Development of the NPP Designs Based on the VVER Technology

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VVER - WATER COOLED WATER MODERATED POWER REACTORS

Constructed: 66 reactors

In operation: 59 reactors

NPP-91

2 reactors

Reactors of Small series

5 reactors

1st generation

16 reactors

2006 — VVER-1000, Tianwan-1, China

1984 — VVER-1000, Zaporozhie-1

1980 — VVER-440, Novovoronezh-5

1977 — VVER-440, Loviisa, Finland

1971 — VVER-440, Novovoronezh-3

1969 — VVER-365, Novovoronezh-2

1966 — VVER-70, Reinsberg, East Germany

1964 — VVER-210, Novovoronezh-1

Reactors of Large series

21 reactors

2nd generation

19 reactors

Modern NPPs with VVER-1000 reactors

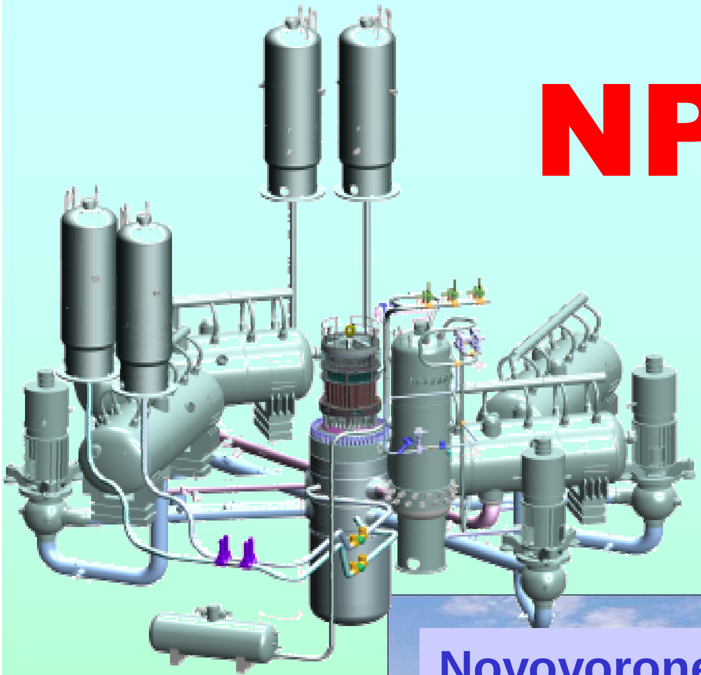
Main goals of the NPP-2006 Project

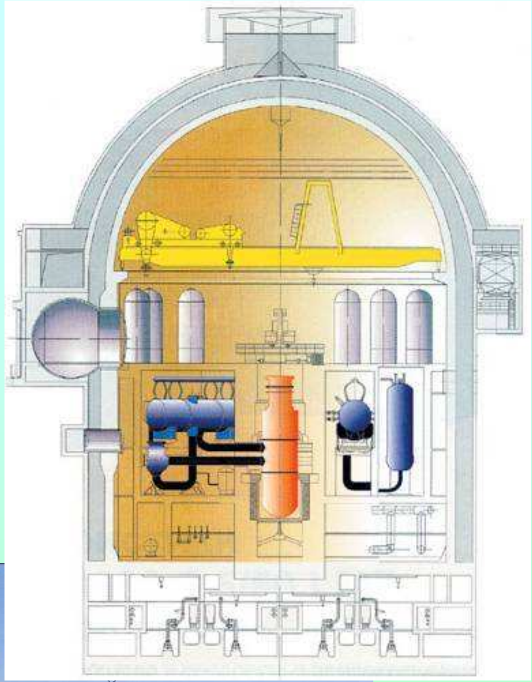
- NPP-2006 nominal electric power - to be at least 1200 MW (gross);
- Design service life of the NPP main equipment – 60 years;
- Availability factor – 92%;
- Load factor – 90%;
- Duration of the overhaul life – not less than 8 years;
- Fuel cycle length – up to 24 months;
- Requirements for load follow characteristics –according to EUR;
- Feed water inventory - to be sufficient for decay heat removal within 24 hours;
- Total frequency of the core degradation – less than 10^{-6} per reactor-year

