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NUCLEAR SAFETY IMPROVEMENT ACTIVITIES RELATED TO WWER-440 UNITS IN BULGARIA

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Abstract

The systematic evaluation of the deficiencies of the original design of the WWER reactors brought to the development of a Short Term Programme for Safety Upgrading and Modernisation of Kozloduy WWER-440 units. The implementation of this Programme was completed in 1997. The strive for continuos improvement of Kozloduy Nuclear Power Plant (NPP) safety level, the new requirements of the Bulgarian Nuclear Safety Authority and the public concern initiated the development of new Complex Programme for Safety Improvement (PRG'97), now in a process of implementation.

1. INTRODUCTION

Since 1974 the nuclear power in the country started to continuously increase its share in the overall electricity production. This share rapidly increased in the years 1987-1993 with the commercial start up of the two 1000 MW units at the Kozloduy site. Récently the installed nuclear power capacity contribute 30% of the overall installed power capacity in the country and 40-43% of the electricity generation (Table 1).

TABLE 1 - INSTALLED CAPACITY AND GENERATED ELECTRICITY IN 1997

Source	Generated Electricity 1997		Installed Capacity	
	GW.h	%	MW	%
Thermal Power Plant	12 142	**28,4**	**4 940**	**39**
Nuclear Power Plant	17 751	41,4	**3 760**	**30**
Hydro Power Plant [a]	8 243	19,2	2 370	19
Other sources [b]	4 673	**11,0**	1 640	12
Total:	42 809	100	12 710	100

[a] Including hydro pump storage.
[b] District heating + industrial power producers.

At present, Bulgaria has six nuclear power units in operation at the Kozloduy site comprising four WWER-440/230 units and two WWER-1000/320 units, as shown in Table 2.

TABLE 2 - KOZLODUY NPP HISTORY

Kozloduy NPP	Reactor Type	Capacity MW(e)		Construction Started	Initial Criticality	Grid Connection	Commercial Operation
Unit No.		Net	Gross	Date	Date	Date	Date
I	WWER	408	440	01.04.1970	30.06.1974	24.07.1974	24.07.1974
II	WWER	408	440	01.04.1970	22.08.1975	01.10.1975	01.11.1975
III	WWER	408	440	01.10.1973	04.12.1980	04.12.1980	01.01.1981
IV	WWER	408	440	01.10.1973	25.04.1982	01.05.1982	01.06.1982
V	WWER	953	1000	01.07.1980	05.11.1987	29.11.1987	01.09.1988
VI	WWER	953	1000	01.07.1984	01.02.1991	02.08.1991	01.12.1993

Ail units are imported from the former USSR. The load factor of the 440 MW units has been reasonably high (up to 80% or more for unit 4) in the eighties. After 1991, when implementation of the Safety Upgrading and Modernisation Programme, has been initiated, these factors have lowered to 60% or less. The 1000 MW units operate with a load factor determined by the specific requirements of the grid.

2. SAFETY UPGRADING

2.1. Short Term Program

2.1.1. Initial stage

The process of safety enhancement at the Kozloduy NPP has been continuous since the commercial start up of unit 1 in 1974. A lot of improvements have been made, initiated by the Regulatory Body and the plant itself. Some of the safety upgrading activities implemented before the Short Term Program are listed below:

* Replacement of the Pressurizer (PRZ) Safety Valves;
* Seismic upgrading after the Vrantcha earthquake in 1977;
* Design improvement - three trains of the safety systems;
* Design improvement - emergency control room;
* Measures to reduce the neutron flux on the Reactor Pressure Vessel (RPV);
* Measures to reduce the thermal shock of the RPV in case of an accident;
* Replacement of the batteries of the reliable power supply system;
* Replacement of the flammable cables; etc.

2.1.2. Programme development

A systematic analyses of units compliance with the current safety requirements and internationally accepted standards and practices started in Bulgaria in 1990 and have been initiated by the IAEA Safety Review Mission and ASSET expert mission. The IAEA teams evaluated the status of the plant and made a lot of recommendations for safety improvement of units 1 to 4.

