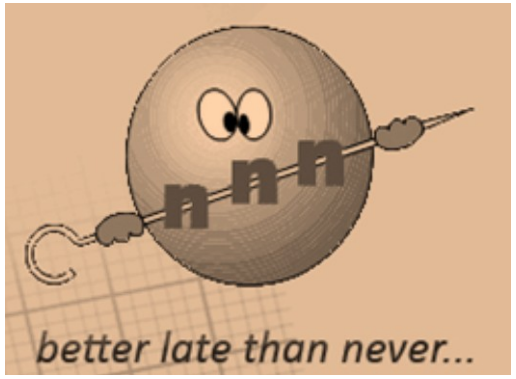
International Seminar on Interaction of Neutrons with Nuclei

May 29 – June 2, 2023



THERMAL MODEL OF THE IGR RESEARCH REACTOR

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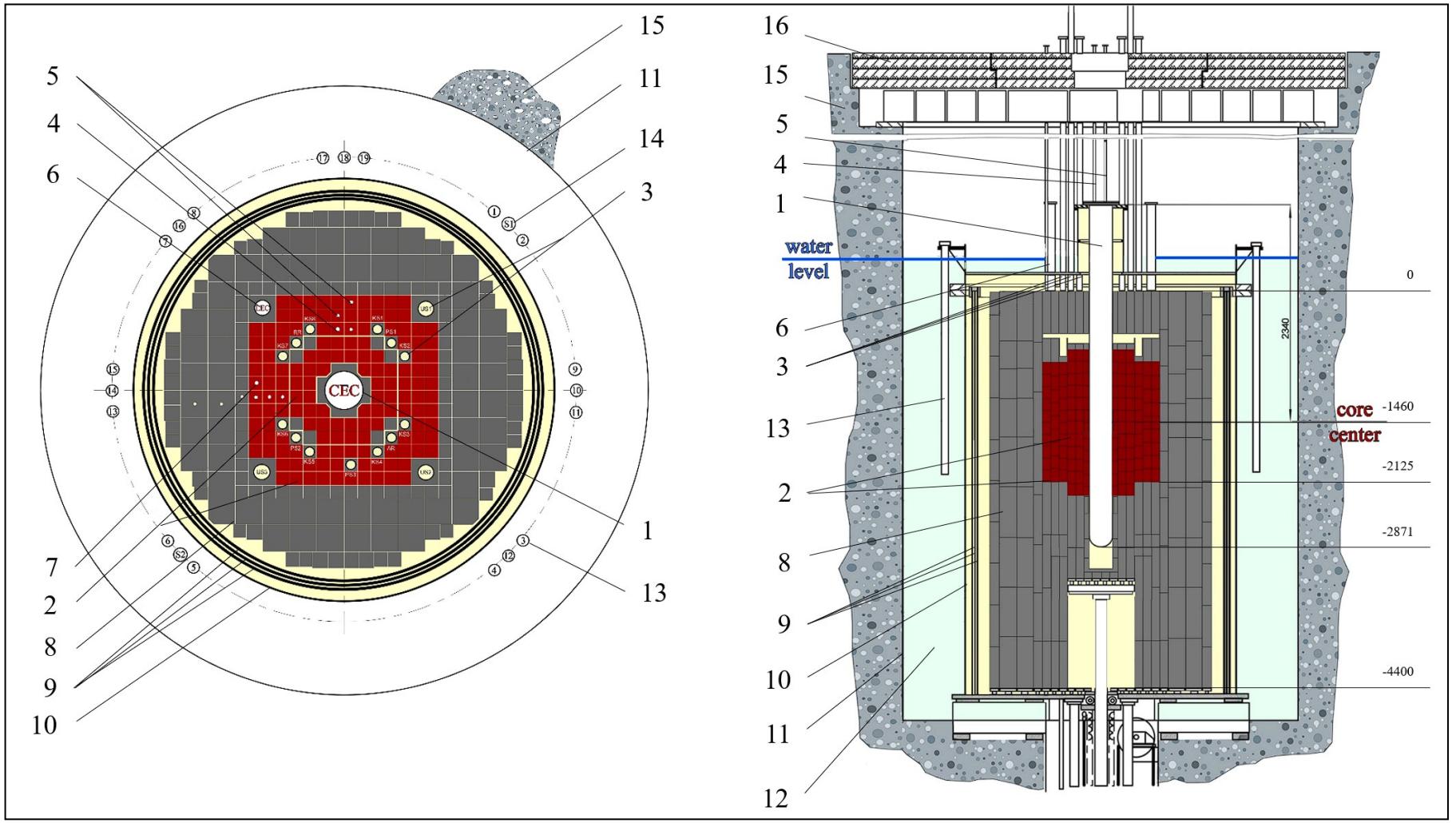
Dubna, 2023