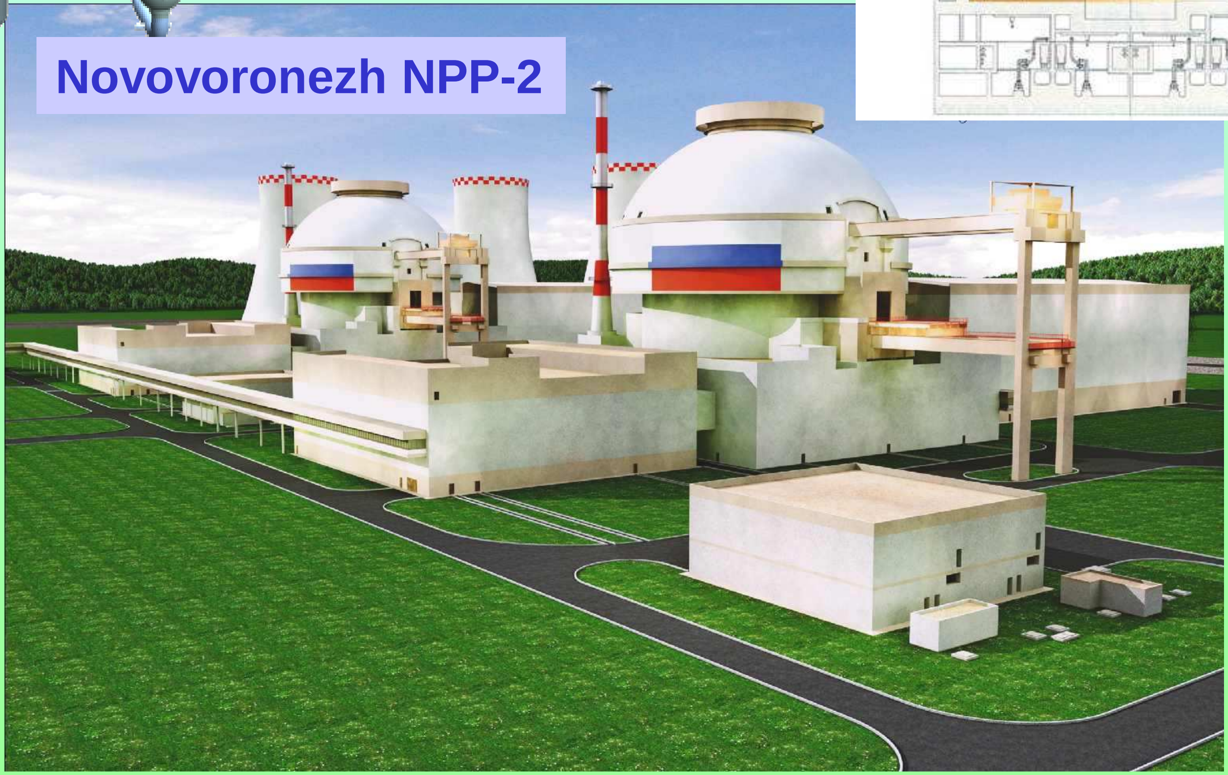
Achieved goals of the NPP-2006 Project

- **Thermal power has been increased up to 3200 MW and Efficiency factor (gross) of a power unit has reached 36.2%, due to:**
  - ***Removal of excessive conservatism;***
  - ***Improvement of steam turbine thermal circuit;***
  - ***Improvement of steam parameters at the steam generator outlets;***
  - ***Decrease of pressure losses in steam lines.***
- **Economic efficiency has been improved through:**
  - ***Optimization of passive and active safety systems;***
  - ***Unification of the applicable equipment;***
  - ***Decrease of materials consumption;***
  - ***Shortening of construction phase duration.***

