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Validation of the SC-INT code using experimental data on coolant mixing in a 37-rod fuel assembly with heat exchange intensifying spacer grids

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Abstract – *This article is devoted to validation of the SC-INT code against experimental data on the mixing of coolant flowing through a 37-rod fuel assembly with heat exchange intensifying spacer grids. The experimental data obtained using the test facility 'KS' (NRC 'Kurchatov Institute') are represented. A calculation model employed in the SC-INT subchannel code is described. Calculating total errors are given.*

I. INTRODUCTION

The great importance in dealing with increasing the power of nuclear power plants over the values established by the project is the NPP safety. Departure from nucleate boiling ratio is one of the limiting factors increasing the power. DNBR is an important characteristic in the safety analysis.

Increasing power output of the existing nuclear power plants above the nominal 100% value requires enhancement of heat transfer in the reactor core provided by means of heat exchange intensifying spacer grids (ISG) for maintaining the designed DNBR values and reducing steam quantity.

Therefore correct analysis of thermal-hydraulic conditions in fuel assemblies (FA) with intensifying spacer grids is to be performed.

The SC-INT [1] code designed for subchannel thermal-hydraulic analysis of FAs with ISGs upon stationary and non-stationary conditions is a software package that allows the user to account for the effects of intensifying spacer grids. Currently at NRC 'Kurchatov Institute' investigations on the effects of intensifying spacer grids of different types on coolant mixing and DNBR values are carried out.

The test facility 'KS' [1] (RRC 'Kurchatov Institute') is used for the investigations of thermal-hydraulic behaviour of water-cooled nuclear reactors typical for normal operation, transient modes, and accident events. The experiments at the test facility 'KS' demonstrated that the installation of intensifying spacer grids in FAs results in considerable useful effect. The results of the experimental studies carried out can be used for validation of different computer codes. This report is focused on validation of the SC-INT code against experimental data on the mixing of coolant flowing through a 37-rod fuel assembly with heat exchange intensifying spacer grids

II. DESCRIPTION OF THE ACTUAL WORK

In the present paper the results of comparison between the calculated temperatures of coolant in the FA subchannels and the experimental data obtained using the test facility 'KS' (RRC 'Kurchatov Institute') are represented. The standard configuration of a FA simulator equipped with test models of standard spacer grids for a FA-2M-type fuel assembly employed for VVER-type reactors units (RU), and a FA simulator with intensifying spacer grids of UDRI [2] (a general-purpose heat exchange intensifying spacer grid) type designed by RRC 'Kurchatov Institute' were investigated. Validation of the SC-INT code against the obtained experimental data was performed.

III. DESCRIPTION OF EXPERIMENTS

1. Test facility 'KS'

For the experiments the test facility 'KS' (NRC 'Kurchatov Institute') designed for simulation of thermophysical processes was used. The test facility comprises three independent primary coolant circuits including a low-pressure loop (LPL) and two high-pressure loops (HPL-1 and HPL-2).

The experiments discussed in this paper were carried out using the HPL-1 loop.

The HPL-1 equipment includes the following systems:
- primary coolant circuit;
- cooling system (secondary and tertiary circuits);
- charging and volume control system;
- water treatment and purification system.

Parameters of the primary circuit:

- coolant	distilled water, steam and water mixture;
- maximum operating pressure, MPa	16.7;
- maximum coolant flow rate through the FA simulator, t/h	50;
- available electrical power supplied to the FA simulator, kW	8000;
- circuit volume, m^3	0.8.

Coolant circulation system in the HPL-1 primary circuit consists of the following elements (see Fig. 1): circulating pump MCP -131 (H1) - reactor simulator - heat exchangers AT7 and AT8 - mechanical filter (MF) - inlet of circulating pump MCP -131.

The reactor simulator consists of the reactor downtake channel simulator, core simulator, and protective tube unit simulator.

Power supply to the test section is provided by means of a converter substation of 8,000 kW. In the experiments the test section B-37 of the test facility 'KS' is used (see Fig. 2). The test section is represented by a vertical housing with a bundle of fuel rod simulators arranged inside. Heat production is provided by passing rectified current through fuel rod simulators. The employed rod simulators are represented by stainless steel tubes with outer diameters of 9.00 – 9.07 mm. The tubes are placed with a pitch of 12.75 mm with their positioning on the triangle. The heat producing part of the simulators has length 2500 mm.

