less cost-efficient.

3.1. Relocation of steam generator emergency feed-water supply

The emergency feed-water pumps of steam generators earlier were located in the turbine building, in a position vulnerable to a fire or seismic event. The piping of the system was routed along the main feed-water and steam lines involving the danger of high energy line break. The pumps have been relocated to a new, protected position under the localisation (bubble condenser) tower, and the piping has been re-routed via the primary building. The part of the system inside the containment including containment penetrations remained unchanged.

3.2. Emergency gas removal from the primary coolant system

In order to eliminate the danger of blocking circulation in the primary coolant system by gathering of non-condensable gases, new gas removal lines were installed in the highest positions of the primary coolant system: primary collectors of steam generators and central control rod assembly of the reactor. The blow down from the system can be released into the containment area.

3.3. Hydrogen management in the containment

Safety analysis of design bases accidents concluded that hydrogen might be generated in the containment area. 16 appliances of catalytic recombiners have been installed inside the containment of each unit to cope with this situation.

3.4. Protection of containment sumps

The Barseback event indicated that debris of heat insulation may cause clogging of containment sump strainers. A new design of strainer elements elaborated by Imatran Voima has been installed to eliminate this problem.

3.5. Preventing of emergency core cooling system tanks from refilling

The specific design of pipe layout of the ECC system at Paks allowed in some cases inadvertent refilling of ECC tanks during cooling in recirculation mode, what could lead to loss of water available for emergency core cooling. A new line-up has been introduced to exclude this possibility.

4. Design safety upgrading measures under implementation

4.1. Increasing seismic resistance

The seismic characteristics of the plant site were re-evaluated in 1996, and the safe shutdown earthquake with return period of 10 000 years was determined to be corresponding to 0,25 g horizontal ground peak acceleration. In 1998 the seismic resistance of primary coolant loops' main equipment (steam generators and main coolant pumps) was improved by installation of hydraulic dampers on all four units. The program for 1999 is the upgrading of the nuclear island equipment. The enforcement of the building structures and the balance of plant equipment is scheduled with final completion in 2002 for all units. The building structure of the reactor hall can be improved by enforcement of the turbine hall's structure, therefore no additional equipment has to be installed for cooling down the reactors, but the existing residual heat removal system has to be upgraded and protected from damage by the neighbouring systems.

4.2. Containment assessment

The containment structure with passive pressure suppression system including bubble condenser and air-traps is a unique feature of the V-213 type units.

The maximum design pressure in a LOCA event is 1,5 bar over-pressure, but this lasts only for a few minutes, and during the rest of the event sequence the containment pressure is below atmospheric. Therefore the maximum permitted leakrate (14,7 volume-%/day) of these containments can not be compared with Western containments in a straightforward way. Fig. 2 shows the results of the yearly integral leakrate tests of the Paks containments. The different level of tightness can be explained by the quality of construction works being improved from unit 1 to unit 4. We have two programs in this respect, one to decrease the containment leakrate of unit 1, the other to develop alternative method for leakrate measurement in addition to the existing one.

An other concern is the dynamic behaviour of the containment during design basis accidents. Although this has been studied analytically and with model tests, there is a common desire to confirm the results with additional large scale tests. These tests will take place on EREC test facility in Russia as a joint effort for interested parties with funding from PHARE project.

The ability of the Paks containments to withstand static load of pressure is encouraging due to the architect engineering solutions and choice of materials during construction.

4.3. Reactor protection system refurbishment

The nuclear units of Russian design are frequently criticised because of their obsolete I&C systems. Although the low reliability of the individual components is balanced by the redundant design of these systems - taking also into consideration the workload of maintenance and difficulties in spare part supply - we decided to replace nearly all safety related I&C systems: reactor protection, ESFAS protection and load sequencer program of diesel generators.

The equipment chosen as replacement is a digital I&C system (TELEPERM XS) providing multiple redundancy with diverse features of software and physical separation of hardware of different trains. In parallel with replacement of hardware equipment the reactor protection logic was reviewed, and changes were decided to assure diverse physical signals for detecting each postulated initiating event and to eliminate unnecessary input and output signals.

