ОКБ «ГИДРОПРЕСС»

ПРЕДПРИЯТИЕ ГОСКОРПОРАЦИИ «РОСАТОМ»

НИЦ «Курчатовский институт»

Advanced Design of VVER Reactors

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VVER Development

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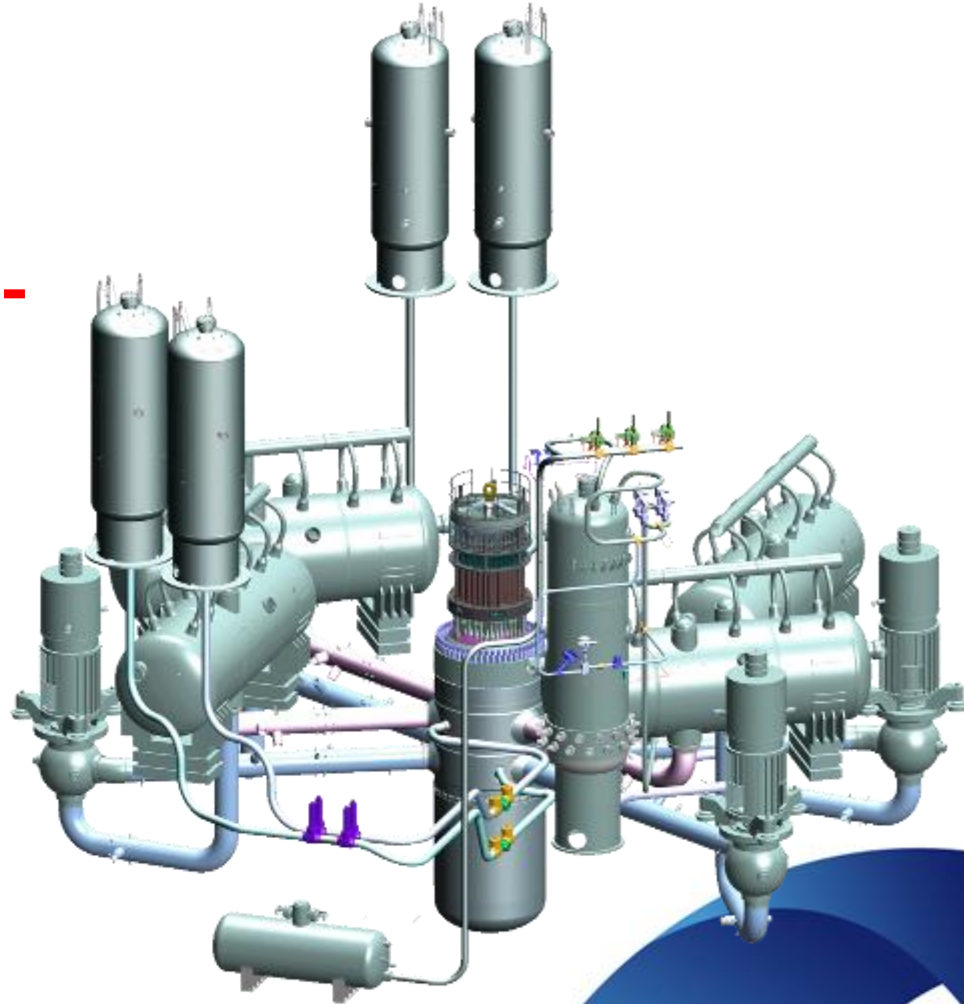
The basis for evolutionary development and improvement of VVER reactors is VVER-1200 design for NPP-2006 which presently is being built at Novovoronezh-2 and Leningrad-2 sites.



VVER Development

New designs

- ✓ 4-loop **VVER TOI** reactor;
- ✓ 2-loop **VVER-600** reactor based on components and processes of VVER-1200;
- ✓ 2-loop **VVER-1200A** reactor applying design decisions for SG PGV-1500;
- ✓ 3-loop **VVER-1800** reactor applying design decisions for VVER-1500 and VVER-1200A;
- ✓ Adaptation of designs for MOX-fuel;
- ✓ Evolutionary variant **SUPER-VVER** with spectrum regulation (natural uranium saving up to 30%);
- ✓ Innovative variant SUPER-VVER with super critical steam parameters (**VVER-SKD**) for operation in close nuclear fuel cycle (fuel reproduction factor ~ 1).

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VVER TOI

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TYPICAL:

- Referentiality
- Unification
- Licensing

OPTIMIZED:

- Cost and terms of construction, specific NPP factors
- Safety level
- Operation factors

INFORMATIZED:

New technologies of information management on NPP life

Optimization of VVER processes

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VVER TOI

Main reactor parameters

Parameters	V-392	VVER-1200	VVER TOI
Nominal thermal reactor power, MW	3000	3200	3300
Capacity factor	0,8	0,9	0,93
Reactor coolant pressure at reactor outlet, MPa	15,7	16,2	16,2
Reactor coolant temperature at reactor inlet, ºC	290	298,6	297,2
Reactor coolant temperature at reactor outlet, ºC	320	329,7	328,8
Maximum linear thermal flow, Вт/см	448	420	420
Steam pressure at SG header outlet (absolute), MPa	6,27	7,0	7,0
Calculated pressure in primary circuit, MPa	17,64	17,64	17,64
Calculated pressure in secondary circuit, MPa	7,84	8,1	9,0
Maximum depth of fuel burn-up in FA being reloaded (in basic stationary fuel cycle), MW day/kgU	49	up to 70	up to 70
Duration of fuel cycle, month	12	12/18	12/18
Period of fuel staying in the reactor core, year	4	4-5	4-5

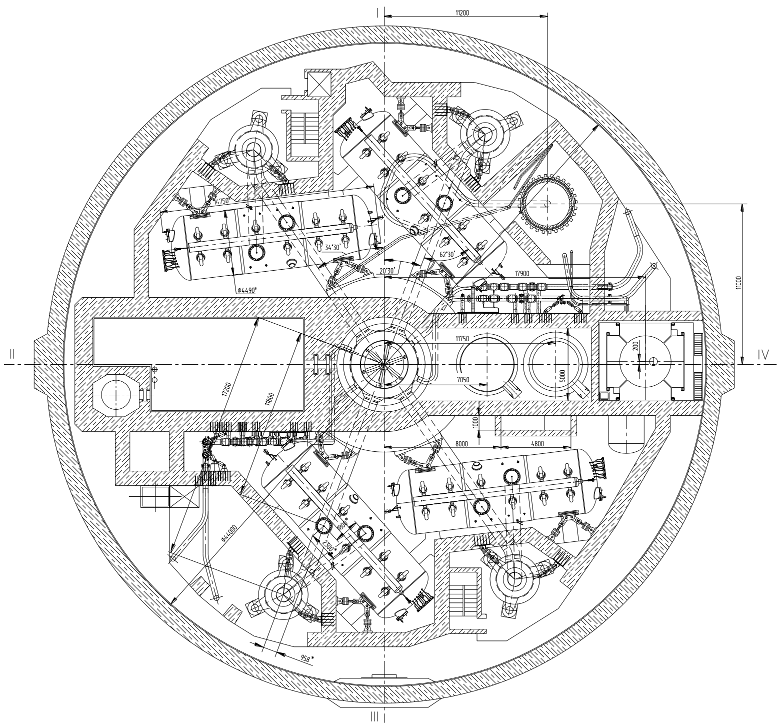
Main Directions of VVER TOI Optimization