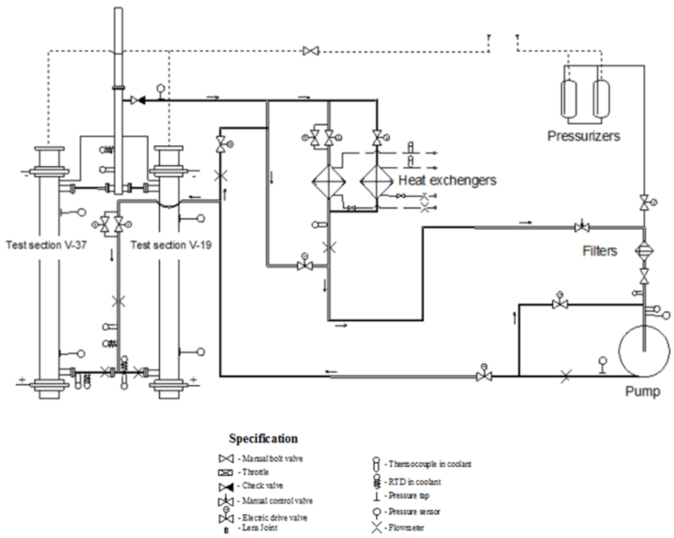

Fig. 1. Principal diagram of the high-pressure loop (HPL-1) of the test facility 'KS'.

In the report the experiments for a FA equipped with standard spacer grids (standard FA) and for a FA with UDRI-type intensifying spacer grids are described.

The housing of the rest section included a barrel with the upper, lower, and two lateral flanges welded to it. The upper, lower, and lateral flanges are connected with a bundle of heating elements, lower current-carrying plate, supply and discharge lines respectively. The diameter of the test section housing is 133 mm. The distance between the inlet and outlet is 5267 mm.

Inside the housing of the test section there are placed insulated talc chlorite thimbles forming a hexagonal channel with width across flats 79.2 mm.

In the channel made of talc chlorite thimbles there are inserted 37-rod fuel assemblies simulating FA-2M-type fuel assemblies equipped either with standard spacer grids (SG) only or with standard SGs placed along the lower FA section and UDRI-type spacer grids along the upper FA section.

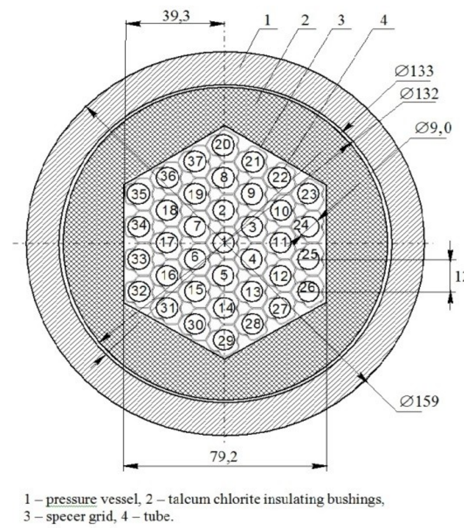

Fig. 2. 37-rod FA simulator of a FA-2M-type fuel assembly with spacer grids placed 340 mm apart.

The FA simulator is equipped with 'dry' thermocouples installed into the rod simulators which are intended for departure from nucleate boiling identification and with 'wet' thermocouples for measuring coolant temperatures above the upper boundary of the heat production zone. The experiments discussed in the report were carried out using a fuel assembly with the radial power peaking factor $k_r = 1.4$ and the axial power peaking factor $k_z = 1$. Power output distribution for the simulators is shown in Fig. 3.

