Safety of the VVER key design features in compliance with regulatory requirements of Russian Federation.

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### Fundamental safety functions

<table>
<thead>
<tr>
<th></th>
<th>Reactivity control</th>
<th>Removal of decay heat to the ultimate heat sink</th>
<th>Confinement of radioactive materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>• Prevention of uncontrolled reactor power increase.</td>
<td>• Cooling of the shut-down reactor.</td>
<td>• Prevention of considerable radioactive releases in the environment.</td>
</tr>
<tr>
<td></td>
<td>• Ensuring fast safe shutdown of the reactor, if necessary.</td>
<td>• Cooling of the spent fuel.</td>
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### Fukushima lessons learned

1. Fundamental safety functions have to be ensured even in case of:
   - loss of power supply and/or;
   - loss of ultimate heat sink.

2. The systems providing fundamental safety functions have to be protected from all possible threats both natural and man induced.

3. Contents of the reactor have to be protected so that to prevent big radioactive leaks even after core melt.

*International consensus is to ensure redundancy and diversity of the safety systems.*
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International Acceptance of VVER technology

VVER 1200 Design International Expertise

2009 - feasibility study of Loviisa-3,
2013 - feasibility study of Hanhikivi-1

2012 - Baltic NPP has been verified for compliance to EUR requirements.

2013 - MIR.1200 for Temelin 3&4 NPP verified for compliance to CEZ a.s. BIS (EUR based requirements).

2013 - TAEK has approved the «Basic Report for Akkuyu NPP site», the «Reference Plant Report» and «Site Parameters» Report.


Reference design for VVER 1200 – Tianwan NPP (AES-91 design) had undergone an examination by the Chinese Nuclear Authority and IAEA (more than 20 special missions)

AES-91 design AES-92 design
# VVER-1200 Key Technical Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed nominal output per one power unit, MWe</td>
<td>1198 *</td>
</tr>
<tr>
<td>Aux power consumption, %</td>
<td>7.48 *</td>
</tr>
<tr>
<td>Lifetime, years</td>
<td>60</td>
</tr>
<tr>
<td>Efficiency, % gross</td>
<td>37.3</td>
</tr>
<tr>
<td>Autonomy, hours</td>
<td>72</td>
</tr>
<tr>
<td>Availability factor – EUR methodology, %</td>
<td>&gt;90</td>
</tr>
<tr>
<td>Seismicity: maximum credible earthquake, peak ground acceleration</td>
<td>Up to 0.25g *</td>
</tr>
</tbody>
</table>

* Depending on the project and site conditions.*
Active and Passive Safety systems

**Active**

- Used as priority safety systems to handle abnormal events and design basis accidents.
- **Quick** reaction on deviations.
- Need reliable AC power.

**Passive**

- Used for **reliable** reactor shutdown and as diverse systems to provide decay heat removal when respective active systems have failed.
- Do not need AC power.

**NP-082-07 “Rules of nuclear safety of reactor installations of nuclear power plants”, 2.3.1.4:**

The Reactor Installation design shall provide for at least two reactor shutdown systems, each one being capable independently from others of rendering the reactor to subcritical state and maintaining it in this state considering the single failure criterion or human error.
Safety systems

Types of safety systems (NP-001-15)

Safety systems and elements are classified according to their functions:

- Protective
- Supporting
- Localizing
- Control

The title of NP-001-15 is «General provisions of safety of nuclear power plants» and it came from previous document OPB-88. This highlights, the general safety conception is based on principles established after the Chernobyl disaster. This is a backbone document from RF codes-n-standards family in the area of use of nuclear power. Nowadays it is harmonised with IAEA SSR-2/1 document.
Protective safety systems (1/5)

**NP-001-15, 3.5.1:**
NPP design shall provide for the protective safety systems ensuring the reliable emergency reactor shutdown and confining the reactor in the subcritical state under operational occurrences, including design basis accidents.

- Reactor protection system (passive)
- Emergency boron injection system (active)
- Hydro accumulators (passive)
- Emergency core cooling system (active)
Protective safety systems (2/5)

Reactor control and protection system

1. All VVER reactors can be shut down by cutting power of the electromagnets that hold them above the reactor core:
   - **Gravity force** causes the rods to drop into the core.

2. VVER-1200 plant reactor has a **unique safety feature** when compared with other pressurized water reactors:
   - When control rods are in the core the reactor will **stay in shutdown state down to temperatures below 100°C.**
Protective safety systems (3/5)

**HP injection system**
- Filling of loss of the primary circuit coolant and heat removal from the reactor core at small leaks of pipelines of the primary circuit (rupture of pipes by the diameter of about 100 mm inclusively).