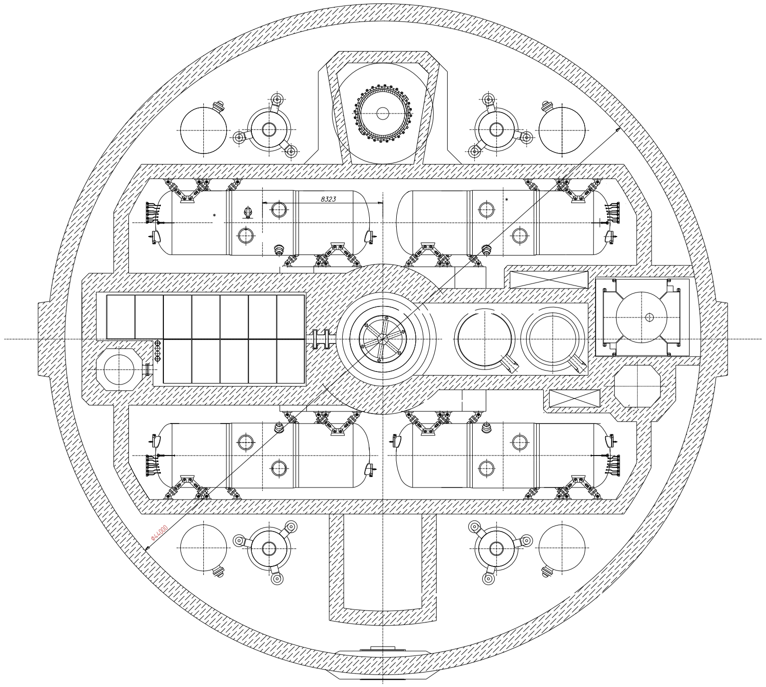
1. Power increase
2. Reactor components layout
3. Optimization of reactor vessel design
4. Optimization of reactor core design
5. Optimization of SG design
6. Optimization of RCP design
7. Achievement of KTI (КТИ) 0,93
8. Optimization of safety systems

VVER TOI.
Reactor Components Layout

Novovoronezh-2

VVER-TOI





New layout allows for location of longer steam generators while containment inner diameter stays the same (44 m)

VVER TOI. Optimization of Reactor Vessel Design

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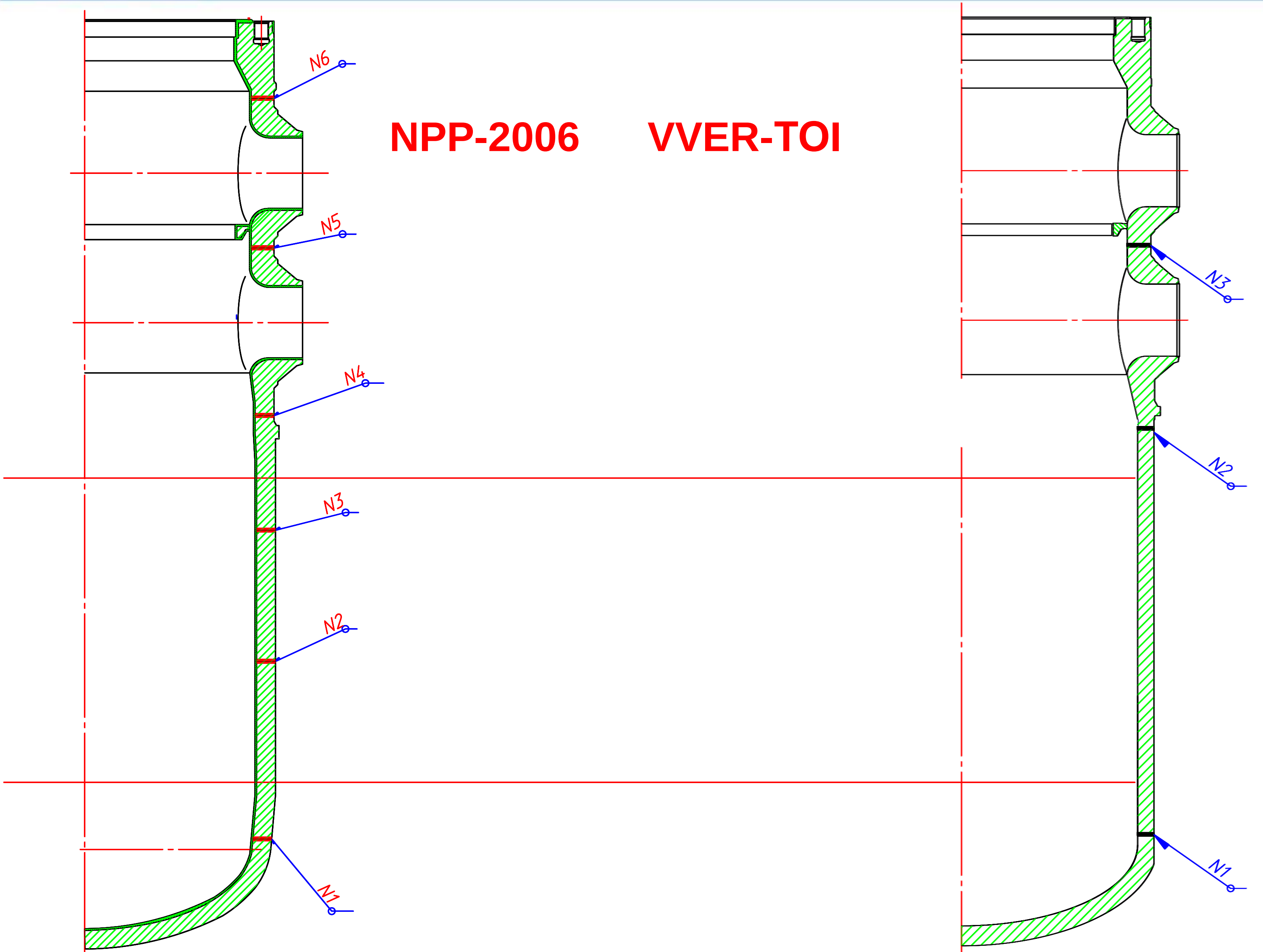

VVER TOI.
Optimization of Reactor Core Design

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Directions:

-Increase of fuel load in the reactor core and the heat exchange surface:

- Increase of fuel column length
- Increase of external diameter of fuel pellet
- Reduction of central hole diameter in fuel pellet
- Increase of fuel elements number in fuel assemblies
- Increase of fuel enrichment up to the value exceeding 5% (in the future)

-Optimization of in-core and control rod detectors location;

-Application of fuel element axial profiling by absorber content;

-Application of uranium-erbium fuel (in the future);

-Intensification of heat exchange and reactor coolant mixing in fuel assemblies (in the future).

