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BACKFITTING OF NUCLEAR POWER PLANT BOHUNICE V1 IN SLOVAKIA

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ABSTRACT

Nuclear power plants in the Slovak Republic generate almost 55% of electricity. The operating organization and the Nuclear Regulatory Authority of the Slovak Republic pay a great attention to safe and reliable operation of four units with VVER 440 reactors at Bohunice site end one in Mochovce side. Engineering and design organizations in cooperation with well known international companies prepare evaluation of safety conditions, safety analyses and projects for the implementation of modifications to upgrade the nuclear safety of the units in operation. A gradual safety upgrading (reconstruction) of the V-1 Bohunice plant has been in progress, a modernization of the V-2 Bohunice plant is being prepared. Simultaneously the commissioning of Unit 2 at the Mochovce plant is being implemented.

INTRODUCTION

Nuclear power plants have a significant position as a source of electricity in the conditions of the Slovak republic. Five units of the VVER 440 in operation type generate 55% of electricity. Both the operating organization and the Nuclear Regulatory Authority pay permanent attention to their safe and reliable operation. The experience of Slovak engineering and design organizations and of the operators accumulated during long term operation together with the know how and experience of experts in well known companies in Western Europe have been used when evaluating, planning and implementing the activities related to the upgrading of safety standards of units in operation. A gradual safety upgrading (reconstruction, backfitting) is going on currently of the V-1 Bohunice plant, a modernization of the V-2 Bohunice plant is being prepared, and the commissioning of the Mochovce Unit 2 is in progress. The fraction of nuclear electricity will exceed 60% following the commissioning of Mochovce-2. By the end of 1999, six units of VVER 440 will be in operation.

SAFETY UPGRADING

Plants with VVER 440 operated in Slovakia were designed according to earlier codes and standards being in effect at the time of design development. To ensure a continuous enhancement of nuclear safety, projects for reconstruction and modernization of units in operation on Bohunice site and of units under construction on Mochovce site have been developed and implemented.

Nuclear Power Plant V-1 Bohunice

The nuclear power plant V-1 Bohunice consists of two VVER-440 units with V-230 reactors. Unit 1 was commissioned in 1978 and Unit 2 in 1980. Large experience and knowledge from the operation of previous units with V-230 reactors were incorporated into the V-1 design, which resulted in a higher level of safety and operational reliability of these units. The most significant improvements in the V-1 design were the addition of super emergency steam generation feedwater system, higher capacity of emergency core cooling systems, addition of automatic connection among primary and secondary systems, and a higher level of automatization in the secondary system. The process of increasing the safety level and operational reliability of the V-1 units started immediately after their commissioning. More than 1200 design modifications resulting from the evaluation of operating conditions, operational experience and international recommendations and standards were implemented. The most significant ones are as follows:

Addition of dummy assemblies in order to reduce neutron fluency on reactor pressure vessel and decrease the risk of reactor pressure vessel brittle fracture, reconstruction and addition of operational computer systems, addition of diagnostic systems.

1. *Small reconstruction (1991 - 1993)*

Another significant step in the enhancement of nuclear safety level came following 1990 when a number of both national and international expert missions visited the plant. These expert missions focused on the assessment of the conditions of nuclear safety and operational reliability of the V-1 units. Based on short-term and long-term measures and recommendations resulting from these expert missions, the Nuclear Regulatory Authority issued its Decision No. 5/91 in which 81 measures for further enhancement of the level of nuclear safety and reliability of the V-1 were specified, and the Decision No. 213/92 in which other 14 measures were specified. These measure - the so called Small Reconstruction - were implemented in the period of 1991 ÷ 1993. The domain in which a significant improvement occurred following the Small Reconstruction was a reduction in the probability of a severe accident down to a half (decrease of the probability of reactor core damage from the value of $1{,}7.10^{-3}/a$ down to $8{,}9.10^{-4}/a$ based on a probabilistic analysis developed), a significant reduction of the reactor core damage risk from possible fires (enhancement in the conditions of fire protection which resulted in a drop of the contribution to the reactor core damage probability from the original 30% down to 2%). Another benefit from the Small Reconstruction was a demonstration of an extremely low probability of a break in the reactor coolant system ($10^{-6}/a$) by the application of the „leak before break" method at RCS. In the course of the Small Reconstruction, reactor pressure vessels were annealed at both V-1 units, the leak rate of the confinement was reduced, remote control room for manual shut-down of the reactor and control and monitoring of main unit parameters was established. A number of modifications were implemented in the reactor protection system where qualified sensors were installed. In order to provide two separate redundant essential power supply systems from diesel generators and batteries, a new diesel generator and a new battery were installed. Modifications intended to enhance seismic resistance of buildings, process and electrical equipment up to the level 8 in the MSK64 scale were implemented. By implementing these measures, the V-1 plant, with regard to the probability of core damage, got among the plants whose operation is acceptable from the nuclear safety point of view, but continuation of work in this area is necessary.

