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VVER 1000-NPP TEMELIN SAFETY UPGRADING

Jiři Fleischhans, Olga Ubra
ŠKODA Praha, a. s.
Prague, Czech Republic

A modernisation program upgrading Temelín plant to meet internationally adopted standard has been implemented during plant design and construction phases. The initial Czech-Russian design (primary system was of Russian design, secondary system was of Czech design) has been extensively modified and adapted to present western safety criteria and operational requirements. The goals are to achieve a high level of safety, reliability, availability and load- following ability. The load-following ability and response to grid frequency changes are very important for the Czech Republic, since the nuclear capacity represents a high proportion of the overall electrical system there.

On the basis of IAEA OSART missions and Halliburton NUS audit results and in compliance with recommendations of The State Office for Nuclear Safety, Czech Power Company and Czech scientists and researchers a modernisation program project for Temelín has been carried out. It includes three main groups of VVER1000 MW unit innovations:

- Modernization and upgrading of the safety and control systems.
- Fuel replacement and modification of the reactor core.
- Innovation of some components of the primary and secondary systems.

The tenders for instrumentation and control system, nuclear fuel, diagnostic system and radiation monitoring system were issued to the world-well known suppliers. The US company Westinhouse Electric Corporation (WEC) was selected to submit contract for the delivery of instrumentation and control system, primary side diagnostic system and for the delivery of nuclear fuel. The contract was signed in 1993.

1. Modernization and upgrading of the safety and control systems.

Initially designed Czech instrumentation and control system is replaced by the modern, reliable and proven Westinghouse Integrated Instrumentation and Control System. Two Temelín units VVER 1000 are being upgraded with the following instrumentation and control technology:

- Primary Reactor Protection System.
- Diverse Protection System.
- Reactor Control and Limitation System.
- Plant Control System including Turbine Control System.
- Post Accident Monitoring System.
- Incore Instrumentation System.
- Unit Information System.
- Main Control Room, Emergency Control Room and Technical Support Center.

Primary Reactor Protection System

The Primary Reactor Protection System performs the following functions:

- Provides an automatic reactor trip when plan conditions reach safety limits.
- Provides for automatic actuation of engineered safety features to prevent or limit the consequences of any accident condition.

- Provides information to the Information System and Post Accident Monitoring System so that these systems are able to alert the plant operators to any abnormal plant conditions.

The Primary Reactor Protection System is divided into three safety trains physically and electrically separated from each other.

The system is environmentally and seismically qualified to operate before, during and after a seismic event. It is testible at power and its design is a subject of independent verification and validation.

Diverse Protection System

The Diverse Protection System reduces the probability of the Reactor Protection System failure. Like the Reactor Protection System the Diverse System performs reactor trip and engineered safety actuation functions. The hardware and software used for Diverse Protection System is different from Primary Reactor Protection System.

The architecture of this system consists of:

- Diverse Reactor Trip System.
- Diverse Engineered Safetyguards Features.
- Main Control Room and Emergency Control Room Diverse Monitoring System and Diverse Manual Controls.

Diverse Protection System as well as Primary Reactor Protection System is environmentally and seismically qualified to operate during seismic event.

Reactor Control and Limitation System

The Reactor Control maintains key process within a range about nominal value and a Limitation System prevents reactor trip for specified initiating events such as:

- Certain disturbances and component failures.
- Drift of selected process parameters outside specified limits.

In response to these events the limitation system provides the following actions:

- Control rod bank withdrawal block.
- Control rod bank insertion.
- Partial reactor trip (a drop of pre-determined number of control rod banks).

The reactor control functions have a direct influence on the primary system. Under normal conditions preference is given to the turbine follow-reactor mode of operation. Reactor control functions must also be able to support the grid requirements, mainly weekly and daily load follow operation.

The Reactor Control System provides the following functions:

- Reactor power control.
- Pressurizer pressure and level control.
- Feedwater control (steam generator water level control).
- Steam dump control.
- Control Coordinator functions.

The Function groups are interconnected by a redundant, fibre optic data highway. Communication over this highway is done in a deterministic way to guarantee that the exchange of vital data is timely and consistent.

The Reactor Control and Limitation System is manufactured from the same main quality hardware modules that are used in the Primary Reactor Protection System.

Plant Control and Turbine Control System

The Plant Control System including Turbine Control System provides the primary and secondary non-safety data acquisition and control functions as well as various start up and shut down sequential controls. The system is integrated by a common communication data highway.

The overall Temelín system architecture is based on a redundant highway with a capacity of approximately 200000 points transmitted at one second intervals to all drops on the ring highway. The system can also transmit data at 0,1 second intervals as required.
Operating, control and monitoring will be perform through the **Main Control Room, Emergency Control Room and Technical support Center.**

The application of the above described microprocessor based digital technology and a high speed distributed data highway results in an upgrade state which meets international safety and design standards.