Results:

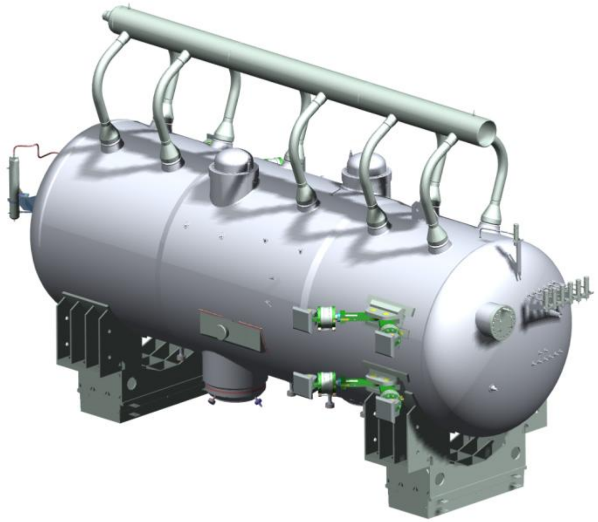
With increased (compared to NPP-2006) thermal power (3300 MW) it is possible to:

-implement 18-month fuel cycle;

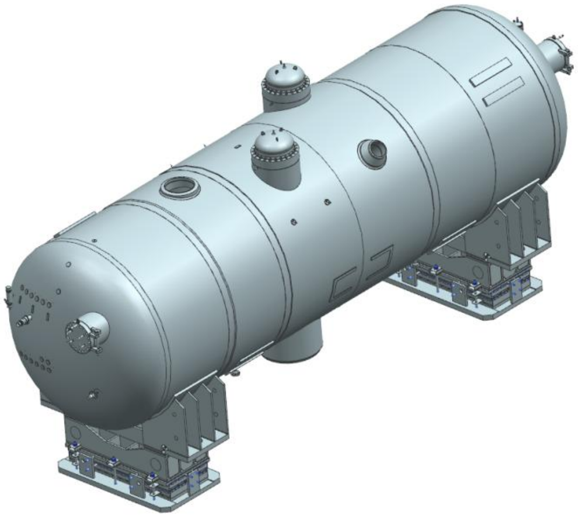
-keep restrictions on maximum linear thermal flow;

-achieve design criteria on supply before heat emission crisis.

VVER TOI.
Optimization of Steam Generator Design



SG-1000 MKP Mass- 337 t, Length- 13820 mm



SG-1000 MKO Mass - 353 t, Length 14820 mm

Steam generator SG-1000 MKO has optimized area of evaporation mirror (based upon 3300 MW reactor power) and heat exchange surface.

Due to increase of SG size it is necessary to assess SG transportation possibilities by railway.

P_{calc}=9,0 MPa

VVER TOI.
Optimization of RCP Design

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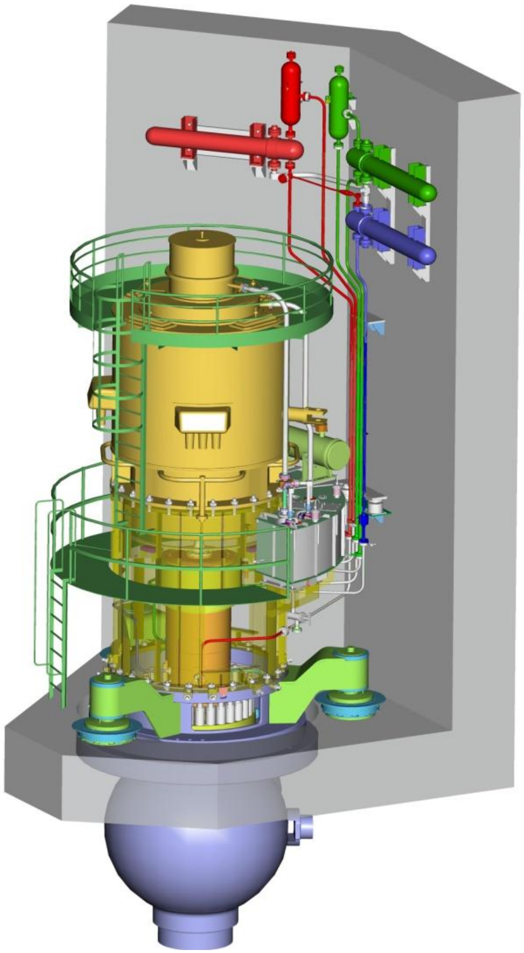

For NPPs with VVER-1200 and VVER TOI it is planned to apply RCP with **water**-cooled and lubricated pump which allows to :

- Avoid oil presence in RCP unit;
- Improve NPP fire safety;
- Simplify NPP fire fighting system;
- Simplify components layout in RCP unit;
- Simplify RCP start-up procedure.

VVER TOI. Achievement of KTI (КТИ) 0,93

- 18-month fuel cycle;
- minimum 4,5 year maintenance cycle of components;
- application of automated maintenance tools;
- reduction of welds number in components;
- application of fast-removed elements in design;
- optimization of each maintenance schedules;
- application of advanced processes during maintenance (overlapping maintenance activities, performing part of activities when the unit operates at power).

VVER TOI. Safety System Optimization

Combination of passive and active safety systems without inner redundancy.

Directions of optimization:

- application of additional reactor coolant supply for primary circuit makeup in ЗПА to provide for autonomy after 24 hours (up to 72 hours);
- expansion of functional requirements and design basics for passive safety systems, based on, primarily, their possibilities to get over design accidents;
- eliminating inner redundancy in active safety system channels and due to this obtaining saving of components, pipelines, cables, installation and operation costs;
- optimization of accumulator-1 characteristics to provide for continuous supply of reactor coolant together with accumulator-2 under conditions of ECCS active part failure.

