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Key results of commissioning activities for the emergency and scheduled cooldown system of the AES-2006 unit with the V-392M reactor plant

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Abstract

The paper describes the combination of safety and normal operation functions adopted in the AES-2006 design, as illustrated by a two-channel structure of active safety systems, showing the major innovative solutions and their differences from earlier designs, such as:

– The use of a pump-ejector assembly in the primary circuit emergency and scheduled cooldown and spent fuel pool cooling system;

– The emergency and scheduled cooldown and spent fuel pool cooling system is designed as two fully independent channels (each channels consists of two legs, each channel leg has a capacity of 100%);

– The redundancy rate is $2 \times 200\%$.

Differences in the emergency and scheduled cooldown systems are considered for the V-392M и V-320 designs. Compliance with the acceptance criteria is shown based on test results, including additional tests performed in different modes during the commissioning of the Novovoronezh NPP II Unit 1 with the V-392M reactor plant. A description and a pattern are provided for the full-scale simulator tests to justify the long-term performance of the pump-ejector assembly scheduled for 2017, including an inspection of the water-jet pump nozzle inner surface condition and the water-jet pump service life tests followed by an examination for possible damage and visible defects on the nozzle surface.

As a result of the innovations, the overall reliability of safety systems has been improved. The successful completion of the life tests of the pump-ejector assembly of the emergency and planned cooling system made it possible to confirm the reliability and efficiency of the water-jet unit used for the first time in the NPP safety systems.

Keywords: Redundancy; Combination of functions; Reliability; Safety case; Tests; Ejector; Emergency cooldown; Fuel cooling.

Introduction

The NvNPP II Unit 1, the main unit of the AES-2006 design with the V-392M RP, was commissioned on February 27, 2017.

When designing systems that are part of the active part of safety systems, in order to increase the functional reliability, it was decided to adopt the principle of combining safety and normal operation functions. The design implements circuit solutions that make it possible to put operating channels into safety function execution mode without activation commands, or switching mechanisms, or with a minimum amount of switching valves only. This principle significantly reduces undetected failures [1–5].

The development of the principle of combining functions made it possible to adopt simple technological solutions that ensure the execution of a number of successive safety functions in the course of accident evolution by a single set of mechanisms (e.g., supplying water into the active zone at high

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and low pressures), which eliminates the need for additional switch over operations which are failure sources, reduces the number equipment items, pipelines, fittings, locks, etc.

One of the differences of the AES-2006 design with the V-392M RP from serial NPPs with VVER-1000 reactors as well as from the AES-92 project is a two-channel structure of active safety systems. This is also one of the main differences between the NvNPP II design and the LNPP-2 design.

The compliance with the no-single-point-of-failure principle in the V-392M RP (AES-2006) design was substantiated by analyzing both the reliability of active security systems and the allowable outage time for channels of these systems. Possible failures of the third channel of safety systems are due to the presence of passive systems that duplicate the execution of safety functions associated with heat removal from the reactor core, i.e., the secondary hydraulic accumulators (HA-2) and the passive heat removal system (PHRS) via steam generators [6,7,8].

One of the main innovative design solutions is the use of a pump-ejector assembly (a bunch of a high pressure pump and a water jet pump) in the primary circuit emergency and scheduled cooldown and spent fuel pool cooling system; the functional properties of the assembly are equivalent to the combined action of low and high pressure pumps in other NPP designs [7,8,9-11].

This scheme differs favorably from the known solutions, since it makes it possible to increase the overall reliability of safety systems, reducing the load on the emergency diesel generator, to reduce the number of stages of automatic diesel generator start, and to reduce the amount of valves and interlocks.

AES-2006 emergency and planned cooldown system compared with V-320 analogous system

The emergency and planned cooldown and spent fuel pool cooling system (JNA) consists of two completely independent identically equipped channels.

Each channel consists of:

- Emergency and scheduled cooling heat exchanger 11(12)JNA10(20)AC001;
- Low pressure axial pump 11(12)JNA11(21)AP001;
- High pressure axial pump 11(12)JNA12(22)AP001;
- Water-jet pump 11(12)JNA12(22)BN001;
- Reverse and safety valves, shut-off and control valves;
- Pipelines.

The system channel consists of two legs that reserve each other (except for the emergency primary circuit makeup function in “small break” modes). Each channel leg has a capacity of 100%. One leg of the channel is connected between the drain line check valves of the primary hydraulic accumulator system, supplying boron solution to the reactor collection and pressure chambers; the second leg is attached to the hot and cold legs of the MCC loop. Any of the channel legs can work on the spent fuel pool cooling circuit. The primary coolant is taken from the hot legs (two DN300 connectors on Loops 2 and 4) for scheduled cooldown and from the cold legs of the same MCC loops for repair cooldown. The coolant is taken from the MCC loops with no connected piping of the emergency and scheduled cooldown and spent fuel pool cooling system, which ensures reliable circulation of the cooled coolant through the reactor core.

In case of emergency cooldown with loss of integrity of the primary circuit, water supply to the reactor in the initial period is carried out from the spent fuel pool with further transition to supplying from the containment pit.

The main purpose of the leg with one high-pressure pump and one water-jet pump is to feed the reactor in small break modes when the primary circuit pressure is below 8 MPa. In this mode, the water-jet pump plays the role of hydraulic resistance and ensures the functioning of the high-pressure pump in the functional area of the head-capacity curve.

An additional purpose of this leg is to reserve the leg with a low-pressure pump (in case of failure) in the following modes:

- Emergency reactor makeup low pressure;
- Emergency reactor plant cooling down;
- Scheduled reactor plant cooling down;
- Reactor plant cooling down for maintenance.

The leg with one high-pressure pump and one water-jet pump reserves the spent fuel pool cooling system.

In these modes, the water-jet pump works for its intended purpose, i.e., to increase the flow rate supplied by the high-pressure pump.

Spent fuel pool cooling mode: In normal operation mode, fuel cooling in the SFP is provided by one of the SFP cooling system channel (FAK10-20). JNA is a backup system: it ensures fuel cooling in the SFP when the FAK10-20 system equipment (Fig. 1) is removed out of service for repair. When the core is completely unloaded in the SFP, the required temperature is maintained by the joint operation of one channel of the FAK10-20 system and one channel of the JNA system.

Reactor water reserve maintenance and emergency cooldown mode: In case of large break accidents (the rupture of a pipeline larger than 100 mm in diameter, including the rupture of the main circulation pipeline with a diameter of 850 mm), heat removal from the core and maintenance of the required coolant inventory in the reactor are provided by continuous circulation of boron solution with the help of the primary circuit emergency and scheduled cooldown and spent fuel pool cooling system.

At the starting point of the accident, boron solution is supplied to the reactor from the SFP. Sometime after the beginning of the accident, the water level in the SFP drops to such a minimum value that the pumps switch to work from the pit. By this time, a sufficient supply of boron solution is created in the pit due to the blowdown from the primary circuit (including the water reserve of the hydraulic accumulators of the passive core flooding systems), which is necessary to ensure the cavitation-free operation of the pumps. After switching