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Thermal-Hydraulic Calculations for the New Integral Small Modular Reactor VVER-I with Natural Circulation in Primary Circuit

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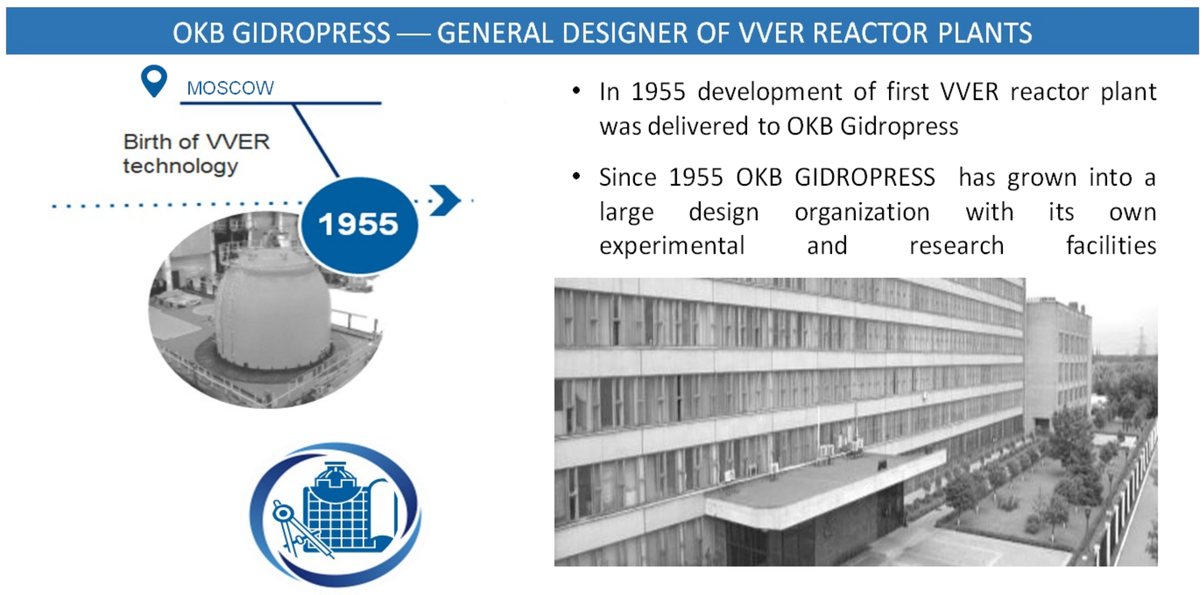
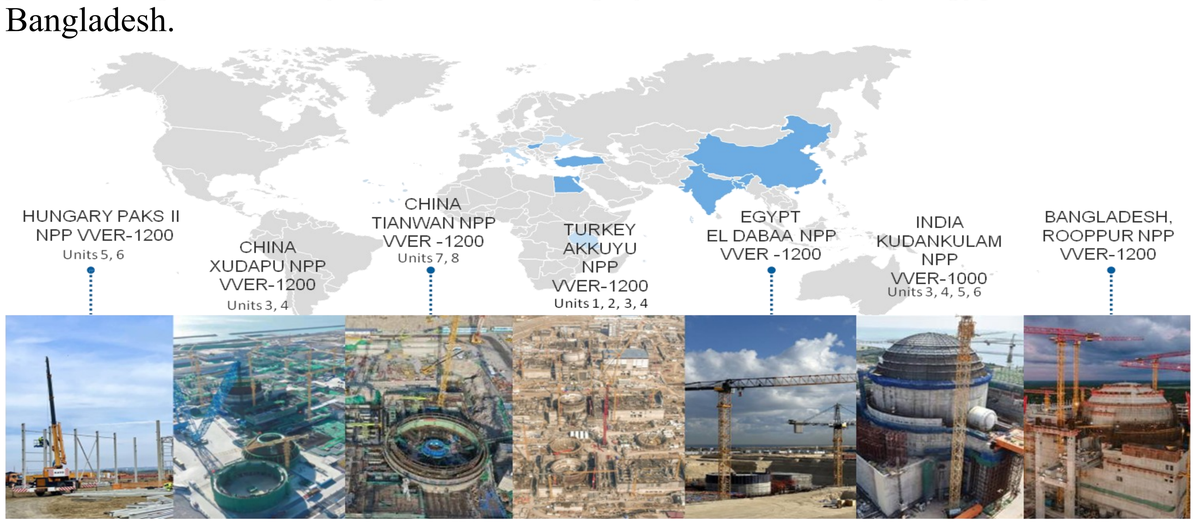


Today the construction of NPPs in accordance with OKB GIDROPRESS reactor plant designs is carrying out in Hungary, China, Turkey, Egypt, India and Bangladesh.