Informatization of life cycle, Implementation of Data-centric Technologies, 3D-designing

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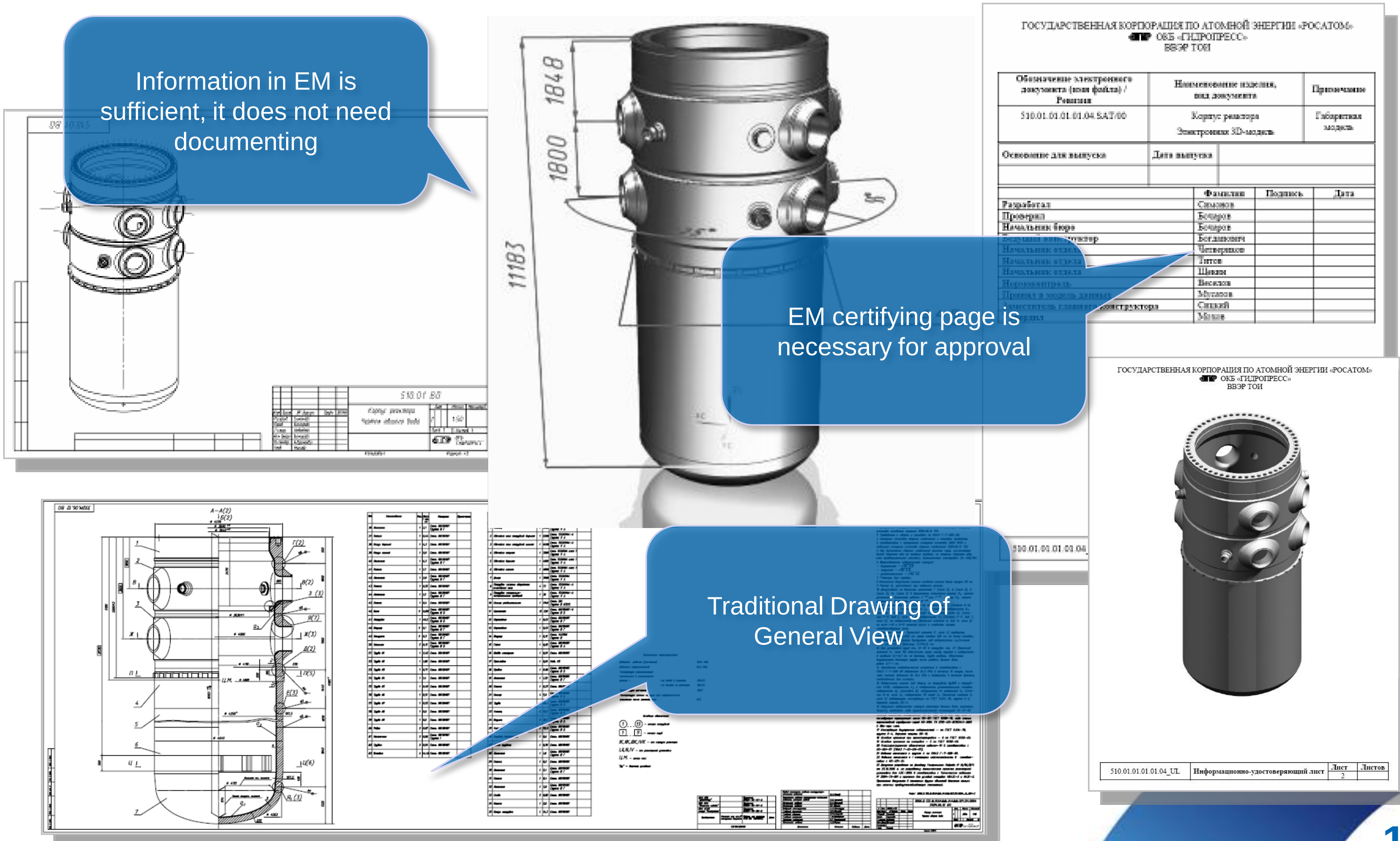
Electronic Model (EM) of VVER TOI Reactor

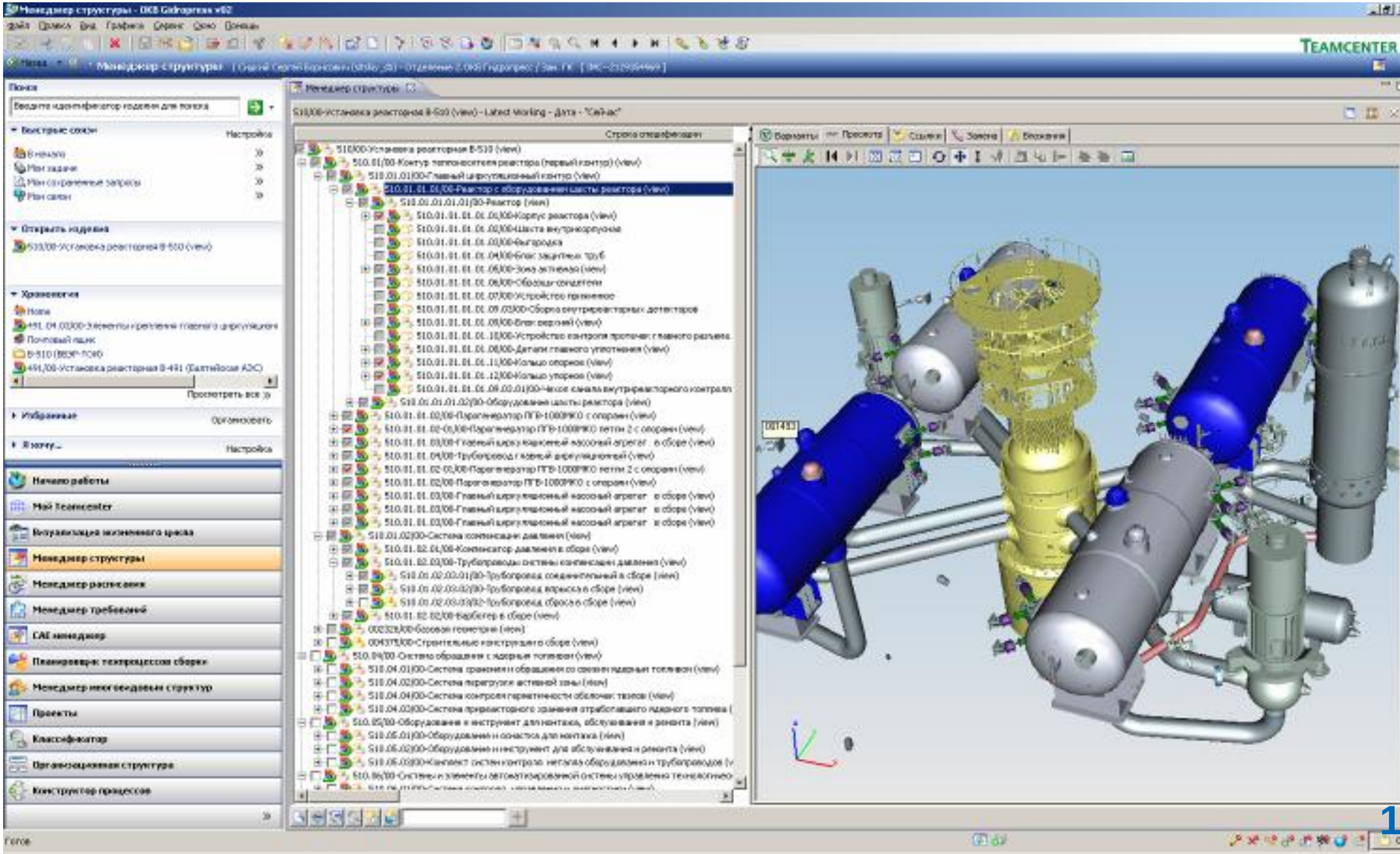


ОКБ «ГИДРОПРЕСС»