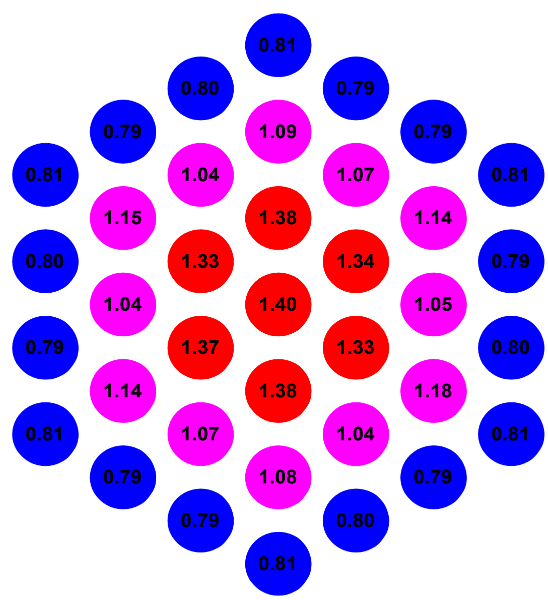

Fig. 3. Relative power density distribution for the fuel rod simulators.

The arrangement of the hot junctions of thermocouples used for measuring coolant temperatures within the subchannels of a FA with k_r = 1.4 at the heat production zone outlet is shown in Fig. 4 (coloured circles). The thermocouples are made of a jacketed cable with the outer diameter of 1 mm. The hot junctions of all thermocouples are arranged 40 mm above the upper boundary of the heat production zone.

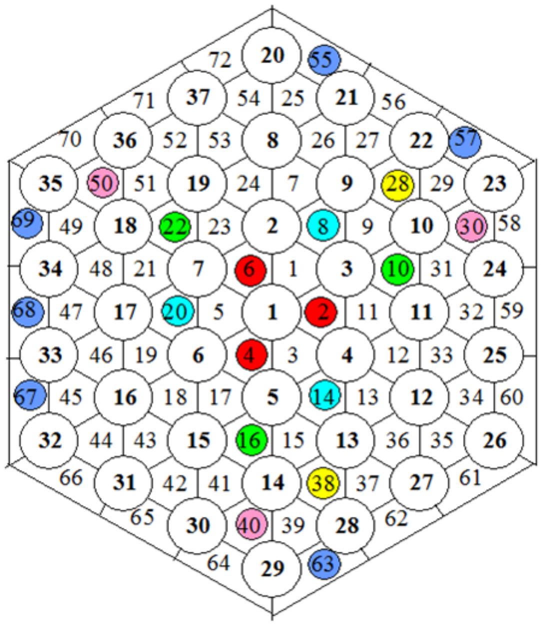

Fig. 4. The arrangement of thermocouples at the core outlet and meshed FA cross-section employed in SC-INT

2. Special features of spacer grids

The simulators of standard SGs for TVS-2M-type fuel assemblies employed for VVER-1000 and VVER-1200-type reactors (see Fig. 5) contain 25 central and 12 outer cells connected to each other by contact welding.

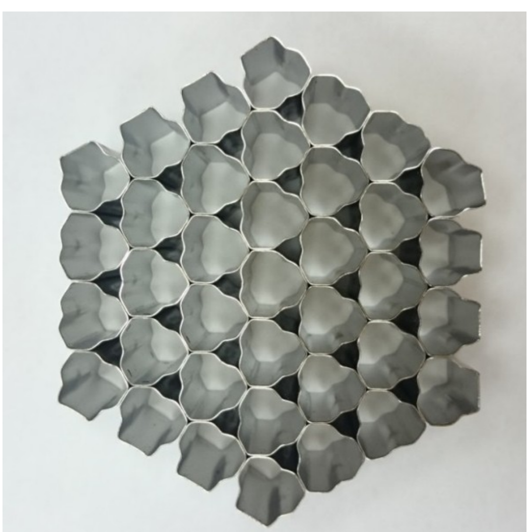

Fig. 5. SG model used in the experiments.

In the experiments spacer grids were placed 340 mm apart along the fuel assembly with a first spacer grid arranged 70 mm above the lower boundary of the heat production zone.

3. Special features of UDRI-type spacer grids

The configuration of UDRI-type intensifying spacer grids designed at NRC 'Kurchatov Institute' is derived from a honeycomb spacer grid.

ISG simulator of UDRI-type given in Fig. 6 is a standard spacer grid with cell height of 20 mm that is equipped with blades mounted on the outer edges of the grid. The blade is trapezoidal with height of 8 mm, lower base 5 mm and upper base 1.5 mm. The blade forms 25^o angle with the channel centre line.

