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Thermal Model of the IGR Research Reactor

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1. Introduction

The pulsed graphite reactor (IGR) is one of the research nuclear reactors of the National Nuclear Center of the Republic of Kazakhstan. The active zone of the IGR is a graphite stack surrounded by protective housings. The stack consists of columns assembled from graphite blocks and graphite bushings. The cavities between the columns are filled with helium. Unlike most nuclear reactors, this one does not have fuel elements, and uranium fuel in the form of a solution is dispersed into some graphite blocks, which form the core (Fig. 1). The reactor has a negative temperature coefficient of reactivity, and when the operating temperature limit is reached, natural power dissipation occurs. As means of measuring the temperature in the core, thermoelectric converters (TEC) are used, which are located in the channels of the following reactor columns: ***А7, Б7, а9, б9, в9, г9***.

Several main elements of the core can be distinguished: the movable part of the core, the fixed part of the core, the side reflector, the central experimental channel (CEC), the lateral experimental channel (LEC), the neutron source channel, the channels of thermal converters, the rods of the control and protection reactor system, biological protection [1].

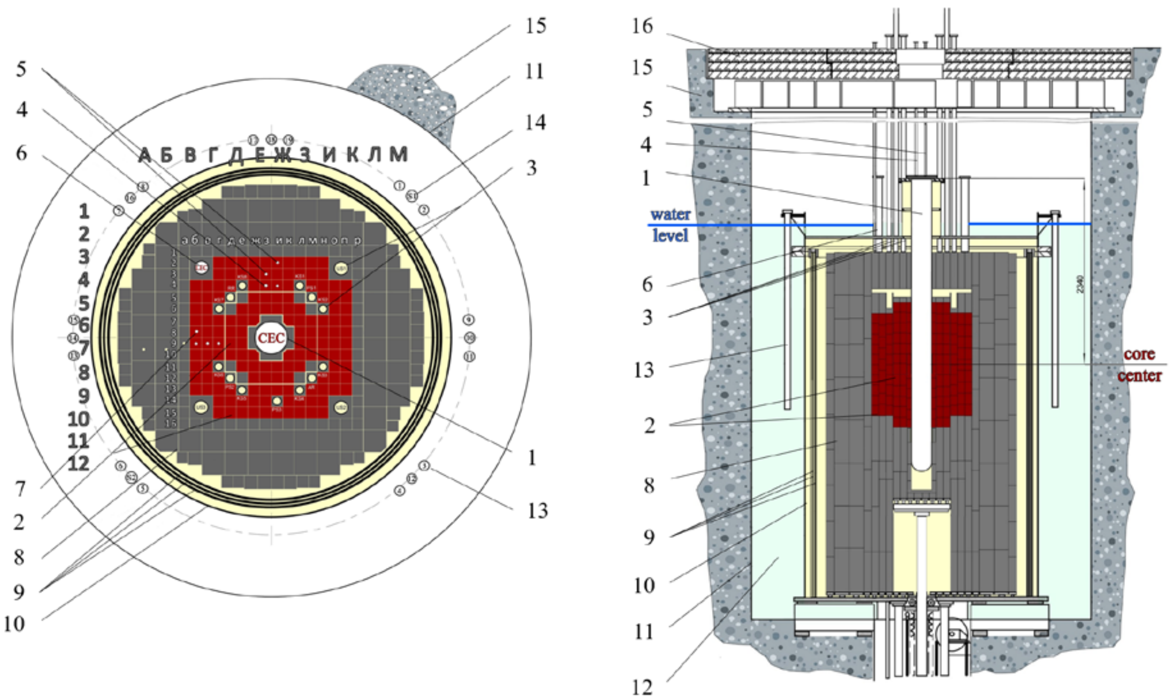

Fig.1. Vertical and horizontal section of the IGR reactor: 1– CEC; 2– active zone; 3– control rods channels; 4– channel for physical measurements; 5– TEC channels; 6– LEC; 7– neutron source channel; 8– reflector; 9– side screen (three shells); 10– casing; 11– water tank; 12– cooling water cavity; 13– ionization chambers; 14– neutron counter channel, 15– biological protection; 16– upper lid.