Informatization of life cycle, Implementation of Data-centric Technologies, 3D-designing

ПРЕДПРИЯТИЕ ГОСКОРПОРАЦИИ «РОСАТОМ»

3D Model of VVER TOI Reactor



2-loop Reactor of Average Power VVER-600

VVER-600 (650, 700) design concept:

- ✓ 2-loop reactor;
- ✓ Developed on the basis of VVER-1200 (Leningrad-2):
  - direct borrowing of components;
  - referentiality;
- ✓ Providing for safety of the same level as requirements for 3+ generation NPP;
- ✓ Designed life time - 60 years;
- ✓ Retaining core melt inside the reactor vessel during BDBA severe;
- ✓ Maximum application of R&D results for VVER-1000 and VVER-1200 reactor design;
- ✓ Arrangement of components manufacturing does not need much costs.

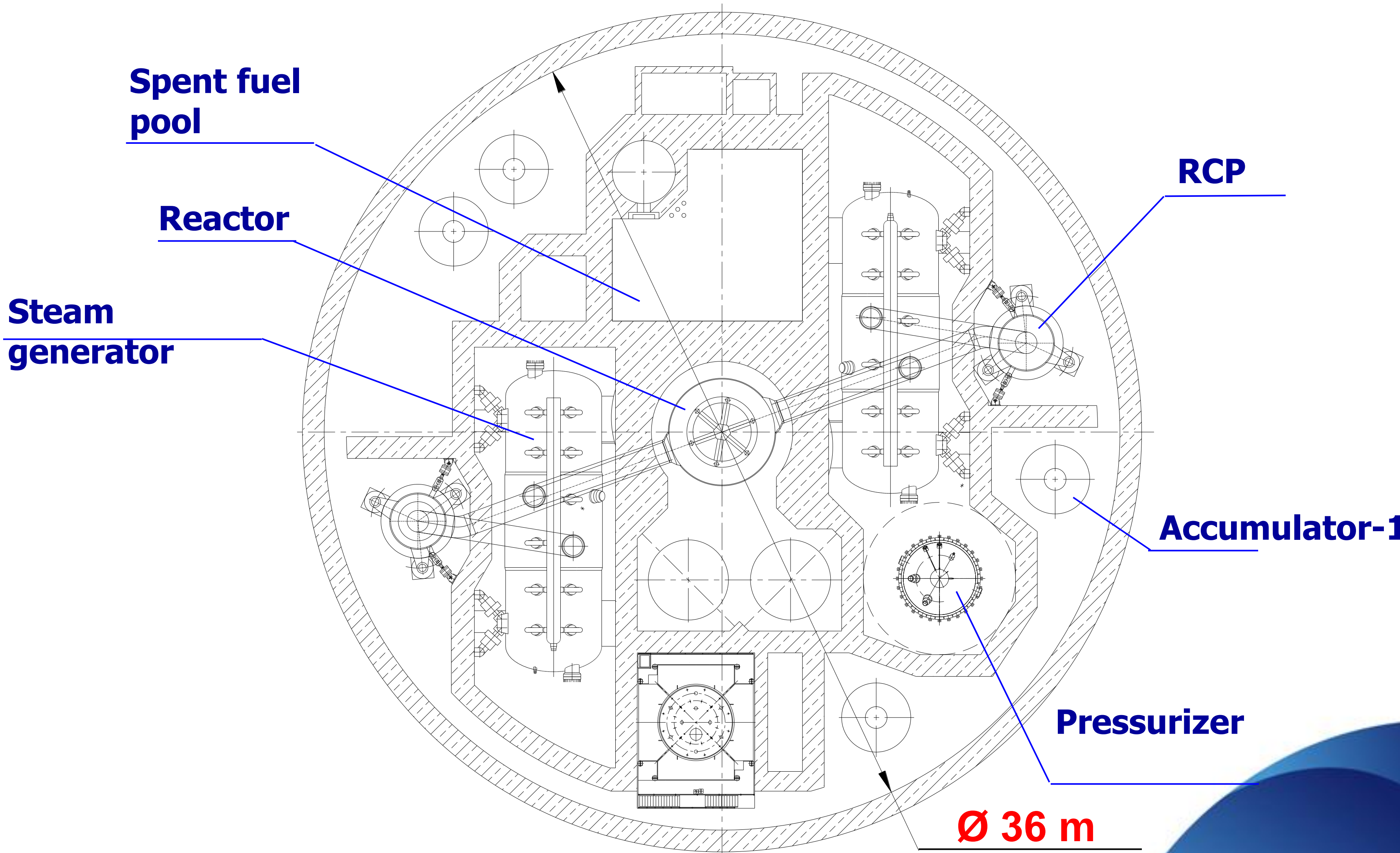
2-loop Reactor of Average Power VVER-600

Advantages of 2-loop design over the 4-loop one:

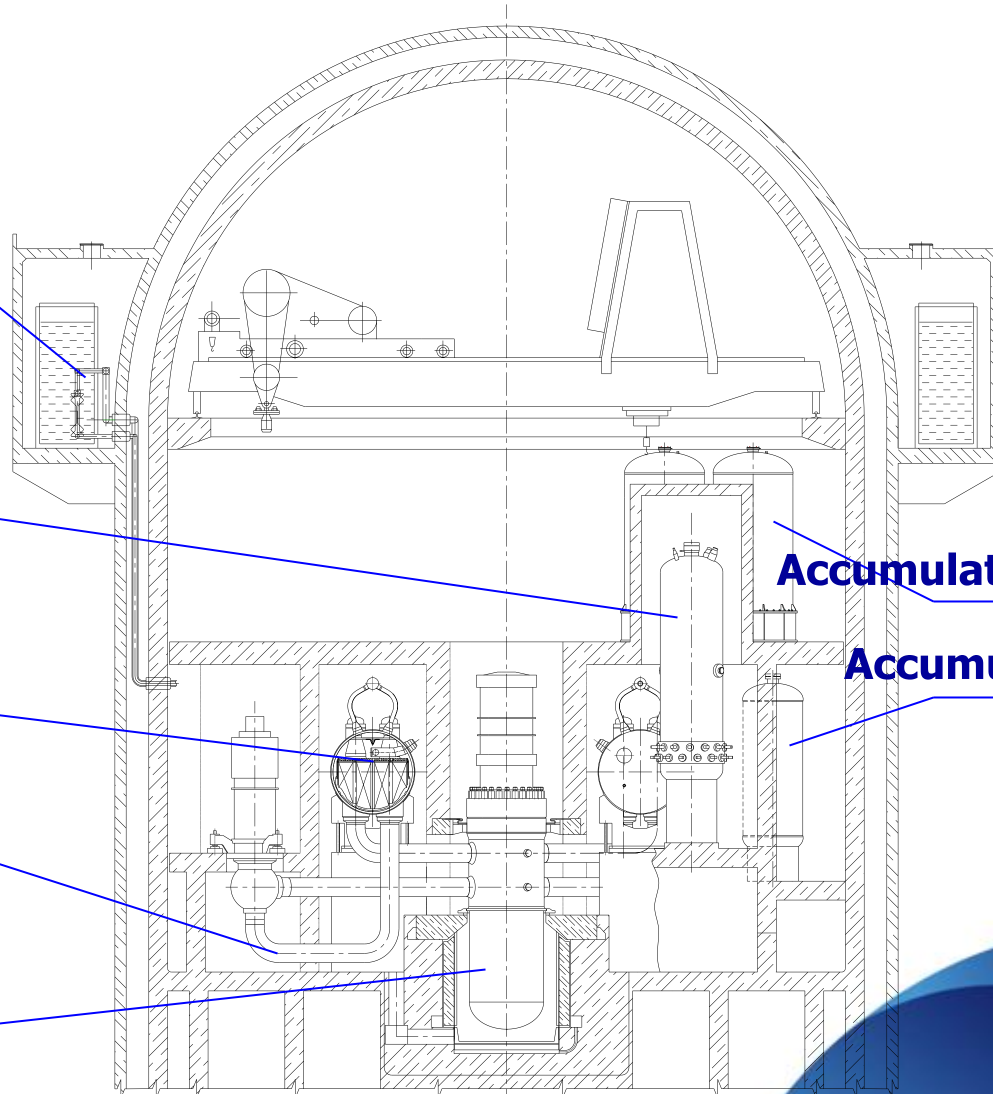
- ✓ **Reduction of reactor specific metal consumption;**
- ✓ **Reduction of component installation terms;**
- ✓ **Reduction of containment inner diameter;**
- ✓ **Reduction of operational costs by 20-25%.**

Maximum borrowing of main components from VVER-1200 design allows for reduction of reactor design development and simplification of components delivery to the site.

2-loop Reactor of Average Power VVER-600



2-loop Reactor of Average Power VVER-600



2-loop Reactor VVER-1200A

VVER-1200A Design Concept

2-loop reactor;

- ✓ **cancellation of requirement on transportation of reactor components by railway;**
- ✓ **VVER-1200 reactor with increased diameter of Main Circulating Pipeline (Dnom1000);**
- ✓ **steam generator based on PGV-1500 (with increased length and area of heat exchange surface);**
- ✓ **improvement of working and calculated parameters of secondary circuit ($P_{working.\ II\ circuit}$ = 7,35 MPa; $P_{calc.\ II\ circuit.}$ = 9,5 MPA);**
- ✓ **RCP – new design;**
- ✓ **Providing for safety of the same level as requirements for 3+ generation NPP;**
- ✓ **Designed life time 60 years.**

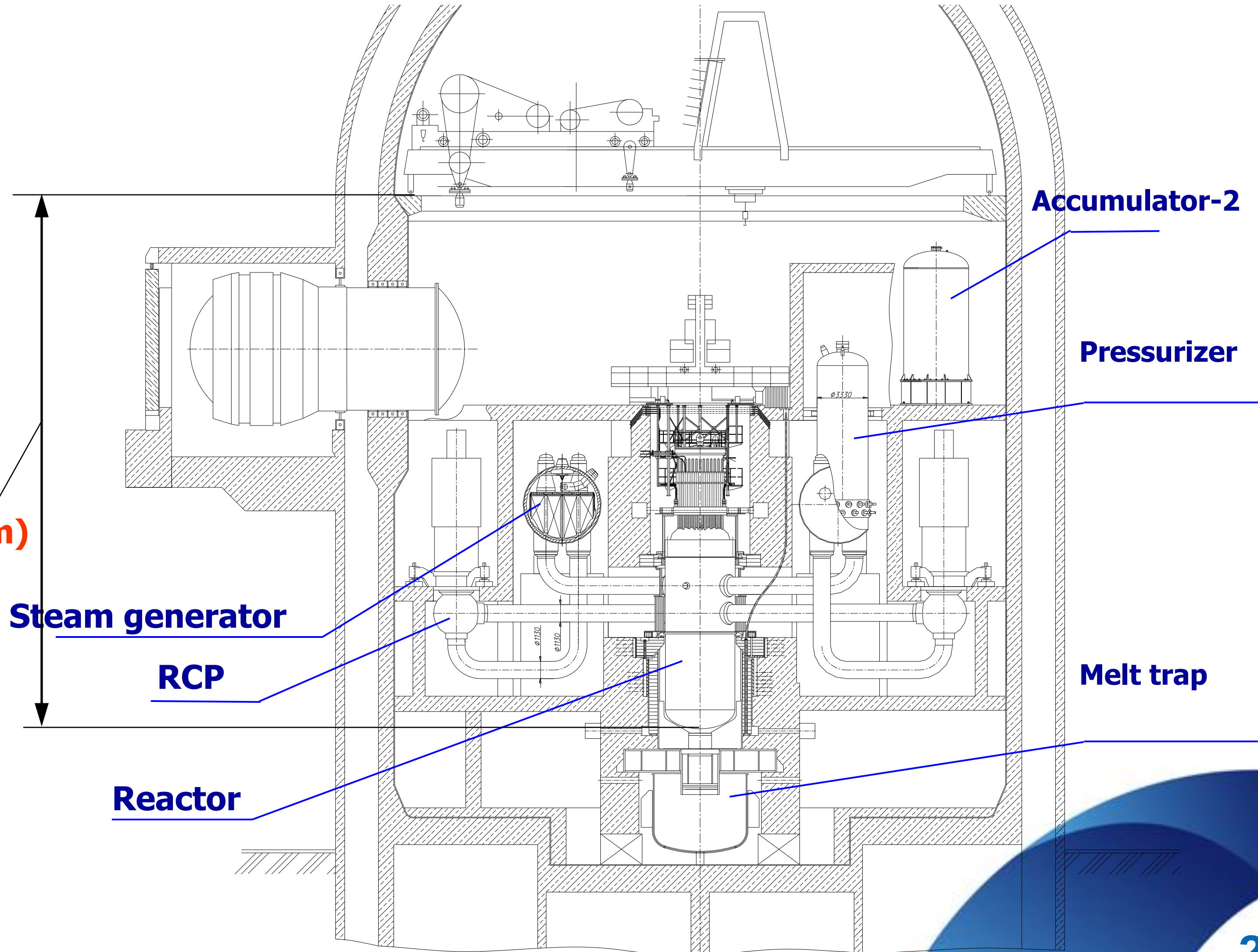
2-loop Reactor VVER-1200A

Component layout

Vertical cross section of reactor

35,9 m

(AP-1000 – 47 m)



