EXPERIMENTAL & DESIGN ORGANIZATION GIDROPRESS

2009

VVER reactors: clean and reliable source of energy in the past and in the future

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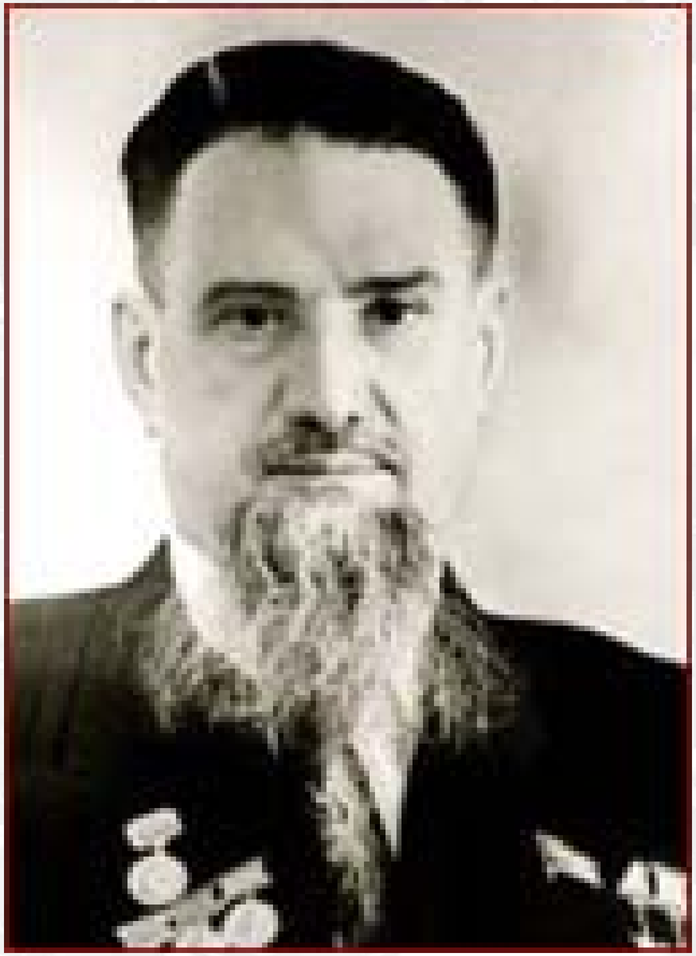
International Conference on Opportunities and Challenges for Water Cooled Reactors in 21-st Century

- “Reactors with water moderator combine high breeding factor with simple and compact design. In our opinion, they are promising reactors for a large-scale nuclear power engineering of the nearest future” *

* - *quotation from the report of I.V.Kurchatov in Harwell, England, April,1956*



Contents

- History, main features and peculiarities of VVER technology
- Operation experience and the indicators achieved
- Goals of development and the challenges of today
- Development of VVER technology
- Advance designs of large power
- Advance designs of large power
- Innovative designs of reactor plants

Main design features of VVER

- ✓ Reactor core with hexahedral assemblies;
- ✓ Horizontal steam generators;
- ✓ Transportability of main equipment by railway;
- ✓ Arranging the spent fuel pool inside the containment;
- ✓ Absence of openings in the reactor bottom;
- ✓ Reactor vessel from forged shells without longitudinal welds;
- ✓ Fuel rod claddings of zirconium-niobium alloy;
- ✓ Reactor vessel of carbon alloy steel;
- ✓ SG tubes of stainless steel with relatively thick wall

Main safety features of VVER

- ✓ Distinctive features of all VVER reactor plants are wide usage of RP inherent safety principle.
- ✓ Capability of VVER RP to limit the development of initiating events as well as of their consequences under accident conditions during a long period within the boundaries of design safety criteria, and is assured by the following structural and design features:
  - increased coolant volume above the core;
  - increased coolant volume in the primary circuit in respect to fuel mass and thermal power of the core;
  - increased capacity of the pressurizer;
  - reliable natural circulation;
  - considerable water inventory in horizontal steam generators on the secondary side.

VVER history

- **1955 –** beginning of activities on VVER
- **1964 –** commissioning of the first VVER
- **1971 –** first standard VVER-440
- **1980 -** commissioning of the first VVER -1000

The oldest VVER at Unit 3 of Novovoronezh NPP has been operated since 1971 without replacement of SG, reactor top head and other main components (license till 2016)

VVER history

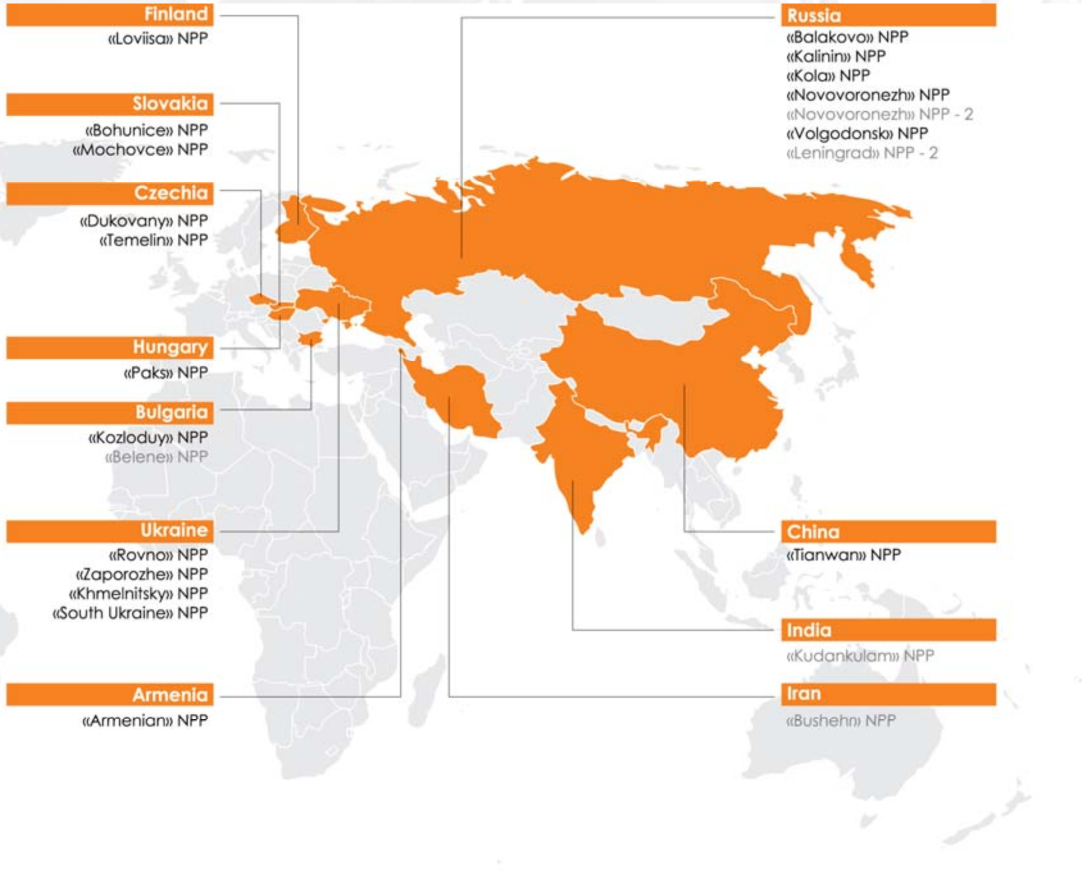
- ✓ Totally there are 51 NPP Units with VVER in operation (about 20% of population of the pressurized light water reactors)
- ✓ To date accumulated operating life is more than 1290 reactor-years
- ✓ 39 Units have been commissioned in the world since 1999 and 8 of them are Units with VVER reactors