**Emergency Core Cooling System**
- Cool-down of the reactor plant down to 70°C after the reactor shut-down, when heat removal through steam generators becomes ineffective ($PI < 1.96 \text{ MPa}$, $T < 130°C$).
- Heat residuals removal from the fuel in the fuel pool in all modes of unit operation.
- Introduction of agents, for coupling radioactive iodine, into the primary coolant at the accidents with leak.

**Passive decay heat removal system**
- Decay heat removal from the reactor core via steam generators at the accidents with the loss of all alternating electric power supply sources.
SG emergency cool-down and blow-down system

- Heat residuals removal from the reactor core and cooling-down of the reactor plant in emergency situations related to de-energizing or loss of possibility of normal heat removal through the secondary circuit including leaks of steam pipelines and feed-water pipelines of SG.
- Heat residuals removal from the reactor core and cooling-down of the reactor plant in emergency situations related to the primary circuit depressurization including primary circuit coolant pipeline rupture (through undamaged loops) and the leak form the primary into the secondary circuit.

Main steam pipeline isolation system

- Fast and reliable isolation of Steam Generators on steam side in the following modes:
  a) leaks of steam or feed-water pipelines. The purpose is to exclude abrupt cool-down of the reactor and to provide operation of emergency heat removal system;
  b) leak from the primary into the secondary circuit. The purpose is to localize the broken-down Steam Generator on steam;
  c) failures of normal heat removal through the secondary circuit. The purpose is to provide operation of SG Emergency Heat Removal System.
Protective safety systems (5/5)

Hydraulic accumulators

• Supply the reactor with boric acid solution at any, requiring it operation, initial event (including leaks causing a dependent failure of one of system channels) taking into account one single failure, independent from the initial event, in one of the channels.

• In case of loss of coolant accident supply the reactor with boric acid solution with concentration no less than 16 g/kg and temperature from 50 to 70°C at pressure in the primary circuit less, than 5,9 Mpa.

• Design of accumulators shall exclude the ingress of nitrogen into reactor when they run out of water.

• Shall actuate inactively manner under occurrence of emergency situations which require its actuation.
NP-001-15:

3.6.1. The localizing safety systems shall be provided to confine radioactive substances and ionizing radiation within the design-specific boundaries in case of accidents.

3.6.3. The localizing safety systems shall be provided for each NPP unit and shall perform specified functions under the design basis and beyond design basis accidents.
Localizing safety systems (2/6)

**Secondary Containment**
- reinforced concrete

**Primary Containment**
- pre-stressed reinforced concrete
- leak tight metal liner

**Hydrogen mitigation system** (passive)
- passive catalytic recombiners

**Containment Spray System** (active)
Containment

- Primary (internal) containment is a pre-stressed concrete structure with steel liner and is intended to retain radioactive substances with the purpose to limit their spreading into environment under beyond design-basis accidents.
- Secondary (external) containment is intended to protect systems and elements of the reactor compartment against special and environmental and man-made effects including aircraft crash.
- The both containments provide biological protection against ionizing irradiations.

Spray System

- Reducing pressure and temperature inside the containment in case of loss of coolant accident by injecting boron solution into the containment air with a concentration of 16 g/kg.
- Pressure decrease time down to atmospheric pressure < 24 h.
- binding of radioiodine contained in the steam and air of the sealed volume.
Localizing safety systems (4/6)

- The system of pre-stressing with orthogonal arrangement of bundled reinforcing bars (FREYSSINET technology) is used for pre-stressing of inner containment.

- Horizontal type bars in the cylinder - **53** pcs.

- Horizontal type in the dome - **15** pcs.

- Vertical type - **60** pcs.
Localizing safety systems (5/6)

**Containment isolation system**

- Isolating pipelines passing through the boundary of the hermetic containment to prevent release of fission products to the environment.

**Hydrogen mitigation system**

- Prevention of explosive mix formation in accident localizing area by supporting volumetric hydrogen concentration in the mix below the criteria, set for design basis accident and beyond design basis accident.
Localizing safety systems (6/6)

Molten corium localizer

• Placed below the reactor vessel to protect the containment structures against impact of molten core

• Retains and cools core melt and solid fragments of the core, parts of the vessel and reactor internals resulting from core damage

• Transfers passively the heat to cooling water surrounding the “core melt pot” and thus ensures long term cooling and solidification of the molten core
Localizing safety systems (6/6)

**NP-001-15:**

3.7.1. NPP design shall provide the required support safety systems to supply the safety systems with working fluid and energy and to create the required conditions of their operation, including heat transfer to the ultimate heat sink.

