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# MULTIZONE KINETICS METHOD VERIFICATION FOR NUMERICAL BENCHMARK TEST

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*Verification of the MRNK+KEDR-D software system being developed for calculating reactor dynamics is performed using the numerical benchmark-test PWR MOX/$UO_2$ Transient Benchmark. The nonstationary process leading to an abrupt change of power caused by injection of large positive reactivity ~1.1 ß in 0.1 sec is studied. Analysis and a comparison of the obtained results with similar calculations performed using different software showed that the compared parameters are in agreement with one another to within admissible deviations.*

The development of enhanced accuracy methods for calculating transient processes in nuclear reactors, including uncontrollable accidents, accompanied by the release of large positive reactivity is now attracting special attention, since they have important practical application in the safety validation of existing and planned reactors. As a rule, the computational accuracy is increased by switching from simplified mathematical models and methods to more rigorous methods that take account of special features of the geometry and make-up of the studied objects. This makes it possible to obtain more accurate spatial-temporal characteristics of the core in the entire volume and describe more accurately the behavior of a reactor in transient processes.

The development of computational technology and the adoption of parallel programming in practice have made it possible to use different approaches based on the Monte Carlo method to solve the non-stationary equation of neutron transport [1, 2]. This also includes the method of multi-zone (multi-point) kinetics studied in the present article [3, 4]. A unique feature of this method is that the computational region is represented as a collection of interconnected sub-regions. A change of the neutron fission power in each sub-region is modeled on the basis of differential equations which contain coefficients describing the connection of the sub-regions. These coefficients are calculated by the Monte Carlo method in full-size models of the core [5]. it should be noted that the use of this method for solving the equations of multi-zone kinetics has definite advantages over other approaches – detailed description of the neutronic processes, possibility of reproducing the geometry in detail, focus on modern multiprocessor computers, and others.

The MRNK software based on the method of multi-zone kinetics was developed at the Kurchatov Institute [6]. It has been checked on simple test problems and in switch-back calculations of the neutron kinetics in a full-size model of the core of the KLT-40S reactor [7, 8]. Processes without the influence of feedback on these thermophysical properties of the materials were studied in these problems.

To take account of feedback, the software code KEDR-D, which is based on the KEDR code for calculating stationary regimes, was joined to MRNK in order calculate the thermohydraulic non-stationary process [9]. In the KEDR-D code, the thermohydraulic parameters of FA are determined by a channel-wise (cell-wise) method. The MRNK and KEDR-D codes are now in the verification stage.

Ordinarily, the correctness of developed codes is determined by comparing a calculation with benchmark experiments. In some cases recourse is made to switch-back calculations performed using different codes, one of which is a high-precision code or has been verified, for purposes of comparison. The performance of experiments with the introduction of a large

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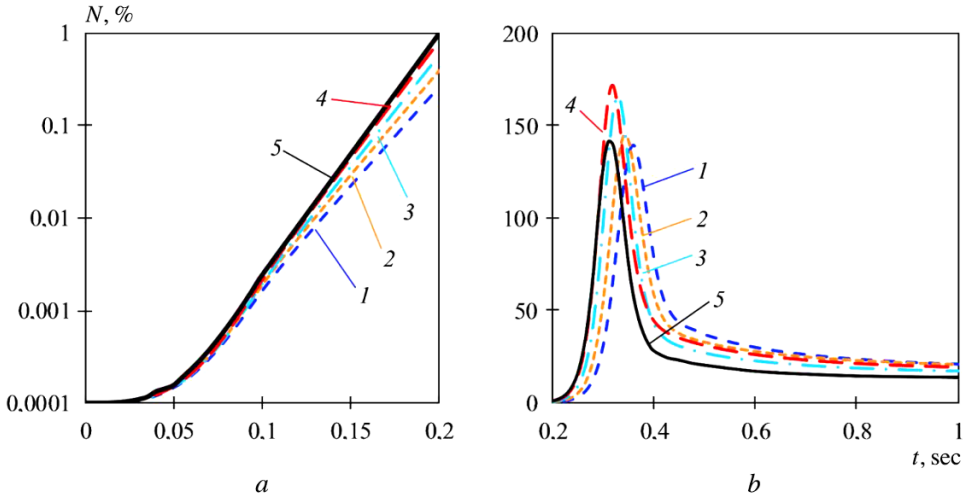