Operating NPPs with VVER reactors and NPPs under construction

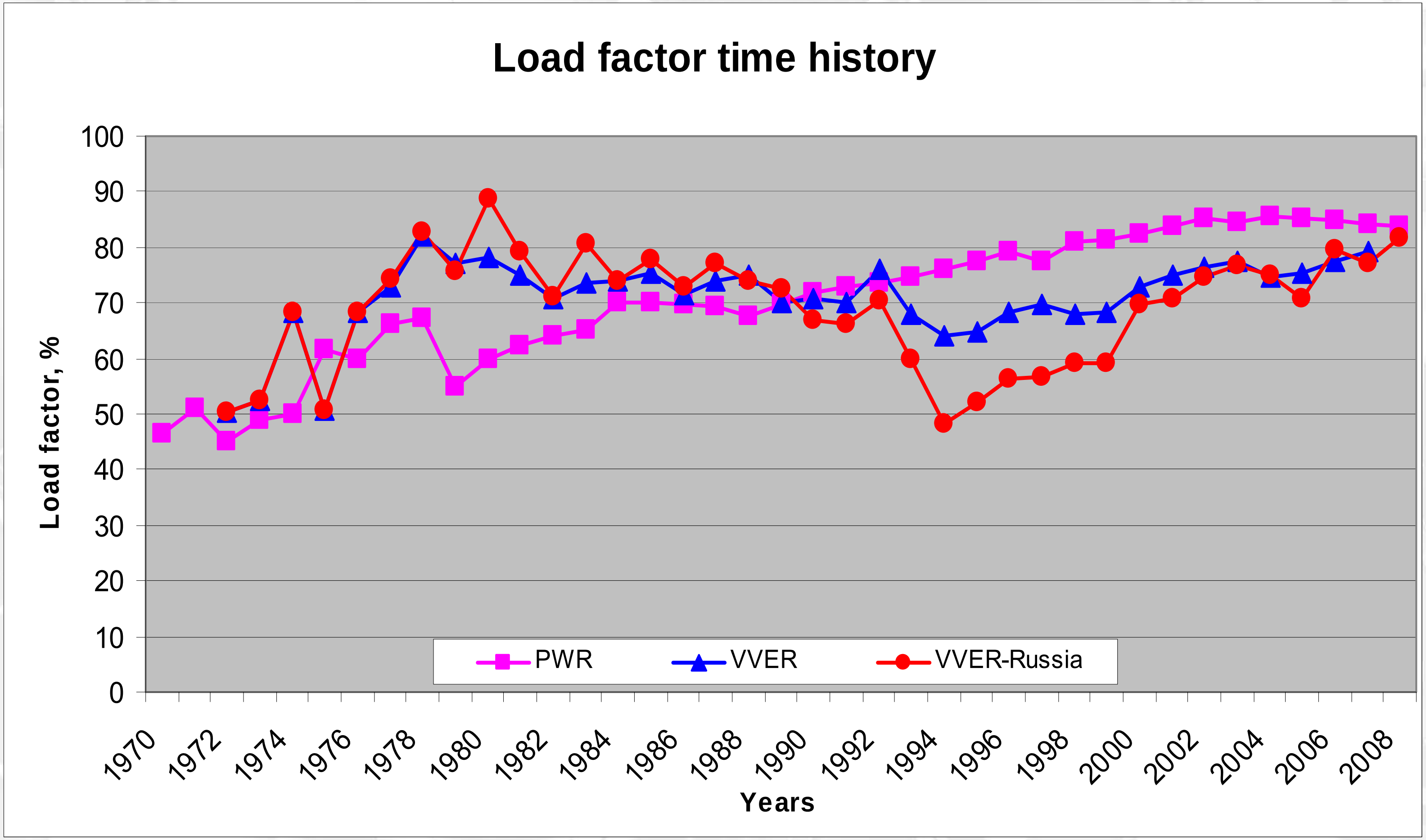
52 NPPs under construction in the world, of which