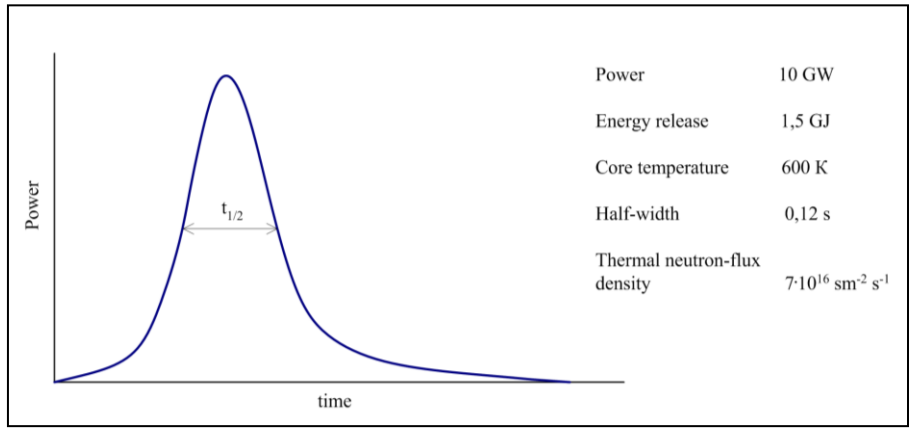
IGR RESEARCH REACTOR. CORE DESCRIPTION



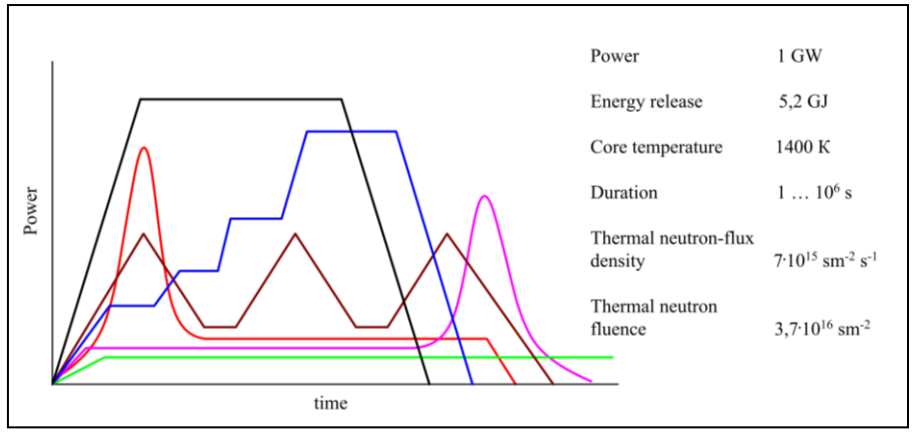
1 – central experimental channel (CEC);
2 – core (movable and fixed part of the stack);
3 – channels of control rods;
4 – physical measurement channel;
5 – thermocouple (TEC) channel;
6 – lateral experimental channel (LEC);
7 – neutron source channel;
8 – reflector;
9 – side shield (three shells);
10 – casing;
11 – water tank;
12 – cooling water cavity;
13 – ionization chambers;
14 – neutron counter channel;
15 – biological protection;
16 – top shield.

IGR RESEARCH REACTOR. MAIN CHARACTERISTICS

«Neutron burst» mode

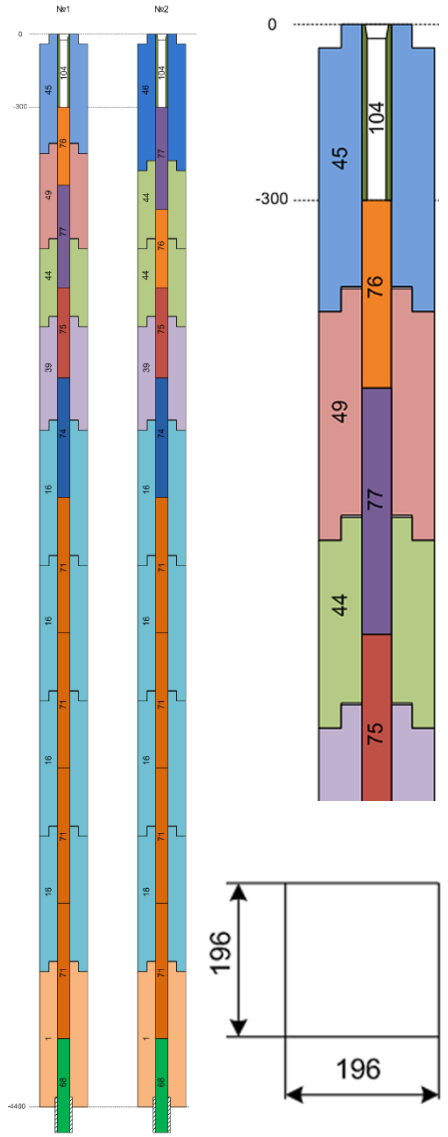


«Impulse» mode

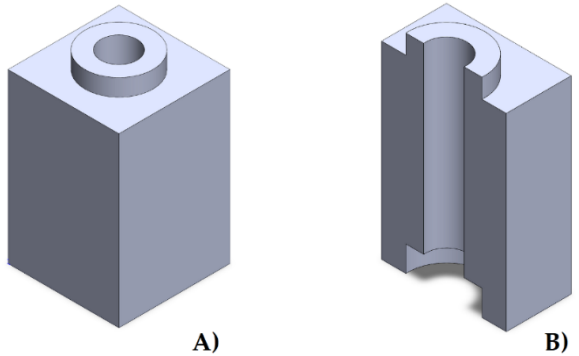


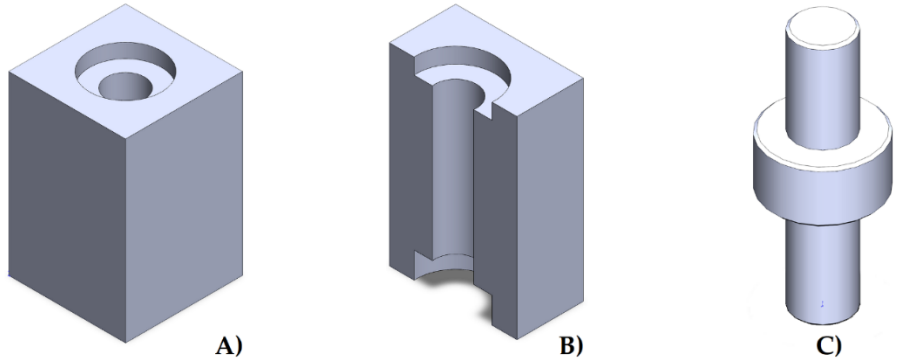
Neutron spectrum: thermal;
Fuel: $UO_2(NO_3)_2$, 90% enrichment by U-235;
Core: homogeneous, heat capacity type;
TCR: negative;
Maximum energy release: 5.2 GJ;
Maximum graphite temperature: 1400 K;
Medium: helium;
Control rods:
starting, compensating, automatic and manual control rods;
Experimental channels:
central d=282 mm, lateral d=82 mm;
Operating modes:
Unregulated – Neutron burst

