MICROFUEL BEHAVIOR UNDER THE ACTION OF NEUTRON PULSES IN THE BIGR REACTOR

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The results of experimental and computational investigations of microfuel behavior under the action of neutron pulses in the BIGR reactor are presented. The methods used in the present work made it possible to determine the change in the structure of the irradiated samples, specifically, to record interlayer gap formation in the microfuel and the actual fracture of the microfuel. The results of this work could be helpful for evaluating the service life of microfuel and the consequences of emergency situations in HTGR as well as for developing and perfecting the corresponding computational software.

The foundation for developing the HTGR was created back in mid-1990s by advances made in our and other countries in the technology of gas turbines and high-efficiency heat exchangers. It was assumed that an energy conversion system based on the high-efficiency Brayton gas-turbine cycle with efficiency ~50% will be implemented in this reactor [1]. The fuel considered for HTGR was comprised of microfuel: fuel particles with a multilayer protective coating which are homogeneously distributed in a graphite matrix, forming a fuel compact with a prescribed shape [2]. As a rule, microfuel consists of spherical uranium-dioxide particles (kernels) confined in a strong, multilayer, high-temperature shell consisting of layers of pyrocarbon and silicon carbide capable of effectively containing the fission products. The use of microfuel opens up prospects for substantially increasing the fuel temperature in reactors and thereby the efficiency with which atomic energy is converted into electricity.

The aim of the present work is to investigate the serviceability of microfuel under the conditions of pulsed nuclear heating. The results of experimental and computational studies of the behavior of samples of microfuel under the action of neutron pulses in the BIGR reactor are presented below. In the experiments, the surface temperature of the microfuel and the energy released in the kernel were determined and possible fracture of the microfuel was recorded. The experiments with fracture of the microfuel approximately reproduced the processes occurring in design-base and unanticipated emergency regimes under conditions characteristic for HTGR. The experiments were accompanied by careful temperature and thermo-mechanical calculations.

Two reasons were proposed for the appearance and development of possible accidents in HTGR:
1) sharp increase in the reactivity, one consequence of which is an increase in the neutron flux density, energy release and temperature of the fuel elements;
2) reduction in or cessation of the coolant flow in the core, directly resulting in an increase in the fuel temperature. An increase in the temperature of the kernels can result in their melting, undesirable chemical reactions and local thermal stresses, i.e., damage to and even destruction of the fuel elements. In addition, this can cause a reduction in the tem-
perature coefficient of reactivity quenching at the moment of the fission pulses, since in uranium-graphite the reactivity decreases as a result of the graphite matrix and not the uranium being heated.

**Experimental Arrangement.** The samples of microfuel with kernels comprised of uranium dioxide with 36% enrichment and a four-layer coating consisting of silicon carbide and pyrolytic carbon were tested in the pulsed reactor BIGR [3]. The kernel diameter was ~450 μm and the microfuel diameter ~900 μm [2]. Before the pulse tests, the samples were examined under a microscope, weighed and irradiated in a static operating regime of the reactor and the relations between the total number of fissions (energy release) in the core and kernels of the microfuel were determined. These relations were subsequently used in planning the parameters of the fission pulse in the reactor which are required to obtain the prescribed number of fissions in the kernels. The irradiation geometry for the samples in the static and pulsed experiments is identical.

Two series of pulsed experiments were conducted. In the course of the first series, the microfuel was irradiated in pulses on prompt neutrons with duration 3.2–5 msec and in the second series on delayed neutrons with duration 0.5–2 sec. In the first series, the samples were irradiated only near the side surface of the core and in the second near the side surface and in the central experimental channel. The form of the time dependence of the neutron flux density in a pulse was recorded with the aid of metrologically certified and checked channels for measuring the neutron leakage flux.

The experimental arrangement near the side surface is shown in Fig. 1. A sample was placed in a steel container (crucible) located inside an evacuated ampoule. A fiber-optic light-guide, which is part of the system for performing no-contact measurements of the surface temperature of microfuel and serves to transfer optical radiation to photodetectors, was introduced into the crucible. To increase the number of fissions in a kernel, the ampoule was enclosed by a polyethylene moderator. The polyethylene block with the ampoule was placed inside a cavity in a graphite block of the reflector-moderator, increasing the heating of the microfuel as a result of a reduction in the energy of the neutron spectrum. In some experiments, an additional crucible, holding up to three samples in separate vertical channels, was placed inside the ampoule.

The density of $^{235}$U fissions in the kernels in the indicated geometry is $5 \times 10^{12}$ per 1 g per 1 MJ energy released in the reactor core. The maximum planned energy release in the core of the BIGR reactor is 280 MJ.

In the central channel, the microfuel was placed in a zirconium cassette inside a steel vacuum ampoule. The ampoule was placed in a polyethylene block enclosed by a boron carbide shell in order to protect the fuel rings of the reactor from overheating by moderated neutrons. The density of the $^{235}$U fissions in the kernels in the irradiation position in the central channel is 80% higher than the fission density in the reflector-moderator block near the side surface ($9 \times 10^{12}$/g per 1 MJ in the core).

The surface temperature of the sample was measured by optical pyrometry in the course of the irradiation. The optical radiation from the heated sample enters the input end of the light guide and is output from the high-temperature zone to

![Fig. 1. Schematic diagram of the irradiation experiment near the side surface of the core: 1) fuel rings of the BIGR core; 2) graphite block of the reflector-moderator; 3) polyethylene block; 4) experimental ampoule; 5) microfuel; 6) light guide.](image-url)