Nowadays 66 units constructed according to Russian designs produce electricity practically all over the world. And if we speak about high powered VVER reactor plants about 10 percent of nominal thermal power can be removed by means of natural circulation during emergency situations. Based on these principles the new VVER-type reactor plant preliminary design with natural circulation in primary circuit which is called VVER-I was developed (Fig. 1).

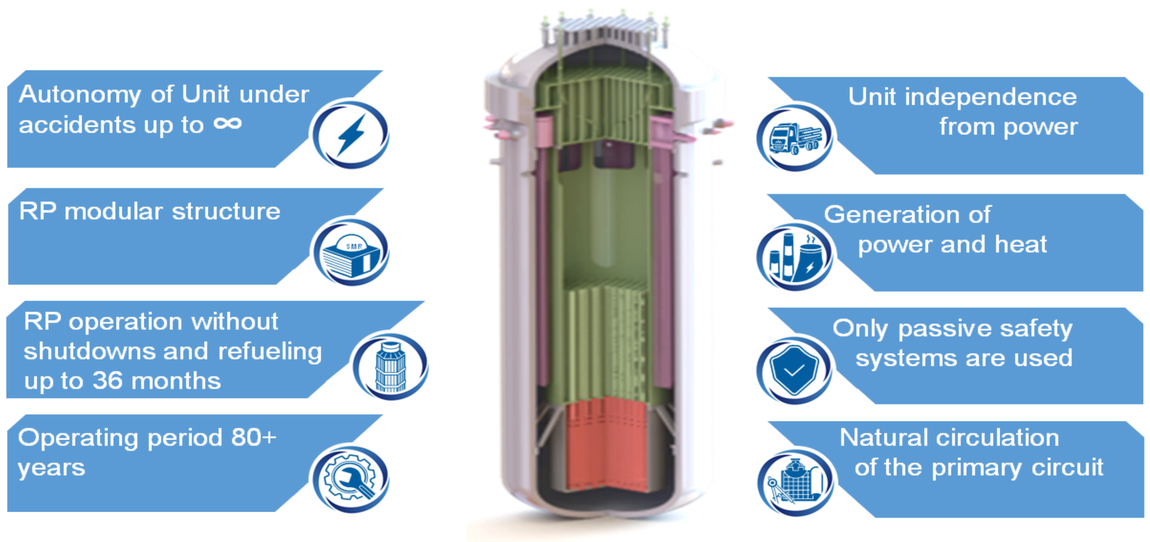
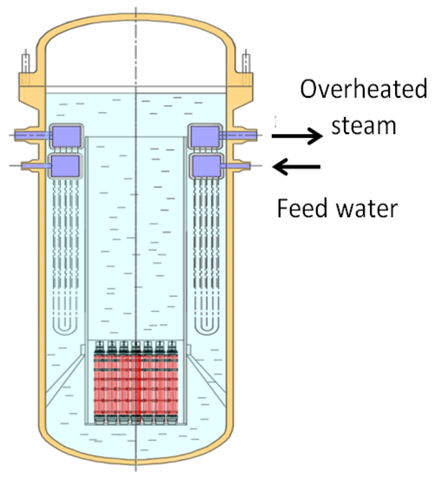
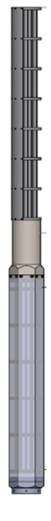


Figure 1: VVER-I conception

VVER-I is water-cooled reactor with natural circulation in primary circuit. Pressurizer is moved outside the reactor vessel. Steam generator is integrated into the reactor vessel (Fig. 2 (left). VVER- I reactor control system is close to control systems of operated nowadays high powered VVER reactors. Safety conception includes 4 levels of defense in-depth protection. The core consists of 91 shortened fuel assemblies with draft block under the heating part of each fuel assembly (Fig. 2 (right)) for relative enthalpy at the outlet of the most powerful fuel assembly decreasing to negative number.



