THE EFFECTIVE TEMPERATURE OF WWPR FUEL IN THE ASSESSMENT OF SAFETY ASSURANCE

Nedyak M. S., Kahn A. Y., Kuzmin A. V.
Scientific Supervisor: Kuzmin A. V., Ph.D., Associate Professor
Tomsk Polytechnic University, Russia, Lenin str., 30, 634050
E-mail: nedyak.mikhail@mail.ru

ЭФФЕКТИВНАЯ ТЕМПЕРАТУРА ТОПЛИВА ВВЭР В ОЦЕНКЕ ОБЕСПЕЧЕНИЯ БЕЗОПАСНОСТИ

Недяк М.С., Кан А.Ю., Кузьмин А. В.
Научный руководитель: Кузьмин А.В., к.т.н., доцент
Национальный исследовательский Томский политехнический университет,
Россия, г. Томск, пр. Ленина, 30, 634050
E-mail: nedyak.mikhail@mail.ru

The express-evaluation technique of the effective temperature of fuel aimed to monitor the nuclear reactor self-acting control and safety is considered. The features of calculation are illustrated on the example of the uranium-water reactor lattice of a water-moderated water-cooled power reactor (WWPR).

In power reactors the materials of the reactor core (r.c.) are exposed to high temperatures – in WWPR the temperature in the center of the pellets made from uranium dioxide can be near 2000°C. Therefore, even a minimal deviation from the rated duty) leads to considerable absolute temperature changes. These temperature changes are great under transient modes of operation of the reactors.

Power effect reactivity ρ_N, % and power coefficient reactivity $\alpha_N = \mathrm{d}\rho_N / \mathrm{d}N$, 1/% or 1/ MW are among the reactor characteristics determining the level of the temperature influence of the fuel on reactivity. These two characteristics determine the reliability and safety of the nuclear reactor.

These characteristics depend on effective or average temperature of the whole volume of fuel $\grave{O}_{eff}$ in the reactor core. The values of power reactivity effect and power coefficient of reactivity are obtained as a result of complicated step-by-step thermal and neutron-physical calculations on a computer [1] and further labor-intensive and neutron-physical measurements [2]. Thermal-hydraulic calculation techniques are aimed to determine peak (maximum) temperatures and critical thermal fluxes of the most power-intensive fuel assemblies and the following comparison with the permissible value for the useful materials of reactor core. The mentioned above techniques do not satisfy the assigned task.

The calculation technique of ρ_N and α_N will be demonstrated on the example of WWPR with known mass and volume characteristics of water, zirconium and uranium fuel in the fuel assembly, reduced to two-region equivalent Wigner-Seitz macrocell. We consider the reactors to satisfy the conditions of thermal engineering reliability.

Power effect reactivity is mainly concerned with Doppler broadening of ^{238}U resonance levels and is determined by the relation of effective resonance integral from the absolute temperature of fuel. We will use the following equation to determine the effective absolute fuel temperature [3]:

$$\grave{O}_{eff} = \grave{O}_{\tilde{n}} + 0,4 \cdot \left(\grave{O}_{\max} - \grave{O}_{\tilde{n}} \right),$$

where $T_{\max}$ and T_c – are the temperatures on the axes and the surface of the fuel element. Thus, it is enough to carry out thermal design of a reactor aimed to calculate $T_{\max}$ and T_c for the equivalent microcell possessing average power to determine the power effect reactivity on any current value of heat output of a nuclear reactor.

Without taking into account the heat emission in the moderator, let's find the average surface heat flux of the reactor $\overline{q}_F = Q_{hp} / S_{hs}$.

The surface of the heat exchange S_{TO} is determined by the following expression:

$$S_{hs} = P_{hp} \cdot n_{nfe} \cdot H_{cs} = P_{hp} \cdot n_{nfe}^{FA} \cdot N_{FA} \cdot H_{cs}$$

Here, P_{hp} is the heated perimeter of the fuel element; n_{nfe} , n_{nfe}^{FA} are the number of fuel elements in the reactor core and in one fuel assembly, correspondently.

