

Bohunice Nuclear Power Plant Safety Upgrading Program

Alexander Tóth, Ľudovít Fagul'a,

Bohunice NPP, 919 31 Jaslovské Bohunice, Slovak Republic

1. Abstract

Bohunice Nuclear Power Plant generation represents almost 50 % of the Slovak Republic electric power production. Due to such high level of commitment to nuclear power in the power generation system; a special attention is given to safe and reliable operation of NPPs.

Safety upgrading and operational reliability improvement of Bohunice V-1 NPP was carried out by the Bohunice staff continuously since the plant commissioning. In the 1990 - 1993 period extensive projects were realised. As a result of "Small Reconstruction of the Bohunice V-1 NPP", the standards of both the nuclear safety and operational reliability have been significantly improved. The implementation of another modifications that will take place *gradually* during extended refuelling outages and overhauls in the course of 1996 through 1999, is referred to as the **Gradual Reconstruction of the Bohunice V-1 Plant**. The general goal of the V-1 NPP safety upgrading is the achievement of internationally acceptable level of nuclear safety.

Extensive and financially demanding modification process of Bohunice V-2 NPP is likely to be implemented after a completion of the Gradual Reconstruction of the Bohunice V-1 NPP, since the year 1999. With this in mind, a first draft of the strategy of the Bohunice V-2 NPP upgrading program - based on Probabilistic Safety Assessment consideration - was developed.

A number of actions with a general effect on Bohunice site safety is evident.

All these activities are aimed at reaching the essential objective of Bohunice NPP Management - to ensure a safe, reliable and effective electric energy and heat generation at the Bohunice site.

2. Energy Strategy of Slovak Republic

2.1 General Overview

The Updated Energy Strategy of Slovak Republic (Ministry of Economy of SR) provides an analysis as well as a solution, at a substantially higher level, of ways to meet the power demand by the year 2010 and of distribution of sources within the Power System as far as the stability, dynamic performance, and operational economy are concerned. The primary energy resources demand forecast is based on the expected development of the Slovak economy and is expressed in terms of the Gross Domestic Product (GDP) development. It also evaluates the fulfilment of international obligations of the Slovakia in the field of environmental protection.

The power generated by the nuclear power plants represents almost 50% of the Slovak Republic electric power generation. Due to such high share of nuclear power sources in the overall power generation system, a special attention is given to a safe and reliable operation of the existing NPPs. Therefore, a

gradual reconstruction of the Bohunice V-J NPP is essential to maintain their operational service life. Commissioning of the Units 1&2 of the Mochovce NPP (WWER 440/V-213) becomes a key environmental issue and a strategic concern for meeting the future power demand.

Strategic target of the Energy Policy is a supply of fuel and energy for all consumers. The following restrictions should apply:

- * safe and reliable operation of all power sector energy resources
- * acceptable international safety level of nuclear power plants
- * minimised power generation costs and ecological impact
- * safe and reliable power transmission to the consumers
- * efficient power consumption in the process of power generation, transmission and utilisation.

2.2 Current Power Production Base of Slovak Republic

The development of power production base structure in the former Czechoslovakia back to the sixties can be described as follows:

- * increase in the proportion of the thermal power production sector in the 60-ties and 70-ties
- * beginning of a nuclear energy deployment in the 70-ties with an extensive development in the 80-ties at Bohunice and Dukovany sites
- * growing power consumption up to the year 1990 followed by a decrease in the beginning of the 90-ties due to economy transformation process.

The 1990-1995 Slovak Republic power production and consumption diagram highlights the following:

- * indispensable role of the nuclear energy sector in power production base represented almost by a 50% permanent share in the power generation
- * increased power generation from hydro power sector in 1993 as a result of a successful commissioning of the Gabčíkovo Hydro-Power Plant
- * permanent decline of power generated in the thermal power production facilities
- * distribution of electric power sources in Slovakia in 1995:
 - * Nuclear energy 42%
 - * Thermal energy 23%
 - * Hydro energy 19%
 - * Others 11%
 - * Imports 5%

Current status of the main power producer in Slovak Republic - Slovenské elektrárne (SE), Joint Stock Company, production facilities:

- * fossil fuel thermal power stations at NOVÁKY (ENO) and VOJANY (EVO) Unit 1 are approaching the end of their operational service life. To keep these plants operational would require extensive reconstruction,
- * EVO Unit 2 power plant's service lifetime will expire in the year 2005,
- * certain part of the hydro power plants installations have reached the end of their operating life and a their capacity depends on hydro-geological conditions.

