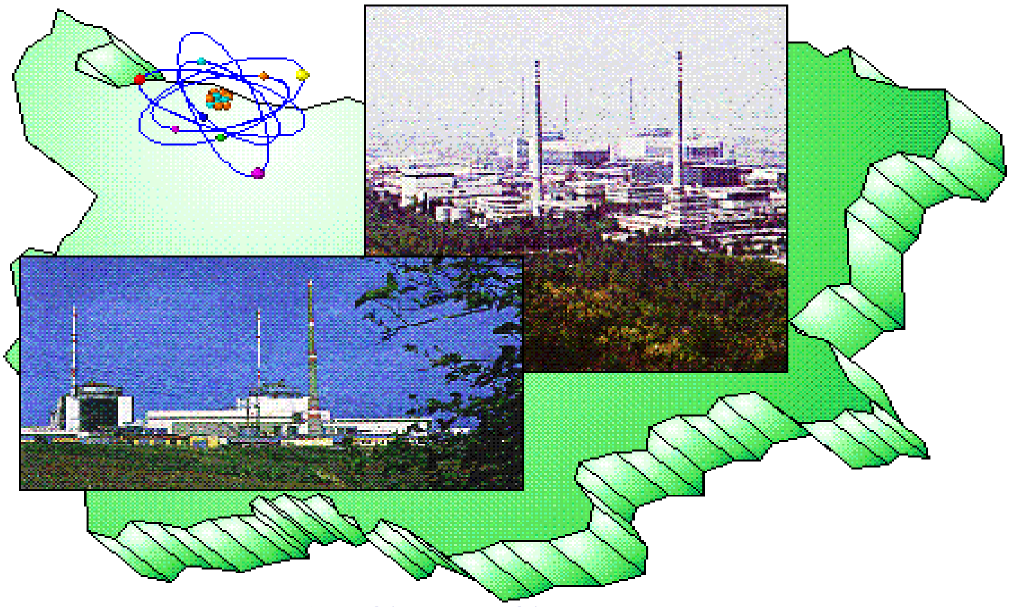

A CONCEPT, A TECHNICAL SOLUTION AND ANALYSES FOR MODERNIZATION OF THE LOCALIZATION SYSTEM OF UNITS 3&4 KOZLODUY NPP, BULGARIA

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CONTENT:

1. BACKGROUND

Many NPP's, having reactors WWER-440/B-230 undertook considerable efforts to implement safety improvement measures during last 10-15 years in order to bring the safety in accordance to the recent safety standards and to eliminate issues that were subject of international concern. Systematic evaluation of the original design of this type of reactors had been initiated by IAEA in the beginning of 1990 and brought to developing a comprehensive list of recommendations, which required implementation of technical and other measures in all plants - TECDOC-640.

Bulgaria has one nuclear power plant at Kozloduy, with four WWER-440 reactors and two WWER-1000 reactors in operation. The power station produces usually more than 45% of the country's electricity.

In 1991, as a result of Bulgarian Ministry council decision, at Units 1 to 4 started implementation of urgent measures for safety upgrading. Kozloduy NPP developed and implemented the so called "Short term program for safety upgrading". During the process of an in-depth safety analysis implementation for defining current level of the safety, based on internationally accepted analysis methodology a set of specific measures were defined and unified in so called "Complex program for modernization of units 1 – 4" – PRG'97/A Modification of some important for the safety systems was planed in the frame of the program, including theMODERNIZATION OF THE LOCALIZATION SYSTEM OF UNITS 3&4 – theme M.5.3.

Although Units 3 & 4 have been traditionally referred to as WWER-440/B-230 model, in their original design there are number of important differences from a standard B-230 model, which makes them closer to a standard B-213 design. Those include a cladded pressure vessel, a functional capability of the safety systems, (3 X 100%, high pressure-low pressure injection), emergency control room, etc. Following the EBRD and PHARE projects and the Kozloduy NPP own safety upgrading program, units 3 & 4 received a substantial back-fitting and design changes, which further improved the original design and brought the actual status of those units close to other WWER-440/B-213s.
During the last few years a vast modernization program of Units 3 and 4 is under implementation. The goal of the modernization program is to significantly improve the safety of Units 3 and 4 and reaching a level, comparative to the level of safety of western PWRs of the same vintage by elimination of the design limitations of these units and creating a basis for removing of the units from the list of B-230 units. This new design safety level of the units is presented as a new model B-209M.