The temperature on the surface of the fuel element shell $\grave{O}_{fes}$ is found by the following equation:

$$\grave{O}_{fes} = \grave{O}_f + \frac{\Delta \grave{O}_f}{2} + \Delta \grave{O}_\alpha .$$

In the above mentioned equation, $T_f = \left(T_1 + T_2\right)/2$ is the average temperature of the coolant in the core; $\Delta T_f = (T_2 - T_1)$ is the full heating of the coolant in the reactor; ΔT_α is temperature head «wall-liquid», which is determined by the following equation:

$$\Delta T_\alpha = \frac{\overline{q}_F}{\alpha},$$

where α is heat-transfer coefficient of rod bundles , accepted as constant in accordance with the height of the fuel rod. The values α в in the fuel assembly are in relation depending on the different fuel element packages [1].

Taking into account all thermal resistances the value of maximum temperature of fuel is determined by the following equation:

$$\grave{O}_{\max} = T_f + \frac{\Delta T_f}{2} + \Delta T_\alpha + \Delta T_{sh} + \Delta T_{gap} + \Delta T_{fuel} ,$$

where ΔT_{sh} stands for temperature difference on the fuel element shell; ΔT_{gap} is temperature difference in gas gap; ΔT_{fuel} – temperature difference in the fuel block.

The temperature difference on the thin shell of the fuel element can be represented as follows:

$$\Delta \grave{O}_{sh}^{\max} = \overline{q}_F \cdot \frac{2 d_{ext}}{d_{ext} + d_{\text{int}}} \cdot \frac{\delta_{sh}}{\lambda_{sh}},$$

where $2 d_{ext} / \left(d_{ext} + d_{\text{int}}\right)$ is multiplier, intended to correct the value of flux on the average diameter of the shell; δ_{sh}, λ_{sh} is the thickness and thermal conductivity coefficient of the shell.

Let's write down the equation for temperature difference in the gas gap:

$$\Delta \grave{O}_{gap} = \overline{q}_F \cdot \frac{2 d_{int}}{d_{int} + d_{fp}} \cdot \frac{\delta_{gap}}{\lambda_{gap}},$$

where d_{fp} is the diameter of the fuel pellet.

If we neglect the relation of the distribution pattern of flux density of thermal neutrons, whose value in the surface layers of the fuel element is higher and we take the average value of energy release then we will get parabolic law of temperature:

$$\grave{O}_{fuel}\left(r\right) = T_c + \frac{\overline{q}_v}{4 \overline{\lambda}_{fuel}} \cdot \left(r_{fuel}^2 - r^2\right).$$

The radial temperature difference on the fuel element will be equal to:

$$\Delta \grave{O}_{fuel} = \grave{O}_{\max} - \grave{O}_{\tilde{n}} = \frac{\overline{q}_v \cdot r_{fuel}^2}{4\overline{\lambda}_{fuel}} = \frac{\overline{q}_l}{4\pi \cdot \overline{\lambda}_{fuel}}.$$

In these relations $\overline{q}_v$ and $\overline{q}_l$ mean the average volume and linear thermal fluxes.

It is to be noted that when making the evaluative calculation of the effective fuel temperature ($T_{эф}$) thermal-physic properties of couplants play a vital role. The thermal-physic properties of the media were specified over the last years and are presented in the reference book [4]. The process of thermal calculation has an iterative nature.

The change of effective temperature depending on the nuclear reactor output (capacity) by the application of the control (tuning) software at the constant pressure in the second loop approaches the linear relationship:

$$T_{eff} = 0,099 \cdot Q_{hp} + 280,8.$$

The value of the effective temperature of fuel at rated reactor output (capacity) determined by the suggested technique was compared with the assessment of this characteristic at the initial stage of three fuel companies of the first unit of the Rostov nuclear power plant [5] and this technique demonstrated satisfied results. Thus, there are no obstacles that can hinder to carry out the assessment and calculation of the average power coefficient of the reactivity of the reactor on the suggested technique.

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