The IGR reactor is used to perform tests on fuel assemblies of designed reactor plants to justify their operating modes [2]. All reactor tests are accompanied by computational studies, including computer simulation of the thermal state of the reactor core and test object [3]. The simulation of the thermal state of the core of the IGR reactor is performed by the finite element method in the ANSYS software package [4]. This requires a qualitative model of the reactor core. With the growth of the computing power of personal computers and the development of computer simulation methods, a need arose to develop a new high-precision thermophysical model of the IGR reactor. At the same time, a number of requirements were presented for the new model. The new model should: 1) take into account all dimensional and material characteristics and physical properties of the core; 2) include a detailed core, taking into account the features and nuances of the design; 3) be formed programmatically, for example, using the VB.NET programming environment [5] directly from finite elements using the «bottom-up» method; 4) contain the optimal number of elements for describing the geometry, 5) provide the possibility of mutual data exchange with the neutron-physical model of the IGR reactor core.

2. The core design features

The IGR reactor core consists of 340 square columns. The columns are divided into several types depending on the blocks included in the column. The blocks differ in design. They have technological holes, protrusions, and grooves, which provide the possibility of their mutual engagement (Fig. 2.). For example, graphite blocks with a cross-section of ~ 98×98 mm impregnated with a solution of uranium are used to form the core columns, and unimpregnated graphite blocks with dimensions of ~ 197×197 mm^2 are used for the side reflector. The height of the blocks varies from 140 mm to 148 mm.

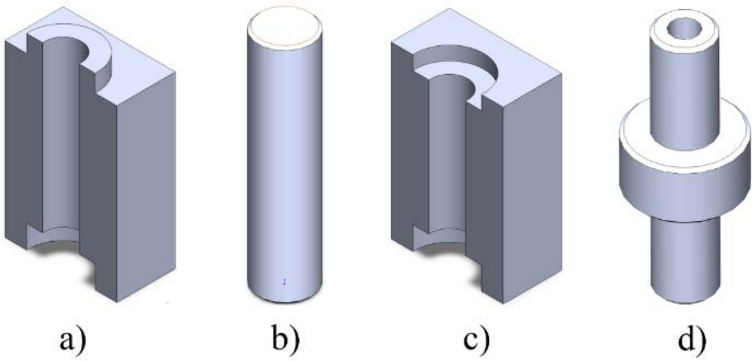

Fig. 2. External view of 3D models of graphite blocks and bushings.

Several fundamental mesh structures were developed for the most accurate description of each topology of graphite blocks by finite element methods. Mesh structures contain information about the location of nodes and their number. Based on this data, finite elements (mainly hexahedra) are generated, each of which consists of eight nodes (in rare cases, six). The mutual arrangement of nodes directly affects the quality of the elements of the future mesh, so their coordinates were calculated and optimized individually for each structure. For example, elemental grids of two types of graphite blocks are given, formed from one mesh structure (Fig. 3), consisting of 33 nodes and 24 hexahedral elements.

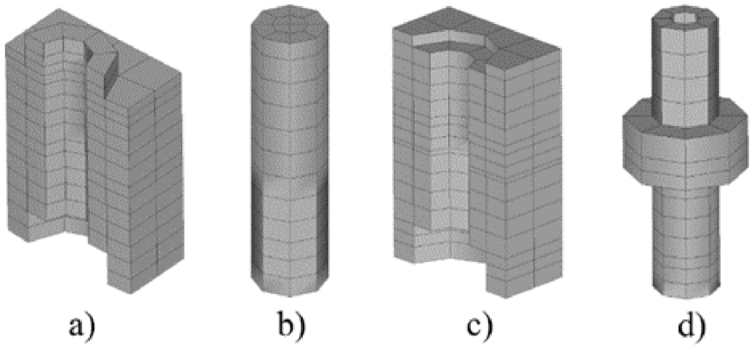

Fig. 3. Graphite details mesh.

The versatility of this structure makes it possible to model most of the core blocks by layer-by-layer construction of elements, as well as to form holes, grooves, and protrusions at different height levels without changing the number of nodes and the shape of the elements. The presence of a structured grid in graphite blocks greatly facilitates the generation of helium elements surrounding the columns and makes it possible to obtain a high-quality grid.