NPP-2006





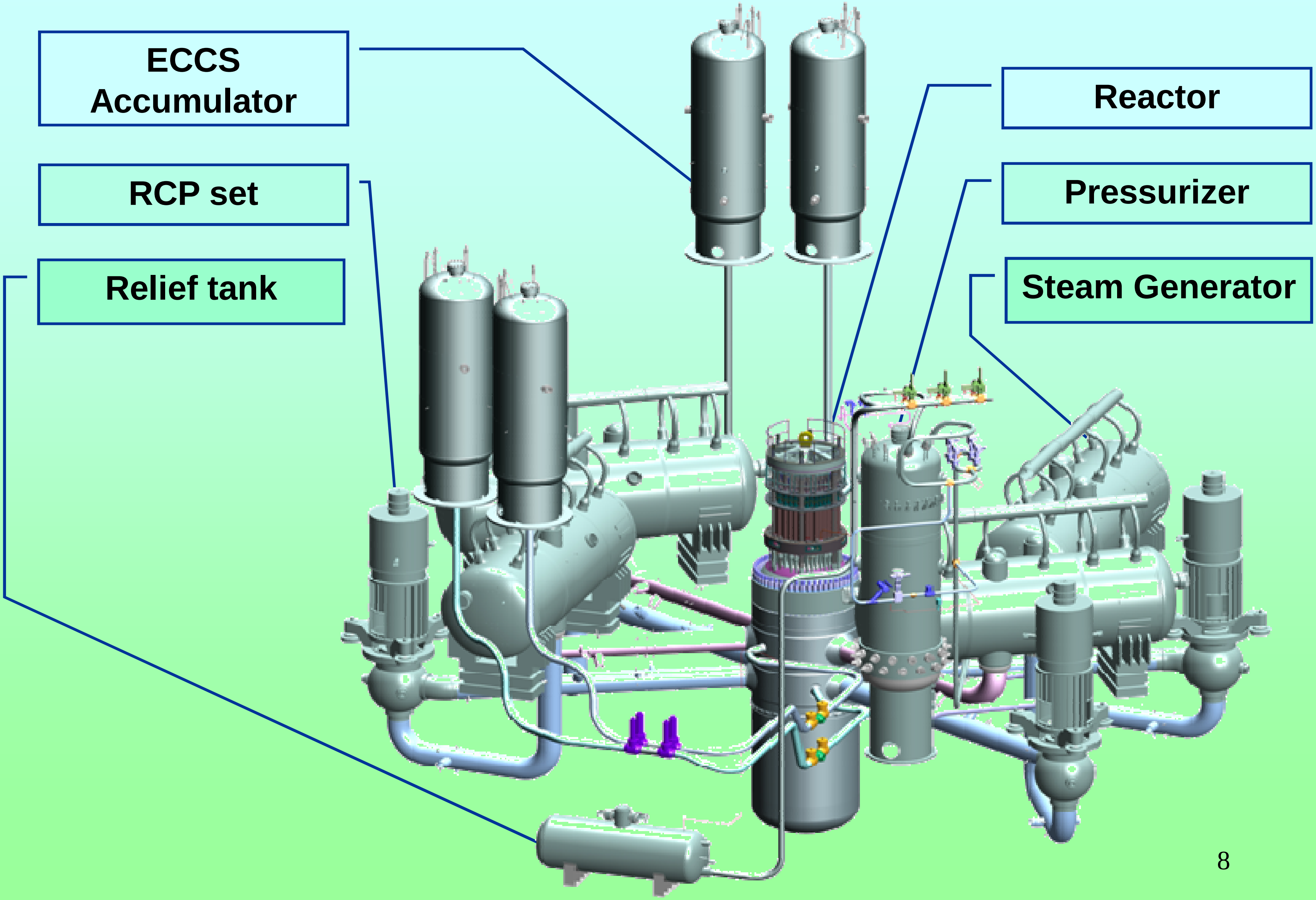


Novovoronezh NPP-2

Main parameters of the Reactor Unit

Parameter	NPPs with VVER-1000	NPP-2006
The reactor nominal thermal power, MW	3000	3200
Load factor	0.80	0.92
Coolant pressure at the reactor outlet, MPa	15.7	16.2
Coolant temperature at the reactor inlet, °C	290.0	298.6
Coolant temperature at the reactor outlet, °C	319.6	329.7
Maximum linear heat flux, W/cm	448	420
Pressure at the outlet of the SG steam header, MPa	6.27	7.0
Mass flow rate in the core, $kg/(m^2 \cdot s)$	3850	3930
Minimum DNB ratio	1.30	1.38
