Models and computer codes, developed based on them, for simulating the swelling of uranium dioxide (BARS) and the stress–deformation state of a fuel element (SDS) under high-temperature irradiation are presented. It is shown that when developing a design for high-temperature fuel elements and validating their serviceability the quantitative indicator required for the swelling of uranium dioxide in the range ≥1400°C is the change in the external dimensions of the fuel caused by constant formation and growth of bubbles containing gaseous fission products during irradiation. The results of computational investigations using the models indicated are examined. These results eliminate the inconsistency of the data on the effect of the main operating parameters – the temperature and burnup – on the radiation characteristics and service life behavior of a fuel element. It is shown that the central channel in the fuel kernel and strengthening of the cladding improve the dimensional stability fuel elements.

The cladding deformation caused by swelling of uranium dioxide is one of the main factors which limit the service life of high-temperature fuel elements of space nuclear power systems [1]. The computational-theoretical and experimental data on swelling under high-temperature irradiation are limited and contradictory [2]. According to some data, the swelling increases linearly with burnup, while according to other data the swelling saturates. Some works predict the existence of a maximum temperature dependence of swelling, while other works predict a sharp increase of swelling with temperature. These discrepancies could be due to the characteristic behavior of uranium dioxide due to the migration of bubbles of gaseous fission products and structural changes under high-temperature irradiation. The existing computational-theoretical models do not fully take into account the combined effect of these processes.

The BARS statistical model of swelling (Bubble Analysis of Radiation Swelling of Fuel), which takes account of the characteristic behavior of bubbles of gaseous fission products and the change in the size and shape of uranium dioxide grains at high temperature, is proposed for analyzing the effect of the operational parameters on high-temperature swelling of uranium dioxide and to search for ways to increase the radiation resistance of oxide fuel.

Reactor tests of samples [3] have made it possible to obtain data on free (not restrained by cladding) swelling of various modifications of uranium dioxide at high temperature and to develop a model of the deformation behavior of fuel elements SDS (Stress-Deformation State of Fuel Element). Fuel samples tested for density, oxygen content, grain size and shape, phase composition, and impurity content were used to obtain data on unrestrained swelling. This made it possible to determine the specific nature of the high-temperature radiation behavior of uranium dioxide and its modifications and to provide representative input data for the SDS codes. This factor and the possibility of performing additional tests on the model for mechanical interaction in the kernel–cladding system, using independent results of reactor tests on natural fuel elements, provide representative data for optimizing the construction and validating the service life of fuel elements.
The present article describes the models developed and presents the results of an investigation of the radiation behavior of uranium dioxide and fuel elements at high temperatures in a wide range of operational parameters.

**Model and the BARS Computer Code.** In this model, just as in the prototype model [4], a local section of fuel consisting of uranium dioxide grains and bounded in the direction of the temperature gradient by the distance $H$ between the open surfaces (Fig. 1), is studied. An equiaxial grain is approximated by a cube of the same size with edge length $X_b$ and filled with dislocations in the form of a regular cubic network. The size of a dislocation cube $X_d$ is determined by the dislocation density. It is assumed that the gaseous products of fission, which are formed during irradiation, create nuclei of bubbles, whose size $d$ is determined by the equation of state

$$\left(\frac{4\gamma}{d} + \sigma\right)\left(\frac{\pi d^3}{6} - mB\right) = mkT,$$

and migration occurs by surface diffusion and is determined by the expression

$$V_b = \frac{6D_SQ_Sa_0}{kT^2d}\text{grad}T,$$

where $\gamma$ is the surface tension of uranium dioxide, $\sigma$ is the hydrostatic pressure acting on the fuel near a bubble, $m$ is the number of atoms of gaseous fission products in a bubble, $B$ is a constant, $T$ is the temperature, $D_S$ and $Q_S$ are, respectively, the coefficient and the activation energy of surface self-diffusion of atoms, $a_0$ is the lattice parameter, and $k$ is Boltzmann’s constant.

Migrating bubbles attach to dislocations and grain boundaries. Their location and rate of coalescence with newly arriving bubbles are evaluated by the Monte Carlo method. The bubbles are assumed to be in equilibrium, so that coalescence is accompanied by an increase in the total volume. In the process, the bubbles reach a critical size and detach from the defects indicated. The critical size of bubbles on a dislocation $d_d^{ct}$ and a grain boundary $d_b^{ct}$ are determined by the expressions

$$d_d^{ct} = 2\left(\frac{\tau_d a_0^3T}{\pi Q_S \text{grad}T}\right)^{1/3};$$

$$d_b^{ct} = \left(\frac{4\gamma}{d} + \sigma\right)\left(\frac{\pi d^3}{6} - mB\right)^{1/3}.$$