**List of supporting safety systems**

- Essential component cooling system.
- Cooling water system of the essential users.
- Emergency electric power supply systems.
- Room heating, ventilation and conditioning systems.
- Fire-fighting system.
Supporting safety systems (2/3)

**Essential component cooling system**

- Removing heat residuals from the equipment located in buildings of essential users and diesel generator buildings to the system of cooling water of essential users in all modes of unit operation including the emergency modes.

**Cooling water system of the essential users**

- Heat removal from the component cooling of essential users of the reactor compartment and from stand-by diesel electric power station.
Emergency electric power supply systems

- Power supply of safety systems consumers in all NPP operational modes, including the case of power supply loss from operational and reserve sources.

Room heating, ventilation and conditioning

- Cooling of air in rooms of safety system equipment within the allowable limits during the process equipment operation.
- Life supporting of main control room and reserve control room operators.
- Heat residuals removal and maintaining of specified temperature of air in rooms of electrical equipment and automated and control parameter system equipment.
Control safety systems

NP-001-15:

3.4.4.1. Control safety systems shall automatically perform their functions if the NPP design conditions occur.

Systems (components) intended for initiation of the safety systems and for monitoring and control of them in the course of performance of their functions.

3.4.4.2. Control safety systems shall be designed so as to eliminate the possibility of their disconnection by the operational personnel during 10-30 min after their automatic actuation, but not to interfere with correct actions of the operator in emergency conditions envisaged by the operating regulations, emergency operating procedures, guideline for management of beyond design basis accidents.
Spent Fuel Pool retention

Backup system for water supply to spent fuel pool using motor pump

Mobile diesel generator

7th BDBA power supply train

Distillate or boron solution tank (4x700 m³)

Spent Fuel Pool

- Mobile diesel pump unit
- L = 120-150 m
- G = 60-90 m³/h
- M = 800 kg

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NP-001-15:

3.1.3. Specific technical tools shall be provided in the NPP design that ensure management of beyond design accidents.

List of severe management systems

• Passive heat removal system.
• Hydrogen recombination system.
• Corium retention and cooling system.
Passive heat removal system (1/2)

- Residual heat removal via water boiling at the atmosphere pressure.
- Natural recirculation driven with capacity of up to 2% of the rated power.
- Four-train system, each channel having 33% capacity.
- Upper tanks on the roof with total capacity of 72 hours water boiling.
Passive heat removal system (2/2)

Passive heat removal system (wet type)

1. Emergency Heat Removal Tanks (EHRT) outside the containment; heat is removed by boiling of water in EHRTs at atmospheric pressure for both PHRS-SG and PHRS-C.
2. Steam lines.
3. Condensate pipelines.
4. PHRS-SG valves.
5. Heat exchangers of containment heat removal system PHRS-C, it is a separate system but uses the same EHRTs.
6. Steam generators.
7. Cutoff valves (valve in steam line belongs to PHRS-SG).
Hydrogen recombination system

- 154 passive catalytic recombiners.
- Maximum hydrogen concentration in the long term – 0,56%.
- Local peak hydrogen concentration at any time in dry air condition – 1,8%.
- Eliminates any possibility for accumulation of potentially blasthazardous concentrations.
Corium retention and cooling system

• Molten core is mixed with neutron absorbing material placed inside the “core melt pot” to ensure that no chain reaction can start in the mixed materials inside the core catcher.

• In no accident scenario there is water inside the “core melt pot”. This eliminates the risk of steam explosion.

• Core catcher decreases significantly the hydrogen generation (typically by factor 4) because the hot metal captures oxygen from the aluminum oxide in the pot and not from water.

• Crust formed on the top stops release of radionuclides into the containment.
Conclusions

1. VVER-1200 has a balanced combination of active and passive safety systems.
2. Such combination ensures both quick (due to active part) and reliable (due to passive part) mitigation of any accidents that can occur.
3. Every active system is supplied by a passive one with the same target.
4. Each system of one origin is able to mitigate an accident alone (without support of a system of complementary origin).

Unique safety feature – re-criticality temperature is less than 100°C.
THANKS FOR YOUR ATTENTION