14

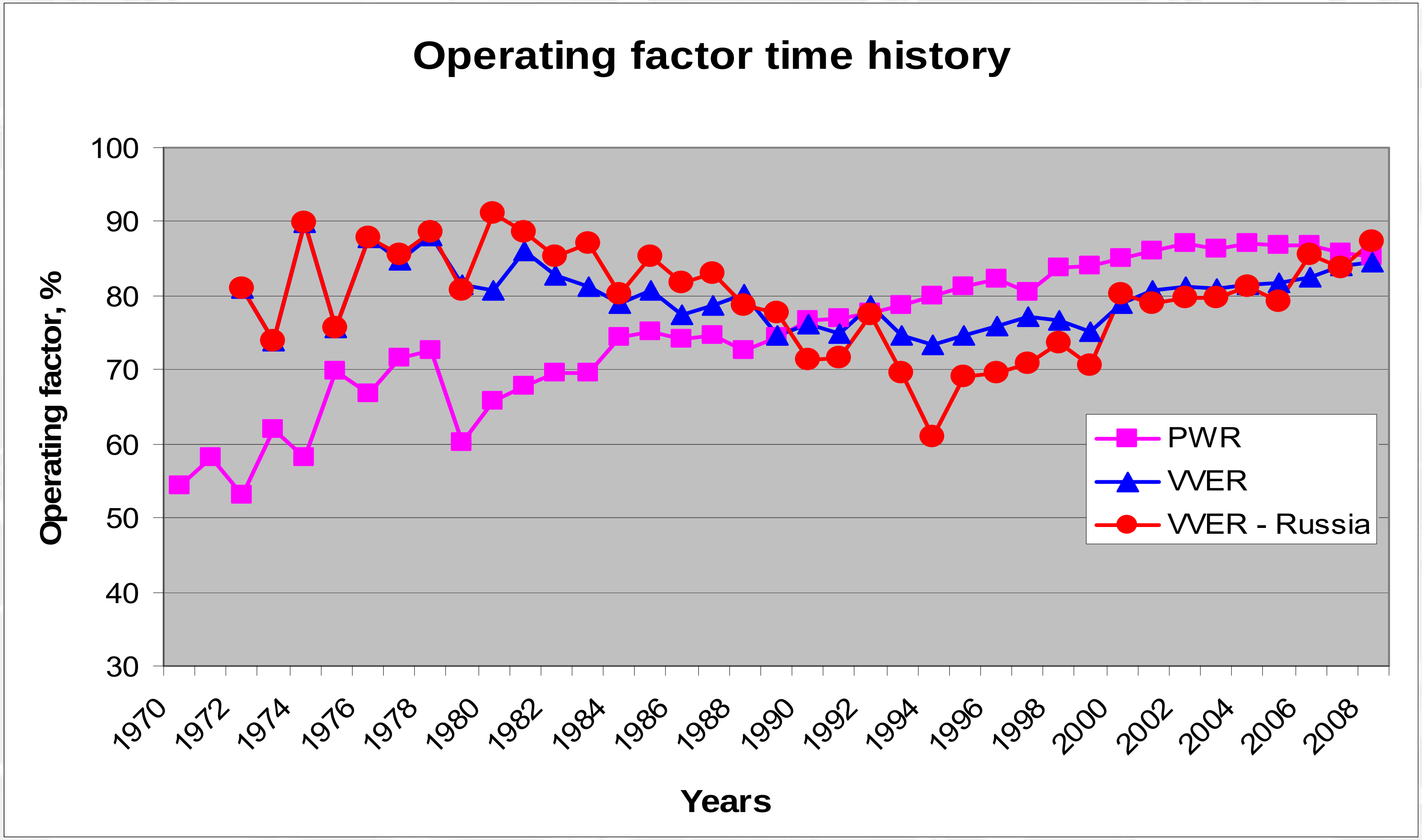
Units with VVER reactors



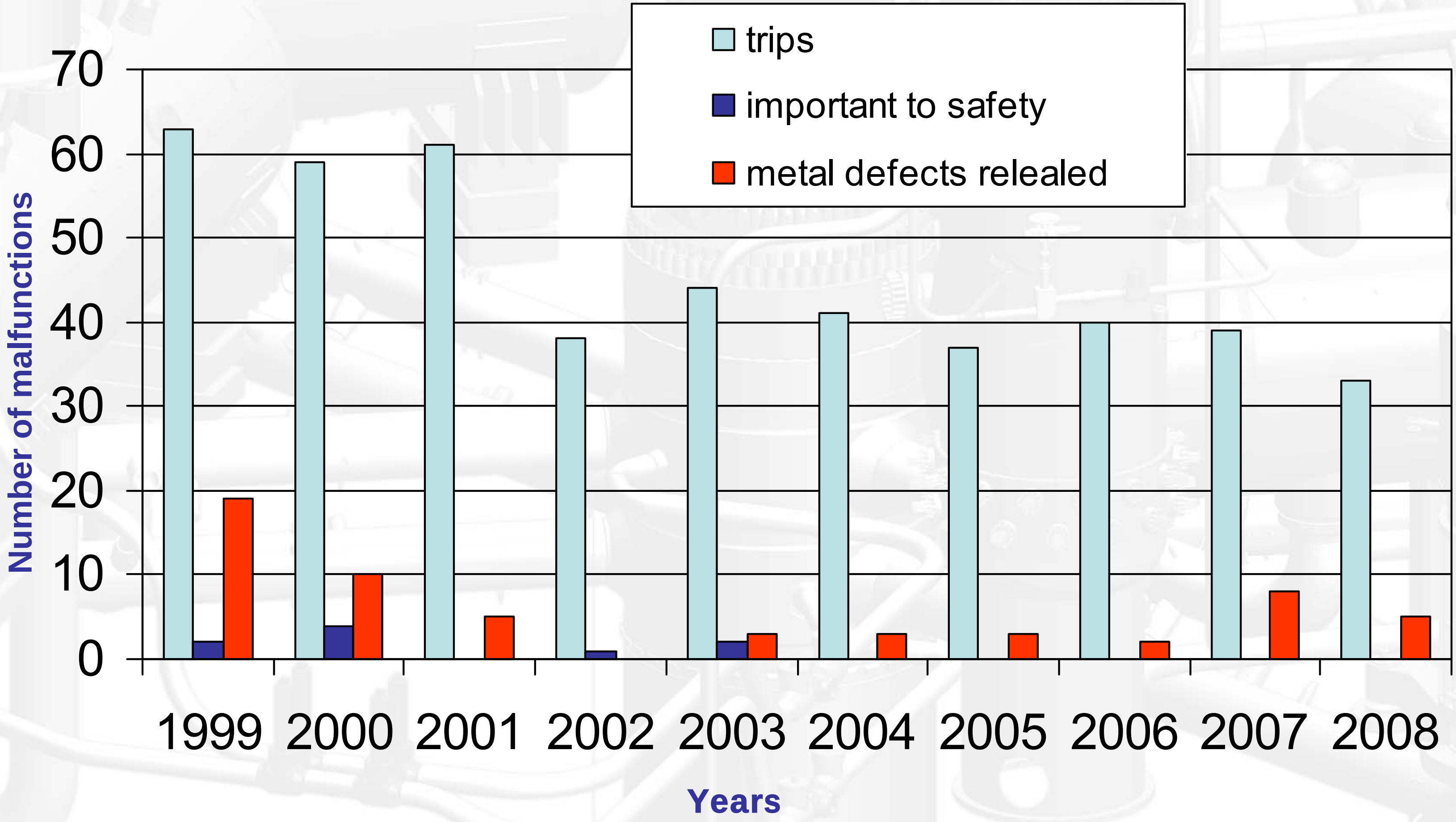
Indicators achieved



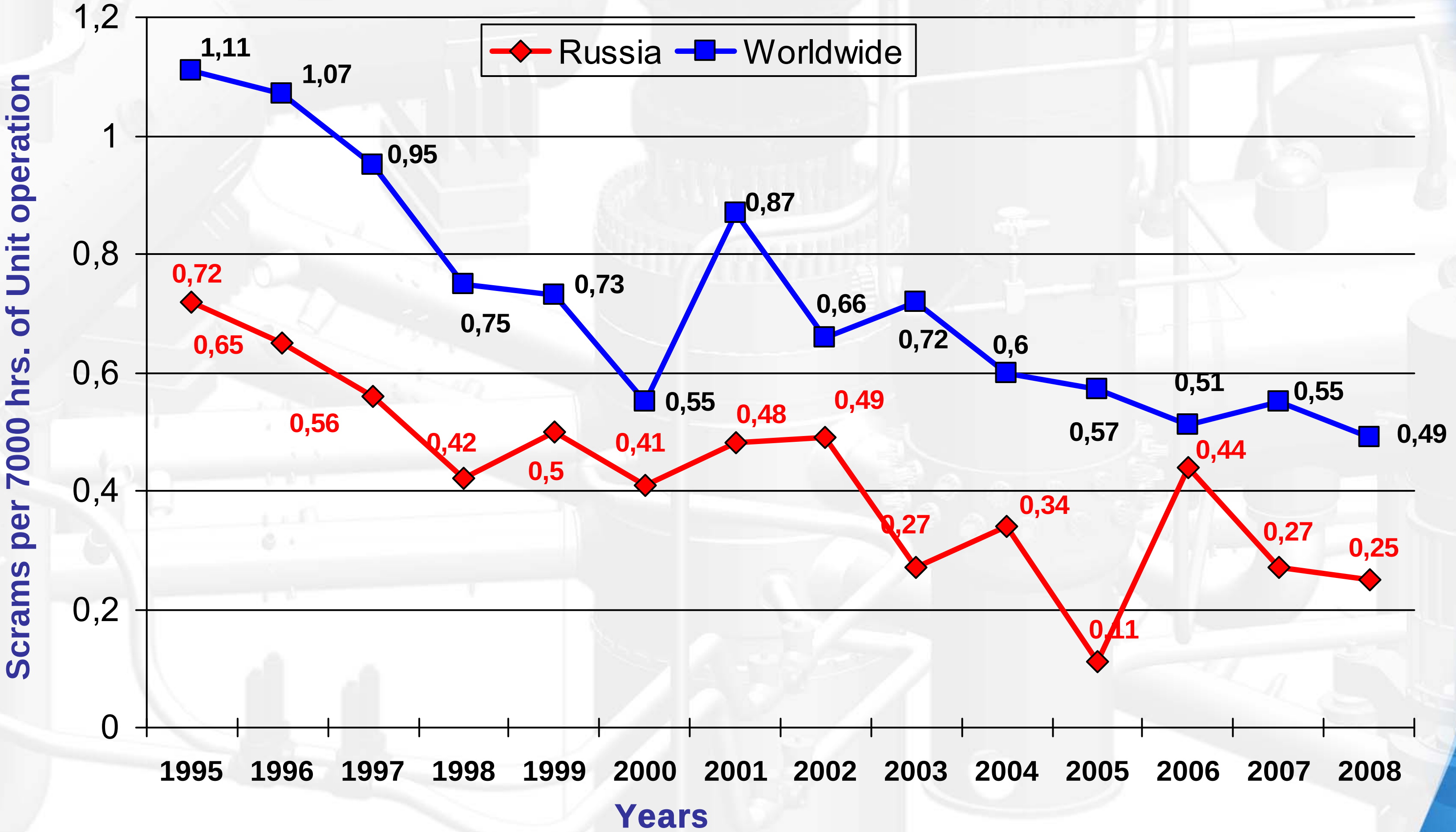
Indicators achieved



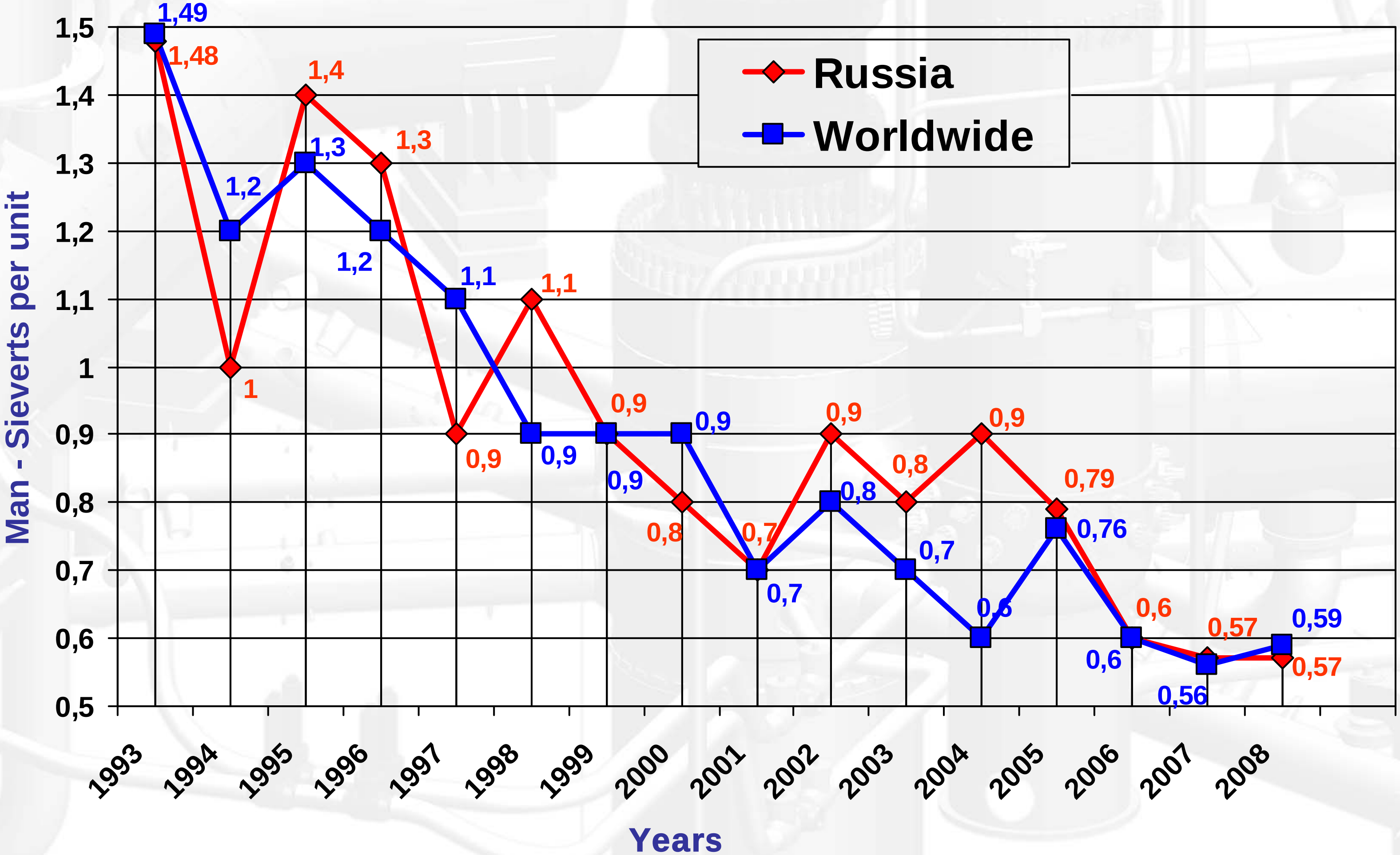
Indicators achieved
Malfunctions in NPP operation



Trend of the reactor scrams in Russia and worldwide (according to WANO methodology)



Collective radiation dose per personnel, VVER Units



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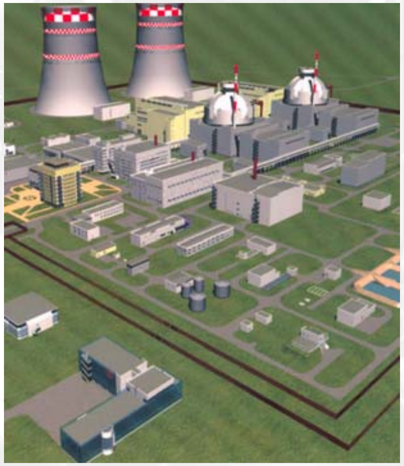
Goals of development



- ✓ Challenges of today
  – The goal is set to redouble the generation of electric energy at nuclear power stations of Russia by 2030 having brought it to 25%-30% of total volume of generation. For this purpose 26 NPP Units are to be built. Solution of the problem on the basis of VVER technology.