Financial costs on the implementation of the work related to the Small Reconstruction at the V-1 plant were 2,0 billion Sk (USD 67 million).

2. *V-1 gradual reconstruction (safety upgrading 1996 ÷ 2000).*

Subsequent operation of V-1 after 1995 was conditioned by the regulatory Decision No. 1/94 by a gradual upgrading of nuclear safety up to a level accepted internationally. The Decision defines main goals of the Gradual Upgrading:

- Establishing of two separate safety systems in the mechanical, electrical, measurement and control parts;
- Modification of the systems providing safe and reliable management of both design and beyond design basis accidents (emergency core cooling, improvement of integrity and strengthening of confinement);
- Modification of the reactor control and protection system in such a way that the probability of its failure was less than 10^{-5}/a;
- Enhancement of safety and reliability of the mode with residual heat removal during a seismic event (bleed and feed at secondary system) and in the case of a loss of functions of secondary system (bleed and feed at primary system);
- Increase the reliability of essential power supply from diesel generators and from batteries;
- Enhancement of seismic resistance and fire safety.

The Siemens company which won an international bidding process developed these basic goals for the Gradual Upgrading into the so called Basic Engineering (BE). For the implementation of the Gradual Upgrading in line with the BE, Rekon consortium was established consisting of Siemens and VÚJE. The implementation of the Gradual Upgrading is scheduled for the time period of 1996 ÷ 2000 with the budget of 8,5 billion Sk (USD 200 million). By the implementation of the Gradual Upgrading, the compliance with the following goals is intended:

- Management of the newly defined design basis accident with a loss of coolant through an opening of ϕ200 mm in a conservative manner, and management of a beyond design basis accident with a loss of coolant through an opening of ϕ500 mm in a best-estimate way;
- Confinement integrity and consequence mitigating systems have to ensure in such a way that dose equivalents of 50 mSv at whole body and 500 mSv at thyroid in the monitored vicinity of the plant are not exceeded in the event with coolant loss through ϕ200 mm, and dose equivalents of 250 mSv at whole body and 1500 mSv at thyroid are not exceeded for a discharge through ϕ500 mm by best-estimate methods;
- Reliability of safety system actuation on demand shall be 10^{-3}/a as a minimum;
- Probability of a severe core damage should the not exceed 10^{-4}/a;
- Reliability of the reactor protection system on demand shall be at least 10^{-5}/a;
- Seismic strengthening of all safety systems up to 8^0 MSK specifically for horizontal acceleration of 250 cm/s^2 and for vertical acceleration 130 cm/s^2.

The works in the Gradual Upgrading are split into the reconstruction of the following parts:

- Safety relief valves at pressurizer;
- Super emergency SG feedwater;
- Main steam dump stations to atmosphere;
- Power supply from Madunice hydro power plant;
- Emergency core cooling system;
- Fire safety;
- Electrical systems;
- I&C systems;

- Confinement spray system;
- Bubbler-condenser confinement system;
- Confinement integrity;
- Confinement strength;
- Ventilation;
- Essential service water system;
- Ventilation systems;
- Seismic improvements.

The Gradual Upgrading of the V-1 represents a technically and organizationally complex process, which requires an excellent cooperation of the main supplier, subcontractors and investor. With regard to a large extent of the upgrading, the model of suppliers is very complex. The intention was to engage Slovak organization as much as possible in such a way that they provide approximately 60% of outputs from the supplies for the Gradual Upgrading. The VÚJE institute as a vendor and a member of the Rekon consortium provides the development of design documentation, implementation and coordination of installation activities in mechanical, electrical and civil construction areas. An important factor affecting the quality and deadlines of work implementation is that personnel from the investor are actively involved in the whole process. Bohunice personnel were allocated for the work on this project who work in the group for design preparation, review design and safety documentation, cooperate at the preparation of normal maintenance activities during refueling outage and to the works in the Gradual Upgrading. The personnel from the plant have valuable technical experience and their cooperation in addressing the interrelations between the newly installed advanced technology and that which remain in operation following the completion of the V-1 Gradual Upgrading, is invaluable. In the following part, basic information on important systems upgraded during the Gradual Upgrading of the V-1 units 1 and 2 are shown.