Maximum level of fuel burnup, MW-day/kgU(FA)	55.0	59.7
Averaged level of fuel burnup, MW-day/kgU(FA)	49	55
Period between reloadings, months	12	12/18

Basic pattern of the NPP-2006 Reactor Unit



Design solutions for the basic equipment of NPP-2006 reactor units

Reactor unit

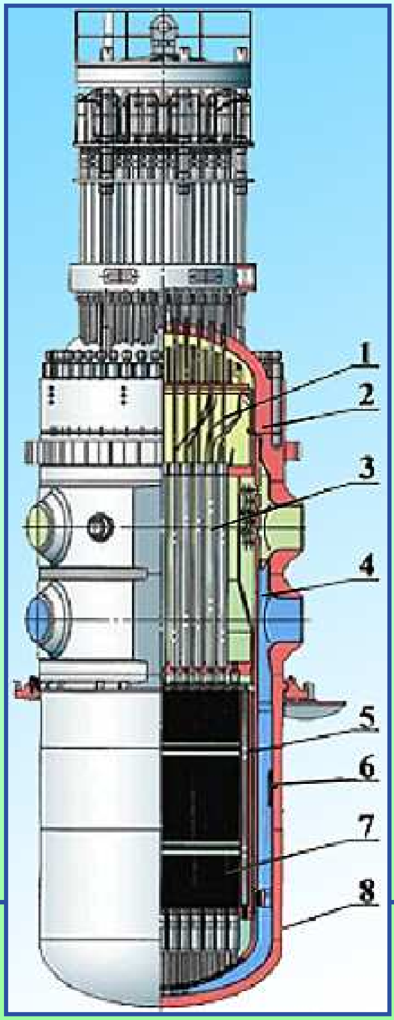
Basic design distinctions:

- RPV inner diameter is extended by 100 mm as compared
to the VVER-1000 RPV;

- Core baffle height is increased by 200 mm;

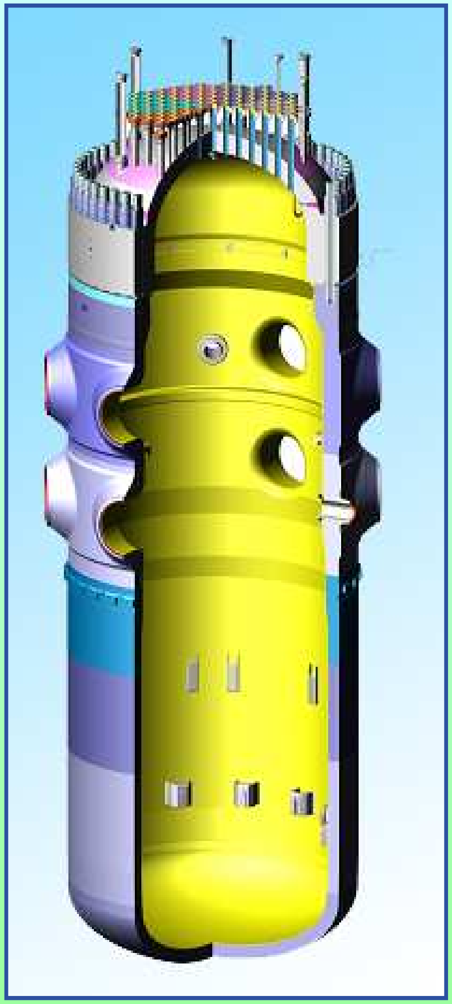
- The guiding frame for the CPS control rods in the protective tube unit is extended