2-loop Reactor VVER-1200A

Comparison of primary circuit components weight for VVER-1200 and VVER-1200A

	VVER-1200	VVER-1200A
Reactor	940 t	940 t
Main Circulating Pipeline	252 t	145 t
Steam generators	4 3450 t	2 3790 t
Pressurizer	215 t	215 t
RCP	4 3139 t	2 3200 t
Total weight of primary circuit components	3763 t	3280 t
Specific weight of primary circuit components, t/MW(therm.)	1,18	1,03

Super-VVER

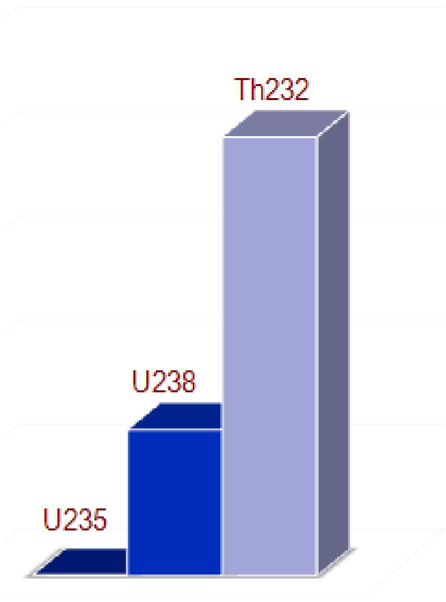
«Rosenergoatom» set a goal to develop VVER reactors of 4th generation to operate in transition period and in close fuel cycle.

This direction of innovative reactor with improved significantly fuel application got the name of «Super-VVER».

Motivation for Super-VVER Design Development

- Application of ~0,4% only of natural uranium in current nuclear power engineering, mainly uranium-235 which supply is quite limited.
- Availability of a large amount of uranium-238 and thorium-232 which energy resource is much more than the one of oil and gas.
- Need for development of reliable and stable nuclear power engineering in Russia based on multi-component structure of nuclear power engineering.

Относительные энергетические запасы ядерного топлива



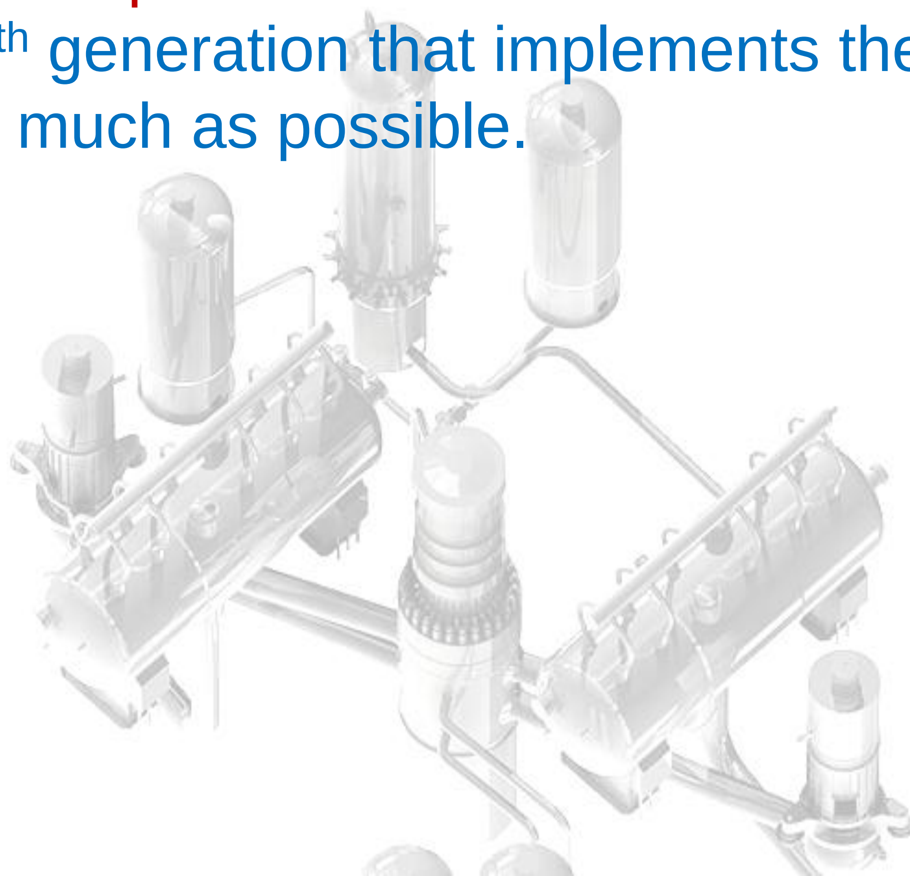
The Goals of Super-VVER Project

- Improvement of economical efficiency and competitiveness of VVER commercial technology in different «market areas»;
- Orientation to the commercial (serial) production based on world experience and advanced technologies;
- Maximum application of commercial technologies based on light water coolant in close fuel cycle;
- Reduction of natural uranium consumption up to (130 – 135) t/GW(e) a year;
- Development of reactor that can be adapted to the requirements of research nuclear plant (ИЯЭС) with close fuel cycle in the frame of the concept of stable development.

Variants of Super-VVER

Evolutionary Super-VVER– transient variant that applies maximum traditional VVER technologies.

Innovative Super-VVER– a variant of a highly efficient NPP of 4th generation that implements the goals of Super-VVER as much as possible.



Evolutionary Super-VVER

Outline:

- parameters of traditional VVER;
- tight grid of fuel elements;
  - ✓ harder spectrum;
  - ✓ increased burn-up factor (КК);
- spectrum control;
- maximum reduction of absorber number in the reactor core during the process of burning-up;
- wide operational possibilities (maneuvering, fuel cycles etc.)

To achieve the goal it is necessary to change FA, control rods, reactor internals, control rod drives in traditional VVER (probably it will be necessary to modify the height of reactor vessel and RCP design).

Evolutionary Super-VVER

Two variants

Average power

- VVER-600SR reactor
  (based on VVER-1200);
- two loops;
- fuel element ∅ 9,1mm;

High power

- VVER-1000SR reactor
  (based on VVER-1000 or 1200);
- four loops;
- fuel element ∅ 6,8 mm;

Evolutionary Super-VVER

Expected characteristics of the fuel cycle:

- burn-up factor about 0,7 - 0,8 (0,4 in NPP-2006);
- natural uranium consumption about 137 t/GW_e with uranium-235 content in uranium slag ~0,1% (197 t/GW_e in NPP-2006 with uranium-235 content in uranium slag ~0,2%);
- lack of liquid and burning out absorber.

Innovation Super-VVER(VVER-SKD)

Innovative Super-VVER is a water-cooled reactor (VVER-SKD).