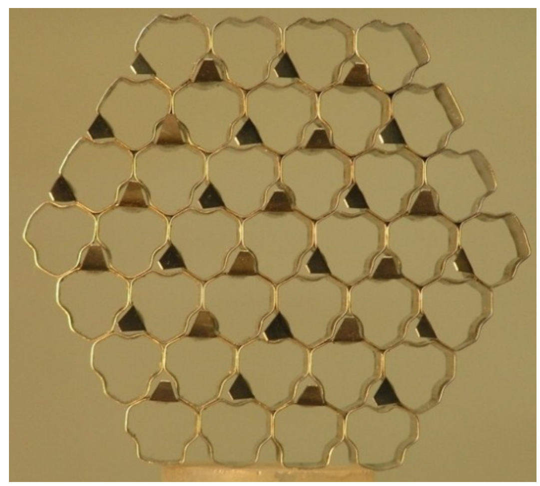

Fig. 6. UDRI-type spacer grid model used in the experiments.

ISG of UDRI-type provides coolant 'sector running'. Along the neighbour sections coolant flows are diverted into opposite directions. The interaction of the transverse counter flows within the neighbour sections leads to the rotation of coolant flows around the assembly rods. In the experiments 6 UDRI-type spacer grids are placed 170 mm apart along the upper FA section with the length of 1020 mm. Standard SGs are arranged along the lower FA section.

4. Experimental conditions

The experiments discussed in this report were carried out under the following conditions:

- pressure 15-16 MPa;
- inlet coolant temperature 170 – 300 ^{o}C;
- coolant mass flow rate averaged over a fuel assembly 1000 – 4300 kg/(m^{2}s).

In temperature distribution evolution experiments for fuel assemblies with standard and UDRI-type spacer grids 83 and 23 data points were obtained respectively. Drag coefficient values for the spacer grids (see Table 1) were obtained from hydraulic resistance measurements.

TABLE 1. Drag coefficients (DC) for the spacer grids.

Grid type	DC
SG model	0.36
UDRI model	0.52

In the analysis of outlet coolant temperature distributions the data measured via thermocouples were grouped in accord with the subchannel type (subchannels of the same type have identical axially symmetric arrangement within the FA cross-section). The following subchannel groups are strictly identical: 2, 4 and 6; 8, 14 and 20; 10, 16 and 22; 28 and 38; 30, 40 and 50; 55, 57, 63, 67 and 69 (see Fig. 4). Six groups of thermocouples are assumed to be located in six orbits wherein the first of the listed groups is located in the first orbit and the last is located in the sixth orbit. The last group also included a thermocouple located within the subchannel 68.

The data for 10 modes of the experiments on outlet coolant temperature distributions for fuel assemblies with standard SGs and with UDRI-type spacer grids are given in Tables 2, 3 and Tables 4, 5 respectively.

Tables 2 and 4 contain operating conditions employed in the experiments. Tables 3 and 5 contain measured temperatures averaged over the orbits for fuel assemblies with standard SGs and UDRI-type spacer grids respectively.

TABLE 2. Experiments for a fuel assembly with standard SGs Operating conditions

N	P	T_{in}	G	W
1	153.6	202.3	1882	2500
2	155.8	268	1995	1616
3	156.8	230.6	2110	2100
4	155.2	290.7	2779	2214
5	157.5	249.2	3023	2820
6	156.4	228.1	3143	2820
7	153.9	279.8	3537	2615
8	153.5	252.3	3715	3420
9	156.6	200.1	4013	4020
10	155.7	178.9	4134	4030

TABLE 3. Experiments for a fuel assembly with standard SGs Temperatures for the orbits

N	T1	T2	T3	T4	T5	T6
1	316.4	305.8	295.0	281.9	273.3	270.8
2	336.6	331.4	326.7	318.3	314.6	309.6
3	323.5	317.1	309.2	298.0	291.8	286.9
4	346.0	345.3	342.6	335.5	332.4	328.2
5	332.6	326.5	319.3	309.6	304.5	300.1
6	314.2	307.4	299.6	289.5	283.9	280.1
7	339.2	336.1	331.4	325.0	319.7	315.2
8	334.3	328.0	321.2	311.5	306.4	301.4
9	299.8	289.6	281.7	271.3	264.9	262.7
10	279.7	269.1	260.2	250.1	243.5	241.7