4.4. Emergency electrical supply reliability improvement

In the original design the safety related electrical supply system feeds the ECCS systems from diesel generators regardless whether normal on-site or off-site power is available. This is not optimal for reliability in a high voltage electcal network with multiple loops. Therefore we modify the logic so that the diesels will start only when normal electrical supply is not available. This requires not only modification of the diesel start-up logic, but also to speed-up the start of diesels at unit 1 and 2 to achieve start-up time less than 15 sec instead of the present 30 sec.

4.5. Analysis of internal hazards

Analysis of internal hazards is in progress. The hazards taken into consideration are fire, internal flooding and high energy line-break.

5. Design safety upgrading measures under preparation

5.1. Bleed and feed procedure

To improve the reliability of decay heat removal "bleed" through the pressurizer safety valves and "feed" through the high pressure core cooling pumps will be introduced. To assure the operation of the safety valves in two-phase-flow conditions the valves have to be replaced by a new type. At the moment basic technical design work is going on, installation on unit 1 is scheduled for 2000.

5.2. Reactor over-pressurisation protection in cold state

To eliminate the danger of brittle fracture of the reactor vessel new relief valves have to be installed on the pressurizer. The installation will be done in parallel with the bleed and feed modification, and the control functions of the relief valves will probably be incorporated into the new reactor protection system.

5.3. Treatment of steam generator primary to secondary leak accidents

The present design can cope with break of a single tube of the steam generator's heat exchange surface. The new design basis will be the opening of the steam generator's primary coolant header's cover, which also equals to multiple tube break of the heat exchange surface. This requires high pressure back up boron spray to the pressurizer to quickly reduce pressure and new or requalified steam generator safety valves to assure closure in two-phase-flow conditions. Automatic isolation of the steam generators has to be introduced on "high level" signal with modification of safety injection logic into the primary coolant system in order to eliminate unnecessary operation.

6. Schedule and funding of safety upgrading

The schedule of implementation of safety upgrading measures is determined by the overall safety re-assessment of unit 1 and 2. For the most important measures the schedule is indicated in table 3.

The hardware modifications are costly and work consuming. The safety upgrading program for 1996-2002 is financed from depreciation of the equipment according to the decision in 1996 of the owner (general assembly of shareholders) of the Paks plant. The investment money spent in the period 1996-1998 is shown in table 4, the funds still required in the future are in table 5.

The price of electricity sold by Paks NPP to the Hungarian Power Companies in 1999 is 2,57 cent/kWh. It covers among other items:

- 0,36 cent/kWh depreciation (which is the source of funding hardware safety upgrading modification);
- 0,30 cent/kWh payment to the decommissioning and nuclear waste fund;
- third party nuclear liability insurance;
- property loss insurance;
- 0,35 cent/kWh return on investment (profit).

This level of price allows to cover all costs necessary for the safe operation of the nuclear units and at the same time to maintain economical competitiveness of nuclear power generation in the Hungarian electric energy system.

7. Operational safety improvements

Operational safety is as important as design safety from the point of view of overall safety performance the nuclear units. Paks NPP being the only nuclear plant of Hungary has always been opened to international comparison and advise by inviting independent reviews (see table 1). Many of these reviews were concentrating on aspects of operational safety. As a result much has been done and is still in progress to match internationally accepted good practices of operational safety.

7.1. Safety culture

In 1994 a safety culture improvement program was launched with the methodological and financial support of the IAEA. The program included international information exchange, elaboration of training aids and introduction of self-questioning working attitude. The effectiveness of the program is obvious from comparing the results of the safety culture reviews performed before starting the program in 1994 and after its completion in 1999.

7.2. Training methods and facilities

The importance of simulator training was recognised in the early years of operation, and the plant was equipped with a full scope simulator. The capabilities of the simulator have been improved several times since then, including the introduction of computerised assessment of the operators' performance.

The need for a facility to train maintenance personal became obvious as new generation of maintenance craftsmen began to replace those who had been trained during construction and start-up works. The maintenance training centre created with the financial support of the IAEA utilises not mock-ups but real equipment such as reactor vessel and internals, steam generator, main coolant pump. This facility is used not just for training, but also to test new repair methods before performing them in high radiation environment.