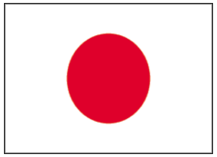
Development of such water-water power reactors with super critical parameters of steam and controlled neutron spectrum is provided by the Energy Strategy of Russia which was ratified by the Order of the RF Government of и 13.11.2009.

In July 2011 Russia signed system agreement of the International Forum «Generation-4» (GIF) in the field of supercritical water reactors (SCWR).

Memebers of GIF in the field of SCWR:

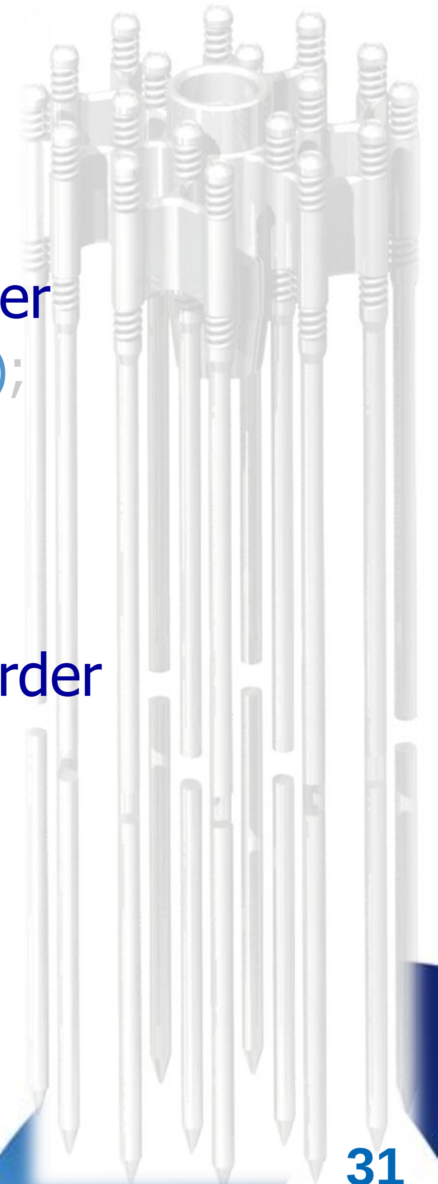
EU Canada Japan Russia






Expected advantages of NPP with VVER-SKD

- reduction of capital costs;
- application of series components from thermal power engineering in the turbine hall (turbines, heaters etc.);
- reduction of construction terms;
- high efficiency factor (41-43%);
- High factor of fuel reproduction (0,9-1,0) due to harder neutron spectrum;
- low consumption of natural uranium.



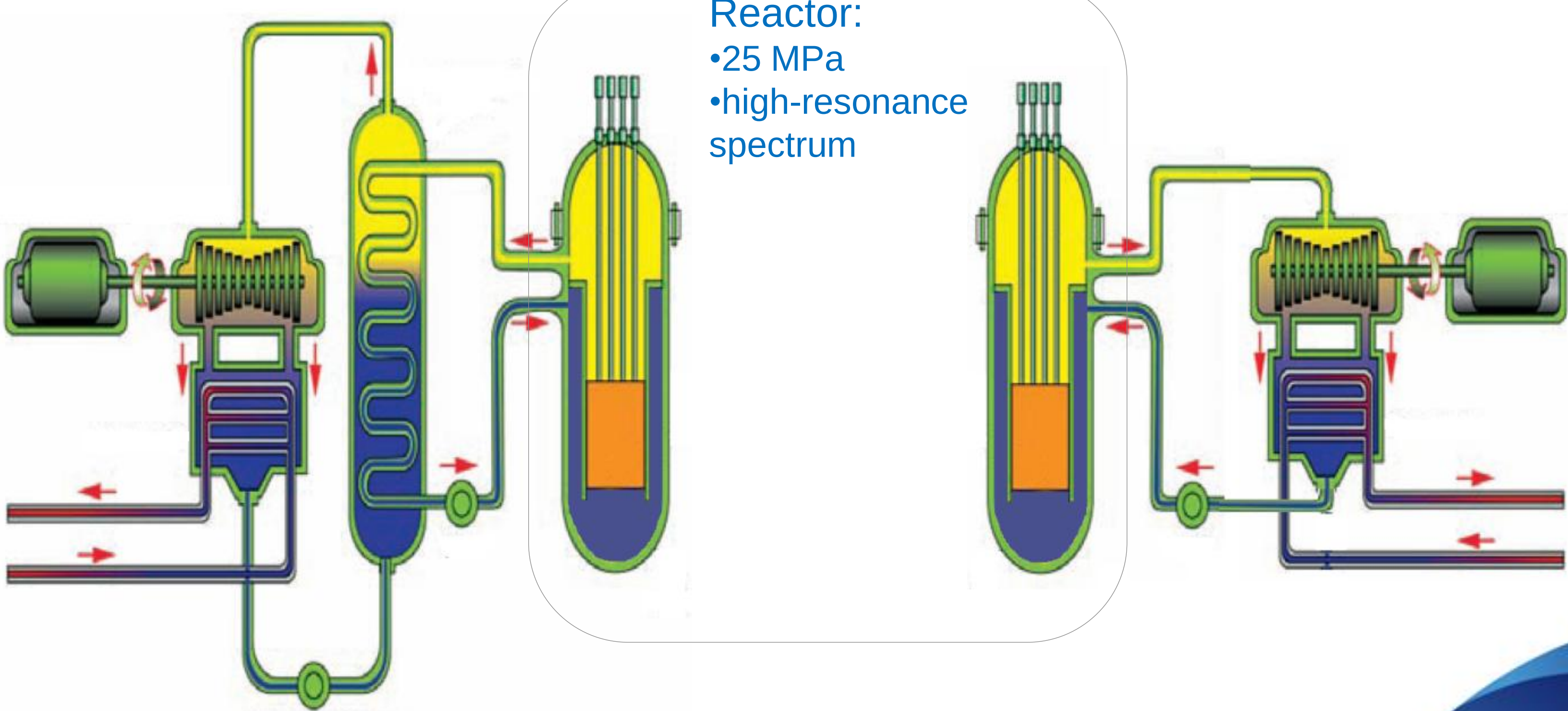
Innovation Super-VVER(VVER-SKD)

VVER-SKD Concept

Two-loop reactor

One-loop reactor

Reactor:
- 25 MPa
- high-resonance spectrum



2 loop: 24 MPa

Innovation Super-VVER (VVER-SKD)

International cooperation

1.In the frame of GIF:

- It is necessary to sign project agreement on existing projects:
  - ✓ thermal hydraulic and safety,
  - ✓ materials and water chemistry.
- It is necessary to propound initiative of a new project agreement on development and construction of a low power experimental reactor in Russia (member-countries demonstrated their interest);

2.In the frame of bilateral agreements and contracts with interested parties.

3. In the frame of IAEA coordination research projects.

THANK YOU!