Goals of development

- ✓ Four Units of new advanced VVER-1200 design are under construction
- ✓ Commissioning - 2012

Goals of development

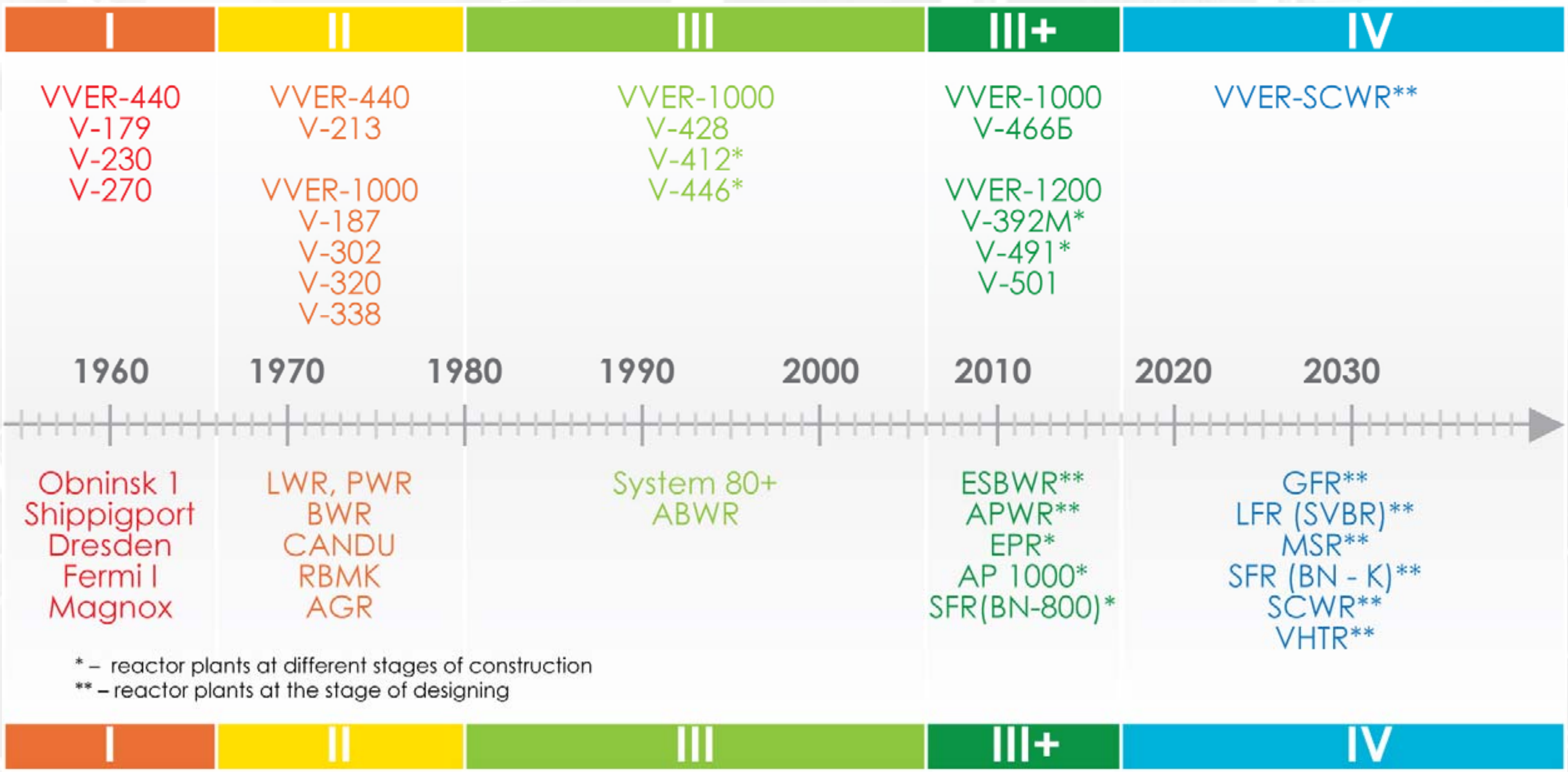
Challenges of today

- Competitiveness of NPP with fossil-fired power plants:
  - Reduction of capital costs and construction period.
  - Increase in efficiency and load factor.
  - Implementation of load-follow modes.
- Implementation of NPP of the following power range 1600…1200…1000…600…300 MW
- Effective use of VVER in the closed fuel cycle

Safety criteria:

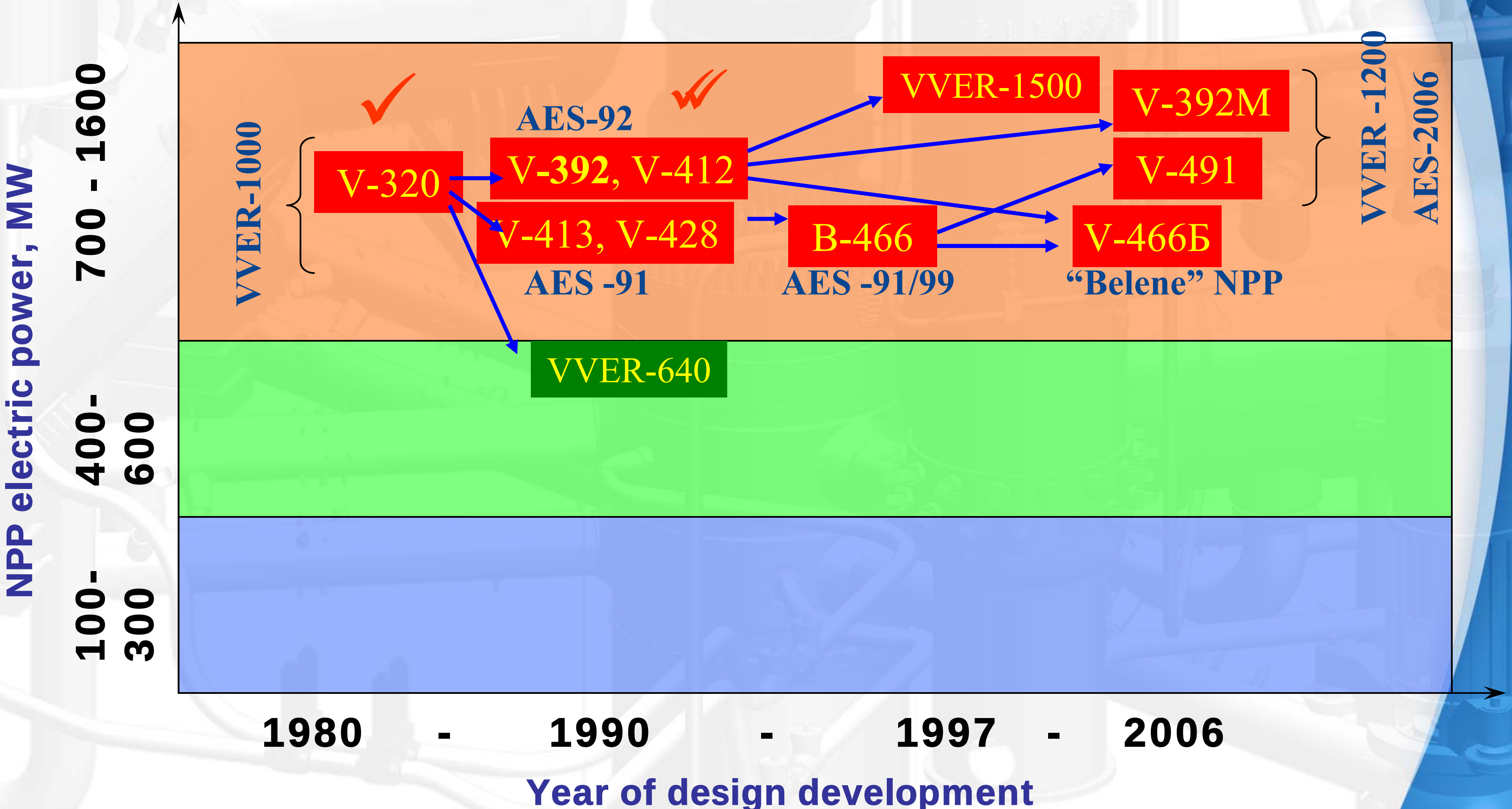
- Meeting the safety requirements of Russian regulations, IAEA recommendations and EUR requirements;

