This paper is devoted to the construction of a tabular method for calculating critical heat fluxes in fuel-element assemblies with a square arrangement. The method consists of a basic table and a system of correctional functions, describing the dependence of the critical heat flux on the important independent parameters. Experience in developing such a method for triangular assemblies is used. The method is compared with experimental data and other computational methods. The advantages of the new method are shown: maximum width of the range of parameters, possibility of taking account of the influence of the most important parameters, possibility of using in cell-by-cell (channelwise) calculations, and high accuracy of the description.

The publication in 1997 of the international version of the tables for critical heat fluxes in pipes [1] laid the foundation for the development of similar tables for critical heat fluxes in other channels. The tables for pipes are the core in describing a crisis in channels and are the basis for developing tabular methods for describing and calculating a crisis in many channels with a complicated cross-section and in fuel-element assemblies. Subsequent works performed at the Physics and Power-Engineering Institute developed methods for tabular description and calculation of critical heat fluxes in ring [2] and other single channels [3], in triangular assemblies of cylindrical fuel elements [4, 5], and in the assemblies with a mixed arrangement of fuel elements [6].

Tabular methods for calculating critical heat fluxes in channels have substantial advantages over conventional methods and are widely used in practical calculations using approaches based on an analytical (in the form of formulas) description of experimental data. Tabular methods make it possible to describe a wider range of parameters, and are based on a wider experimental base, give a continual description of critical heat fluxes in the entire field of parameters, and are convenient for estimating the aggregate influence of the parameters and for monitoring the results of calculations.

The Tabular Method of the Physics and Power Engineering Institute for Assemblies with a Square Arrangement of Fuel Elements. The following have been used in developing a method for PWR, BWR, RBMK, and other assemblies with a square arrangement of fuel elements: 1) experience in constructing tables for pipes, ring channels, and assemblies with a triangular arrangement of fuel elements [4, 5] and 2) developments, presented in [7], where it is shown that critical heat fluxes in assemblies with triangular and square arrangements of fuel elements differ substantially from one another. Experimental data arrays for assemblies from the database at the Physics and Power Engineering Institute were used [8]. These data are published in [9–17]. Unfortunately, the extensive data of Columbia University [18–20] are inaccessible. The following parameters characterize the array used in the present paper: the number of experimental points 963, the diameter of fuel elements from 10.2 to 15 mm, the relative spacing from 1.15 to 1.88, the number of fuel elements in the assemblies 4, 9, 16, and 20, geometry of the cross section of the shell – rectangular, relative length of an assembly (ratio of the length to...
the thermal diameter) 40–960, all fuel elements are heated, heating is uniform along the length and over the cross section, pressure range 4–15.6 MPa, mass velocity range 115–4810 kg/(m²·sec), and steam-content range from −0.17 to 0.87. This array contains data with the different turbulizing effect of the spacing lattices, including in the absence of such an effect. There are also data with a different balancing indicator of the assemblies ($d/h_1$), including data for assemblies with maximum balancing ($d/h_1 = 1$).

The base table for assemblies with a square arrangement of fuel elements was constructed for geometric parameters close to the parameters of the current PWR assembly: relative spacing $s/d = 1.3$, thermal diameter of a microcell $d_h = 11$ mm, relative length $L/d_h > 300$ (when the correction coefficient $K_3$ is close to 1), the assembly is completely balanced, all macrocells are thermohydraulically equivalent and there is no influence due to the spacing lattice. Thus, Table 1 is given for the case where the correction functions, taking account of the influence of various parameters, are 1: $K_1 = K_2 = K_3 = K_4 = K_5 = K_6 = 1$, i.e., for an “ideal cell” of an assembly. An ideal cell is a cell with the transverse cross section of the reactor assembly, which is confined between four neighboring fuel elements (with identical power release), arranged far from the shells and guiding channels.

The following relation is used to calculate the critical heat flux, using the proposed method, with power released uniformly along the length:

$$Q = Q_{sq} K_1 K_2 K_3 K_4 K_5 K_6,$$

where $Q_{sq}$ is determined from Table 1 by means of three-dimensional interpolation (linear or, even better, quadratic); $K_1 = F(d/h) = (d/h/11)^{−1/3}$ – the correction function for the thermal diameter of a cell; $d_h = d[1.274(s/d)^2 − 1]$ – the thermal diameter of an ideal cell; $K_2 = F(s/d) = −1.41 + 2.86(s/d) − 0.78(s/d)^2$ – correction function for the relative spacing $s/d$; $K_3 = F(L) = 1 + 0.6\exp(−0.01L/d_h)$ – correction function for the relative distance $L$ from the location of the crisis to the entrance into the assembly; $K_4 = F(K_3) = 1 + A\exp(−0.1Z/d_h)$ – a correction function taking account of the influence of the spacing lattice; $A = 0.9K_0^{0.5}(G/1000)^{0.2}$; $Z$ – distance from the location of the crisis to the closest spacing lattice; $G$ – mass velocity; $K_f$ – coefficient of hydraulic resistance of the spacing lattice; $K_5 = F(D/d_h) = 0.6 + 0.4(d_h/d_{h1})$ – correction function for the thermodynamic nonequivalence of the assembly; $d$ – rod diameter; $s$ – spacing of the rod arrangement; $d_{h1} = 4F/\Pi$ – thermal diameter of the entire cross section of an assembly; $F$ – cross-sectional area of an assembly; $\Pi$ – heated perimeter of the cross section of an assembly; $K_6 = 1 + 5(N − 1)(0.5 − 0.04P)$ – correction function for the nonuniformity of power release over the cross section of an assembly; $P$ – pressure, MPa; $N = Q_m/Q_{av}$ – ratio of the maximum heat flux to the average heat flux over the cross section. The correction function $K_6$ has been constructed and optimized by the present authors for the experimental data obtained with a nonuniform power release over the cross section of an assembly (these data are present in the database). It takes account of the limiting transition from nonuniform to uniform power release over the cross section.

At this stage of the development of tabular methods, it is hypothesized that the effects of certain significant factors appearing in the correction functions are mutually independent of one another. The main mutual effects of the parameters are identified and taken into account. For example:

• the basic table consists of a dependence on three regime parameters; for example, the dependence on the balance steam content is different for different values of other regime parameters; this correlation is so complex that it is impossible to obtain, when constructing a description, compact analytical relations for such a wide range of regime parameters (pressure, mass velocity, balance steam content); the authors of the Columbia University method did this at the expense of lower accuracy of the description and limitations on the ranges; switching to tabular approximation of data, which results in satisfactory results, helps;

• the influence function of the spacing devices takes account simultaneously of the dependence on the coefficient of resistance of the lattices, the mass velocity, and the distance from the location of the crisis to the closest spacing lattice located at the front;

• the function showing the influence of the nonuniformity over the cross section on the crisis takes account of the nonuniformity parameter and the pressure.

These interrelationships are clearly expressed and were amenable to description. Other interrelationships are, apparently, weak (fall within the statistical spread of the data) and could not yet be identified from the experimental data. This concerns the parameters $d_h$, $s/d$, and $L/d_h$.