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Thorium-loaded low-power reactor installation operated with super-long fuel residence time

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Abstract

It was established in numerical experiments conducted at the Institute for Safety Research and Reactor Technologies (ISR-2) of the research center Forschungszentrum Jülich (1998–1999) that thorium-plutonium fuel composition ensures due to the presence of anomaly in the dependence of resonance neutron absorption on the ratio of moderator volume to fuel volume the possibility to organize super-long duration of fuel residence in the cores of VVER-type reactors. Such possibility was demonstrated in the present study for high-temperature thorium-loaded reactor installation with 60 MW power. In this case the ratio of moderator volume to the volume of resonance absorber in the reactor core is within the interval of (45–60). It is specifically such type of low-power reactor installations that may constitute the basis of regional power generation in Russia.

The purpose of the study was to investigate the neutronics characteristics of thorium-loaded low-power reactor installation with fuel blocks and fuel pellets with different configurations in order to select the reactor core design and the core fuel load ensuring optimal utilization of thorium in it and obtaining maximum possible generation of energy in the course of super-long fuel residence in the core.

Implemented studies and numerical experiments were performed using verified computation codes included in the MCU5 [1] and WIMSD5B [2] software packages, updated libraries of evaluated nuclear data (ENDF/B-VII.0, JEFF-3.1.1, JENDL-4.0, ROSFOND, BROND, ABBA [3,4] and others) and multi-group approximations.

It was established that thorium-loaded reactor installation with suggested design is the installation operated with fast and intermediate neutrons. Results of calculation allow making the conclusion that reactor installation with suggested configuration of the fuel block and the fuel pellet, as well as with the fuel composition in question can be operated during not less than 3500 effective days at the power level of 60 MW without reloading.
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Keywords: Thorium; Plutonium; Thorium-loaded low-power reactor installation; Super-long fuel residence.

Status of studies implemented during the first phase of calculation of thorium-loaded low-power reactor installation

Scientific research conducted in Russia for the purpose of implementation of new technological platform is based on the ideas of fuel breeding within the closed nuclear fuel cycle and the physical principles of fast reactors [5–7]. Innovative designs of low-power reactor installations (RI) also fall under the scope of this new technological platform. High-temperature gas-cooled nuclear reactors loaded with thorium fuel and possessing the properties of mobility, 100% factory fabrication, low time expenditures for their installation and ability to operate during long periods of time without fuel reloading are the promising direction within this sphere of development of power generation industry. It is specifically such low-power RI brought to the level of commercial competitiveness that must constitute the basis of the regional power generation in Russia.

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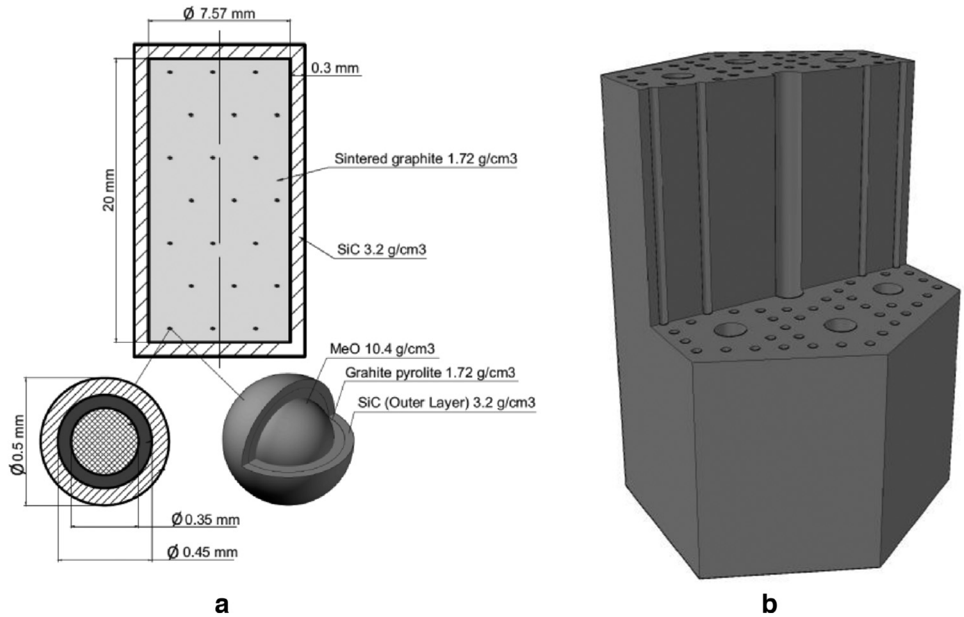