2.3 Energy Sector Development Forecast

In order to make a power demand forecast, knowledge of the most likely future development of the relevant macroeconomical parameters, such as the gross domestic product (GDP), the structure of the economy, the purchasing power parity and the Slovak currency exchange rate is essential.

The power consumption is affected primarily by the rate of the GDP development. In GDP development forecast, an average annual growth rate of 2,89% is expected until the year 2010, what is a figure within the range (2,4 to 3,8%) of the anticipated world economy growth rate (an actual 1994 growth rate was 4,8% and 1995 - 7,4% in Slovakia). The branch structure development over the 1995 - 2010 period assumes a slow decline of the share of industry in the GDP generation.

In the power sector, several alternative power generation studies have been produced. The first **alternative** assumes a completion of four units of the Mochovce NPP (4 x WWER 440/V-213) and complementing the lacking electrical capacity by the combined-cycle resources and by imports. The **second alternative** assumes a substitution of the Mochovce NPP Units 3 and 4 capacity (2x 440 MW) by a thermal power plant fluid-technology-boiler combined cycle. Both alternatives equally assume implementation of the planned refurbishment of the Vojany and Novaky.

The Energy Strategy of the SR by the year 2005 assumed in the basic alternative a completion of the Mochovce Nuclear Power Plant, a **gradual reconstruction and backfitting of the existing NPPs**, gradual decommissioning of the Bohunice V-1 NPP as well as Novaky Units 3 and 4, along with an increased use of the hydro-power potential and a significantly higher usage of natural gas for power and heat production.

All studies show a capacity shortage in power production system in Slovak Republic. Any delay in the commissioning of the Mochovce NPP as well as in reconstruction of other power sources that have reached the end of their service life brings us fast to the date when the system operation becomes **unreliable**. Thus the commissioning of all four nuclear units at Mochovce becomes a key issue from the point of view of both environmental protection and power production in the future. The economic viability of the completion Mochovce units has been assessed and confirmed by several studies, despite relatively high costs of the project.

2.4 Involvement of SLOVENSKÉ ELEKTRÁRNE in International Co-operation in Power Distribution

The energy systems of the Poland, Hungary, Czech Republic and Slovak Republic have been interconnected within the East European energy system - Central Dispatch Organisation (CDO PES) since 1962. Due to an energy deficiency in the former Soviet Union countries in 1993, the CDO PES was split up into three unsynchronized operating systems.

Establishment of a regional club of energy systems of the Czech Republic, Hungary, Poland and Slovak Republic named CENTREL on 11 October 1992 in Prague allowed an increased co-operation within this group and development of mutual contacts with West European countries associated in the Union for Co-ordination of Production and Transmission of Electricity (UCPTE). A catalogue with technical and managerial measures, to be implemented in CENTREL to meet the goal - the synchronised operation of the UCPTE + CENTREL systems, was issued. A schedule of demanding efforts to meet the set of conditions until the year 1997 was prepared.

A status review of the measures implementation in September 1993 and positive results opened a potential for an accelerated interconnection of the energy systems by year-end 1995. After a successful testing preparation the UCPTE General Committee in Zurich issued on 28th September 1995 an agreement to synchronise the both grids. Final connection of the Western and Central European energy systems, the UCPTE and CENTREL on 18 October 1995, was done two years ahead of schedule and since that time it works on high level of reliability.

3. Bohunice NPP Safety Upgrading Program

3.1 General strategy

Currently there are four operating units at BOHUNICE Nuclear Power Plant :

- BOHUNICE V-1 Plant - Units 1&2, WWER 440/V 230 , commissioned in 1978/1980
- BOHUNICE V-2 Plant - Units 3&4, WWER 440/V 213 , commissioned in 1984/1985

These units cover the base load range of the Slovak Power System load diagram and represent the most stable power sources in the system. In order to achieve the maximum safety level, reassessment of the safety level of the Bohunice V-1 and V-2 units has been carried out with respect to international standards and philosophy of safety. The operation of the Bohunice V-1 and V-2 plants has been rated by the Slovak Republic Nuclear Regulatory Authority (SR NRA) as safe and reliable.

A number of international and IAEA missions took part in the safety evaluation of the Bohunice V-1&V-2 NPPs since 1990. Suggestions and recommendations of these missions were accepted by the utility and Bohunice NPP management, and a number of them have already been implemented.

General safety upgrading strategy approach at Bohunice NPP takes into account deterministic as well as probabilistic principles, although the probabilistic approach gains the more significant role in recent years. On the basis of combination of both approaches prioritisation and scope of measures to be implemented are taken.