The modernization should resolve all IAEA safety issues [IAEA-TECDOC 640], the requirements of the Complex Program for Modernization of Units 1 to 4 at KNPP, as well as the IAEA and WENRA missions requirements.

2. A CONCEPT AND THE MAIN PREREQUISITES FOR MODERNIZATION OF THE LOCALIZATION SYSTEM

Initial design of the units WWER–440 type B230 considered that accident, connected with primary break of a pipe with Dn100 with a flow restrictor of Dn32 was DBA.

The confinement civil structure was designed for an absolute pressure of 0.2 MPa. To protect the confinement from destroying were foreseen the passive system, consisted the nine safety flaps for pressure reduction during the initial blow-down phase of LOCA and active sprinkler system, which disperse the boron solution with low temperature in the air volume of the hermetic confinement, for the purpose of a steam condensing and to washout of radioactive isotopes from the atmosphere inside in case of the LOCA.The performed analyses confirmed that the maximum pressure in the confinement is not reached up to LOCA Dn200mm.

Performed further analyses showed that accident localization system, nevertheless of its high efficiency for localization of radioactive releases during the accident progress period, could not guarantee the retaining of the confinement structures integrity during first seconds of a hypothetical instantaneous LB LOCA with double sides guillotine Dn500mm rupture.

There were questions connected also with reliability of the confinement flaps as isolation devices.

Providing of the arguments for units safety operation till the end of their lifetime requires settling the question by applying the adequate technical measures.

For this reason, the implementation of the accident localization units systems modernization was introduced as a main measure in the “Complex Program for Units 1÷4 Modernization – PRG’97/A”.

3. MAIN DESIGN LIMITATIONS OF THE LOCALIZATION SYSTEM OF UNITS 3&4

In accordance with the contemporary approaches to the nuclear safety the localization system of the B-230 units has some design limitations:

1. In case of LB LOCA the pressure inside the confinement exceeds the design pressure with fully open flap valves;
2. Probability for a flap valve to stuck open after the initial release could not be neglected;
3. High leak of the localization system resulting in significant radiological consequences, especially in case of failure of the spray system;
4. Lack of a filtered venting system for severe accident management resulting in significant radiological consequences in case of LB LOCA.

4. POSSIBLE TECHNICAL SOLUTIONS FOR RECONSTRUCTION OF THE LOCALIZATION SYSTEM

To eliminate above mentioned design limitations there had been considered various technical solutions for reconstruction of the localization system and as a result there were distinguished the following variants:
1. Creation of a new full pressure localization system;
2. Reconstruction of the existing one with a controlled release.

The first variant requires construction of additional hermetic volumes, connected to the existing localization system to confine all steam generated as a result of the accident.
This technical solution was found to be unacceptable because of the following:

- Due to the low design pressure it is required a significant free volume for the additional civil structure;
- The high leak rate and the prolonged duration of overpressure after the blowdown leads to release of radioactivity to the environment and unacceptably high radiological consequences.

Localization system with a controlled release is based on the original design solution for keeping a relatively small containment volume with a controlled release of radioactivity to the environment.
The purpose of the upgrading is to minimize that release both at DBA and at BDBA below the regulatory requirements.
This second variant was found out technically and economically acceptable for implementation.

5. PURPOSES OF MODERNIZATION

The main goal of the reconstruction of the confinement system is to improve the original design of these units ensuring localizing safety function for the full spectrum of primary LOCA and to keep the radiation impact to the personnel, population and environment below the allowed limits both at DBA and BDBA post-accident conditions.
To fulfil this goal the modernization should ensure:

- Protection of confinement structures integrity during primary LOCA with equivalent diameter DN 100, 200 and double sided 500 mm, with the objective to avoid uncontrolled release outside of the hermetic zone;
- Retention of radioactive products during different phases of considered accidents with efficiency, ensuring the requirements of BNSA for radiation consequences;
- Removal of the decay heat of disposed radioactive products and maintaining of pressure and temperature below the design limits;
- The modernization should be developed according to modern practice and standards.