Условные обозначения Symbols	
Сборка внутриреакторных детекторов In-core instrumentation detectors	1
Блок верхний Upper unit	2
Блок защитных труб Protective tube unit	3
Шахта внутрикорпусная Core barrel	4
Выгородка Core baffle	5
Образцы-свидетели Surveillance specimens	6
Зона активная Core	7
Корпус ядерного реактора Nuclear reactor vessel	8

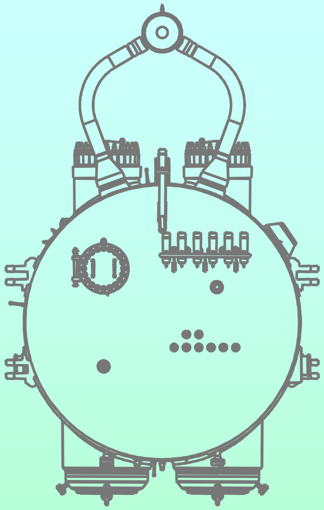


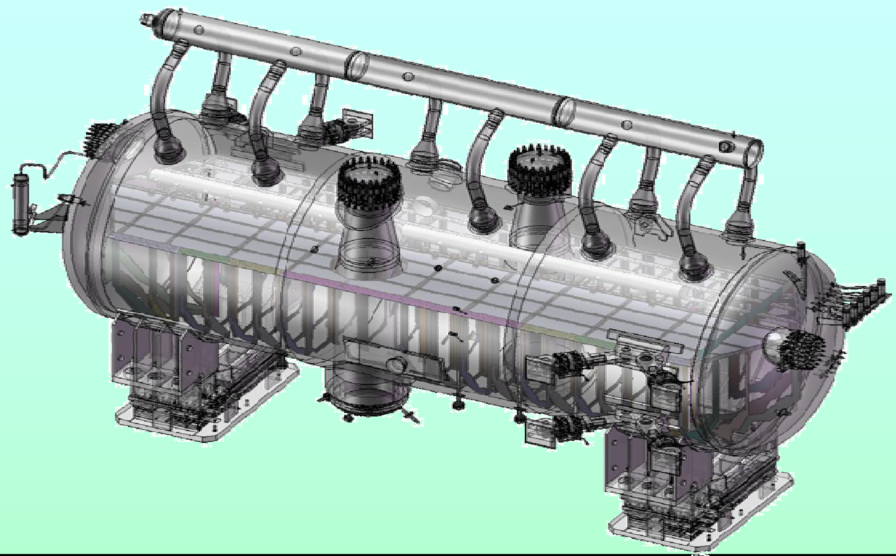
Reactor pressure vessel

Parameter	Value	
	NPP-2006	NPP with VVER-1000
Length, mm	11185	10897
Internal diameter, mm	4250	4150
Wall thickness in the core region, mm	197.5	192.5
Mass, t	330	320