Fig. 1. Variation of the integral power calculated using the codes NUREC (*1*), SKETCH-INS (*2*), CORETRAN (*3*), PARCS (*4*), and MRNK+ KEDR-D (*5*) on a logarithmic scale in the interval 0–0.2 sec (*a*) and on a linear scale in the interval 0.2–1 sec (*b*).

positive reactivity is a difficult technical problem, the solution of which entails heightened nuclear danger. For this reason, world practice has taken the route of creating special numerical benchmark tests, developed on the basis of existing cores, for processes of this type. One such test is PWR MOX/$UO_2$ Transient Benchmark, which models a 193-channel core, is now used to verify codes for calculating non-stationary processes [10, 11].

**Description of a benchmark-test model.** The core of this benchmark test consists of 193 jacketless 373 cm high square FA with cross-section 21.42 × 21.42 cm. The nominal thermal power of the core is 3.6 GW. The core is surrounded by one row of reflector-forming cells with the same dimensions as the FA. On the core side, a cell consists of a steel plate backed by a layer of water whose temperature is equal to that of the water at the ingress into the core.

The FA in the core differ by enrichment and burnup. Fifty-four FA contain mixed uranium-plutonium fuel and the other 139 contain uranium dioxide fuel. Burned fuel, and not initial fuel, is used in each FA. In all, seven levels of burnup are used – 0.15, 17.5, 20, 22.5, 32.5, 35, and 37.5 GW·days/ton. A complete description of the model is presented in the benchmark test specifications.

**Description of the modeled process.** In a benchmark test, a transient process starts from a critical state and is modeled by extracting a fully inserted group of absorbing rods in a single FA at a constant rate in 0.1 sec. After this, the rods remain stationary up to the completion of the process (total process time 1 sec). The initial thermal power of the core is 0.0001% of 3.6 GW. The result of such fast extraction of rods is that the positive reactivity increases to ~1.1 β and power runaway on prompt neutrons occurs. Owing to negative feedback on the thermophysical properties of the system, mainly, because the fuel is heated in a short time, a peak is formed, after which the power shifts to a new level.

Code developers in different countries have used this benchmark-test: NUREC (South Korea), SKEtCH-INS (Iapan), CORETRAN (Switzerland), and PARCS (USA). The computational results obtained using these codes are presented in the benchmark-test as reference data.

**Computational results.** The following assumptions were used in the MRNK code to minimize the discrepancy between the codes in accordance with the benchmark-test recommendations: the spectrum of the production of delayed neutrons is equal to the spectrum of the emission of prompt neutrons; the delayed-neutron characteristics adopted in the benchmark test are used; in the neutronic calculations the heating of the fuel is described on the basis of the Doppler temperature of the fuel:

$$T_f = 0.3T_c + 0.7T_s,$$

where $T_c$ and $T_s$ are, respectively, the temperature at the center of the fuel and on the surface of a fuel rod.