3.2 Bohunice V-1 Plant nuclear safety upgrading

Period since the commissioning until the end of 1993

Safety upgrading and operational reliability improvement was carried out by the Bohunice NPP staff continuously since the plant commissioning. By now, more than 1000 minor or major modifications have been implemented, either by the NPP maintenance staff or by the contractors.

In the 1990 - 1993 period, the following extensive projects have been realised:

- * successful annealing of Unit 1&2 reactor pressure vessels during 1993 annual refuelling outages, carried out jointly by the BOHUNICE staff and the SKODA company
- * installation of a large number of diagnostic systems on technological equipment
- * development of Probabilistic Safety Assessment (PSA) study in co-operation with the Electrowatt.

Based on findings of several international and national safety assessment missions invited by Bohunice NPP in 1990 -1991, the ČSKAE (Czechoslovak Atomic Energy Commission) issued a Decision No.5/91 dated 11th January 1991. This decision lists 81 safety upgrading measures to be taken in different areas. These improvements are referred to as the "**Small Reconstruction of the Bohunice V-1 NPP**". As a result of the "Small Reconstruction", a total cost of which was 2,0 bil. Sk (\$ 67 mil.), the standards of both the nuclear safety and operational reliability have been significantly improved and the core damage frequency has been decreased from $1.7 \cdot 10^{-3}$ /year down to $8.8 \cdot 10^{-4}$ /year.

Current status of the upgrading and plans for the future

In the period of the Small Reconstruction the development of a Safety Report for the Gradual reconstruction has been completed. Based on this report the SR NRA issued the Decision No.1/94 (24th February 1994), in which requires 59 upgrading measures in different areas to be addressed. The development of Basic Engineering of the Gradual reconstruction has been contracted to the Siemens AG.

By the Gradual Reconstruction the Bohunice NPP intends to fulfil the following targets:

a) *deterministic targets:*

- * coping with the new defined maximum DBA (LOCA 2 x Φ 200) by a conservative approach, and coping with BDBA (LOCA 2 x Φ 500) using the Best Estimate method
- * the confinement leaktightness and accident localisation system must assure that dose equivalents (50 mSv for the whole body and 500 mSv for thyroid) are not exceeded in the monitored vicinity of the power plant during DBA LOCA 2 x Φ 200, and 250 mSv for the whole body and 1500 mSv for thyroid during BDBA LOCA 2 x Φ 500 using the Best Estimate method
- * seismically upgraded engineered safety features to withstand 8° MSK-64 (250 cm/s horizontally and 130 cm/s vertically)

b) *probabilistic targets:*

- * safety systems must have failure probability less than 10^{-3} / year
- * Core Damage Frequency (CDF) lower than 10^{-4} / year
- * the failure probability of the reactor trip system should be less than 10^{-5} / year

The substantial upgrading of the following systems and areas are addressed :

- * integrity of reactor coolant system
- * modifications of the emergency core cooling system including residual heat removal in case of a seismic event and provisions for a sufficient boric acid concentration in the reactor coolant system (separation to 2 x 100 %) primary side Bleed and Feed
- * confinement integrity and installation of isolation valves at the confinement boundary pipes
- * confinement strength at maximum overpressure during LOCA 2 x Φ 500 mm
- * backfitting of the accident localisation system to cope with accidents within the confinement
- * hydrogen monitoring and hydrogen recombinators inside the confinement
- * backfitting of the confinement venting system
- * modifications of the sprinkler system (separation to 2 x 100 %)
- * building up the essential service water system for safety related systems
- * electrical systems (motor-generators, diesel-generators, emergency power supply system, internal consumption power supply, power transmission, redundancies of switchboards and consumers...)
- * secondary side Bleed and Feed (emergency feed-water pumps and the steam generators steam dump systems)
- * significant seismic upgrading of the technological equipment
- * fire protection improvements
- * modifications of the ventilation systems.

These measures are provided through contract with the consortium REKON signed on 27th April 1996 and other Czech, Russian and Slovak companies. Consortium REKON was established on 30th November 1995 and consists of Siemens AG company and Nuclear Power Plants Research Institute Trnava.

The general time frame of the Gradual reconstruction is as follows: Basic Engineering of individual systems should have been completed by Siemens by May 1996, detailed design and reconstruction of individual systems will follow. The implementation of the modifications will take place *gradually* during extended refuelling outages and overhauls in the course of 1996 through 1999, which is the origin of the term Gradual Reconstruction. A 65-member team of Bohunice NPP technicians were selected for a full-time program preparation and implementation, with support of 8 co-operating specialists in the project on a part-time basis. The total estimated cost of this extensive upgrading program is 5,5 bil. Sk (180 mil. \$).