The part of the WEC deliveries is also **Diagnostics and Monitoring System** for the NPP primary system. The Temelín monitoring and diagnostic system has two parts - **on-line and off-line.**
The main **on-line system** consists of:
- The monitoring and diagnostic system of the primary side delivered by WEC, which includes reactor vibration monitoring system, digital impact monitoring system, material fatigue monitoring system, rotating equipment monitoring system for the main coolant pumps, control rod drive system and leak monitoring of pipe system.
- The monitoring and diagnostic system of the secondary side which covers up diagnostics of secondary system equipment (turbine, generator, feed pumps and feed water heaters).
- Seismic monitoring system.

The main **off-line** monitoring and diagnostic system consists of portable modules of rotating equipment monitoring and valves monitoring.

2. Fuel replacement and modification of the reactor core

The basis for the modifications to the fuel and core design of the Temelin NPP is the demand of improvement of safety, cycle cost and overall economy, and of operational flexibility.
- Each of the VVANTAGE 6 fuel assembly consists of 312 fuel rods, 18 **guide thimbles**, and 1 central instrumentation tube arranged in a hexagonal array 235 mm across the flat of the hexagon.
- The **central tube** provides a channel for insertion INCORE neutron detectors. The guide thimbles provide channels for insertion of either a rod cluster assembly (RCCA), a neutron source assembly, or a discrete burnable absorber assembly.
- The fuel rod design may include **axial blankets**. The axial blankets consist of fuel pellets of a reduced enrichment at each end of the fuel rod pellets stack. Axial blankets reduce neutron leakage axially and improve fuel utilization.
- The fuel rod may include an **integral fuel burnable absorber** (IFBA). The IFBA fuel pellets are identical to the enriched uranium pellets except of the addition of a thin coating (0,25 mm) of ZrB_2 on the pellet cylindrical surface.
- The **bottom nozzle** serves as the bottom structural element of the fuel assembly. The removable **top nozzle** functions as the upper structural component of the fuel assembly. With the top assembly nozzle removed, direct access is provided for fuel rod examination or replacement.
- The **guide thimbles** are the structural members that provide channels for the control rods, burnable absorbers, and neutron source rods. Each guide thimble rod is

fabricated of Zircaloy 4 tubing having two different diameters. The large tube diameter at the top section provides a relative large annular area necessary to permit rapid control rod insertion during reactor trip. The lower part of the guide thimble is swaged to a smaller diameter, which results in a dashpot action near the end of the control rod travel during trip.

- The fuel rods are supported at intervals along their length by **grid assemblies** which maintain the lateral spacing between the rods throughout the design life of the assembly. The structural grid assemblies provide both lateral and vertical supports for the fuel rods. There are 4 different types of grid assemblies:

1 The inconel top grid (without mixing vanes)
2 The inconel bottom grid (without mixing vanes)
3 The zircaloy midgrid with mixing vanes
4 The zircaloy midgrid without mixing vanes

The location of the grids is shown in the Fig. Mixing vanes are used on six of the zircaloy mixgrids to provide additional flow turbulence and Departure from Nucleate Boiling (DNB) margin.

- **Incore components.** Reactivity control is provided by neutron absorbing rods, burnable absorbing rods, and a soluble chemical neutron absorber (boric acid). The boric acid concentration is varied to control long-term reactivity changes.

- Two types of burnable absorbers are used. The first is the IFBA. The second design is a **burnable absorber**, in which the absorption material is contained in separate rodlets that are inserted into the guide thimbles. The stack lengths of the burnable absorbers are reduced to provide a favourable axial power distribution. By eliminating the absorber material from the top and the bottom of the core, the axial power distribution is flattened and total peaking factors are reduced.

- The inner grids, guide thimbles, central guide tubes and fuel rod cladding are made from Zircaloy 4. The use of Zircaloy instead of the stainless steel sufficiently reduces the neutron absorption and improves the neutron economy.

3. Innovation of some components of the primary and secondary systems

Excluding described innovation of basic character there exists the whole range of improvement of technological subsystems and systems:

- The Czech equipment on processing of low-active waste is replaced by perationally approved one from the western countries.

- Main condenser original tubes were replaced by titanium ones to enable using higher pH value of the feedwater. This change increases the lifetime of steam generators, condensers and feedwater pipeline systems.

- The selected valves were replaced to achieve higher reliability and better flow characteristics.

- Some of the electrical auxiliary equipment were replaced to achieve higher reliability and operational properties.

- One of the project changes is also the replacement of the original Russian designed radiation monitoring system. The consortium of Westinghouse Energy System Europe and Sorento Electronics was selected as a supplier for NPP Temelín for remote radiation monitoring system. The system provides continuous remote measurement of liquid and gaseous media throughout the facility. The various types of the process monitors provide radiation assessment of liquid, steam and exhaust streams. Area monitors and continuous air monitors provide remote measurement of conditions in working areas.