2.1 Pressurizer safety valves (PVKO).

The safety valves at pressurizer prevent an unauthorized excess pressure in RCS. In the course of the Small Reconstruction, pressurizer safety valves were replaced by ones qualified for seismic resistance and for two-phase flow regime of steam and water. The system of pressurizer safety valves, however, was not fully qualified for residual heat removal from the core by feed and bleed procedure mainly with regard to generation of dynamic loading in the case of opening the pressurizer safety valves. In the course of the upgrading, the pressurizer safety valves were equipped with relief valves. For removal of hot water, routing and dimensions of certain pipelines were modified in order to reduce pressure losses. It was verified that the whole system of the pressurizer, i.e. piping, valves, steel and civil structures will meet the increased loading during the discharge of water and steam-water mixture and during a seismic event. The upgrading of the pressurizer safety valve system has been already completed.

2.2 System of super emergency feedwater (SHN).

This system provides a supply of cold water into the secondary sides of steam generators in the event with a failure of both normal and auxiliary SG feedwater systems. The original design consisted of two SHN pumps for two units with pump discharge into the line of SG blow-down and into the line of SG feedwater delivery from normal feedwater pumps. The new design of the SHN system consists of four SHN pumps, with two new pumps added to the original two and in this way a redundant system is established. The discharge of the redundant SHN pumps is connected into a new SG blow-down line for units 1 and 2 and the discharge of the original SHN pumps is connected into the new SG feedwater line, which serves the SHN system only. The SHN pumps have suction from three tanks each with the inventory of 1000 m^3, which provides residual heat removal within 72 hours into the accident. The upgrading of the super emergency SG feedwater system has been already completed.

2.3 Steam dump stations into atmosphere (PSA).

These stations ensure residual heat removal from RCS and unit emergency cool-down in the event with unavailability of the original stem dump stations installed at main steam header. Originally there were two PSAs at the main steam header, which cannot be used following the closure of the main steam line isolation valve or its shut-off valve. The new design consists of PSA, which is installed at the non-isolable section of the main steam line from each steam generator. PSA consists of an isolation valve and a control valve. The isolation valve prevents a SG pressure drop and a subsequent RCS subcooling in the case of a failure of the PSA control valve. PSAs are designed for opening and closing under the conditions of two-phase flow and ensure a possibility to cool the unit down to the temperature corresponding to 0.2 MPa in main steam lines. The upgrading of the steam dump stations to atmosphere has been already completed.

2.4 Electrical systems.

The upgrading of electric power supply systems represents a substantial part of the V-1 Gradual Upgrading. Within the upgrading of electrical equipment, the installed equipment is upgraded or replaced by a new one.

The interconnection of the V-1 plant with the Madunice hydro plant - the so called grid III - provides the power supply for selected components at the V-1 units 1 and 2 in the event of an extraordinary accident situation in the power supply scheme which would result in a complete loss of alternating sources of the unit. In order to ensure an automatic start-up of the hydro plant and of its dedicated generator without external sources of electricity, a diesel generator with the output of 250 kVA was installed at the hydro plant. The hydro generator with the output of 14.4 MW is connected into the power supply distribution grid after approximately 30 minutes since the loss of alternating sources. The water regime of the hydro plant is organized in such a way that continuous power supply for the V-1 plant is assured within 10 hours. The hydro plant represents an autonomous and independent source of electric power supply for selected consumers at the V-1 units 1 and 2. Also the system of vital power supply from batteries has been upgraded with regard to electric equipment. This system provides the power supply for selected consumers in the event with a total loss of alternating sources – black out. The most important components of the system were replaced, namely motor-generator, rectifier and buses by new ones which meets all requirements laid on safety related equipment. This equipment was installed in a new room in such a way that separation and independence of each vital power supply system from batteries is ensured and two redundancies established (2x100%). By the upgrading, system reliability will be improved and ensured. Also the essential power supply system from diesel generator is covered by the program of the V-1 upgrading of electric equipment. This system provides power supply for selected safety related consumers under accident modes in the distribution grid of power supply. In the essential power supply system from DG, the excitation system is upgraded, DG electrical protections are replaced and a new system for DG control is installed.[1] With regard to the extent of replacement of electric equipment, the replacement of 0.4 kV buses is important. This replacement represents a very demanding project from the point of both technical and coordination in relation to cable replacement in such a way that the basic requirement on the establishment of two redundant systems of essential power supply for safety coolant by related drives is met.