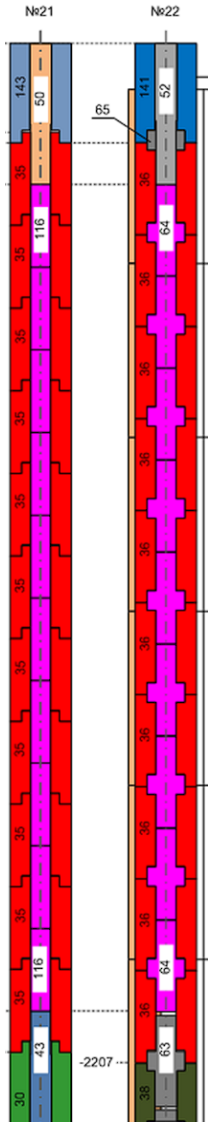
IGR RESEARCH REACTOR. DESIGN FEATURES

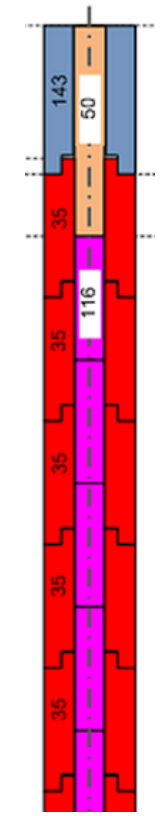


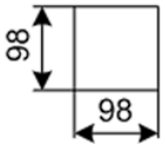
To form the core columns, graphite blocks with a cross section of ~ 98 × 98 mm impregnated with uranium solution are used, and unimpregnated graphite blocks with dimensions of ~ 197 × 197 mm are used for the side reflector. The height of the blocks is from 140 mm to 148 mm.







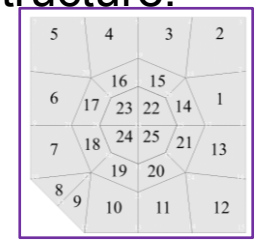




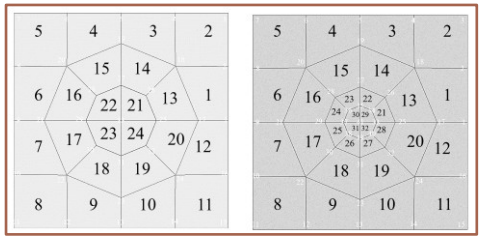
MODELING. MESH STRUCTURES

Mesh structures contain information about the location of nodes and their number. Based on these data, finite elements (mainly hexahedra) are generated, each of which consists mainly of 8 nodes. The mutual arrangement of nodes directly affects the quality of the elements of the future grid, so their coordinates were calculated and optimized individually for each mesh structure.

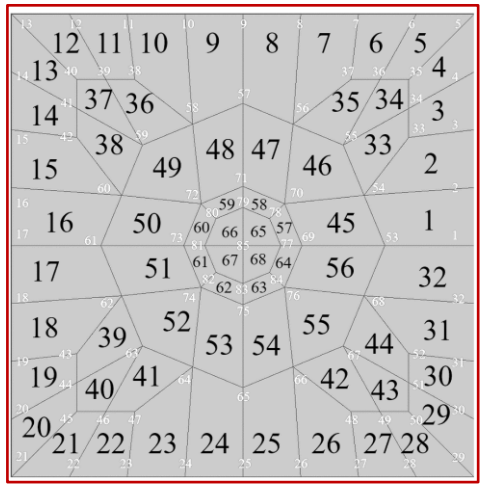
1



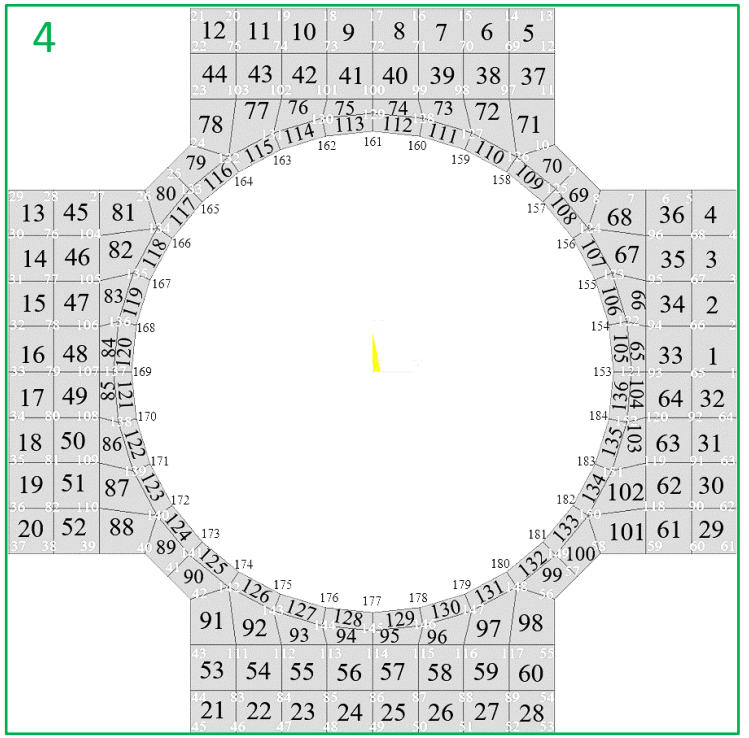
2



3



4

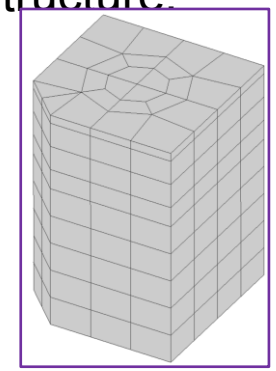


2D schemes

MODELING. MESH STRUCTURES

Mesh structures contain information about the location of nodes and their number. Based on these data, finite elements (mainly hexahedra) are generated, each of which consists mainly of 8 nodes. The mutual arrangement of nodes directly affects the quality of the elements of the future grid, so their coordinates were calculated and optimized individually for each mesh structure.