3. Results

The developed thermophysical model of the IGR reactor is an ordered and structured set of finite elements (Fig. 4), in which the important geometric parameters of graphite parts are preserved.

The model has 4 700 304 nodes, 4 614 328 elements, 8 427 element types, 3 materials, and 9 material types. Element types group the specified elements into individual graphite parts, it allows building of interface for transfer the temperature field from the thermophysical model to the neutron-physical one, and is important when computational studies of the core are performing.

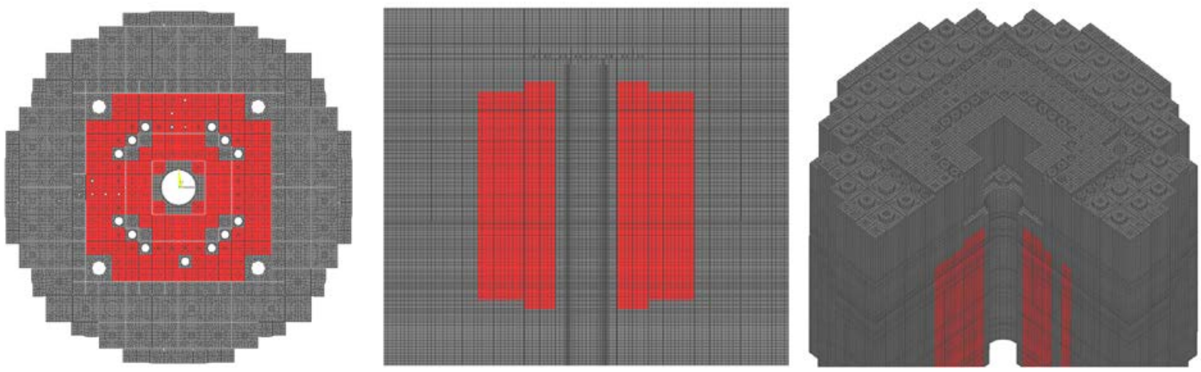

Fig. 4. Thermophysical model of the IGR reactor.

4. Validation

The model was validated by the core temperature measured by thermoelectric converters during the reactor start-up. A comparison of the measured temperature values with those calculated in the ANSYS program is presented in the form of a diagram in Figure 5.

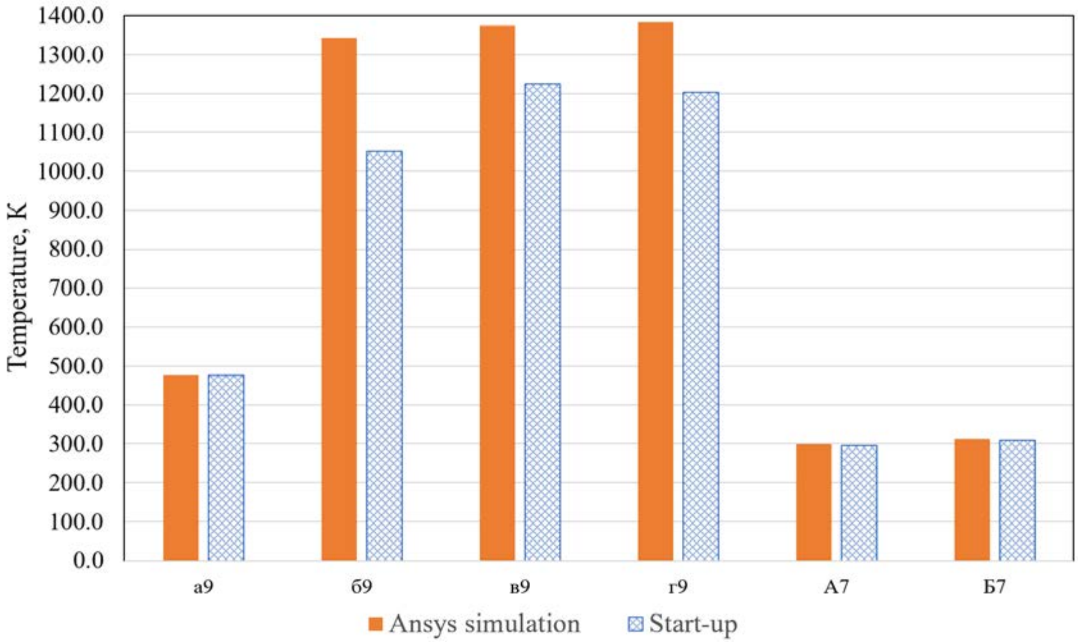

Fig. 5. Comparison of calculated and measured temperatures during start-up.