Generations of nuclear power reactors



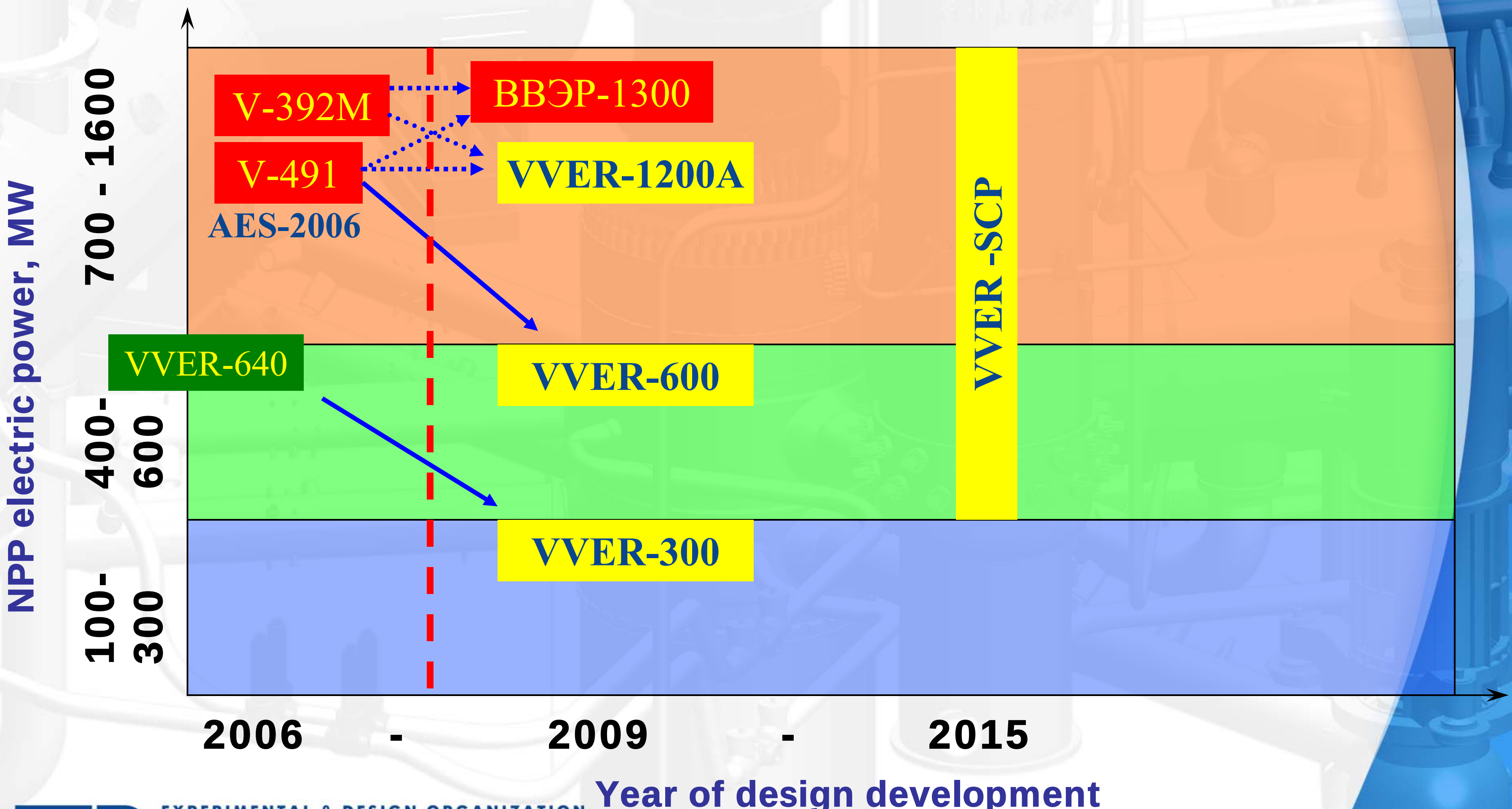
Goals of development

New designs of OKB "GIDROPRESS"

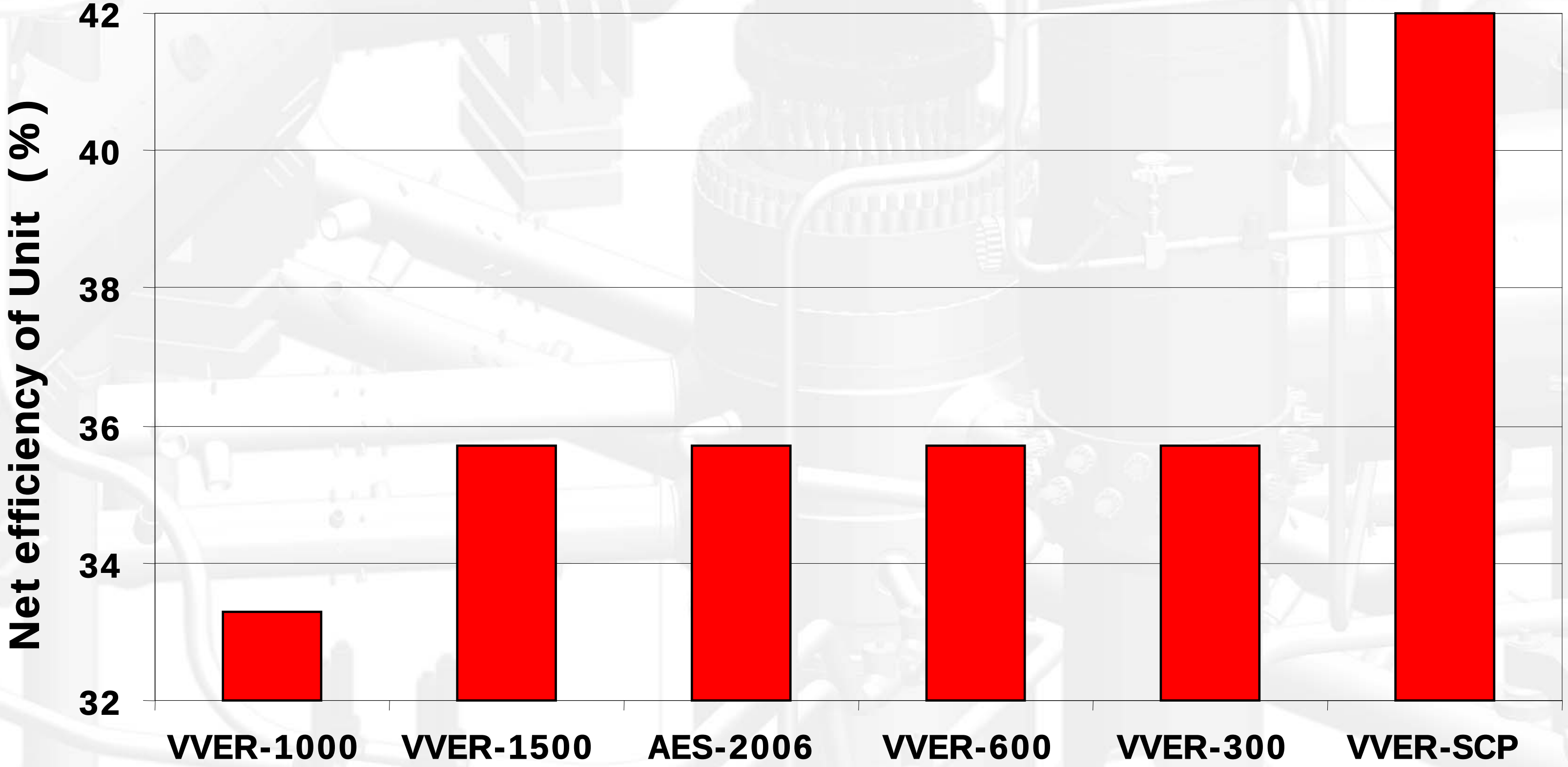


Goals of development

New designs of OKB "GIDROPRESS"



Comparison of VVER designs



EXPERIMENTAL & DESIGN ORGANIZATION GIDROPRESS

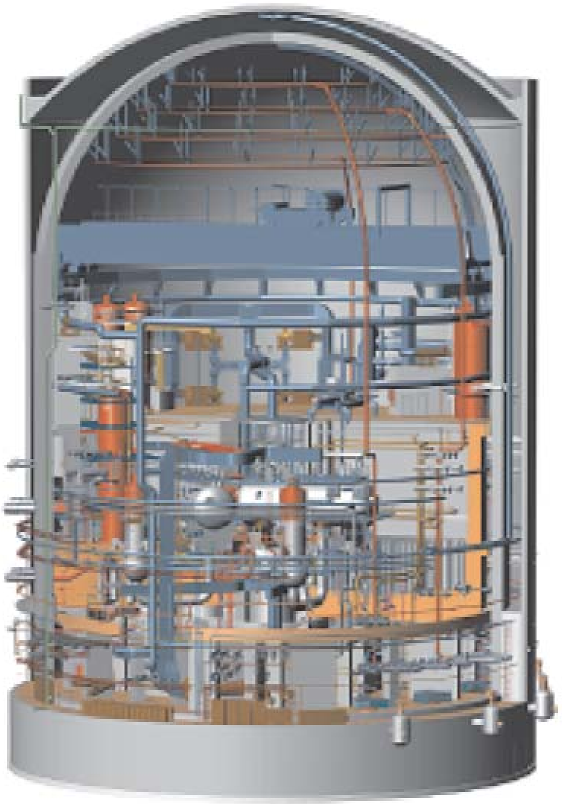
Comparison of VVER designs

Conditions necessary for development

- ✓ Obligatory requirements
  - Optimal combination of evolutionary and innovative development
  - Mature reference technology reduces risks and simplifies licensing
  - Meeting the requirements of regulatory bodies and operators (EUR)
  - Meeting the maneuverability requirements
  - Possibilities for fuel cycle development including MOX and closing cycle
- ✓ Competitiveness
  - Lowest unit capital investments
  - Extension of design service life
  - Increase in efficiency
  - Increase in load factor
  - Cut down of the construction time of the standard Unit
  - Reducing operation expenses
  - Reducing waste