Steam Generator





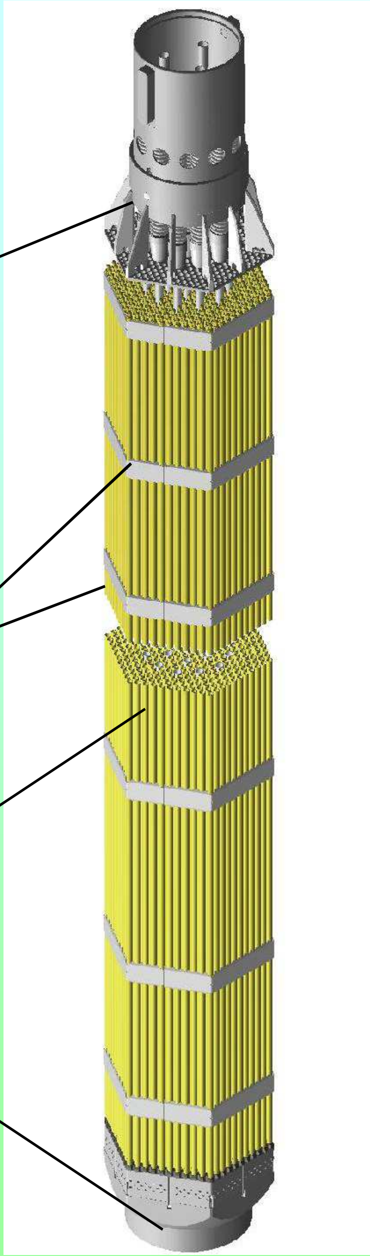
Parameter	NPP with VVER-1000	NPP-2006 SG of PGV-1000MKP - type
Inner diameter of the steam generator vessel, m	4.0	4.2
Tube bundle arrangement	staggered order	corridor-type
Steam pressure , MPa	6.3	7.0

Steam Generator

- **the secondary side water inventory is increased from 52 up to 63 m^3;**
- **rare corridor-type arrangement of tubes is used in the tube bundle;**
- **the flow rate in the tube bundle is increased;**
- **the opportunity of intertube space clogging with the separated sludge is reduced;**
- **easy access is provided** in**to intertube space for inspection;**
- **the space under the tube bundle is enlarged to facilitate sludge removal**

Fuel assembly

Fuel mass has been increased by 18% due to the elongation of the fuel column by 200 mm and to the changing of the fuel pellet sizes



Safety systems

Comparison of Tianwan NPP and NPP-2006 designs

	Tianwan NPP	NPP-2006
ECCS active part	Separated four-channel systems of high and low pressure with a channel redundancy of 4 x 100 % each	Separated four-channel systems of high and low pressure with a channel redundancy of 4 x 100 % each
Emergency boron injection system	Four-channel system with a channel redundancy of 4 x 50 %	Four-channel system with a channel redundancy of 4 x 50 %
Emergency feed water system	Four-channel system with redundancy of 4 x 100 % with emergency feed water tanks	Four-channel system with redundancy of 4 x 100 % with emergency feed water tanks
Passive heat removal system (PHRS)	Not available	Available
Containment passive heat removal system (CPHRS)	Not available	Available
Core catcher	Available	Available

Passive heat removal systems (PHRSs) in the NPP-2006 design

- **SG passive heat removal system (SGPHRS):**

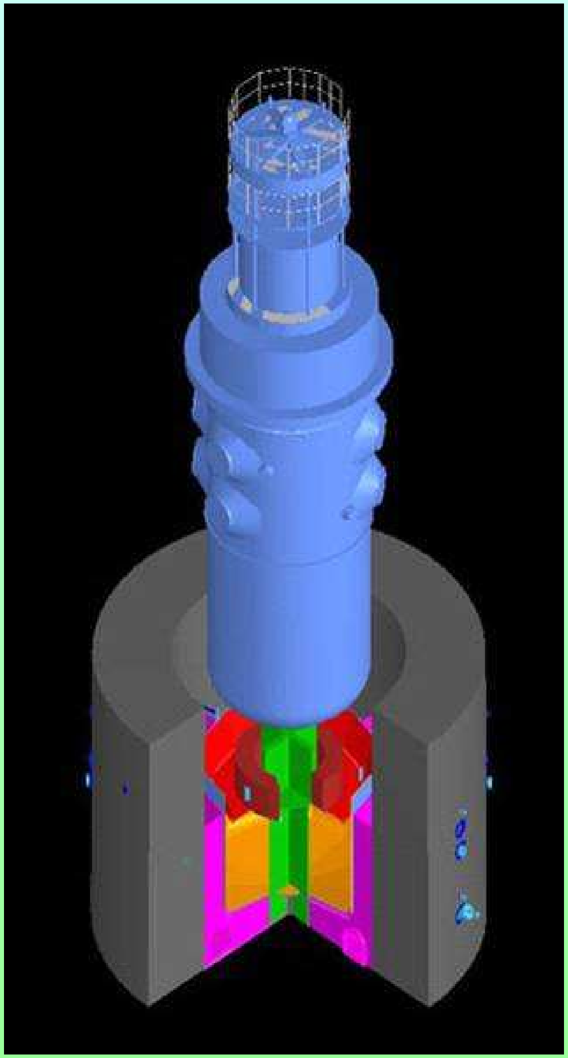
  - prevention of core melting in case of a BDBA