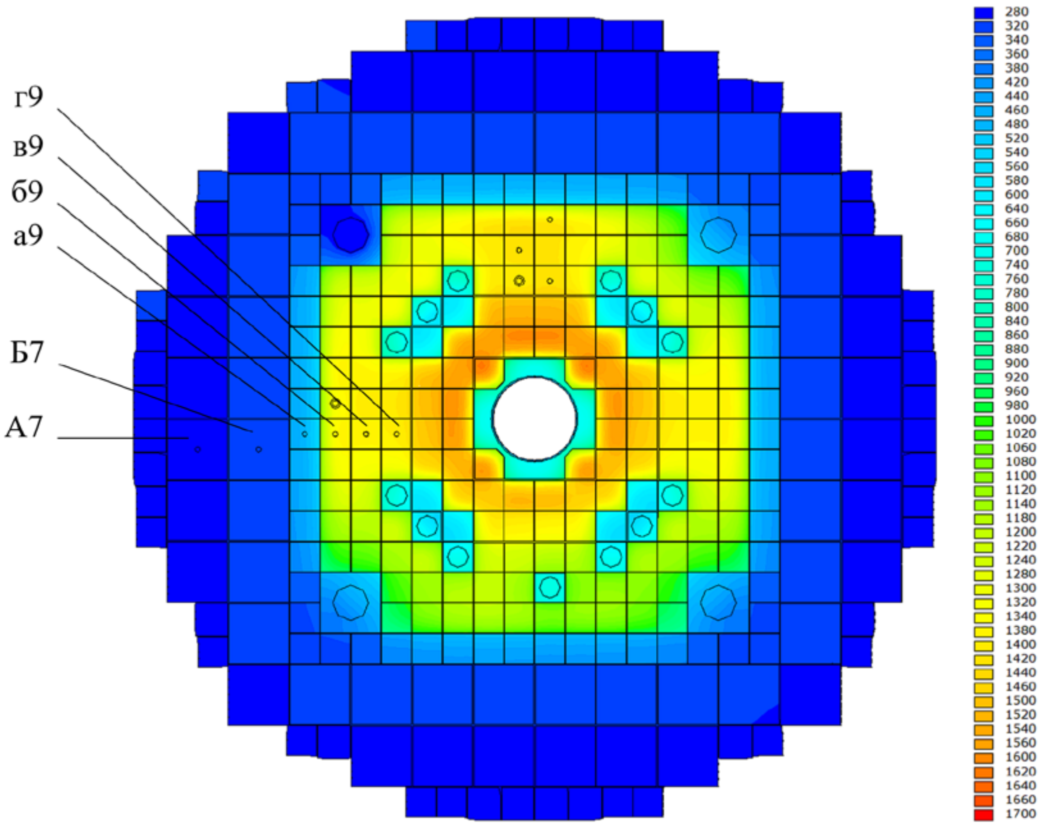

Fig. 6. Temperature distribution in the horizontal section of the core.

The largest deviations were found in columns ***б9, в9,*** and ***г9***, which amounted to 20%, 13%, and 11%, respectively. The temperature values measured in columns ***а9***, ***А7***, and ***Б7*** almost completely coincide with the calculated ones, and the difference does not exceed 1.0%. On average, the deviation of the measured values from the calculated ones does not exceed 7%.

The discrepancy in the measured and calculated temperature values in column ***г9*** is 12% after reaching the steady state at the stage of cooldown.

5. Conclusion

A full-scale three-dimensional model of the IGR reactor was built for carrying out thermophysical calculations, which makes it possible to take into account the uneven distribution of energy release associated with the asymmetry of the core. The model is built from structured and optimized finite elements associated with the neutron-physical model of the reactor. Implemented full interaction of models at the element level guarantees the transfer of data from one model to another in an explicit form. The model was created in the VB.NET programming environment for calculations in the ANSYS Mechanical APDL program [4].

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