The process of plant safety evaluation and qualification of the improvements proposed has been a subject of international attention. This was the basis the following to be organised:

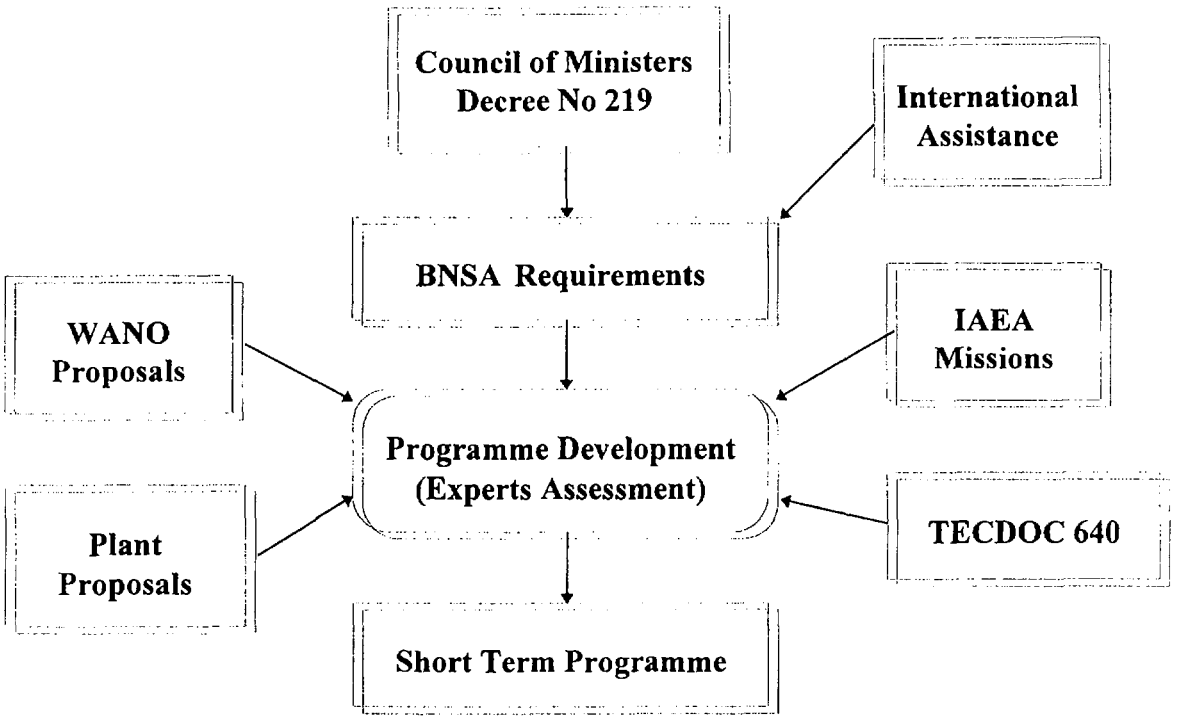
* Technical and financial assistance provided to the Kozloduy NPP in the frame of WANO and PHARE programs;
* Bulgarian Nuclear Safety Authority (BNSA) assistance by the establishment of a Consortium from expert institutes and regulatory authorities from member countries of the European Community including AIB Vincotte Nuclear (AVN) - Belgium; Gesellschaft Anlage und Reaktorsicherheit (GRS) - Germany; Institute de Protection et de Surete Nucleaire (IPSN) - France and UK Atomic Energy Authority (AEA Technology).

A Short Term Program was developed, including implementation of the safety measures into three stages. The program included proposals and recommendations received by IAEA, WANO and made by the plant itself. Measures were reviewed in depth by the Bulgarian Nuclear Safety Authority (BNSA) together with the above mentioned Consortium of Western Regulators and some additional measures were added (fig. 1).

The implementation of the three stage program started during 1991 annual outages of the units. First stage measures were implemented during the planned annual outages of units 1 to 4 in 1992 and 1993.

Within this stage more then 160 major modifications were implemented. The implementation of the measures from the second and third stages started in 1994. Practically, all measures foreseen were implemented until the end of 1997.

FIG. 1 - SHORT TERM PROGRAMME DEVELOPMENT



2.1.2. Programme results

Modifications in some important systems were completed within the framework of the Program. More than 450 major modifications of systems and equipment were implemented and several important new safety systems were installed. In parallel, a lot of studies on safety aspects were performed. Complementary to the technical improvements of the units systems a broad program for improving the operational safety has been implemented in the areas of plant management, operating procedures, plant operation, plant maintenance, training, emergency planing, etc. Some of the results obtained from the Programme implementation are:

(1) Reactor Pressure Vessel - Safe Operation
* 100% ultrasonic inspection;
* annealing;
* templates assessment;
* evaluation of RPV material properties at Units 1 and 2, including samples from RPV metal and study of the embrittlement by re-irradiation of the samples;
* neutron flux monitoring;
* transient analyses;
* protection systems;
* operator actions.