In order to minimize the radiation consequences, it is necessary:

- To cope with the first pressure peak and to avoid exceeding of the strength limits of the confinement structure. In case of release during the first pressure peak, it is necessary to ensure a reliable re-closure of the hermetic zone;
- To control sequential processes of steam generation with a goal to maintain the pressure slightly bellow atmospheric;
- To eliminate the possibility for accumulation and explosion of combustible gases during severe accidents.

6. TECHNICAL SOLUTIONS/SYSTEMS/ FOR RECONSTRUCTION OF THE LOCALIZATION SYSTEM

The main idea of the reconstruction is to keep sub-atmospheric pressure inside the confinement after the initial blow down phase of LOCAs.

In the following Table No1 there are summarized the major processes leading to pressure increase and possible technical solutions to keep the pressure as low as possible.

Table No 1

CAUSE FOR CONFINEMENT PRESSURE INCREASE	POSSIBLE TECHNICAL SOLUTION
1. Blow-down phase of LOCA	Pressure suppression system
2.Decay heat of dispersed FP in the hermetic zone	Spray system
3. Steam generation	Spray system
4.Generation of non-condensable gases	Filter venting system
5. Generation of combustible gases	Passive autocatalytic recombiners, Filter venting system

Considering the design limitations of the confinement, confinement reconstruction should foresee:

1. Replacement of mechanically movable flap valves by passive pressure suppression system (PPSS), capable to protect the confinement integrity for the full spectrum of LOCA and to restore reliably the tightness of the hermetic zone after the initial steam-air blowout. The installation of PPSS compensates the first design limitation of the confinement - small free volume.

2. To compensate the second design limitation (high leak rate), it is necessary together with a maximal possible increase of the confinement tightness, to install technical devices to keep for a long period of time after the accident a sub-atmospheric pressure inside the confinement. Maintaining of underpressure during the later phases of the accident progression will limit the release of radioactive products outside of the hermetic zone of the unit.

7. MAIN STAGES OF JET VORTEX CONDENSER INSTALLATION

In accordance with Complex Program for Modernization of Units 1÷4 realization in 1998/1999 was signed the Contract between Kozloduy NPP and ENPRO-Consult, Ltd. and was developed "Conception for modernization of the localization system", which foreseen installation of JVC as main measure. The systems, connected with severe accidents management (installation of hydrogen recombiners and active filtered venting system (FVS)) were foreseen in the concept to be analyzed.

The conception was approved by KNPP in 1999 and was submitted to BNSA. BNSA reviewed the conception and marked its realization as the most important for KNPP.

In October 1999 the conception was submitted to the organized by IAEA seminar for discussing the most appropriate variants for resolving of this main issue for units WWER-440 type B230. The presented idea met support from all participants.

In April 2000 was prepared Contract with "Atomstroieksport" Russia for installation on Units 3 and 4 Jet-Vortex Condenser. The Contract was in force in June 2000 and consisted: development of the design, SAR, implementation projects for all parts, delivery, installation and commissioning activities of the system. In accordance with Contract clauses all SAR chapters, implementation projects and installation are performed together with Bulgarian design and engineering organizations.

The Project manager is VNIIAES – Moscow. The main designer is AEP – Sankt Peterburg. In the project from Russian side are involved "Kurchatov Institute", VTI – Moscow, OAO"PZEM", Mitishi and OAO"IK Ziomar", Podolsk.

With design and SAR development and activities management from Bulgarian side were involved: ENPRO Consult, RISK Engineering and ENERGOPROJECT.

The design was approved in June 2001, the PSAR was approved in July 2001.

On 20th of August 2001 Unit 4 was shut down for annual outage and preliminary activities, connected with JVC started.