1



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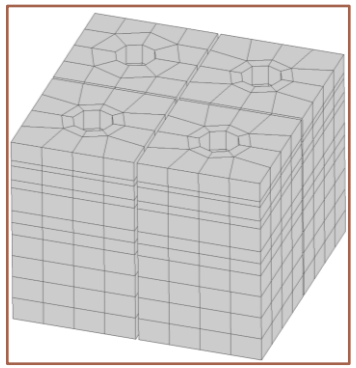
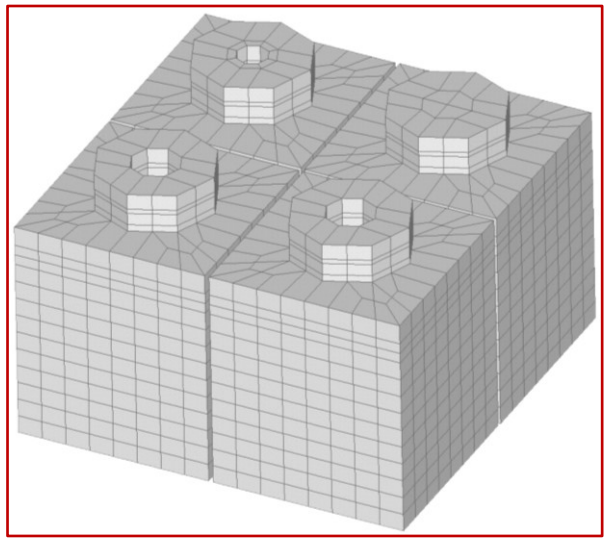


3



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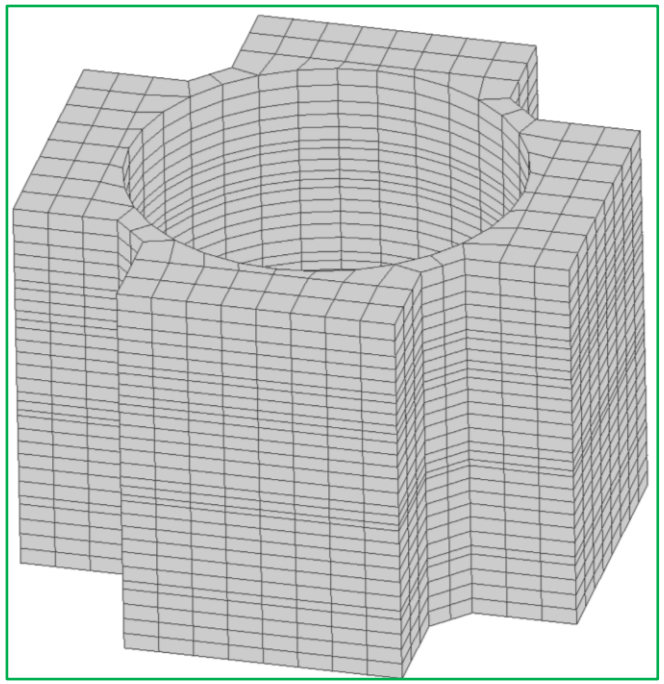
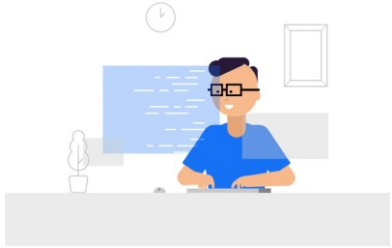
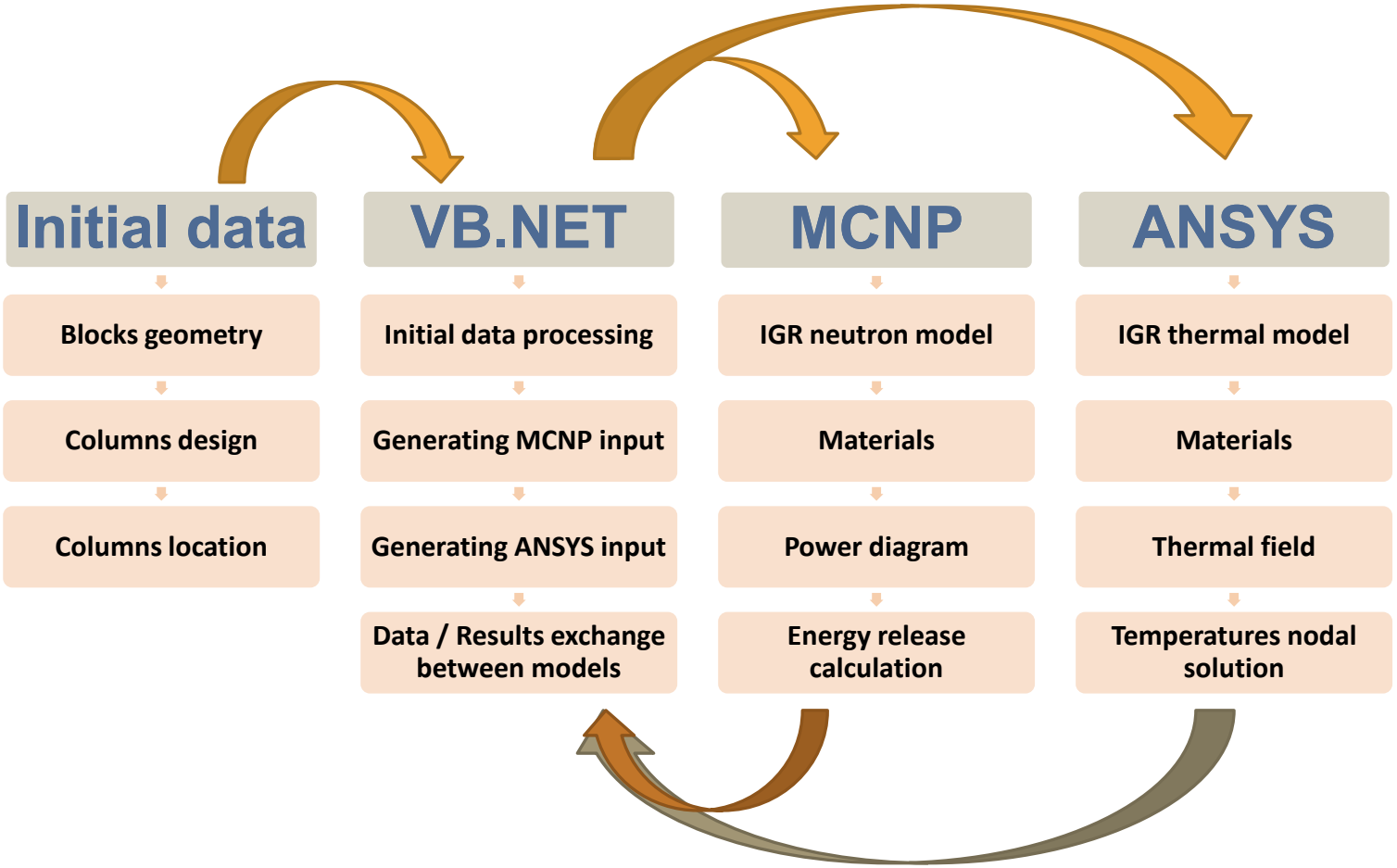