TABLE 4. Experiments for a fuel assembly with UDRI-type spacer grids Operating conditions

N	P	T_{in}	G	W
1	157.8	279.8	1930	1608
2	156	259.9	1965	2092
3	157.4	230.1	1978	2111
4	154.1	189.8	2026	2529
5	156.4	290	2893	2200
6	155.5	268.3	2889	2229
7	154.7	250.2	2992	2825
8	154.7	260.3	2934	2827
9	156.9	240.4	2929	2782
10	154.3	230.1	2984	2794

TABLE 5. Experiments for a fuel assembly with UDRI-type spacer grids Temperatures for the orbits

N	T1	T2	T3	T4	T5	T6
1	329.8	329.9	328.5	328.3	326.2	326.7
2	326.9	326.7	324.6	325.0	322.7	322.9
3	303.4	303.4	301.3	301.6	298.9	299.3
4	280.9	281.4	278.1	278.6	275.1	276.1
5	334.1	333.6	332.8	332.5	331.1	331.1
6	317.5	317.2	316.0	315.8	314.2	314.2
7	312.9	312.4	310.8	310.7	308.7	308.7
8	322.0	321.5	320.0	319.8	318.0	317.9
9	304.9	304.8	303.0	303.0	300.9	301.0
10	295.3	295.2	293.4	293.4	291.3	291.5

IV. DESCRIPTION OF CALCULATION MODEL

1. SC-INT code

Numerical code SC-INT using mesh generation is designed by RRC 'Kurchatov Institute' for thermohydraulic analysis of a selected fuel assembly (or its part), the reactor core (or its part) of VVER reactors in stationary and non-stationary conditions.

Complex SC-INT is applied for calculations of hydraulic resistance of a selected reactor core section, axial and radial distributions of coolant parameters (coolant flow, enthalpy, and steam quantity), critical heat flux ratio and temperatures of fuel rod clad external surfaces.

Complex SC-INT employs the subchannel method [3,4] according to which the cross-section of the selected section of the reactor core is represented by a set of parallel subchannels (cells). The mesh cells are represented by parallel channels with turbulent and convecting mixing of transverse coolant flows.

Special models for calculations of an intensifying spacer grid were used in the numerical code. The models have been optimized for the code using the experiments carried out at the test facility 'KS' (RRC 'Kurchatov Institute') with simulators of 37-rod VVER-1000-type fuel assemblies equipped with ISGs of different designs [1].

2. Introduction of convecting mixing

Heat exchange intensifying spacer grids are equipped with special elements providing considerable transverse component of coolant flow velocity which can not be correctly simulated via a subchannel code without implementation of the model accounting for the extra transverse flows. Calculation models of all subchannel codes usually contain the equation for transverse velocity component and these codes can be adjusted for correct calculations of transverse convective coolant transfer. It can be done by accounting for axial flow share forced transfer from one subchannel into another in the radial momentum conservation equation.

In the SC-INT code the radial momentum conservation equation is employed in the following form:

$$\frac{\Delta X_j}{\Delta t}(w - w^n)_j + \left(\frac{\overline{m}}{\overline{\rho}^* A}\right)_j \cdot w_j - \left(\frac{\overline{m}}{\overline{\rho}^* A}\right)_{j-1} \cdot w^*{}_{j-1} = \quad , \qquad (1)$$
$$= -\frac{1}{2} \cdot \frac{\Delta X_j}{\delta \cdot L \cdot \rho^*} \cdot \zeta_G \cdot |w_j| \cdot w_j + \frac{\delta}{L} \cdot g \cdot \Delta X_j (P_i - P_k)_{j-1}$$

here A - cross-section area, m^2;
g - gravitational acceleration, m/s^2;
L - the distance between subchannel centres, m;
$\overline{\rho}^*$ - coolant density in a 'supplying' subchannel, kg/m^3;
P_i - pressure in subchannel i, Pa;
P_k - pressure in subchannel k, Pa;
δ - gap spacing between fuel rods at subchannel boundaries, m;
Δt - time interval, s;
$\overline{m}$ - axial mass flow (averaged over two neighbour subchannels), kg/s;
w - mass flow rate per a length unit for transverse flow, kg/(m*s);
X - the length of axial section j, m;
ς_G - the drag coefficient for transverse flow.