The results of power calculations performed with the aid of the MRNK+KEDR-D system are displayed in Fig. 1. All foreign code systems employ nodal methods to solve the neutronic part and their own thermophysical modules, presented in

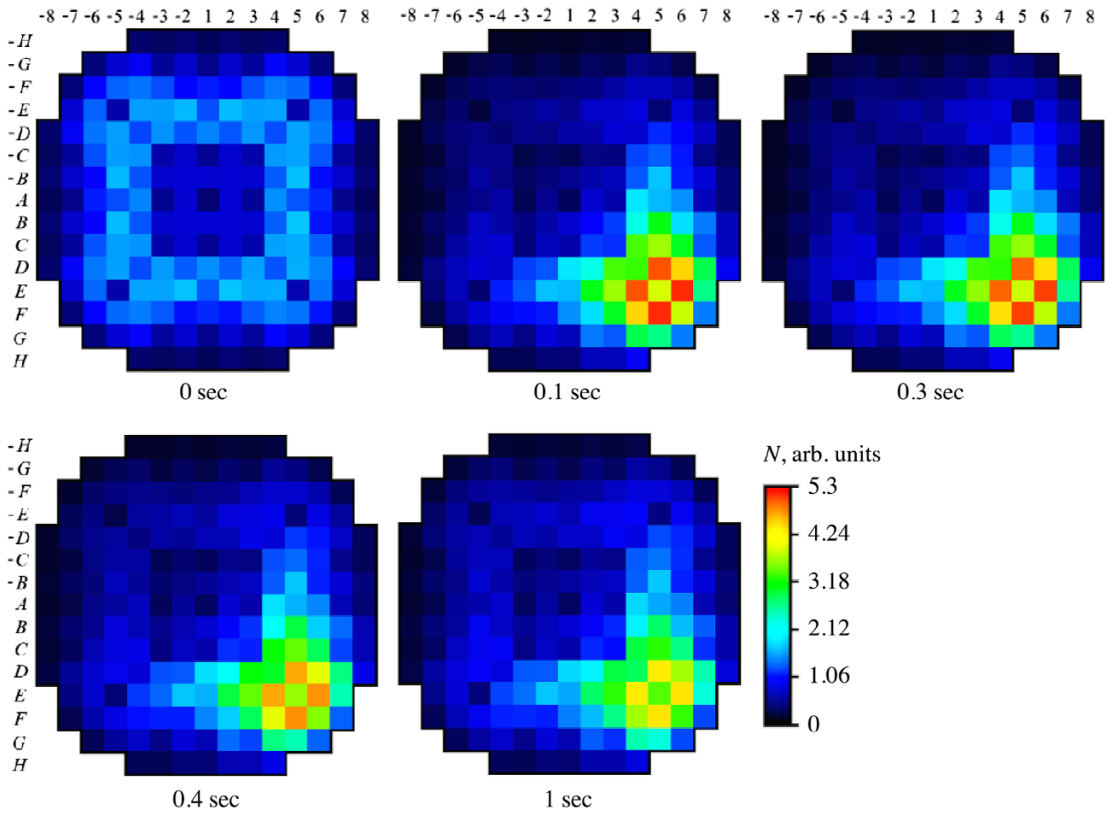


Fig. 2. Variation of the energy release distribution, normalized to the number 193, over the FA in the core.