(2) Overpressure Protection
* alarms and interlocks;
* safety justification of PRZ safety valves setpoints;
* installation of additional PRZ safety valves on primary circuit, combined with special computerised control in order to protect the RPV against cold overpressurization and allowing implementation of the primary feed and bleed procedure;
* improved operating procedures;

(3) Reliable operation of primary circuit
* installation of ALUS (system for leaks detection in the non-working compartments)
* justification and certification of the leak before break (LBB) concept applicability for the main primary side pipeworks (a system for acoustic leak detection is installed on all units);
* improved in-service inspection (ISI) scope and techniques;
* destructive test after 100 000 hours of operation;
* stratification monitoring;
* improved operating procedures;

(4) Reliable operation of secondary circuit
* replacement of the Steam Generators Safety Valves;
* installation of Fast Acting Main Steam Isolation Valves on Main Steam Pipelines of each SG;
* installation of Generator Breakers at Units 3 and 4;
* full seismic qualification of main steam and feed water lines;
* ISI of all lines;
* qualification of safety related I&C equipment for steam line break;
* updated set of accident analyses;
* improved operating procedures;

(5) Confinement tightness
* local tests of pressure boundaries;
* full scope testing of the spray system;
* additional compressed air station;
* full scope confinement testing;

(6) Residual heat removal
* new set of protections;
* SG feed water supply from adjacent unit or fire truck;
* implementation of additional independent system for SG feedwater supply at Units 3 and 4;
* feed & bleed procedure (primary and secondary circuits);
* qualification of the equipment for seismic events and accidents;

(7) Man-machine interface
* improvement of reactor protections;
* operator support computer system;
* implementation of safety parameters display system (SPDS) at Units 3 and 4;
* SG leak detection system (N-16);
* control room habitability improvement;
* control room design review;

(8) Common mode failure
* building of second fire protection pumping station;
* seismic reinforcement of structures;
* fire hazard analysis;
* replacement of flammable cables;
* coating of all cable traces;
* fire doors and barriers improvement;
* tire detection systems improvement;
* fire extinguishing system improvement;
* qualification of the equipment providing reactor safety in case of an accident (**including** seismic impact);

(9) Operational safety
* housekeeping improvement;
* quality assurance (QA) system ;
* documentation;
* training and qualification;
* radiation protection improvement;

* industrial safety improvement;
* emergency planning and preparedness;
* requalification of all safety systems;

2.2. Complex Programme for Safety Reconstruction (PRG'97)

2.2.1. Programme development

In order to define the principles and approach for assessment and implementation of necessary measures for safety upgrading, after completion of the Short Term Program, in March 1995 the plant presented and the BNSA reviewed, supplemented and approved a Concept for Reconstruction of Kozloduy NPP Units 1÷4. The reconstruction objectives are to be guaranteed units 1-4 safe operation by implementation of technical measures, in order to achieve compliance with the current regulatory requirements and safety standards. A set of requirements and criteria for original design improvement were defined:

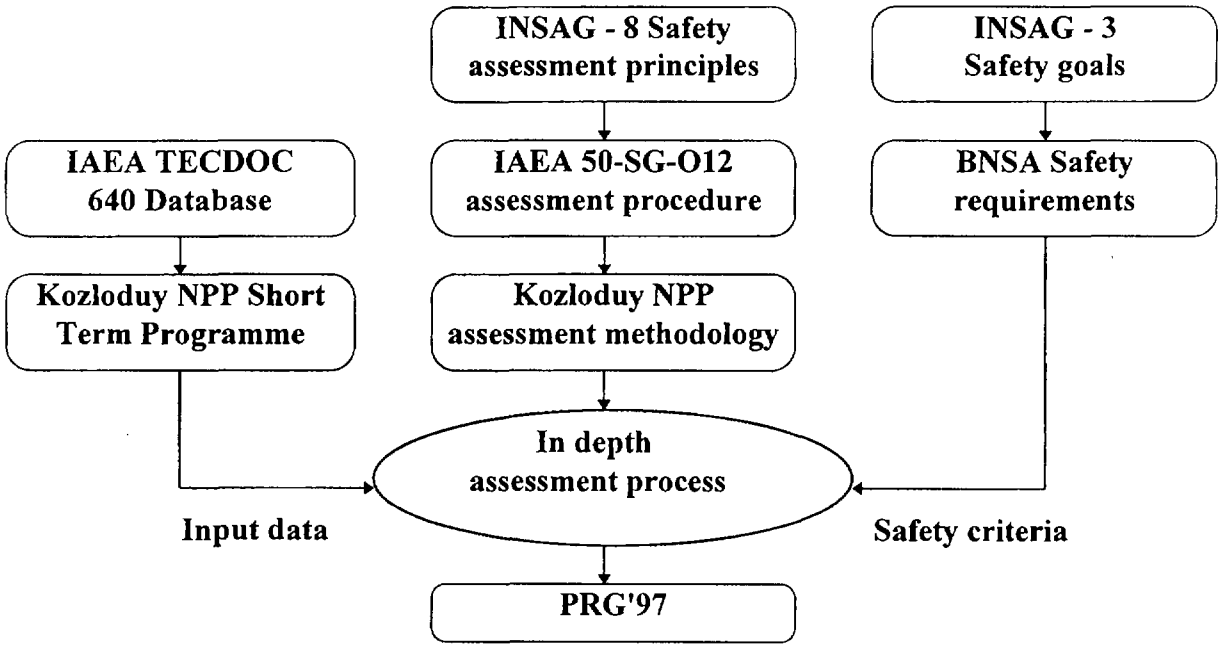
* Increasing the DBA to Dy=100 mm;
* Improvement of the reliability of the primary circuit pipelines limiting the DBA to Dy=100 mm;
* Improvement of the safety systems reliability in order to meet the BNSA safety level criteria for core damage frequency;
* Improvement of the localisation systems and accident management measures;

