ADDITIONAL INFORMATION ON MODERN VVER GEN III TECHNOLOGY

Mikhail Maltsev
Head of Department
JSC Atomenergoproekt

February 12, 2015
The main intention of this presentation is to provide:

- some clarifications regarding the structure and composition of safety systems of modern VVER Gen III NPPs
- information on the improvements implemented in the latest designs based on AES-92 design

Basing on the same Technical assignment for AES-2006 NPP two different NPP designs were developed in two different companies using their own experience, approaches and available groundwork. This determined the presence of certain differences in the designs, but the design targets related to efficiency and safety are met.
Progress of Safety Systems in JSC Atomenergoproekt
VVER-Type NPP Designs

- 3 trains of active safety systems;
- single containment shell;
- emergency heat removal via secondary circuit is limited in time by water inventory in DM water tanks;
- core damage after 2-3 hours in case of active safety systems failure

**NVNPP Unit 5**

**Small series**

**U-87 (V-320)**

**Kudankulam NPP**

**Blene NPP**

**Novovoronezh-2 NPP**

**VVER-TOI NPP**

- 4 trains of active safety systems;
- passive safety systems for all critical safety functions (CSF);
- double containment shell with controlled annulus;
- emergency heat removal via secondary circuit is not limited in time both in active and passive mode;
- long-term (not less than 24 hours) ability to prevent fuel damage beyond the limits specified for DBA;
- The Certificate of compliance with EUR requirements is granted

**AES-92**

**AES-2006**

- 2 trains of active safety systems with internal redundancy;
- passive safety systems for all CSF;
- double protective containment with controlled annulus;
- emergency heat removal via secondary circuit is not limited in time both in active and passive mode;
- long-term (not less than 24 hours) ability to prevent fuel damage beyond the limits specified for DBA under blackout conditions without the operator’s interference;
- assessment of the design compliance with EUR requirements together with EUR experts

**Certificate**

**VVER-TOI NPP**

- 2 trains of active SS;
- passive SS for all CSF;
- double protective containment with controlled annulus;
- emergency heat removal via secondary circuit is not limited in time both in active and passive mode;
- ensuring enhanced Unit resistance to extreme external impacts;
- long-term (not less than 72 hours) ability to prevent fuel damage beyond the limits specified for DBA under blackout conditions without the operator’s interference;
- assessment of the design compliance with EUR requirements together with EUR experts
Safety concept of modern VVER NPPs

Safety concept provides for:

- Use of mutually redundant safety systems of «active» and «passive» principles of action that ensures protection against common-cause failures and allows for increase of safety systems reliability factors by several orders

- Use of «active» part of safety systems for normal operation functions that allows for increase of safety system availability level. Such solution provides for additional protection against common-cause failures and excludes latent failures being a main reason of system non-availability in standby mode.

- Safety systems are designed in such a way that operator interference in case of accident is not needed at least for first 15-30 minutes

- Protection against human errors due to: increase of automatic control level of systems (exclusion of personnel’s actions) in case of occurrence of certain design-basis accidents and, in particular, in the case of primary-to-secondary leaks; use of passive systems, which activation do not require participation of operation personnel

- Use of full-pressure double shell containment with hydrogen removal systems, the catcher for molten core provide no exceeding of maximum release established values during beyond design-basis accidents with core severe damage
Comparison of main safety features

<table>
<thead>
<tr>
<th>Safety systems</th>
<th>AES-2006 Saint Petersburg</th>
<th>AES-2006 Moscow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of active trains</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Number of passive trains</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>GA-1</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>GA-2</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Core Catcher</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Emergency boron injection system</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Passive heat removal system from SG</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>SG Emergency cool-down system</td>
<td>+ (open)</td>
<td>+(closed loop)</td>
</tr>
<tr>
<td>Passive containment heat removal system</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Active containment heat removal system</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Containment hydrogen removal system</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Annulus passive filtering system</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>
Main Engineering Solutions for Safety Systems

The safety assurance concept is based on applying safety systems that use different principles of their operation: active and passive ones.

**SAFETY SYSTEMS**

- Passive part of emergency core cooling system, including stage 2 and 3 hydroaccumulators system
- Emergency primary circuit gas removal system
- Annulus passive filtration system
- Hydrogen concentration monitoring and emergency removal system
- Passive heat removal system (PHRS)

**BEYOND DESIGN BASIS ACCIDENTS MANAGEMENT HARDWARE EQUIPMENT**

- System of the molten core confinement and cooling outside reactor
- Alternative cooling water circuit system with fan cooling tower
- APCS pertaining to safety functions implementing systems

**MAIN SAFETY FUNCTIONS**

- Emergency reactor shutdown and its maintaining in subcritical condition
- Emergency heat removal from the reactor as well as from the spent fuel pool
- Radioactive substances confinement within the specified limits
- Maintaining the reactor pressure circuit boundary integrity

**NORMAL OPERATION POWER SUPPLY SYSTEM**

- Uninterrupted power supply units

**EMERGENCY POWER SUPPLY SYSTEM**

- Storage batteries
- Standby diesel power plant

**SAFETY SYSTEMS**

- Reactor control and emergency shutdown system
- Emergency boron injection system
- Emergency and planned primary circuit cooldown and fuel pool cooling system
- Steam generator emergency cooldown system
- Spray system (1JMN+1FAK10-20)
- Secondary circuit overpressure protection system
- Hermetic enclosure system
- Main steam lines isolation system
- Primary circuit overpressure protection system