Reactor plant design with vertical U-shaped SG tubes



Parameter	Relative mass fraction at the outlet of FA
FA without draft tube	+4.8%
FA with draft tube	-1.8%

Design of FA with draft tube under heating part

Figure 2: Reactor plant design (left), fuel assembly design (right)

Calculations of parameters for normal operation were made using one-dimensional code KORSAR/GP, three-dimensional code CFD and also by using engineering method which is based on equality between natural circulation driving head and total resistance of circulation contour.

Calculation model of VVER-I developed using CFD code, one-dimensional code KORSAR/GP, and the design of the reactor plant are shown in Figure 3.

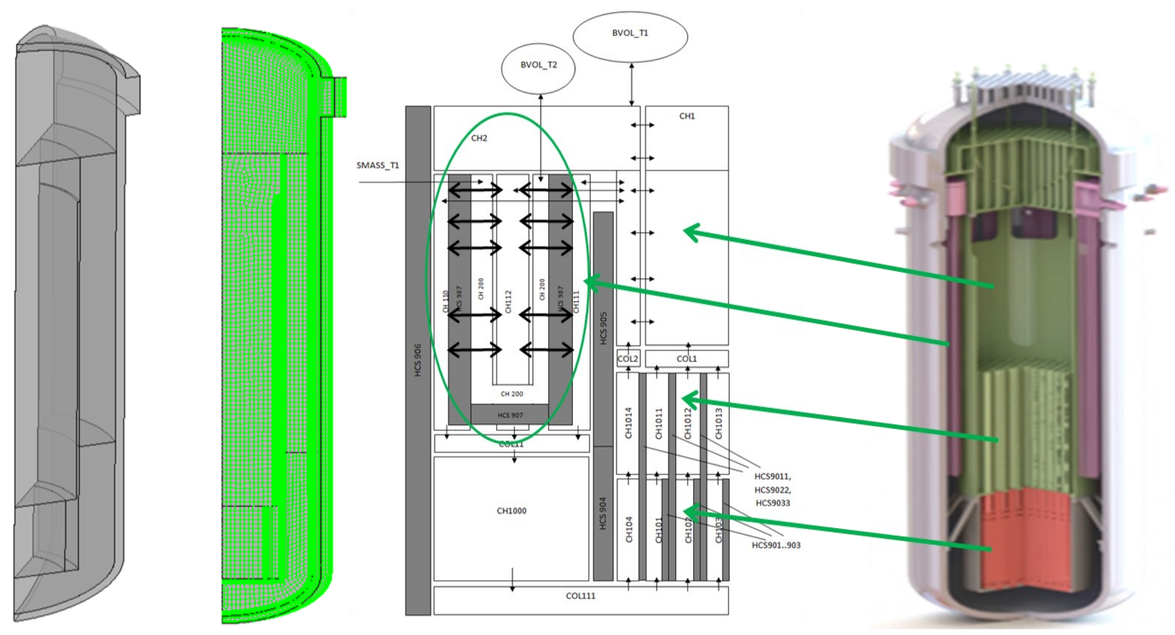


Figure 3: CFD model (left), KORSAR/GP-code model (middle), reactor plant design (right)

The obtained results are presented in table 1. It is seen that calculation results of CFD code, one-dimensional code KORSAR/GP and engineering method are in a good accordance with each other. CFD results are presented in Figure 4.

Table 1: Calculation results

Method	Engineering method	KORSAR/ GP	CFD
Coolant flow rate through the core, kg/s	922	994	917
Temperature at the inlet of the core, °C	258	262	262
Temperature at the outlet of the core, °C	310	310	313
Temperature of superheated steam, ºC	285	295	290