JVC documentation, concerning mathematical and physical foundations, tests, mathematical model and safety-related calculations (from thermohydraulic viewpoint) was analyzed and reviewed by international expertise accomplished by Consortium (British Energy and Empresarios Agrupados"). The received from expertise results proved that JVC accomplished its function as a passive device capable of suppression of high-pressure transients during LOCA in units 3&4 of KNPP, that constructed stand, together with different set of experiments, performed in order to check different parameters provided a good validation of JVC model and that criteria of similarity in terms of dimensionless numbers are accomplished between the stand and the real equipment.

On 17th of December 2001 the installation of JVC was completed .

On 21th of December 2001 Unit 4 was connected to the National grid.

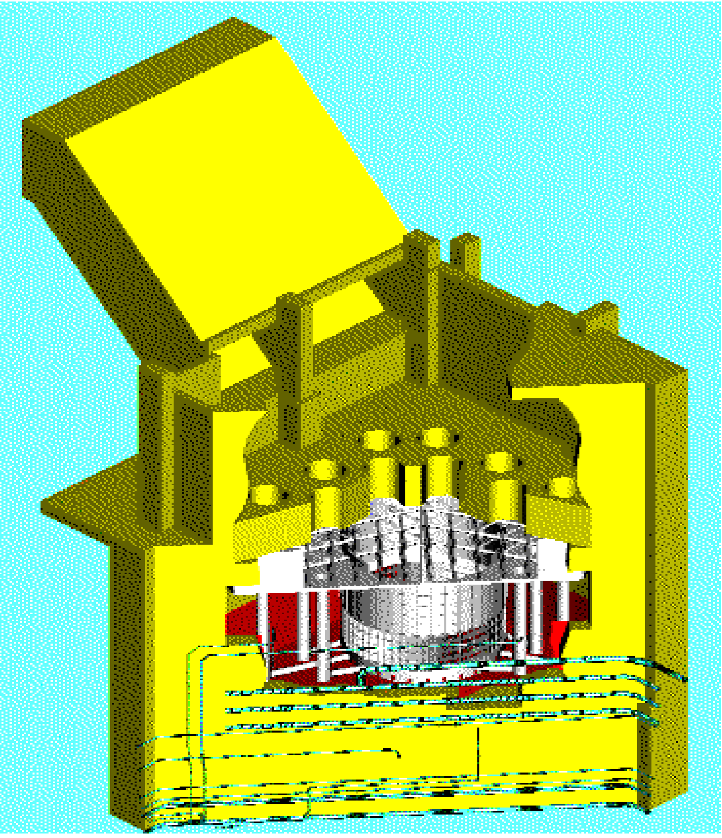
8. JET VORTEX CONDENSER STRUCTURE

All JVC elements are placed in the hermetic confinement at the place, where had been installed the original design passive system, consisted the nine safety flaps. The bottom tank of JVC is situated in the concrete under above mentioned safety flaps construction. The design of the system was developed in accordance with current standards and IAEA rules.

The system was designed to withstand the seismic impact in accordance with current seismic assessment of the Kozloduy NPP site and was qualified to perform its functions by a scaled-down high pressure test facility RU-4 functional tests at GOSNIAEC, Kashira, Russia.

The main elements of JVC structure are following:

- A triangle vessel bottom tank, placed at the current location of the weights of the flap valves at elevation +3.22 with potassium-boron solution volume of 110м^3, surface of 43,6м^2 and nominal level of 2465mm (elevation +5,685m);
- A bottom part of swirlblades device ;
- A swirl blade device (turbine type) in the bottom part of the cylinder, ensuring tangential entrance of the steam-air mixture that causes swirling of the liquid inside the cylinder. Diameter of vortex chamber is 5100mm, the angle of blade's attack is 45°, blades amount – 60, the height of the blades is 1650mm;
- A perforated cone;
- A main cylindrical vortex chamber;
- A upper recycling tank;
- Recycling pipes.



9. PERFORMED ANALYSES FOR JET VORTEX CONDENSER INSTALLATION

For determination of the response of the confinement system with installed VJC were analyzed primary and secondary circuit pipe lines breaks, including a LB LOCA with total loss of ECCS (double sided guillotine break 2xDn500) using a computer code RELAP5/Mod3.2.