Fig. 1. Calculation model of fuel assembly of the HTGCTRI: a) – fuel pellet of the HTGCTRI of 0500 and 1000 types; b) – unified design of the HTGCTRI fuel block.

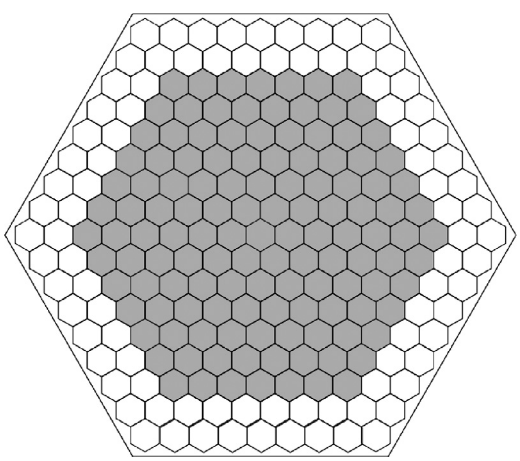

Fig. 2. Calculation model of the HTGCTRI core.

Results of the first phase of neutronics studies of 3D-model of low-power high-temperature thorium-loaded reactor installation (HTGCTRI) on the basis of fuel block with unified design are presented in Refs. [8,9].

Calculation model of the HTGCTRI was developed using the software of the MCU5 series [1] and the approaches developed in Refs. [10,11]. Models of micro-capsulated fuel (MCF), fuel pellets (FP), fuel blocks (unified design of the fuel block) (Fig. 1) and the core of the reactor (RC) were developed (Fig. 2).

Configuration of the MCF, FP and thicknesses of coatings were selected on the basis of scientific research and technical solutions suggested in Refs. [10–19].

Micro-capsulated fuel

The selected configuration of MCF with 500-µm diameter (Fig. 1a) represents the spherical fuel kernel coated with successive layers of pyrolithic carbon (PyC) and silicon carbide (SiC) dispersed inside the graphite matrices of cylindrical FPs arranged inside the HTGCTRI core. Thorium-plutonium fuel composition was used as the fissile material.

Along with burning up of the fissile material fission products accumulated in the fuel kernel diffuse at high temperatures but, due to the system of matrix coatings, they remain within the limits of the MCF and the FP. PyC-layer localizes the gaseous fission products and serves as the first diffusion barrier protecting the second SiC-layer from effects of corrosion due to the solid fission products. SiC-layer due to its perfect physical-mechanical and thermal physics properties is the main supporting coating and the diffusion barrier first of all against solid fission products [15–17]. Additional safety barrier is formed by the graphite matrix and sealing coating on the surface of the FP in the form of SiC-coating with 300-µm thickness.

Low corrosion resistance of SiC in contact with metals (impurities in the nuclear kernel, elements of structures of fuel assemblies) interaction with which takes place at significant rates at temperatures in excess of 950 K which results in the formation of low-melting-point eutectic destructing the coatings [17] is attributed to the shortages of the MCF provided with silicon carbide coatings.

Preliminary estimations of cost effectiveness of power generation demonstrated that technical solution based on the two-layer coatings simplifies the procedure of manufacturing the MCF and FP and significantly reduces the component of production costs associated with fuel.

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