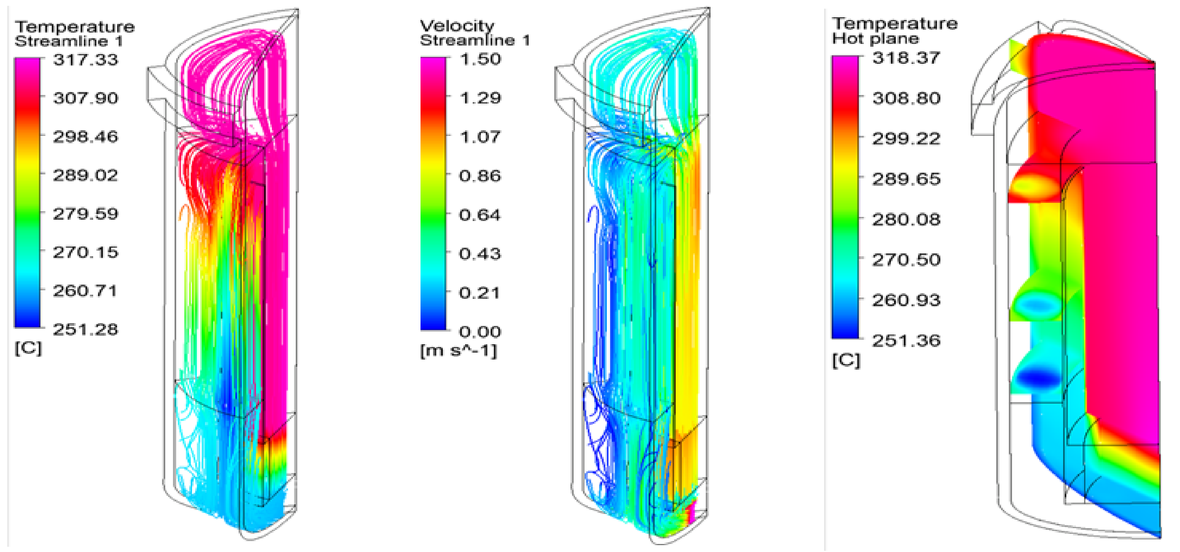


Figure 4: CFD results

To demonstrate that developed design of reactor has a substantial potential for thermal power increasing without significant constructive changes two additional calculations for thermal power 300 and 400 MW were made using KORSAR/GP code. The results show that it is necessary to increase the height of reactor till 15.2 m to force thermal power up to 400 MW.

Position of VVER-I among similar small modular reactors with natural circulation of coolant in primary circuit from the point of view of the reactor height dependence on thermal power is shown in Figure 5. It is seen that VVER-I with nominal thermal power 250 MW and also with forced thermal power 300 and 400 MW quite well fits worldwide trend of such type reactors development.

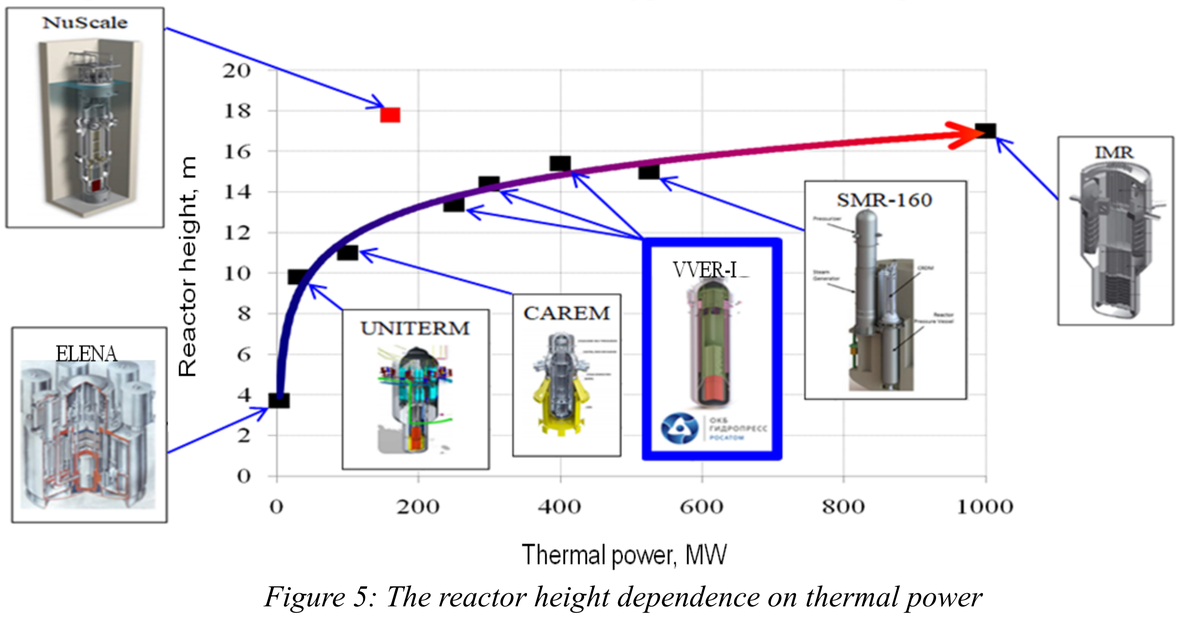


Figure 5: The reactor height dependence on thermal power