3D blocks

MODELING. TOOLS

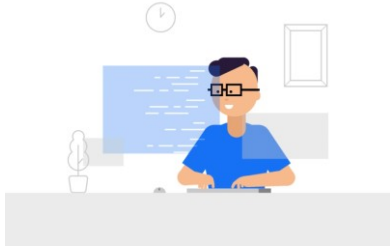
All stages of work: models generating, preparing and performing calculations, processing results, etc., are performed automatically using programming tools.

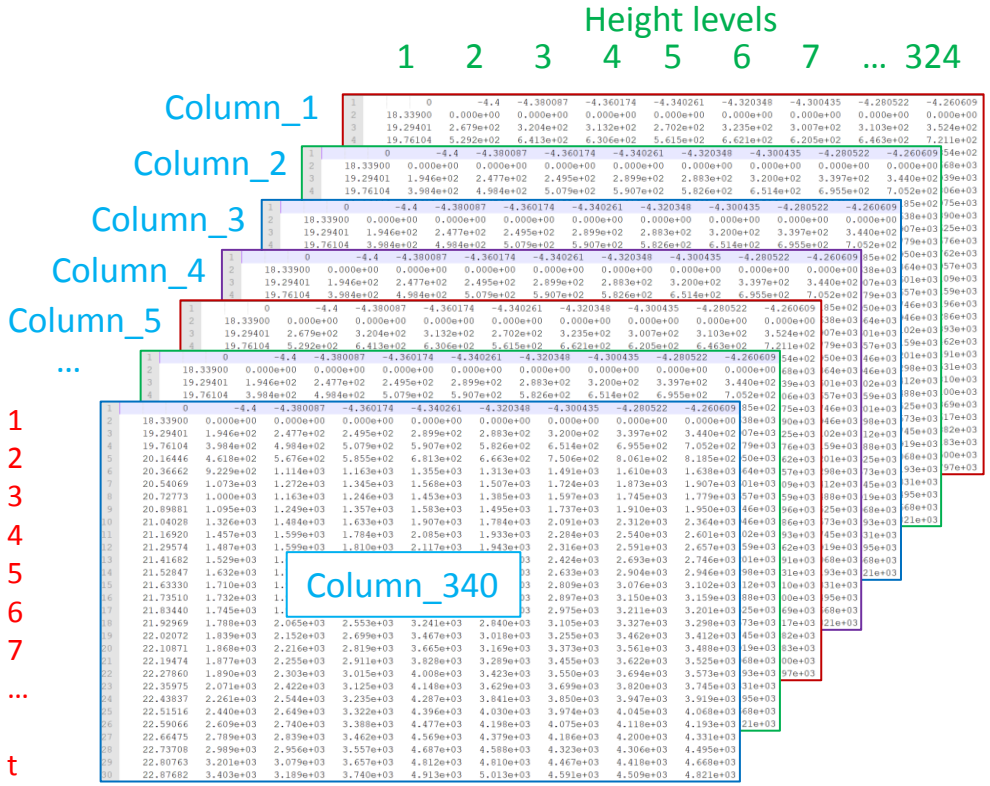




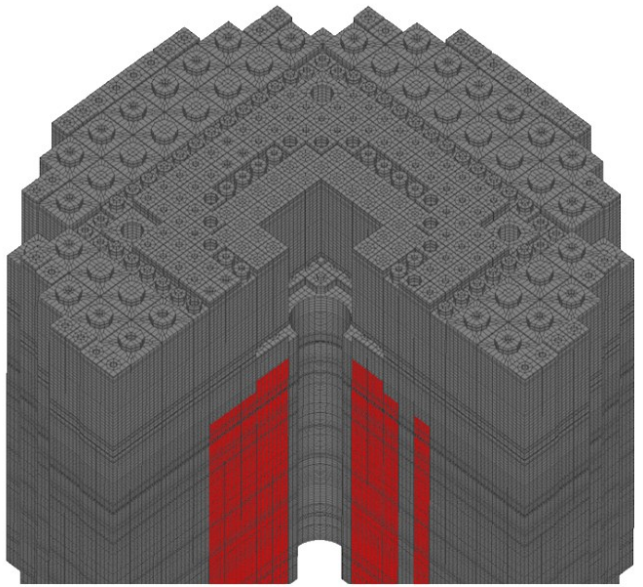
MODELING. LOADS

As an example here you can see the number of data loaded into the model





Maximum **t** value currently used - **1009**