The third element of the IAEA supported model project was the introduction of systematic approach to training, which provides training information in close adherence to the job requirements.

7.3. Symptom based emergency operating procedures

The Paks NPP had made several attempts to develop symptom oriented emergency operating procedures, including an in-house attempt, a joint effort in the VVER-440 Club and activities in the frame of the "Lisbon initiative". Finally we concluded that the desired result can be reached only as product of contracted services. In the project with Westinghouse all instructions with background material will be ready in 1999. In parallel with preparation of the instructions training programs are also being developed. The full set of procedures will be in use by the end of 2001. There are also plans to develop a computerised system to support the implementation of these procedures in the frame of Halden project.

7.4. In-service inspection

Efficient methods of non-destructive material testing are in use to assure component integrity of the primary coolant system. The reactor vessels and the ligament area of the steam generators' primary coolant headers are inspected by the equipment of Siemens.

During the eddy-current examination of steam generators' heat exchange tubes we detected an unexpected degree of degradation in 1997. In 1998 we initiated a six year program to perform 100% inspection of all steam generators. Half of the inspection is done by our own personnel and the other half by INETEC. We believe that replacement of copper alloy tubes of the main condenser by stainless steel allowing higher pH in the secondary circuit will improve the operating conditions of steam generator tubes, because less corrosion and erosion products will be deposited on their surface. In addition higher tightness of the condenser decreases intrusion of impurities from condenser cooling water.

7.5. Fire protection

A fire brigade consisting of 14 firemen are on duty in around-the-clock shift schedule at the plant site. The fire fighting equipment and the building facility is owned by the plant, the staff is available in the frame of contracted services.

The fire detection and alarm system on the units is being replaced by Cerberus equipment with 1 unit/1 year schedule, starting in 1998.

7.6. Ageing monitoring and lifetime management

Assessment of ageing was one of the areas of the overall safety re-assessment of unit 1 and 2 in 1997. Electric cables and iodine filters are examples of equipment where tests are in progress to detect degradation due to ageing.

At the moment no formal program for lifetime extension of the plant is in effect. However we follow a lifetime management program in order to maintain the technical possibility of lifetime extension. Whether it will take place or not, depends on economical and political feasibility and of course on public acceptance at the end of the design lifetime.

8. International assistance in safety upgrading

International co-operation has always been an important factor in the safety upgrading program.

IAEA has contributed to the safety upgrading program in many ways. Firstly, one should mention the regular IAEA services (OSART, ASSET, expert missions) which were required by Paks NPP. The second kind of assistance has been the IAEA VVER Extrabudgetary Program which contributed to safety both by defining the major generic safety issues for VVER-440/V-213 units [6] and also by the co-ordinated efforts in assisting the development of methodology for deterministic and probabilistic analyses. As it has been mentioned above the third major contribution is the IAEA Model Project which resulted in the establishment of the Maintenance Training Centre and is the introduction of systematic Approach to Training.

EU assistance programs PHARE and TACIS and certain bilateral (e.g. with Germany and Belgium) programs started in the beginning of the nineties. In this framework several foreign organisations assisted in the work of the AGNES project, as GRS and Tractebel. The regional PHARE projects assisted in the solution of selected problems of the Hungarian, Czech and Slovakian NPPs. They contribute to the implementation of the safety upgrading program at Paks NPP, though timing problems definitely exist. [4] The PHARE programs provide about 5% of funding of safety upgrading at Paks.

The co-operation of research institutes has had a very positive effect. Hungarian institutes (KFKI Atomic Energy Institute and VEIKI Institute for Electric Power Research Co.) have taken the responsibility for safety analysis both during the re-assessment period and also during the preparation of design modifications. From among the partners in safety analysis one can mention IVO Power Engineering Company (Finland), GRS mbH (Germany), IPSN (France), AEA Technology (Great Britain), Tractebel (Belgium), VTT (Finland). Traditional contacts with Russian organisations (Hidropress and Kurchatov Institute) do exist, however, their level unfortunately does not reach that in the seventies or eighties. Similarly, co-operation with other Eastern European partners is rather scarce (except in joint European efforts).