  - mitigation of radiological consequences of accidents with leakage from primary into secondary loop

- **Containment passive heat removal system (CPHRS):**

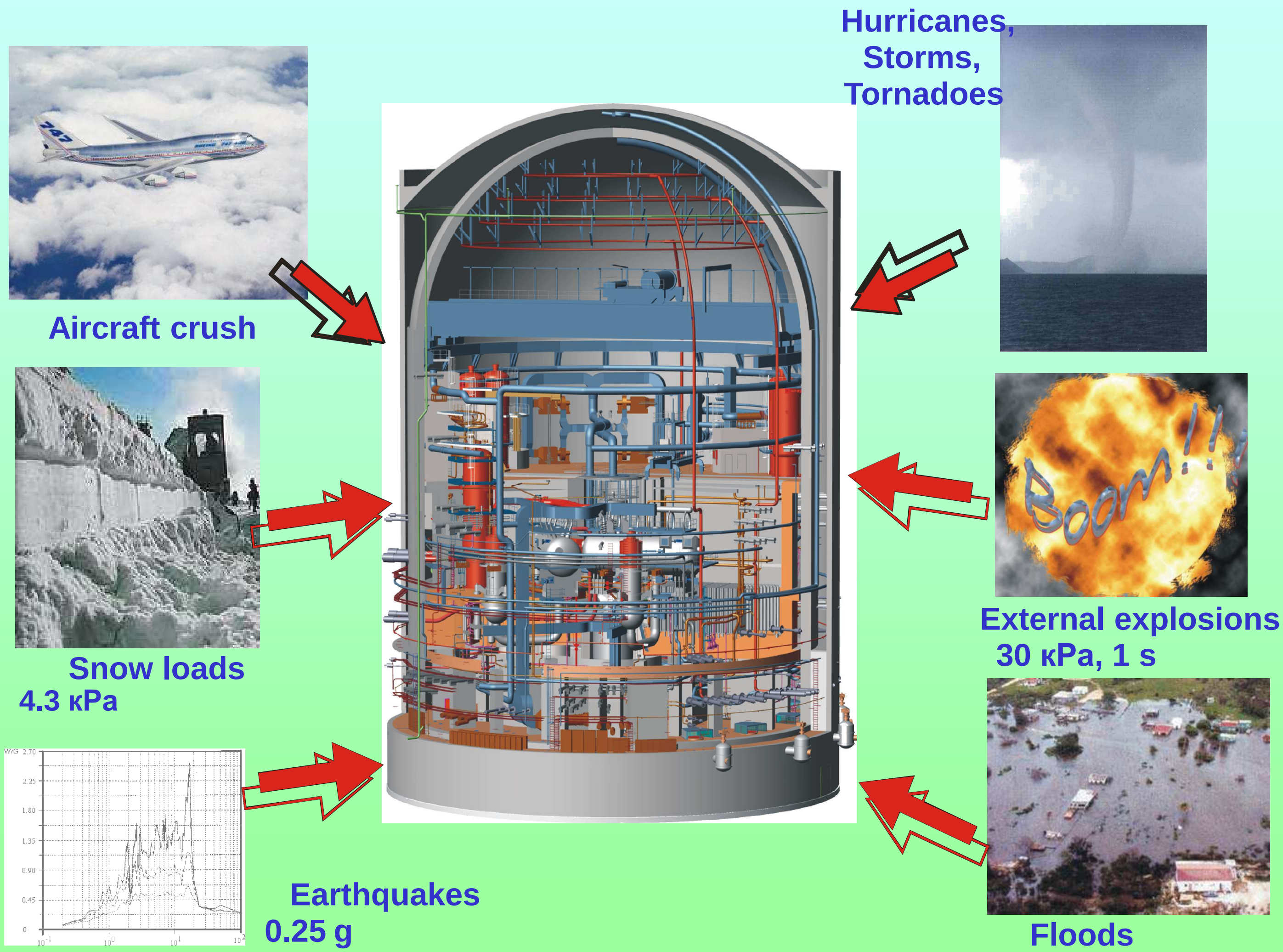
  - long-term heat removal from the containment in case of any BDBA