For the calculation of the thermo-dynamic parameters in the confinement were used code VSPLESK(modernized taking into account JVC) and code MELCOR 1.8.3. for small leaks Dn20, Dn32 in cases when there is no impact of the media rotation on JVC, i.e. the MELCOR code was used for calculations of such processes in the confinement, which do not impact the execution of JVC functions - pressure reduction down to the design value in case of the accident related to 2xDn500.

The analyses were done with operable spray system. The leak tightness of the confinement was assumed equal to the tightness already achieved at the plant – equivalent to leak from the confinement through an orifice of Dn50. For the analyses there were developed and introduced to the codes an *ad hock* models of the pressure suppression system, the auto-catalytic recombiners and the filtered venting system.

There were performed analyses for the same accident scenario with flap valves of the confinement and with JVC replacing the flap valves.

The purpose of the analyses was determination of:

- Confinement response to the accident;
- Response of the JVC to the accident;
- Release of steam-air mixture to the environment;
- Release of fission products to the environment;
- Input data for sizing of the new systems:
  1. Number and location of PARs;
  2. Flow rate through the FVS.

For comparison and for justification of the main findings from the analyses, in this presentation there are presented results for:

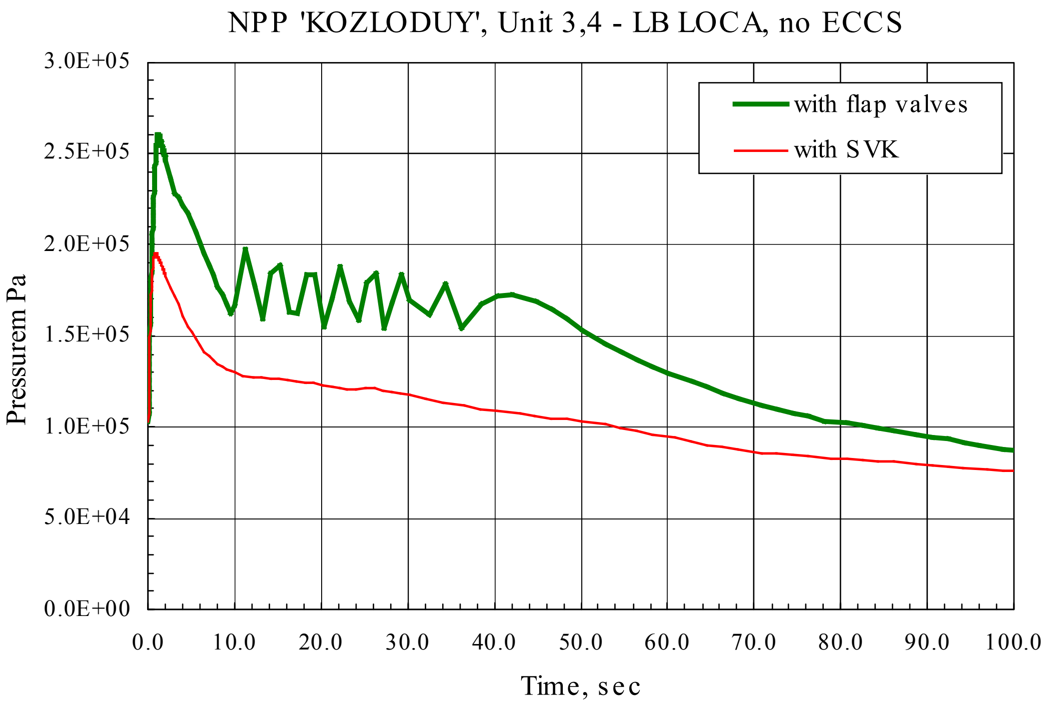
- case with installed only JVC (no FVS, no PARs)
- case with installed JVC, FVS and PAR
- current plant design with flap valves (no FVS, no PARS, no JVC)

9. PERFORMED ANALYSES FOR JET VORTEX CONDENSER INSTALLATION - Continued

On Figures 1 is presented the pressure response of the confinement during the first 100 seconds after the break.