AES-2006

Design of AES-2006 with VVER-1200 meets the mentioned trends to the highest extent

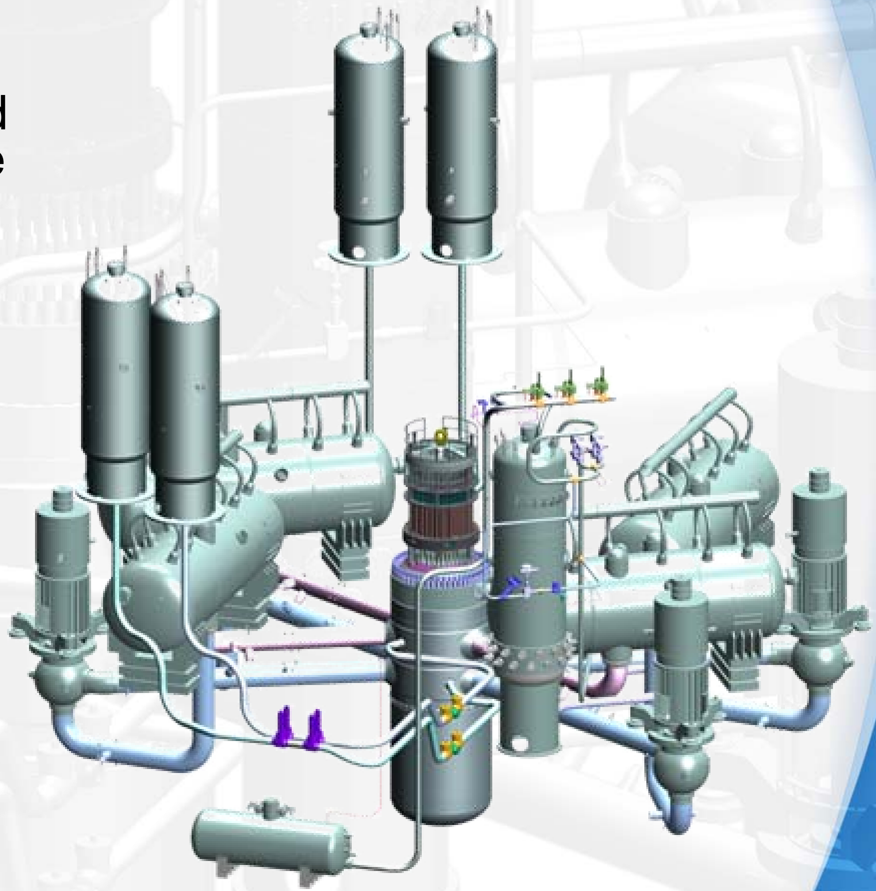


- ✓ Power increased up to 1200 MWt
- ✓ Design service life is extended to 60 years.
- ✓ Efficiency is increased to 36 %.
- ✓ Load factor is increased to 90 %.
- ✓ The requirements for Unit load-follow conditions are provided in the design

AES-2006

Design of AES-2006 with VVER-1200 meets the mentioned trends to the highest extent

- ✓ Evolutionary development with application of reference technical solutions based on VVER-1000 and a wide use of up-to-date knowledge and advanced technologies.
- ✓ Current requirements of Regulatory documents and EUR requirements are met.
- ✓ Using of 121 CPS control rods in the reactor core presents wide possibilities for development of fuel cycles including those with MOX fuel
- ✓ Design value of collective dose for operating personnel per one Unit throughout the whole service life at normal operation of all systems does not exceed 0,4 man·Sv/year.



AES –2006 as an example of VVER advantages

- ✓ Inherent safety properties:
  - – usage of additional water inventory in hydroaccumulators of the second stage core cooling system (for NV NPP-2 as compared to VVER-1000 and to PWR).
  - – actuation of control rods under scram due to gravity forces;
  - – properties of self-limitation of the core power due to negative reactivity coefficients by fuel and coolant temperature and by power;
  - – usage of passive elements, isolation, limiting and discharge devices;
  - – usage of inertia coastdown of special flywheel masses of RCP set to provide the required drop of flow rate through the core under loss of power.

Fuel cycles

- ✓ To date the 12-month fuel cycle is accepted as the base cycle with annual loading of 43 FAs (4-year fuel cycle) that makes possible to assure the following:
  - meeting the requirements for length of fuel cycle considering the mass of FAs loaded;
  - limitation of power non-uniformity.
- ✓ In implementation of 18-month fuel cycle:
  - number of FAs makeup in equilibrium cycle – 78 pcs.;
  - fuel mass in one FA– 530 kg (первый этап модернизации);
  - average enrichment of makeup fuel - 4,85 % in 235U;
  - operation length - 521 EFPD (load factor ~ 0,95);
  - maximum burnup fraction of FAs (without engineering safety factor) - 64MW*day/kgU;
  - average burnup fraction of FAs unloaded – 46,7 MW*day/kgU.
- ✓ In principle, implementation of 24-month fuel cycle. With this, usage of long-term fuel cycles makes increase in NPP load factor and decrease in efficiency of fuel utilization.

Maneuverability

- ✓ One of the main requirements for current design of RP and NPP is the requirement for possible operation of the Unit in the conditions with changing the load. The list and characteristics of these conditions are prepared taking into account the lists of Russian utility and EUR requirements. Comparison of characteristics of main conditions with changing of load is presented in the Table.

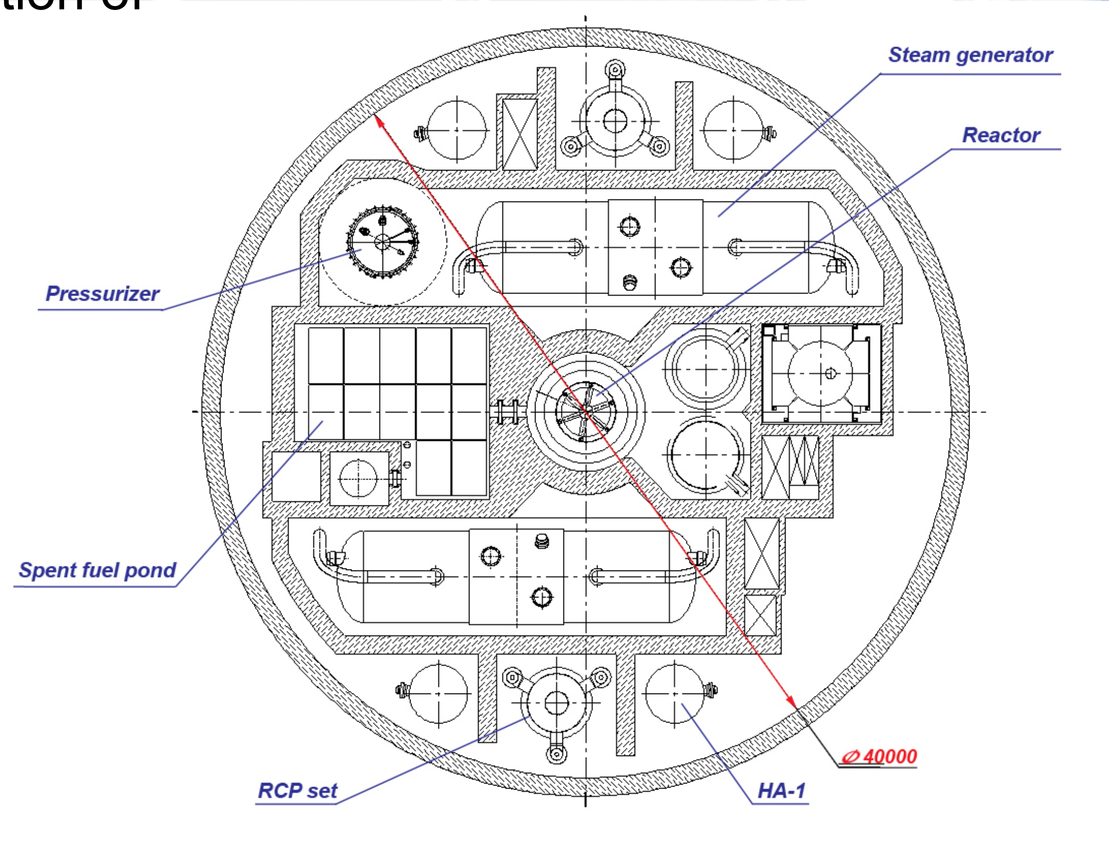
Conditions	AES-2006	EUR
Primary control		
Change in Unit power	not more than ±5 % Nnom	±5 % Nnom
Rate of power change	1 % Nnom/s	Not regulated
Number of cycles	$7{\cdot}10^6$	Not regulated
Secondary control		
Change in Unit power	not more than ± 10 % Nnom	not more than ± 10 % Nnom
Rate of power change	not more than 5 % Nnom/min	not more than 5 % Nnom/min
Number of cycles	$5{\cdot}10^6$	Not regulated
Power change of the Unit according to the schedule		
Power change of the Unit	50-100-50 % Nnom	20-100-20 % Nnom
Rate of power change	not more than 5 % Nnom/min	not more than 3 % Nnom/min
Number of cycles	15000 (5 times a week)	2 time/day, 5 times/week 200 times/year

Prospective RP designs of large power. Alternative design VVER-1200A (V-501)