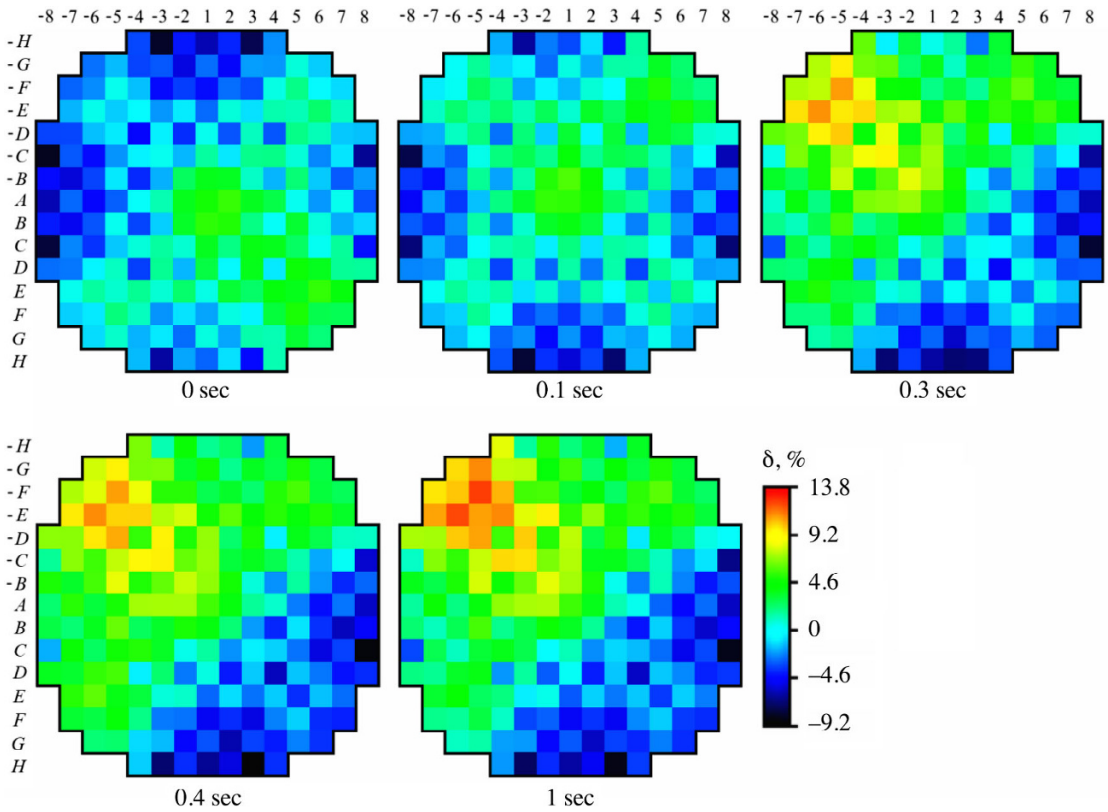


Fig. 3. Variation of the deviations of the normalized energy release from the PARCS calculations.

the benchmark test. It should also be noted that the same neutronic library of few-group cross-sections was used in the nodal calculations. In contrast to the nodal codes, libraries of nuclear constants based on the evaluated nuclear data libraries BNAB, ROSFOND, and ENDFB/VII were used in the MRNK code.

As we can see in Fig. 1, the change of power calculated with the aid of the MRNK-KEDR-D code agrees with the nodal determination. Before the influence of feedback, the results are almost identical to the PARCS results. The time at which the peak is reached and the peak power deviate very little from the values calculated using other codes. The maximum deviation of the power in the peak is equal to 18% in the PARCS code and 14% in NUREC code in terms of the peaking time.

The computational results for the normalized distribution of energy release over the core are displayed in Fig. 2. Initially ($t$ = 0 sec), the energy release distribution is symmetric relative to the center. The symmetry of the energy release distribution breaks down at 0.1 sec after the absorbing rods in FA *E*5 are extracted, and a significant spike concentrated in groups of adjoining FA appears. Subsequently, the power is somewhat redistributed over the core as a result of the influence of feedback.

The deviation of the normalized energy release from the PARCS calculation is shown in Fig. 3 for the same time. Initially, and after extraction of a rod, the discrepancy at 0.1 sec later remains virtually unchanged. However, after the fuel is heated the discrepancies increase sharply in the most energy-dense FA. The maximum discrepancy is equal to 13% in FA *F*-5 at time 1 sec. In addition, the deviation does not exceed 2% in the most energy-dense regions.

**Conclusion.** This analysis has shown that the computational results, obtained using different codes, for the integral power and normalized power distribution over FA are in agreement with each other within the limits of admissible deviations. Specifically, the largest deviation of the maximum integral power was equal to 18% from the PARCS result, and the largest deviation of the peaking time was 14% from the NUREC value. In the process the power increases from $3.6 \cdot 10^{-6}$ to 5 GW.

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