2.5 Instrumentation and control system (I&C).

I&C system for reactor protection system (RPS) and the engineering safety feature actuation systems (ESFAS) safety systems as designed in sixties according to the standards in effect at that time is still valid. The main identified I&C issues for safety systems are redundancy, separation, independence, qualification, reliability, interconnection among protection and control functions, priorities of signals, possibility to test, etc. The existing reactor protection system and ESFAS will be implemented based on a modern programmable system. This system makes possible new accident scenarios and modifications of safety systems, complies with qualification requirements, consists of two independent and separate trains, is isolated from process I&C systems and has better diagnostic possibilities. The Siemens KWU as a part of the REKON consortium ensures the design and delivery of new safety related I&C systems based on Teleperm XS.

2.6 Emergency core cooling system (ECCS).

The system provides coolant injection into the reactor core during accidents with a loss of coolant. The ECCS has to meet reliably the following requirements: the system has to have two independent subsystems (2x100%) consisting of a low-pressure part and of a high-pressure part; each subsystem has to be functionally independent in the mechanical, electrical and I&C parts; the system has to be seismically resistant. The original design consisted of six HP safety injection pumps split into two groups. The new design consists four HP SI pumps and two LP SI pumps split into two trains (2x100%). The suction of both HP and LP pumps is from a boron acid tank with the concentration of 12g/kg with the volume of 800 m^3. The common discharge of two HP pumps, as well as the discharge of a LP pump in the appropriate subsystem is connected to the non-isolable part of a RCS cooling independence of redundancies within the unit will be loop. The connection of the two HP pumps and of the LP pump in the other subsystem is the same. HP and LP ECCS pumps thus provide injection into four loops of RCS in the case of an accident. The existing ventilation cooling system, which ensures cooling of the ECCS pump room is supplemented, by an additional cooling system cooled by essential service water. The upgrading of the ECCS system represents one of the most extensive actions in the V-1 Gradual Upgrading.

2.7 Confinement spray system.

This system ensures reduction of pressure and temperature in the confinement following a loss of coolant accident, ensures the establishment of negative pressure in the confinement, ensures absorption of radioactive aerosols from reactor injecting chemical reagents together with sprinkler water. The original design consisted of 3 pumps, 2 coolers and 2 discharge lines of the spray system into the confinement. Besides the above mentioned basic functions, the new design provides for cooling of the 800 m^3 tank and maintaining peak tank temperature of 95^0C. For long term core cooling, it is possible to supply coolant into the cold leg of the loop through an interconnection from the recirculation line of the spray system into the ECCS system. From the hot leg, it is possible to let down the coolant by a let-down line into the boric acid tank with the volume of 800 m^3.

2.8 Confinement integrity.

Separation of the confinement is necessary in the case of an accident at equipment containing fluids with radioactive materials to prevent their release into the environment and ensure their isolation in the confinement. Main attention is paid to ventilation systems where a new recirculation system will be installed, hermetical flaps will be doubled and other modifications carried out. The implementation of the mentioned design measures will increase the safety level and confinement integrity and the probability of a failure in confinement isolation will be reduced.

2.9 Essential service water (TVD).

This system ensures a reliable cooling of safety related consumers during both normal operation and accident situations. The original design of the essential service water system failed to meet all requirements on the system, e.g. with regard to seismic resistance. The new design of the essential service water system will consist of two independent subsystems, which will be separated physically, electrically and from the point of fire protection. The subsystems will be seismically resistant and their performance will be demonstrated under extreme conditions. Each subsystem consists of a pumping station with four pumps and a cooling station with four cooling towers. Two pumps and their associated cooling towers in a subsystem are supplied electrically from unit 1, the remaining two pumps from unit 2. cooling of the ECCS pump room is supplemented, by an additional cooling system cooled by essential service water. The upgrading of the ECCS system represents one of the most extensive actions in the V-1 Gradual Upgrading.