Here w_{j-1}* is mass flow rate per a length unit for forced transverse flow for the previous layer defined by the user.

In the iteration process for solving the equation system for mass flow rate per a length unit for transverse flow corresponding to the next axial layer, for the spacing gaps where forced flow from one subchannel into another is to be introduced w_j is represented by the percentage of axial flow from 'supplying' subchannel into 'accepting' subchannel divided by the length of the test axial interval. Transverse flows through spacing gaps for which forced transverse flows are not defined are calculated via solving the equation system (1).

It should be noted that correct calculation of transverse velocity component for every axial layer requires adding the extra flow value for the current layer to the transverse flow value corresponding to the previous layer. To account for the convective component concerned with hydraulic resistance for a intensifying spacer grid deflecting element the layers for which drag coefficient and forced transverse flow are defined are not to be the same. For example, DC for j-1 layer can be introduced. Then the correlation for mass flow rate for forced transverse flow for j layer can be represented as follows:

$$w_j = w_{j-2} + M \cdot \alpha / \Delta z \,, \qquad (2)$$

here w_j - total mass flow rate per a length unit for transverse flow for j layer, kg/(m*s);
w_{j-2} - mass flow rate per a length unit for transverse flow for a layer preceding one for which DC for the intensifying space grid is set, kg/(m*s);
M - axial mass flow for a 'supplying' subchannel, kg/s;
α - percentage of axial flow forced to escape from a 'supplying' subchannel;
Δz - length of test section in axial direction, m.

In order to perform correct calculation of pressure losses in the neighbour subchannels caused by forced transverse flows differential pressures concerned with a local resistance and forced transverse flow are to be accounted for.

When all transverse flows are calculated axial flows for the current layer are to be obtained from the mass conservation equation.

The main challenge is related to correct definition of the axial flow share forced to escape from a 'supplying' subchannel at the deflecting element location (α).

The correlation between the factor α and spacer grid design features (subchannel shielding by spacer grid elements, the angle of attack, and some other crucial parameters) can be obtained via analysis performed using CFD-codes. CFD-analysis can substitute experiments for obtaining correlations for the axial flow share deflected by spacer grid elements and forced to move from a 'supplying' subchannel into 'accepting' subchannel.

For our investigations the STAR CCM+ code [5] was implemented. By means of this code correlations for mass flow rate per a length unit for transverse flows caused by spacer grid deflecting blades were obtained. These correlations are described in more detail in study [1]. Input data for the SC-INT code included the values of factor α for

UDRI-type intensifying spacer grids. From the preliminary calculations via the STAR CCM+ code the factor $\alpha = 0{,}15$ was obtained.

Convective flow in fuel assemblies with spacer grids was derived from the major equation system without introduction of extra transverse mass flows ($\alpha = 0$).

3. Turbulent mixing model

Turbulence is a phenomenon that can be observed in fluid and gas flows which includes formation of multiple vortices of different sizes and therefore random fluctuations of hydrodynamic and thermodynamic parameters (velocity, temperature, pressure, density) with their irregular time-dependent and spatial variations.

A number of different turbulence models were developed for calculation of such flows.

Subchannel codes employ turbulent mixing models based on the mixing length hypothesis. In the SC-INT code for the simulation of transverse turbulent flow in the core of a VVER-type reactor without coolant boiling (quality $x_r<0$) the following correlation is used:

$$W^T = \beta \cdot \frac{S}{L_C} \cdot Re^{-0,1} \cdot \bar{d}_h \cdot \bar{G} \ , \qquad (3)$$

here W^T - transverse turbulent flow, kg/(ms);
S - gap spacing between neighbour fuel rods, m;
L_C - distance between the mass centres of two neighbour cells, m;
Re - Reynolds number calculated using the parameters averaged over two neighbour cells;
$\bar{d}_h$ - hydraulic diameter averaged over two neighbour cells, m;
$\bar{G}$ - coolant mass flow rate averaged over two neighbour cells, kg/(m^{2}s);
β - non-dimensional coefficient.