In compliance with the current international practices, the BNSA determined the following safety criteria, that should be achieved by the measures implemented:

* core damage frequency lower than 10^{-4} for reactor per year;
* probability of significant radioactive release off-site lower than 10^{-5} for reactor per year, assured by accident management measurers and localisation means.

On the basis of these criteria it was decided to perform an assessment of current safety level and define the way for the safety level improvement (fig. 2). As a basis for the assessment methodology and procedures for safety evaluation were selected INSAG-8 - A Common Basis for Judging the Safety of NPPs Built to Earlier Standards and the safety guide 50-SG-O12 - Periodic Safety Review of Operational Nuclear Power Plants.

FIG. 2 - SAFETY ASSESSMENT PROCEDURE



A joint team of leading Bulgarian and Russian design institutes and organizations, together with Kozloduy NPP was established, to perform assessment within a period of two years. The work was carried out under specially developed QA program and after approval of each specific tasks by the BNSA. More then 450 men-months of expert time were spent for the assessment studies.
The analysis was carried out in tree stages:

(1) First stage - deterministic safety analysis

An analysis of the deviations of the original plant design from the current nuclear safety standards, as well as from the IAEA recommendations was performed. Also, it was judged how much these deviations were covered and eliminated by the short term safety upgrading measures. As a result, the safety deficits left were determined and measures were proposed for solving the problems.

(2) Second stage - probabilistic safety analysis level 1

In the scope of the second stage a probabilistic safety assessment level 1 was performed for Kozloduy NPP Units 1-4. All design internal initiators were included in the PSA study and the corresponding core damage frequencies were calculated, taking into account all measures implemented during the Short Term Program.

(3) Third stage - drafting of a Program for Safety Upgrading of the Units 1-4

In this stage operational experience analyses were carried out. As a result of all kinds of analyses, a final list of program measures was developed. No problems were identified that need immediate corrective measures. The fulfilment of the modernisation program will allow the units to operate until the end of their designed life time.

The cost-effective analysis shows that the Programme implementation would not significantly influence the energy price. Considering that, further units operation would allow accumulation of funds for decommissioning, which are now absent and also will have positive effect on the overall economic situation in Bulgaria.

As a result of the above mentioned safety assessment process, 86 technical measures were proposed. The measures were united in a new Complex Program for Long Term Safety Improvement. The measures are grouped in thirteen groups according their relevance to the barrier integrity or the specific aspects of plant operation such as:

- FUEL MATRIX INTEGRITY;
- FUEL ROD INTEGRITY;
- REACTOR PRESSURE VESSEL INTEGRITY;
- PRIMARY CIRCUIT INTEGRITY;
- CONFINEMENT INTEGRITY;
- SAFETY ASSESSMENT;
- SUPPORTING SYSTEMS;
- CONTROL SYSTEMS;
- RADIATION PROTECTION;
- FIRE PROTECTION;
- SEISMIC PROTECTION;
- STORAGE OF FRESH AND SPENT FUEL;
- OPERATIONAL ASPECTS.