The subsystem supplies cooling water for a half of safety systems of the same redundancy at unit 1 and a half of safety systems of the same redundancy at unit 2.

WORK PROGRESS

The work related to the reconstruction (safety upgrading) of each out of 16 functional process (technology) systems has been implemented in the course of extended outages for maintenance and refueling at the particular unit. The normal unit outage duration (approximately 40 days) is extended up to 80÷144 days according to the scope of the reconstruction work planned. The reconstruction work is carried out in parallel with the standard work during the unit maintenance outage. This philosophy of implementation of the gradual reconstruction imposes high requirements on the coordination of activities related to the reconstruction of particular process systems and of standard activities during outages.

Unit 2 outage is being prepared and in the course of the outage the work will be implemented mainly in the area of electric equipment (replacement of distribution boards for the operational control of diesel generator) and the work on the installation of new ventilation systems.

The contract between the Slovak Electric (SE) utility and the Rekon consortium is framed as a comprehensive document, and that is the reason why not only parts of design documentation for the particular functional process systems are developed in the course of the process of documentation preparation for the gradual reconstruction, but also lists of safety-relevant equipment according to the regulation No. 436/1990 and new or modified operating procedures for the system under reconstruction.

During each phase of the reconstruction, the Rekon has to update parts of the Safety Analysis Report. In order to ensure reliable long-term operation of the newly installed equipment and to demonstrate its compatibility with the older one, the Rekon has to develop also programs of pre-comprehensive and comprehensive tests. In the course of these tests, the supplier together with plant staff test all equipment functions and only after that the equipment is handed over to the licensee for use.

It is especially important that the installation of equipment is carried out exclusively by Slovak firms under supervision and with coordination of an implementation group of the VÚJE Trnava Inc. staff. Within the Rekon consortium, the VÚJE assures the coordination in preparation of technical solution of the reconstruction of the particular system and is responsible for both schedule and technical issues in the development of designs in both construction and electric work. The VÚJE has developed also particular parts of design documentation, operating safety documentation, and coordinates the activities of subcontractors within the supply system accepted.

With regard to the scope of reconstruction and the amount of functional process systems reconstructed, the supply system is a complex one. The total coordination within the particular systems and the coordination among systems require excellent coordination with subcontractors and operating staff.

The gradual reconstruction of the V-1 Bohunice unit will be completed by the implementation of remaining projects in the course of the refueling outage at the Unit 2 in September to December 1999, i.e. the work on this units will be completed, and on the Unit 1 during the outage in January to May 2000. This means that only reconstructed units at the V-1 Bohunice plant with V230 reactors will be in operation in 2000 and the implementation of the work at all V-1 systems will be completed.

In line with the recent proposal of Slovak government in the field of concepts of future development of power industry in the Slovak Republic, the operation of the reconstructed V-1 plant is considered till 2010. However, the approval of the operation is conditioned by extending the V-1 operating license by the Nuclear Regulatory Authority (ÚJD).

The regulatory body in cooperation with the IAEA after the completion of the gradual reconstruction will analyze and assess the compliance with the tasks and criteria set for the gradual reconstruction.

The efforts of the licensee to assure the acceptable level of nuclear safety for the nuclear power plant with V230 reactor and for other units with V213 reactors was acknowledged at the international level, too.

CONCLUSION

In the final report from the conference organized by EU, OECD and IAEA held in Vienna on June 14-18, 1999 dealing with safety upgrading of reactor in Eastern Europe, the implementation of measures at the V-1 Bohunice was rated as an example of the safety level which should VVER 440/V230 reactors achieve. This project should provide a pilot project even for other VVER plants and the V1 Bohunice is the first plant with VVER reactor at which digital control equipment was installed, approved and commissioned. This fact reconfirms that the combination of Western control equipment with Russian reactor technology is possible and does not result in any problems (Loviisa, Finland).

The gradual reconstruction of the V-1 Bohunice with V230 reactors represents a comprehensive reconstruction of safety-related systems and equipment. Following its completion, the units will be operated with a safety level accepted internationally.

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