Core melt retention system (core catcher)



- Location under the reactor lower head
- Protection from thermal & mechanical impacts of the corium
- Provision for heat removal from the corium
- Provision for the corium subcriticality
- Reduction of gas release into the containment
- Provision for exothermal reactions

Protection from external impacts in the NPP-2006 design



Expert reviews in the course of development and implementation of the NPP-2006 design

- **The utility's peer review as part of the acceptance procedure :**
  - departments of the Design Engineering branch;
  - departments of the Production & Operations branch.
- **Governmental authorities reviews:**
  - «Glavgosexpertiza» – design documentation and the site investigation results;
  - Rostechnadzor – licensing.

Near-term prospects of the VVER technology development (NPP-2006M)

- **Employment of MOX fuel**
- **Introduction of a renovated vessel steel with increased radiation resistance**

Long-term prospects of the VVER technology development

- **More efficient use of uranium and plutonium**
- **Increasing thermodynamic efficiency**
- **Reduction of investment risks**

Goal features of an innovative NPP unit based on the traditional VVER technology

- **<u>Fuel utilization</u> - operation with breeding ratio (BR) ~ 0.8 – 0.9 and natural uranium consumption 130 – 135 t/GW (e) per year**

- **<u>Thermodynamic efficiency</u> - improvement of the efficiency coefficient by optimization of the steam generator design and by the maximum possible increase of steam parameters**

- **<u>Investment payback</u> – shortening of the construction period down to 3.5 – 4 years due to the industrial modular fabrication**

Fields of R&D towards innovative design of the vessel-type water-cooled reactors

(options of NPPs with SUPER-VVER)

- **Cooling with water of subcritical parameters, with the capability for neutron spectrum control**
- **Cooling with boiling water of subcritical parameters**
- **Cooling with supercritical pressure water in variable neutron spectrum:**
  - **in direct-flow one-loop reactor unit**
  - **in two-loop reactor unit**
- **Steam cooling in subcritical and supercritical pressure ranges of the fast neutron spectrum**

POSSIBLE PATTERN OF NUCLEAR POWER INDUSTRY

Today → **Mid of 21-st century**

VVER-440 NPPs, VVER-1000 NPPs RBMK NPPs

Basic electricity supply → ***NPP-2006, NPP-2006M NPP – VVER-1000***

Electricity supply, extra fuel breeding → ***NPP with Super-VVER for operation in CNFC with BR ~ 0.9***

BN-600 NPP

Electricity supply + fuel breeding → ***BN-800 NPPs NPPs with fast reactors of a new generation***

Bilibino NP

Heat supply + electricity → ***Regional NPs with reactors of low and medium power range***

High potential heat, new energy carriers → ***NPPs with high-temperature reactors***

Open nuclear fuel cycle → ***Closed nuclear fuel cycle***