**ESSENTIAL LOADS COOLING SYSTEM**

- Water system of building 10UJA (20UJA)
- Essential loads, closed cooling system

**ESSENTIAL POWER SUPPLY SYSTEM**

- Storage batteries
- Standby diesel power plant
Main passive safety systems

Inner containment

Outer containment

Annular space

Second stage HA

Passive Heat Removal System

PHRS heat exchanger

Main circulation pump

Core catcher

Primary circuit

HA-1

HA-2

HA-3

HA-2 - HA-3

HA-1 - HA-2

HA-1 - HA-3

HA-1 - HA-3

HA-2 - HA-3

Primary circuit

Core catcher

Main circulation pump

Annular space
Passive core flooding system

Core flooding system is a passive part of emergency core cooling system (ECCS) consisting of hydraulic accumulators (HA) of the 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> stages. **HA-1** are required for emergency flooding of the core with boric acid solution if primary pressure goes below 5.9 MPa.

**HA-2** are used to maintain coolant inventory in the primary circuit required for reliable heat removal from the core. They start delivering water when primary pressure drops below 1.5 MPa.

**HA-3** are a “followup” of HA-2 to maintain coolant inventory in the reactor core under beyond design basis accidents with primary circuit leaks and failures of the active safety systems after the expiration of boric acid solution inventory in HA-2.
Results of HA-2 tests at the test bench

- **Flow rate**
  - Experimental flowrate
  - Design flowrate

Test volume

- H = 3500
- D = 2000
Passive Heat Removal System

Passive heat removal system (PHRS) is designed for long-term removal of decay heat from the reactor in case of loss of all electrical power supply sources including emergency ones in case of leak-tight primary circuit and leakages as well.

The system comprises of four independent natural-circulation secondary coolant circuits (4 x 33 %) – one for each circulation loop of the Reactor plant.

Each circuit comprises of heat-exchange modules, steam-condensate path pipelines, air ducts for ambient air supply and heated air bleeding and passive direct-action devices intended to control air flow rate.

The heat exchangers are placed at a height of around 40 m and are protected by civil structures, so that their possible failure caused by floods or other natural or man-induced effects (air shock waves resulted from explosions at the site and the adjacent territories, as well as hurricanes and tornadoes) is excluded.
PHRS arrangement in Kudankulam NPP containment
Steam generator (SG) emergency cooling system is designed for performing the following safety functions under design basis accidents:

- decay heat removal from the core in emergency situations associated with loss of power supply or loss of normal heat removal through the secondary circuit including steamline and feedline leaks
- decay heat removal from the core and reactor cooling down in emergency situations related with depressurization of the primary circuit including rupture of the main circulation pipeline (through intact loops)
The proposed fuel handling concept and the solutions accepted in the VVER-TOI design make it possible to provide the following in case of the MOX-fuel use:

- not to rework the fresh fuel storage facility for MOX FA
- not to upgrade the reactor building systems
- with no additional equipment development and manufacture to deliver safely new MOX FA to the reactor building, to load them into the reactor and to remove the spent MOX FA
Design options for VVER-TOI - Load Following Operation

The design provides for the Power Unit load following operation within the range of 100-50-100 according to the daily load programme during the whole time of the fuel hold-up operation with the constraints as follows:

- During the initial time of the fuel hold-up operation the load following is prohibited – 40 days – fuel side (fuel supplier) restrictions;
- Within 60 to 80% of the fuel hold-up operation time the power decrease rate – 3% per minute and the power increase rate – 1% per minute – can be provided;
- At the final stage of the fuel hold-up operation the load following is inadvisable or the power decrease rate 3% per minute can be provided, then the power increase rate will go down from 1% per minute to 0.2%. If the off-loading intensity is reduced the power ascension rate can be increased up to 1% per minute

For the purpose of the load-following operation realization the following have been implemented in the Project:

- “Mild” temperature control due to the SG pressure change from 0.2 to 0.5 MPa;
- Algorithms using groups of control rods with reduced worth;
- The required capacity of the boron control system and the coolant processing system is provided
Optimization of Reactor Building Layout Concepts

NVO NPP-2 Layout

VVER-TOI - 1\textsuperscript{st} stage ECCS hydro accumulators have been moved below the service elevation.

VVER-TOI – “mirror layout”
Steam chambers side location made it possible to rearrange completely the around-structures at the upper elevations as well as to balance the length of steam lines from all steam generators to FSIV, thus causing the balancing of hydraulic losses and of medium parameters of the steam lines.

Pressure losses of steam lines have been minimized by excluding the steam header from the steam generator steam path.
Evolution of Approaches to Reactor Building Civil Structures Erection

**RPV-320-type NPP**
- Construction time – 46 months, Implemented with Unit 3 of Zaporozhskaya NPP

**NV NPP-2**
- Schedule construction time – 52.5 months for the first two Units

**VVER-TOI type NPP**
- Schedule construction time – 48 months for the main Unit, 40 months for next Units

- reinforcement with individual bars
- reinforcement with spatial frameworks
- reinforcement with reinforced form assemblies with retained frameworks
Modern designs of VVER Gen III (III+) feature a perfect blend of safety technology, reliability and economic performance.

Further increase of NPP performance can be obtained by increasing working parameters resulting in higher coefficients of efficiency.
Thank you for your attention!

Address:
7, bld.1 Bakuninskaya Str.,
Moscow 105005

+7 (499) 949-45-45

news@aep.ru
www.aep.ru