The Program Implementation Schedule is presented in Table 3. It is foreseen to completely

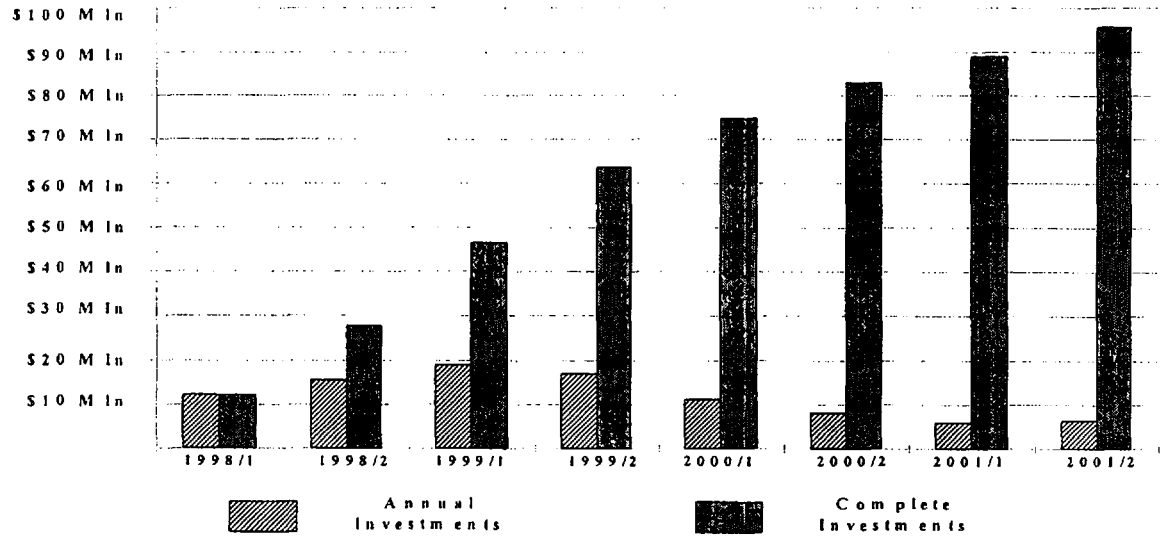
implement the full set of measures during the planned outages within four fuel cycles.

TABLE 3 - SCHEDULE OF SOME BASIC MEASURES OF THE COMPLEX PROGRAM

Measure	1998				1999				2000			
	1	2	3	4	1	2	3	4	1	2	3	4
Control of the neutron flux					■	■	■					
Operative control of the axial power	■	■	■	■	■							
Analyses of the fuel cooling in case of LOCA	■	■	■	■								
Provision of additional FW **supply** to the SGs	■	■	■	■								
Determination of probability for reactor vessel break					■	■	■	■	■	■		
Determination of the reactor vessel rest life time	■	■	■	■	■	■	■	■				
Strength analysis of primary equipment and piping	■	■	■	■	■	■	■	■				
Increasing of operational reliability of primary piping	■	■	■	■	■	■	■					
Improvement of the localisation systems					■	■	■	■	■	■	■	■
Increase of the Spray System reliability	■	■	■	■	■	■	■					
Safety Systems Improvement, based on PSA Ll	■	■	■	■								
Program for rest life-time control and management	■	■	■	■	■	■	■	■				
Physical separation of the DG	■	■	■	■								
Service water system reconstruction	■	■	■	■								
DG back- up cooling	■	■	■	■	■	■	■					
Operator support system modernisation	■	■	■	■								
SPDS (units l&2)			■	■	■	■	■	■	■	■		
Modernisation of the radiation monitoring system	■	■	■	■	■	■	■	■	■	■	■	■
Modernisation of the tire alarm system	■	■	■	■								
Anti-seismic strenghtening	■	■	■	■	■	■	■	■	■	■	■	■
Classification of the equipment and systems	■	■	■	■								
Classification of the equipment	■	■	■	■	■	■	■	■				
Water chemistry control system	■	■	■	■	■	■	■					
Development of training facilities	■	■	■	■	■	■	■	■	■	■	■	

The schedule for investment provision is presented in fig. 3.

FIG. 3 - COMPLEX PROGRAMME INVESTMENTS



It was concluded that the program is accepted as an approach consistent to the policy for systematic and continuos improvement of units safety towards the internationally accepted criteria for safe operation of NPPs. The program was presented to the BNSA for approval. At present BNSA has defined its requirements for further improvement of the program.

After obtaining the results of an independent international review of the Program, the National Electric Company will submit to the BNSA revised version of the Program. The BNSA will license the Program with the assistance of the Consortium of Western Regulators.