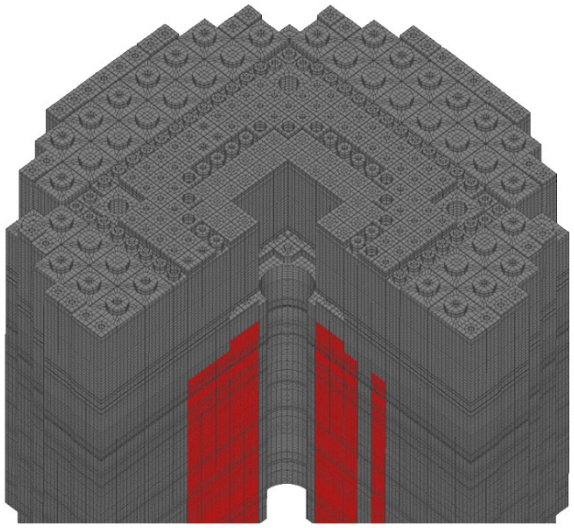
Matrix (340 × 324 x time)
contain more than 100 000 power density loads (W/m^3) for each time value

RESULTS. THERMAL MODEL

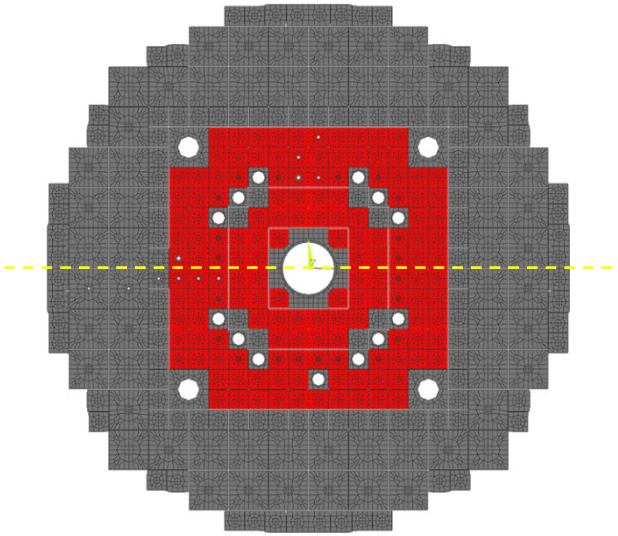
Model composition:
4 700 304 nodes
4 614 328 elements
8 427 element types

Materials:
#1 graphite with uranium (core)
#2 uranium free graphite (reflector)
#3-#10 helium

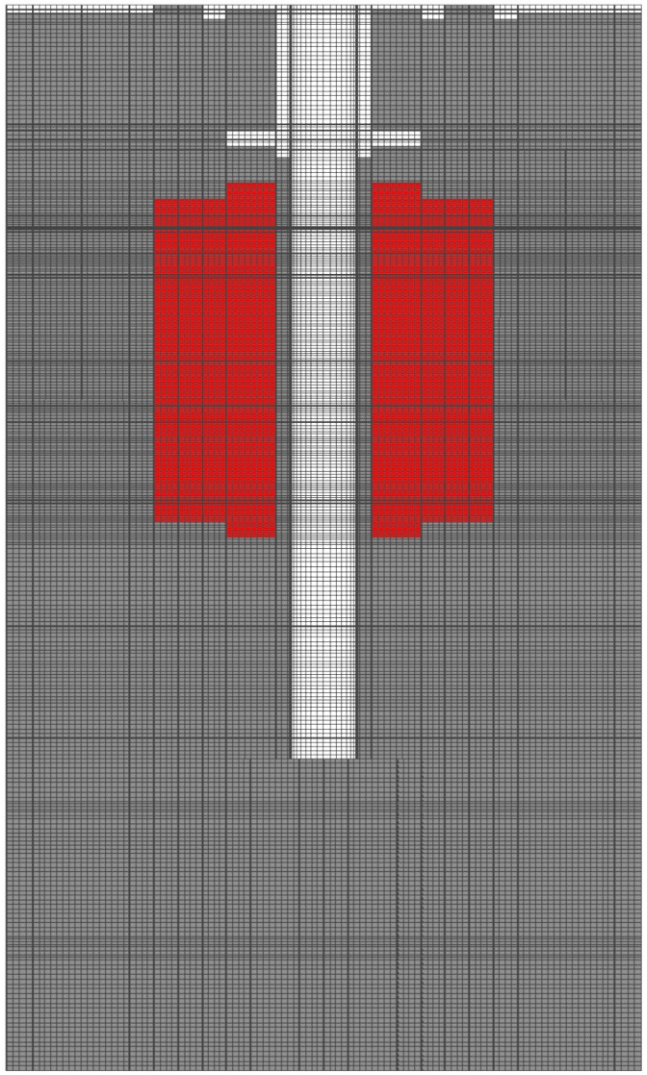
Model dimensions:
6 525 mm height
2 700 mm diameter