The peak pressure for the case with flap valves reaches about 2.6 bar. The peak pressure for the case with JVC does not exceed the design pressure of 2.0 bar (the peak pressure is about 1.8 bar). This means that the installation of the JVC eliminates the first of the design limitations – small free volume of the confinement.

Figure No 1



10. OPERATIONAL PRINCIPLES OF JVC

In case of LOCA the pressure in the localization system rapidly increases. As result of this thewater from the outer tank is pushed through the blades device into the main vortex chamber of JVC. Taking into account that the angle of blade's attack is 45°, it causes water swirling inside of the cylinder that create a Vortex funnel and simultaneously increasing of water level at the periphery and water level decreasing at the center of the cylinder. When the periphery water level reaches the recycling tank, the water starts to overflow in it and by recycling pipes the water goes down to the main pool.

The speed of fluid rotation reaches 10 rad/s, in this case the centrifugal acceleration is 25 to 30g. This practically excludes the possibility for swelling up of the phase splitting up surface. As result of the pressure drops in the upper recycling tank and in the steam-air-water mixture flow, through the blades periphery is injected water. The swirling of the water ensures very efficient condensation of the steam from the steam-air mixture passing through the condenser. The steam and non-condensable air while swirling with the water undergoes scrubbing of radioactive materials (aerosols and radioactive iodine). Non-condensable gases, mainly air, through the upper recycling tank and twelve orifices are send to the outlet corridor.

All these above mentioned leads to reduced release of radioactivity to the environment, initially contained in the primary system and eventually released from gaps of defected fuel elements as a result of the accident.

11. JVC ADVANTAGES

1. The most important positive effect of JVC performance is suppression of the pressure pick in the localization system in case of LB LOCA – Dn500. Activation of the JVC begins at overpressure of $0{,}025.10^5$Pa, while the full JVC load is at $0{,}175.10^5$ Pa overpressure. There are not any regimes, when the pressure can reach the value equal or above the confinement design strength pressure.

2. The mechanical structure of the previous confinement passive system safety flaps is avoided. This ensures full reliability of confinement isolation not only during the first short time phase of overpressure, but and during the subsequent long time phase of subpressure.

3. JVC is installed inside of the hermetic area, which is preferable comparing with the other condensation systems, needed building of separate facility (building) and connected air-pipes.

4. On the bases of the made expertises and experiments performed at scaled-down high pressure test facility RU-4 at GOSNIAEC, Kashira, Russia was proved, that there is not swelling up of the water layer in the condensing pool, which is observed in the quench condensing devices. JVC condenses effectively the steam from steam-air mixture in the first period of the accident.

5. JVC provides less pressure in the confinement in case of DBA LOCA and in parallel less leakages through the untightnesses of localization system, which decreases sufficiently the calculated dose exposure of the KNPP personnel. This also reduces the significance of the comparatively higher confinement untightness to the safety consequences.

6. Steam-air mixture, which during the accident passes JVC, is filtered in the water volume. This provides the JVC function as passive filtering system with definite degree of cleaning. This leads to sufficient decreasing of radiation consequences in case of LB LOCA and resolves to certain extent the issue for installation of a confinement filtered system as a matter of urgency.

12. CONCLUSIONS

1. The installation of JVC resolves the design peak pressure limitation of the localization system for all postulated accidents thus ensuring the preservation of the confinement integrity and reduction of the radiological consequences in case of LOCA events up to Dn500mm.

2. JVC acts as filter in case of DBA and BDBA thus provides reducing of radiological releases to atmosphere comparing with the existing design.

3. The performed analyzes show that hydrogen recombiners system is needed only for management of the accidents connected with core melting. Foreseen further installation of the hydrogen recombiners will provide possibility for ensuring the functions of the system in case of severe accidents, thus increases the safety level above the current requirements.

4. The mechanical structure of the previous confinement passive system safety flaps is avoided. This ensures full reliability of confinement isolation not only during the first short time phase of overpressure, but and during the subsequent long time phase of subpressure.
This ensures a probability for large releases to be less than 10^{-8}.