Following Halliburton NUS recommendation and licensee requirements, a special attention is devoted to the quality of technical documentation, mainly to safety documentation. Preliminary Safety Analyses Reports is prepared in accordance with State Office for Nuclear Safety regulatory guides that are issued from IAEA recommendation and from international (mainly USA) standards.

The chapters of the Safety Analysis Report concerning control system, fuel and accident analyses will be prepared by WEC.

The list of accidents analysed in Safety Analysis Report has been determined and for each category of accidents the acceptance criteria have been defined. The results of the analysis of complete spectrum of plan conditions and accident scenarios demonstrate, that reactor protection system keeps the plant safe. On the basis of safety analyses the limiting conditions for operating requirements and the protection system setpoints are determined.

Following IAEA mission recommendation PSA Level 1 and 2 are prepared. Halliburton NUS has been chosen to perform this work. The project should be finished by October 1995 with the completion of the NPP Temelín living PSA model.

CZECH NPP TEMELÍN

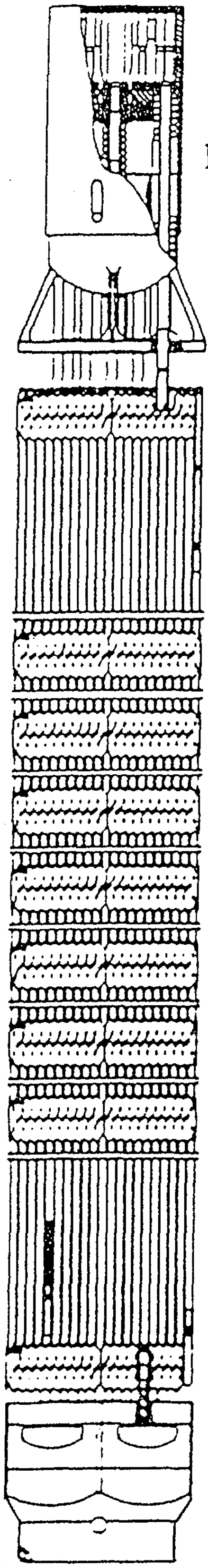
PRESSURIZED WATER REACTOR VVER 1000

REACTOR THERMAL POWER	3000 MWt
NUMBER OF COOLING LOOPS	4
COOLANT PRESSURE	15.7 MPa
REACTOR OUTLET TEMPERATURE	321 °C
REACTOR INLET TEMPERATURE	290 °C
STEAM GENERATOR	
STEAM PRESSURE	6.3 MPa
STEAM TEMPERATURE	278.5 °C
STEAM TURBINE	
POWER	994.5 MWe
STEAM FLOW RATE	1478 kg/s

VVER 1000-NPP TEMELÍN SAFETY UPGRADING

COMPARISON OF ORIGINAL AND CURRENT FUEL ASSEMBLY DESIGN

FEATURE OR PARAMETER	ORIGINAL DESIGN	CURRENT DESIGN
FUEL ASSEMBLY		
OVERALL LENGHT mm	4 570	4 583
OVERALL WEIGHT kg	681	764
MAX. BURNUP MWd/t	47 000	50 000
CENTRAL TUBE MATERIAL	Zr1%Nb	ZIRCALOY 4
GUIDE TUBE MATERIAL DASH POT	 STAINLESS ST. NO	 ZIRCALOY 4 YES
GRIDS No/MATERIAL	15/STAINLESS STEEL	7 /ZIRCALOY 4 2/INCONEL 718
FUEL ROD CLADDING MATERIAL CLADDING THICKNESS mm LENGHT mm ACTIVE LENGTH mm AXIAL BLANKET	 Zr1%Nb 0,69 3 837 3 530 NOT AVAIL.	 ZIRCALOY 4 0,5715 3 889 3630 YES
TOP NOZZLE MATERIAL DESIGN	 STAINLESS ST. FIXED	 STAINLESS ST. REMOVABLE
BURNABLE ABSORB. MAT. DISCRETE INTEGRATED	 CrB_2 IN Al_2O_3 NOT AVAIL.	 B_4C IN Al_2O_3 AVAILABLE IFBA TYPE ZrB_2
CORE COMPONENTS		
RCCA MATERIAL LIFETIME years	 B_4C POWDER 1 TO 5	 B_4C PELLETS Ag In Cd TIPS 10
PRIM. NEUTRON SOURCES	NONE	Cf_2Pd
SEC. NEUTRON SOURCES	NONE	Sb - Be
INCORE DETECTORS DESIGN/MATERIAL	 ORIGINAL/Rh	 WEC/Rh
THERMOCOUPLES	USED	USED FOR PAMS ONLY


REMOVABLE TOP NOZZLE
ZIRCALOY 4 GUIDE THIMBLES
INCONEL TOP GRID
FUEL ROD
ZIRCALOY 4 VANED MID-GRID
ZIRCALOY 4 VANELESS
MID-GRID
INCONEL BOTTOM GRID
BOTTOM NOZZLE