Regulatory assistance programs of IAEA and EU have a certain relationship with the safety upgrading program, since the safety authority had to face with new challenges. Authorities formed their international association to share the experience and to follow a common approach in handling safety issues.

World Association of Nuclear Operators has made a significant contribution to safe operation of nuclear plants. Establishing direct and open contacts between operators the organisation provided an excellent way to share experience to learn from each other. Forcing the use of new communication techniques it promotes safety culture as well. [2]

9. Conclusion

As conclusion I would like to quote the WENRA report on nuclear safety in EU applicant countries:

> "It is expected that after the implementation of planned safety improvements, which are in the design and preparation phase the plant will be able to reach a level of safety which compares well with plants of the same vintage in Western European countries." [5]

10. References

1. Executive summary of AGNES project (safety re-assessment of the Paks NPP), October 1994
2. J. Bajsz, J. Gadó, E. Holló: Safety upgrading at Paks NPP, Science and Technology in Hungary, December, 1997, p. 23-25
3. A. Cserháti: Periodic Safety Review for the Units 1&2 of Paks NPP, WANO MC - VGB Workshop, Hamburg, 15-19 December 1997
4. A Strategic View for the Future of the European Union's Phare and Tacis Programmes, Report by panel of advisors invited by Hans van den Broek, 2 November 1998
5. Report on nuclear safety in EU applicant countries, Western European Nuclear Regulators' Association, March 1999
6. Selected safety aspects of VVER-440 model 213 nuclear power plants, IAEA, 1996

Table 1

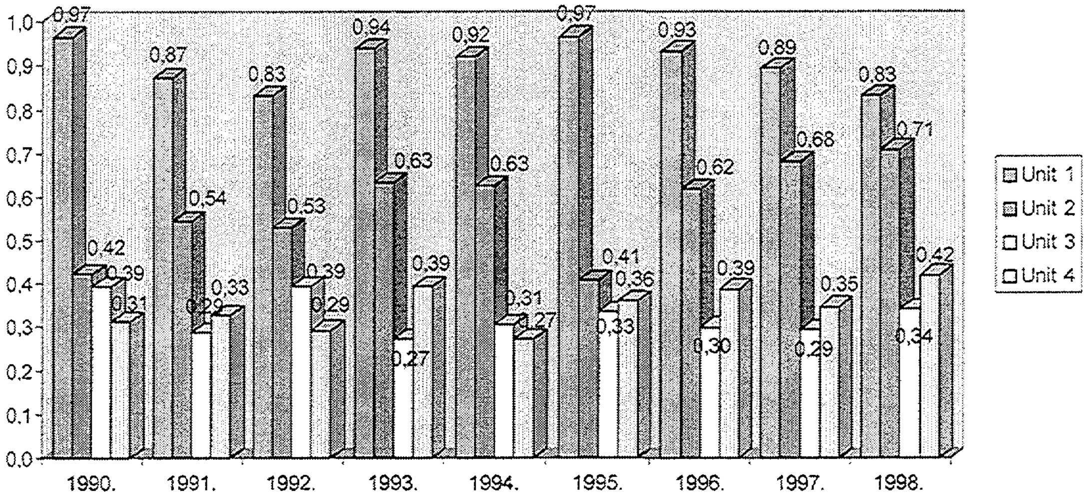
Paks NPP

INDEPENDENT SAFETY REVIEWS

	Year	Subject	Reviewing Team	Man-days
1.	1984	Operations + Maintenance	Group of experts invited by the Russian Supplier	20
2.	1985	"	"	20
3.	1986	"	"	20
4.	1987	"	"	20
5.	1988	OSART	IAEA	195
6.	1990	Operations + Technical Support	Experts from 4 countries invited by Paks NPP	80
7.	1991	Safety design	IVO, Finland	30
8.	1991	OSART Follow-up	IAEA	15
9.	1991	Selected aspects of safety	Committée invited by the Chairman of NAEC	60
10.	1992	Peer Review	WANO	156
11.	1992	ASSET	IAEA	144
12.	1991-94.	AGNES Safety Assessment	KFKI AEKI Atomic Encrgy Research Institute ERŐTERV Power Engineering and Contractor Co. VEIKI Institute for Electric Power Research Co.	120
13.	1995	ASSET Follow-up	IAEA	50
14.	1995	Peer Review Follow-up	WANO	40
15.	1996	Safety Improvement	IAEA	80
16.	1996	Overall Safety Assessment	Paks NPP and contractors, Review by Hungarian Safety Inspectorate	20000
17.	1997	Technical Review	Nuclear Insurance Pools' Engineers	55
18.	1997	Quality Assurance	Blayais NPP	30