By implementation of the above measures achievement of an internationally acceptable nuclear safety level at the V-1 NPP is anticipated.

Results of Bohunice V-1 NPP safety upgrading

- * As a result of Small Reconstruction nuclear safety level and the operational reliability has been improved with the CDF decreased from $1,7 \cdot 10^{-3}$ /year down to $8,8 \cdot 10^{-4}$ / year.
- * A significant reductions of the 24 hour hermetic zone leakage from 5 000 % to 87 % (Unit 1) and 93 % (Unit 2) were achieved in collaboration with Power Installation Research Institute (VÚEZ) Tlmače (Slovak Republic)
- * Extensive Reactor Pressure Vessel Integrity Evaluation Program has been implemented in co-operation with the Nuclear Research Institute Řež (Czech Republic) and Nuclear Power Plants Research Institute (VÚJE) Trnava (Slovak Republic).
- * Successful annealing of Units 1&2 Reactor Pressure Vessels has been carried out during the annual refuelling outage in 1993 by the Bohunice staff and the SKODA Plzeň company, with the technical and scientific support by the Nuclear Power Plant Research Institute Trnava and the Nuclear Research Institute Řež. Herewith a long period of engineering and managerial efforts since 1985 with total costs of \$ 3.5 mil has been completed. To approve the results of the RPV annealing a bulk sampling program is in progress. In co-operation with Rolls-Royce, Ltd. Co. and Nuclear Power Plant Research Institute Trnava the schedule of RPV bulk sampling during 1996 refuelling outages is prepared.

3.3 Bohunice V-2 Plant nuclear safety upgrading

Since the commissioning of Bohunice V-2 NPP more than 300 hardware modifications and software improvements have been carried out. As a main result of first comprehensive program for safety enhancement, developed in 1986 and updated in 1987, is implementation of following measures:

- * additional operation display system,
- * redundant in-core monitoring system,
- * pressuriser relief valve,
- * SG level control valves and feedwater outlet collector,
- * reactor coolant system seismic reinforcement,
- * redundant electrical power supply of the 4-th safety system,
- * new logic of Emergency Diesel Generator start up and loading,
- * replacement of generator and 0.4 kV breakers, DC batteries, emergency electrical power supply, 6 kV and 0.4 kV electrical protections and penetrations,
- * fire protection improvement,
- * new Engineered Safety Feature Actuation System - ESFAS (1 train),
- * high pressure air compressors replacement.

Probabilistic approach has become a basis for any further upgrading considerations also at V-2 NPP. It is based on PSA studies produced by Bohunice experts in co-operation with the Nuclear Power Plants Research Institute Trnava and RELKO, Ltd. The PSA methodology was reviewed, approved and highly valued by the IAEA Peer Review Mission in January 1995 in terms of the input database and in terms of technical approach. Calculated CDF based on Unit 3 PSA model is $6,41 \cdot 10^{-4}$ / year. This result in accordance with the PSA studies of Dukovany NPP and Paks NPP (Hungary) taking into account the fact that PSA studies of both of these plants do not include internal fires (turbine hall) and internal floods initiating events. Implementation of symptom-oriented emergency operating procedures (EOP) and emergency feed water system modifications should decrease the CDF to $7,84 \cdot 10^{-5}$ / year. The strategic probabilistic goal of the Bohunice V-2 NPP safety upgrading program is to reach the CDF value of 10^{-5} / year.

There are two lines of safety upgrading process of Bohunice V-2 NPP running:

- * short term program (1996 - 1999)
- * long term program (1999 - 2004)

Short term program represents modifications with lower costs, which is possible to implement while Gradual Reconstruction of V-1 NPP is running. Following projects are prepared:

- * seismic reinforcement of technology
- * N₁₆ monitoring system
- * emergency feed water improvement
- * fire protection improvement
- * post accident monitoring system
- * in-core monitoring system improvement
- * RPV, SG venting system
- * ECCS sump protection
- * radiation monitoring system improvement
- * chemical regimes monitoring improvement
- * refuelling machine reconstruction
- * steam and feed water lines integrity evaluation
- * main components residual life time evaluation
- * safety system qualification
- * PSA level 2
- * PSA for shutdown mode
- * risk-monitoring system
- * I&C modernisation
- * Life time management

Long term program includes extensive and financially demanding modifications. This process is under preparation and is going to be implemented after the completion of the Gradual Reconstruction of the Bohunice V-1 NPP since the year 1999. With this in mind, a rough schedule of the Bohunice V-2 NPP upgrading program is as follows:

- 1th. period** New safety evaluation of the Bohunice V-2 NPP - safety deficiencies identification and prioritisation of measures
- 2nd. period** Preparation of Upgrading Safety Design
- 3rd. period** Project realisation and implementation of modifications

Within the first period major steps carried out to date are:

- * development of a Updated Safety Analysis Report after 10 years of commercial operation, currently under final redaction
- * IAEA Safety Review Mission (Sept. 1994) reviewing core design, system analysis, component integrity, I&C, electrical systems and accident analysis
- * safety assessment of Dukovany and Bohunice NPPs by ENAC completed in 1996 within a PHARE Nuclear Safety Regional Program for Slovakia and Czech Republic
- * development of PSA level I

First step towards reassessing of the safety of WVER 440 V-213 design has already been done by the issuing of the report IAEA-EBP-WVER-03 Safety Issues and Their Ranking for WVER 440 Model V-213 NPPs, April 1996. This report provides deterministic means to prioritise safety issues brought to light by the operation of V-213 NPPs or disclosed by numerous missions and audits or internal reviews at Eastern European countries. It should be noted, however, that the first impulse to address the known weaknesses was launched by the V-213 operators themselves. Consequently, all safety issues are perceived as real ones and the operators have expressed commitment to solve them.

The second period has been started recently by the elaboration of the first draft of the strategy of gradual safety upgrading of V-2 NPP, prepared for the plant top management. As already stated, the main goals coincide with safety issues as ranked in the IAEA report.

Two activities, very important from the point of view of safety, deserve mentioning. First of them is the development of symptom oriented EOP with Dukovany NPP in collaboration with Westinghouse

Energy Systems Europe (WESE). This project is in the final stage and should be finished in 1997. Second 2 years project, also with WESE as the main contractor, is a Beyond Design Basis Accident Analysis and Accident Management, launched in February 1996. The project is funded by European Commission under the PHARE Nuclear Safety Regional Program for Slovakia, Czech Republic and Hungary. Bohunice V-2 NPP is for this project a lead reference plant. This project is expected to set up the needed analysis base for the development of plant specific Accident Management Guidelines for V-2 NPP. This PHARE project takes a lead role in Severe Accident Management programme development for the V-213 reactors.

In recent years the frequency of different audits and missions to V-2 NPP has significantly increased. As an example, by the end of the year 1996 V-2 NPP hosts IAEA OSART and WANO Peer Review missions. Both missions are expected to provide valuable findings which will be used as a basis for adoption of further software improvements as the most cost-effective measures.

3.4 Common Safety Related Actions at Bohunice NPPs

As a result of all the above projects a number of actions with a general effect on Bohunice site safety is evident:

- * Quality Assurance Program - the implementation is planned for the 1995 - 1998 period

Personal Training Program - in co-operation with the Nuclear Electric Plc. and funded by the UK government

- * Multifunctional simulator - development of a simulator with international co-operation with CORYS, Belgatom and Siemens, funded by the European Commission
- * Installation of a number of diagnostic systems (LBB)
- * AKOBOJE Site Security System - implemented by CEGELEC-TERMATOM
- * Teledosimetric system - monitoring of the 15 km radius area around the Bohunice site

The schedule for the implementation of nuclear safety upgrading measures at the Bohunice V-1 and V-2 NPPs have to take into account the requirement of a uniform distribution of costs and human resources at Bohunice site in the future. The Bohunice V-1 Gradual Reconstruction is currently the first priority. Major investments in V-2 NPP are realistic after its completion in the 1996 - 1999 period.

4. Conclusions

Safety studies have shown that the basic design of WWER 440 reactors sounds good and provides large safety margins in terms of reliability of the first three barriers: fuel, cladding and primary system boundary. Installation of different sophisticated diagnostic systems and high engineering skills of the Bohunice staff, supported by IAEA and western donors, which took part in many training courses given by top US and European companies provides additional safety enhancement. Assessments have discovered deficiencies, but current safety upgrading program of Bohunice V-1 NPP addresses most of known safety issues and brings the plants to the internationally acceptable level of nuclear safety.

5. References

- Slovak Republic Ministry of Economy - Updated Energy Strategy of SR, July 1995
- Slovenské elektrárne, Joint Stock Company - 1991 - 1994 Annual Report
- Czech and Slovak Power Dispatch Centre - 1992 Annual Report
- Slovak Power Dispatch Centre - 1996 Sources and Consumption Development Study
- Bohunice NPP Quality Policy - January 1996