- ✓ Design aim is to minimize cost of construction, manufacturing, mounting and maintenance due to 2-loop arrangement and enlargement of main equipment
- ✓ Design concept:
  - Cutting down the scopes and periods of construction and mounting work, reducing amount of equipment, delivery of maximum-finished equipment to mounting site;
  - Increase in unit power of SG and RCP set;
  - Increase in the secondary parameters to improve the Unit efficiency.
  - Keeping the principal VVER solutions, except for SG transportability by railway;

Prospective RP designs of large power. Alternative design VVER-1200A (V-501)

Plan view at the elevation of steam generators



- ✓ Steam generator:
  - diameter 5,2 m
  - length 20 m
  - mass ≈ 790 t

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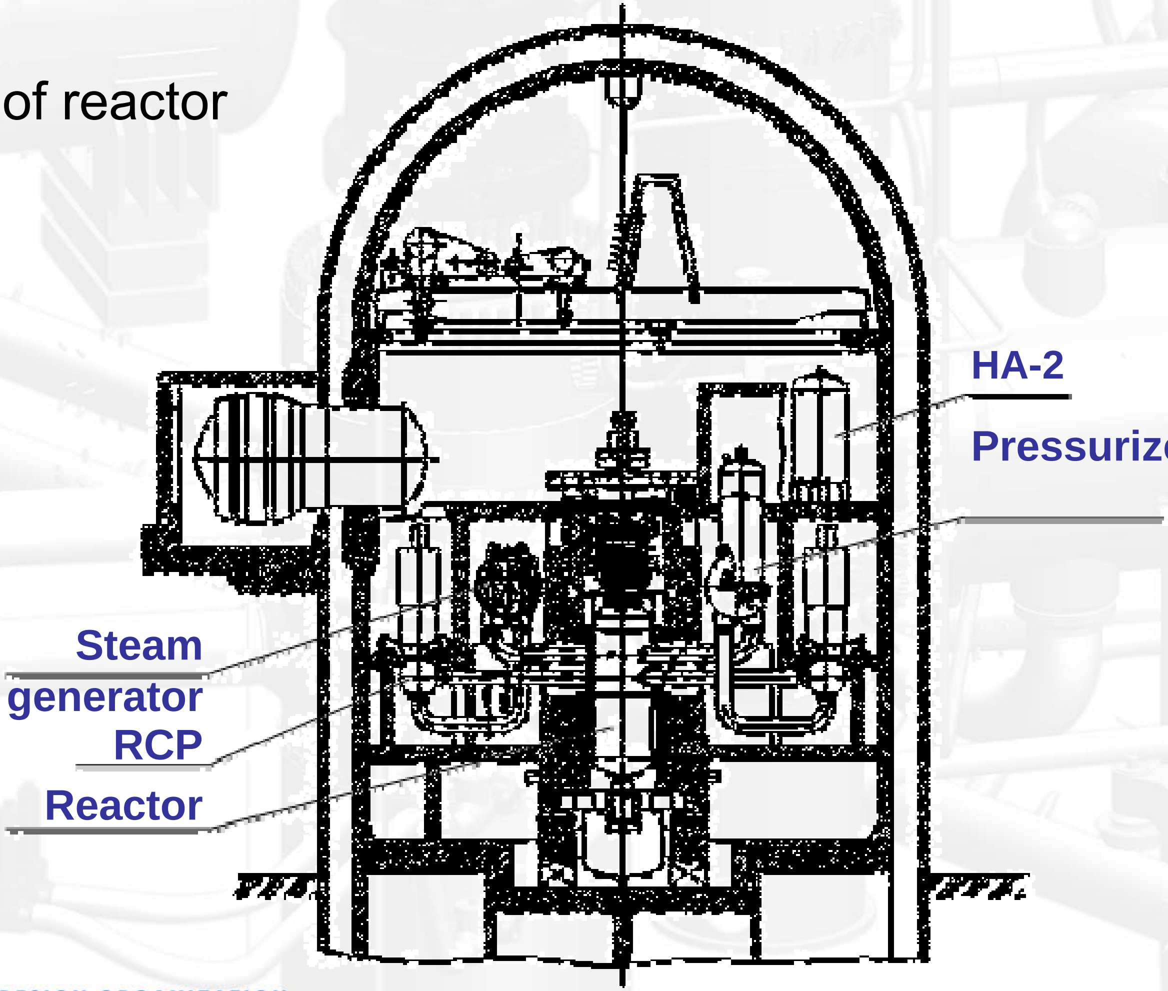
Prospective RP designs of large power. Alternative design VVER-1200A (V-501)

Vertical section of reactor building



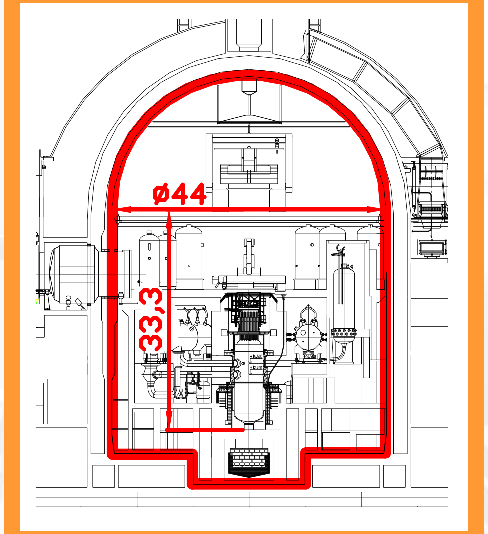
Prospective RP designs of large power. Alternative design VVER-1200A (V-501)

- ✓ Current approaches to optimization of safety systems are realized:
  - Scheme solutions exclude failures dependent of initiating event:
    - Simultaneous failures of channels of passive and active systems,
    - Simultaneous failures of active SS within one channel (HP ECCS and LP ECCS).
  - The requirement of SS diversity, independency, and redundancy is met;
  - Redundancy of two-channel system of emergency power supply, during maintenance of station diesel-generator.

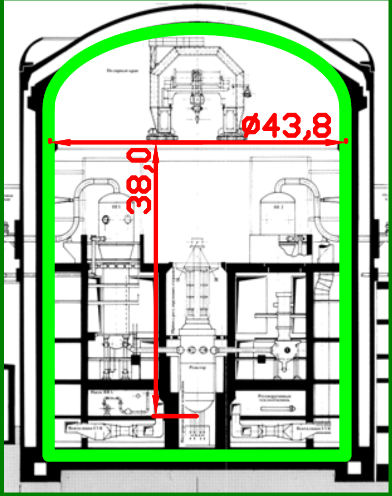
Prospective RP designs of large power. Alternative design VVER-1200A (V-501)

Comparison of weights of the primary equipment

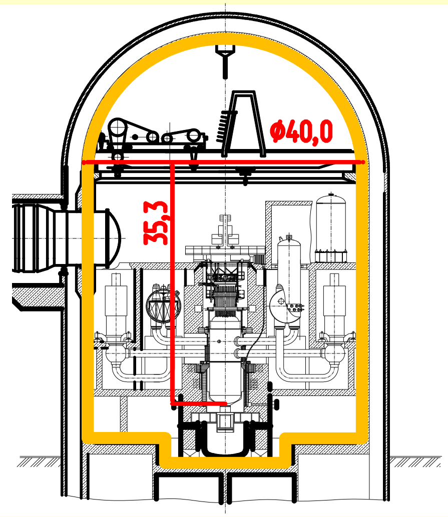
	VVER-1200	VVER-1200A
Reactor	940 t	940 t
MCP	252 t	145 t
Steam generators	4 x450 = 1800 t	2 x790 = 1580 t
Pressurizer	215 t	215 т
RCP set	4 x139 = 556 t	2 x200 = 400 t
Total weight of the primary equipment	3763 t	3280 t
Relative weight of the primary equipment, t/MW(th)	1,18	1,03



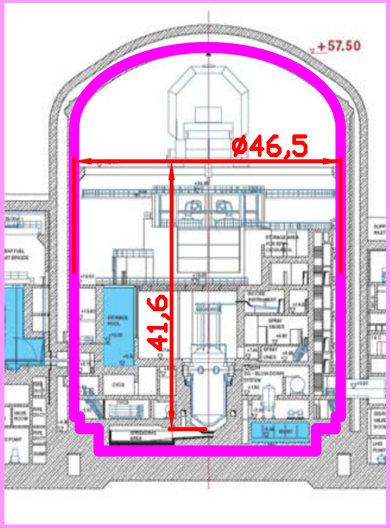
VVER-1200



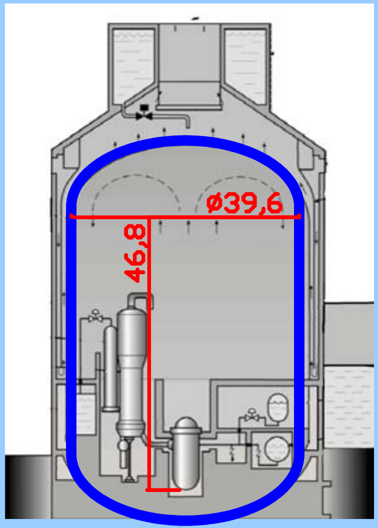
EDF-1300



VVER-1200A



EPR



AP-1000

Design of horizontal SG for VVER

- ✓ Does not contradict the idea of reducing the basement area. Allows for compact arrangement of the equipment, easy maintenance and simplifies withstanding of seismic loads;
- ✓ Keeps advantages in the part concerning:
  - **Reliability** (absence of vibrations, damages from foreign objects, no accumulation of sludge at the tube sheet).
  - **Safety** (reliable natural circulation, effective gas removal, water inventory, “thick” tube).
  - **Convenience of maintenance and repair** (easy access on the primary and secondary sides, low irradiation).