Fig.2

Results of integral containment tightness tests at Paks NPP



Leakrate related to the maximum permitted value (14,7 volume-%/day)

Table 3

Safety upgrading measures of Paks NPP

	Measures		**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
1.	Protection of containment sump against clogging	Unit 1		■					
		Unit 2	■						
		Unit 3		■					
		Unit 4.		■					
2.	Hydrogen management in the contain-ment	1.		■					
		2.	■						
		3.		■					
		4.		■					
3.	Preventing the refilling of ECCS tanks	1.		■					
		2.	■						
		3.		■					
		4.		■					
4.	Installation of protection against loss of off-site power (disconnection relay)			■					
5.	Improvement of spent fuel pond cooling circuit's reliability	1.			■				
		2.	■						
		3.		■					
		4.		■					
6.	Relocation of Emergency Feedwater System	1.		■					
		2.	■						
		3.		■					
		4.			■				
7.	Emergency gas removal from the primary circuit	1.		■					
		2.	■						
		3.		■					
		4.			■				
8.	Reactor protection system refurbish-ment	1.				■			
		2.					■		
		3.						■	
		4.							■
9.	Replacement of pressurizers safety valves	1.					■		
		2.					■		
		3.						■	
		4.							■

	Measures		1996	1997	1998	1999	2000	2001	2002
10.	Elimination of the forced loss of off-site power signal	1.				■			
		2.					■		
		3.				■			
		4.				■			
11.	Management of SG primary to secondary leak accidents (PRISE)	1.					■		
		2.					■		
		3.						■	
		4.							■
12.	Earthquake resistance improvement								
	Site seismic hazard revaluation		■						
	Design of structures reinforcements				■				
	Upgrading the seismic resistance of	1.			■				
	coolant loop's equipment	2.			■				
		3.			■				
		4.			■				
	Upgrading the seismic resistance of	1.				■			
	of primary circuit's equipment	2.				■			
		3.				■			
		4.				■			
	Upgrading the seismic resistance of	1.				■			
	structures and BOP's equipment	2.					■		
		3.						■	
		4.							■
13.	Introduction to symptom oriented								
	emergency procedures						■	■	
14.	Containment function verification					■	■		
15.	High Energy Line Break analysis					■	■	■	
16.	Provision of filtered air to the Control	1.						■	
	Rooms	2.						■	
		3.							■
		4.							■

Table 4

Cost of Safety Upgrading Measures, million USD

	1996	1997	1998	Total
Reactor Protection Refurbishment	0.7	1.77	2.99	5.46
Safety Upgrading Measures	1.1	1.68	2.99	5.77
Earthquake Protection	10.9	10.6	6.85	28.35
High pH water chemistry	0.95	8.56	9.70	19.21
Total (including others)	**35.01**	**33.7**	**24.55**	**93.26**

HUF/USD ratio:

1996	150
1997	183
1998	217

Planned Cost of Safety Upgrading Measures, million USD

	1999	2000	2001	2002	Total
Reactor protection refurbishment	12.96	8.93	8.49	11.83	42.21
Earthquake protection	10.04	10.32	8.19	5.07	33.62
Bleed and Feed	4.14	3.32	1.56	1.02	10.04
Primary- to- Secondary Leakage	0.89	1.09	1.06	0.32	3.36
Process computer replacement	1.37	1.69	1.78	1.77	6.61
High pH water chemistry	9.40	7.99	0	0	17.39
Total (including others)	**46.42**	**43.63**	**31.27**	**27.17**	**148.49**

HUF/USD ratio:

1999	235
2000	251
2001	267
2002	282

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