3D view

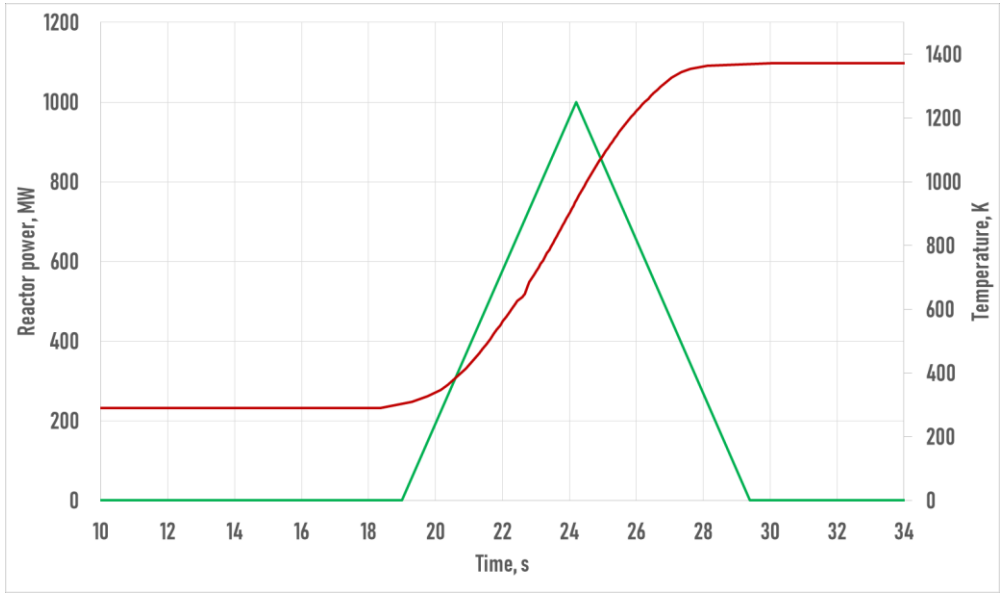


Horizontal section

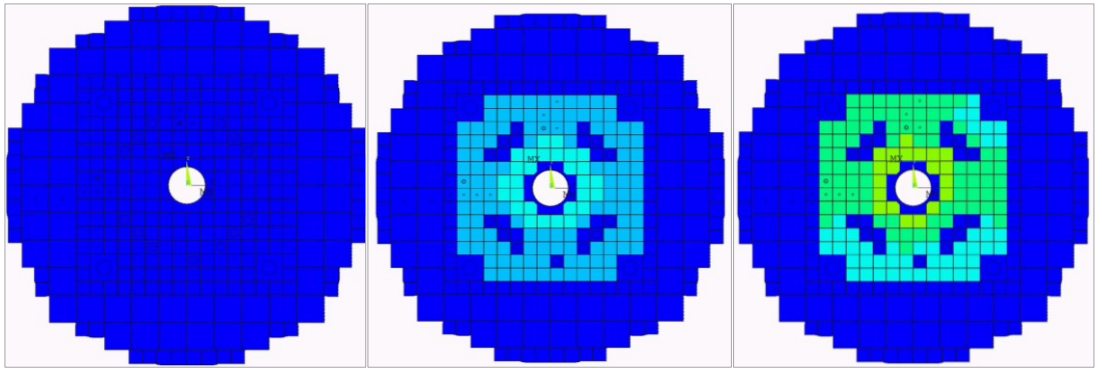


Vertical section

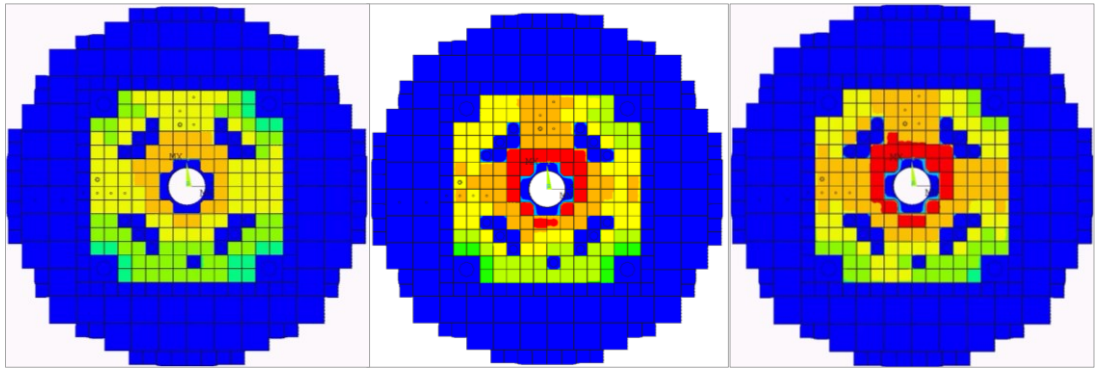
RESULTS. VALIDATION. 10.4 sec start-up



Power diagram and Temperature at TEC location

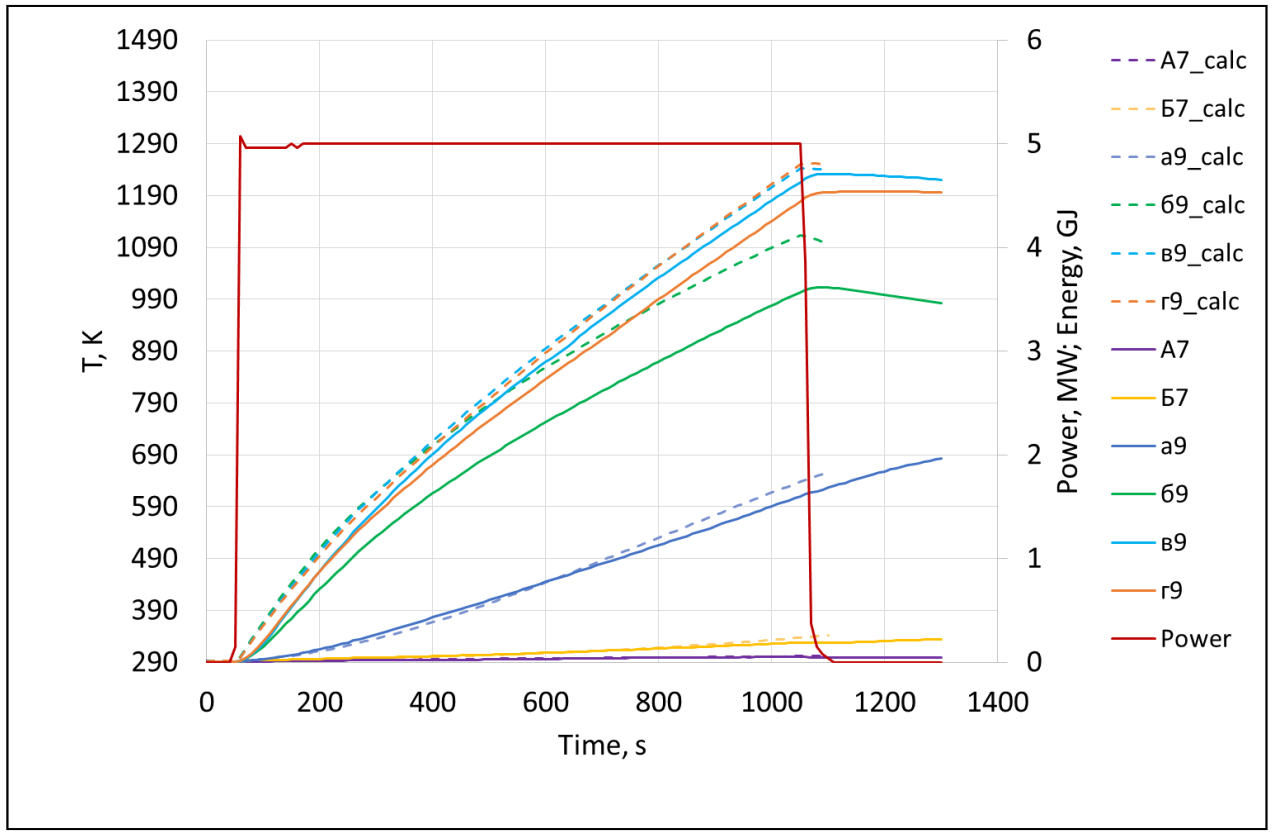


t < 20 sec | t = 22 sec | t = 24 sec

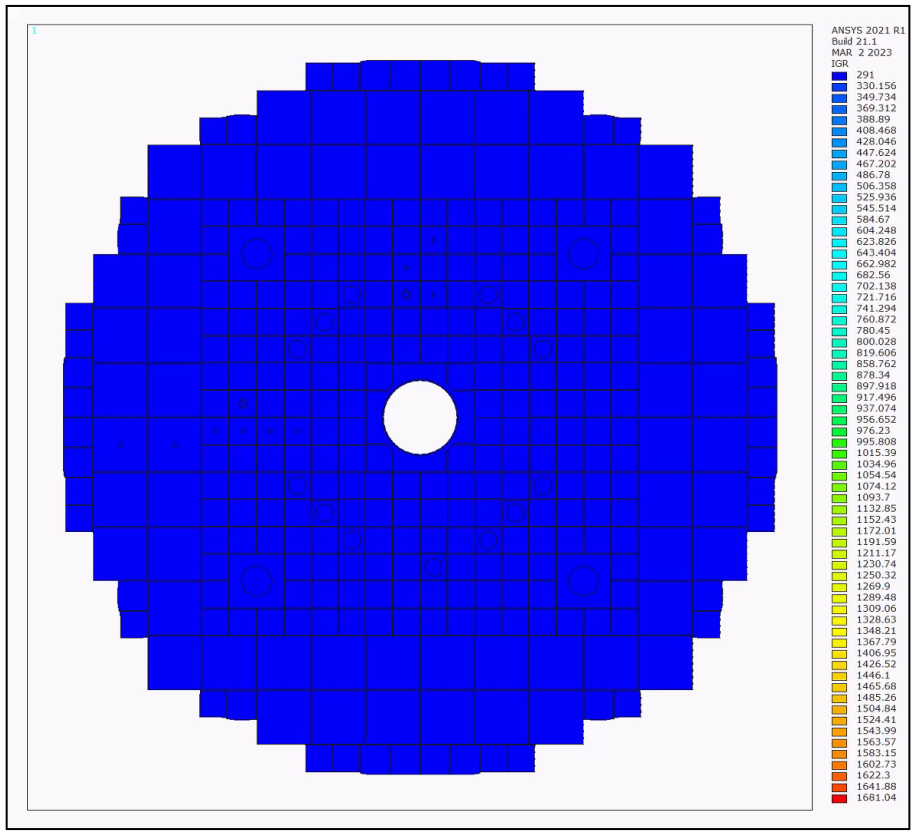


t = 26 sec | t = 28 sec | t = 30 sec

RESULTS. VALIDATION. 1000 sec start-up



Comparison between calculated and measured temperatures



Temperature distribution for horizontal section at the **-1465 mm** level (TEC location)

CONCLUSIONS

A new thermal model of the IGR reactor has been developed, which can be used to calculate the thermal characteristics of the core with a high degree of accuracy due to a number of distinctive features:

1) A full-scale 3D model of the IGR reactor core was built;
2) The geometry and material composition of each graphite block (more than 8,000 pieces) is described in detail;
3) The materials are specified taking into account the dependence of their properties on temperature over the entire range. The influence of the thickness of the helium gap on the heat transfer between the blocks is taken into account;
4) The association of blocks to certain types and their coordination with the neutron model was carried out;
5) Algorithms for setting loads in the form of internal volumetric energy release distributed over the elements of the model (more than 10 million values) have been developed;
6) The model validated on real reactor start-ups in various modes;
7) The results of the thermal calculation contain information about the temperature in each node of the model for each moment of time (hundreds of millions of values);
8) Validation results shows that the discrepancies in the temperature values are in the range from 3% to 15%.

THANK YOU FOR YOUR ATTENTION

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