RP designs of medium power

- ✓ RP designs of medium power include RP designs for NPP of power range of 300-700 MW el. to meet the regional demands and export to developing countries.
- ✓ Designing of RP of medium power is proposed on the basis of main equipment of RP of large power. This leads to:
  - extension of the main equipment service life;
  - increase in heat engineering margins of the core cooling;
  - less stringent requirements for characteristics of safety systems;
  - more flexible fuel cycle.

RP designs of medium power

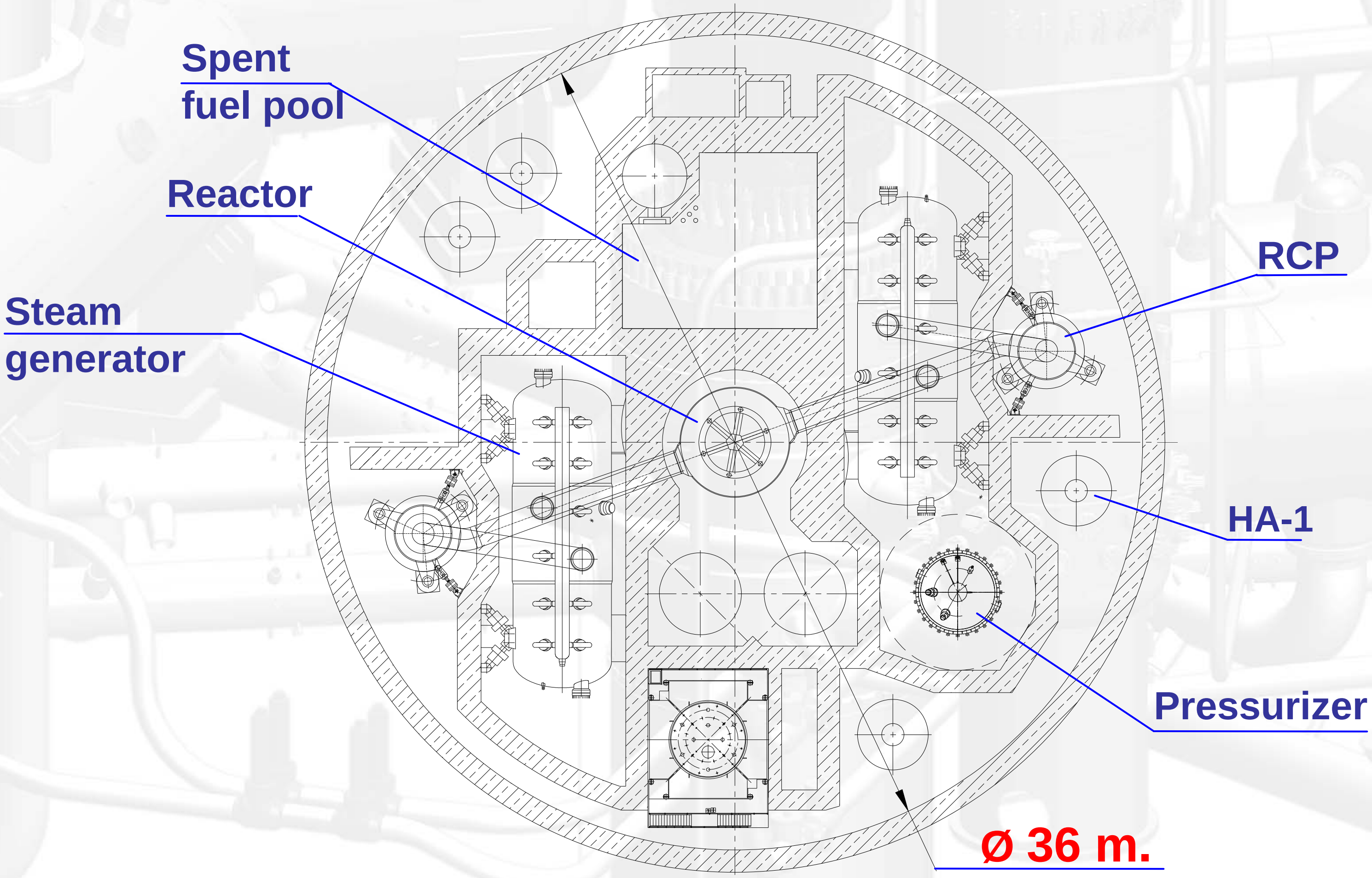
- ✓ RP designs of medium power :
  - VVER-640 (V-407)
  - VVER-600 (V-498)
- ✓ The designs differ in ratio of application of passive and active safety systems and the systems for BDBA management and methods of their technical feasibility.
- ✓ In both designs the proven technologies, units and systems are used in general, based on experience in operation of the preceding generation of NPPs with VVER.

RP designs of medium power

✓ Main conceptions of RP with VVER-600:

- usage of the available equipment of designs V-392M and V-491;
- 2-loop arrangement of RP;
- reactor with 2 inlet and 2 outlet nozzles;
- implementation of optimal application of redundancy, independence and diversity principles for structuring the safety systems with the optimal composition and effectiveness;
- implementation of the concept of the core melt confinement under severe accidents inside the reactor vessel owing to inside and outside cooling.

RP designs of medium power. RP design VVER-600 (V-498)



RP designs of medium power.
RP design VVER-600 (V-498)

✓ Comparison of weights of the primary equipment:

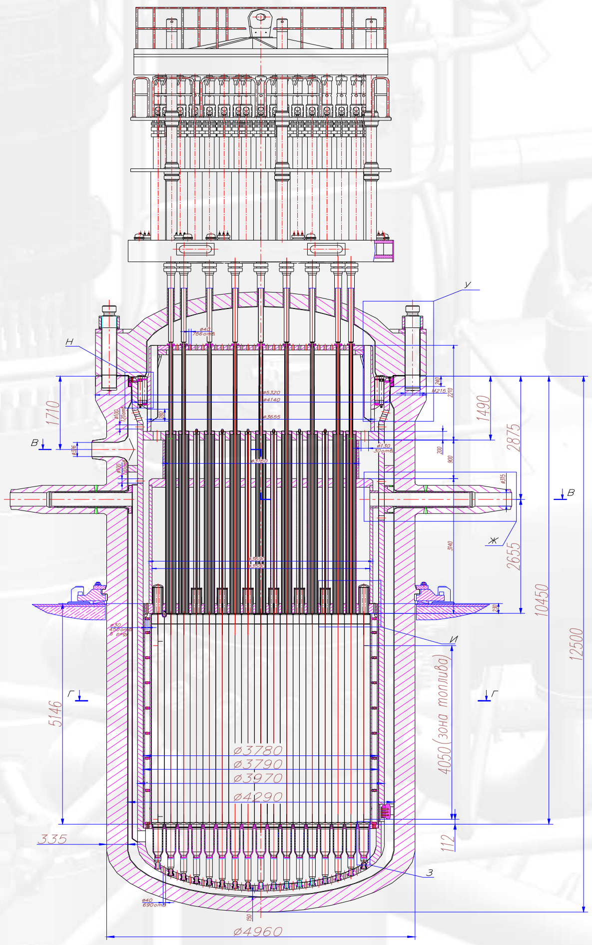
	VVER-1200	VVER-600
Reactor, t	940	700
MCP, t	252	115
Steam generators, t	4 3450 = 1800	2 3450 = 900
Pressurizer, t	215	215
RCP set, t	4 3139 = 556	2 3139 = 278
Total weight of the primary equipment, t	3763	2208
Relative weight of the primary equipment, t/MW(th)	1,18	1,38

RP designs of small power

- ✓ RP designs of small power include RP designs for NPP with electric power of 300 MW for the regions with small grids.
- ✓ In OKB "GIDROPRESS" the design of 2-loop reactor plant VVER-300 is on the stage of feasibility study.
- ✓ The design is based on technical solutions on the equipment of the preceding designs of RP V-407.

RP innovative designs.
One-circuit RP VVER-SCP with supercritical coolant pressure

- ✓ VVER-SCP meets the target indicators of IV-generation VVER to the highest extent.
- ✓ Advantages of the proposed design:
  - High efficiency (42 - 45%);
  - High breeding factor (>0,8);
  - Low capital costs (reducing of: metal consumption; nomenclature and number of equipment and systems; containment sizes);
  - Application of the proven VVER technology and SCP boiler-turbine units.



Reactor VVER-SCP with the core of single pass of coolant

Conclusion

- ✓ VVER reactor plants are based on technical solutions that proved their reliability and effectiveness in the course of more than 40-year operation experience.
- ✓ The developed designs implement the evolutionary concept of VVER reactor plants oriented not only towards safety assurance of Units, but also towards increasing their economic efficiency.
- ✓ The main ways in improving the economic efficiency of reactor plants are demonstrated. The considered trends in development are indicative of high potential of VVER technology development for solving the problems of power engineering in the long-term outlook.