The effects of spacer grids and heat exchange intensifying spacer grids are accounted for by means of the following correlation for the coefficient β:

$$\beta = \beta_0 + K_G \cdot \frac{\xi}{C} \cdot e^{-\frac{(z-z_G)/d_h}{C}} \ , \qquad (4)$$

here K_G - coefficient for a specific spacer grid type, C – coefficient accounting for the effects of local resistances distributed along the flow.

In experiments carried out earlier were obtained values of coefficient K_G [6]. The dependences of the mixing coefficient K_{mix} on the grid type are shown in Figs. 7, 8.

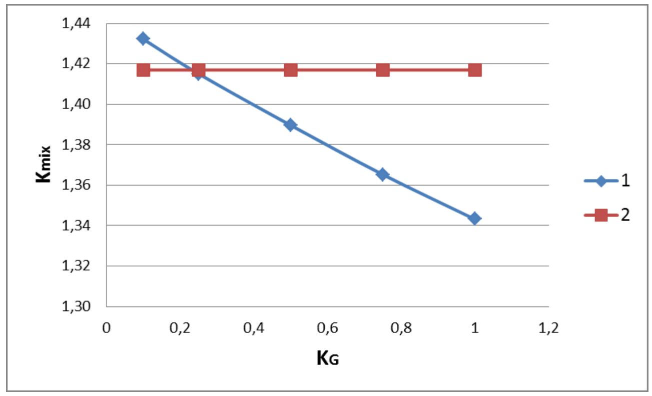

Fig. 7. Mixing coefficient K_{mix} vs coefficient for a standard spacer grid K_G
1 – simulation, 2 – experiment.

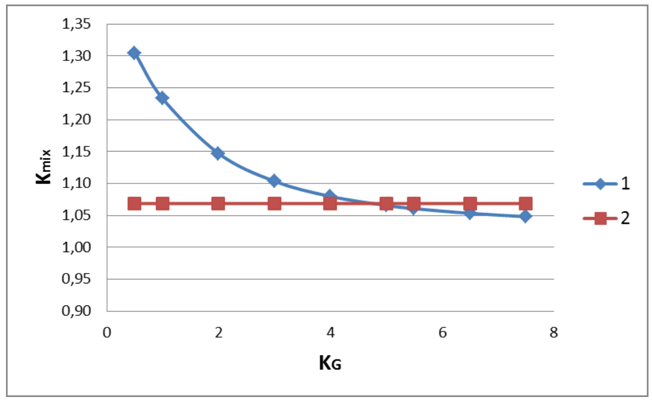

Fig. 8. Mixing coefficient Kmix vs coefficient for a UDRI-type spacer grid K_G 1 – simulation, 2 – experiment

In order to perform a qualitative assessment of the effectiveness of intensifier grids, a peaking factor of temperature profile was introduced as:

$$k_{mix} = \frac{\Delta T_{max}}{\Delta T_{min}} \ , \qquad (5)$$

where ΔT_{max} –maximum heat-up of coolant (in the subchannels of orbit 1); ΔT_{min} – minimum heat-up of coolant (at the periphery of a fuel assembly).

As it can be seen, the highest agreement between the simulation and experimental results is achieved for the spacer grid coefficient K_G = 0.25 for a fuel assembly with standard spacer grids and K_G = 5 for a fuel assembly with UDRI-type spacer grids.

For this analysis: C = 5, for standard spacer grids K_G = 0.25, for UDRI-type spacer grids K_G =5.

V. RESULTS

In the experiments the efficiency of spacer grids for the two test fuel assemblies was estimated via measuring the hydraulic resistance and coolant temperature distribution over the subchannels for the outlet cross-section of a FA.

The arrangement of the hot junctions of the thermocouples used for measuring coolant temperatures within the FA subchannels at the core outlet is shown in Fig. 4.

The calculations were performed via the SC-INT code for the meshed FA cross-section represented in Fig. 4. The calculated temperature values for the subchannels equipped with thermocouples were then compared with the corresponding experimental data. The calculations were performed for 83 data points obtained in the experiments with a fuel assembly with standard SGs and for 23 data points derived from the experiments with a fuel assembly with UDRI-type spacer grids.

Temperature distributions over the orbits for fuel assemblies with standard and UDRI-type spacer grids under different operating conditions are shown in Figs. 9-12:

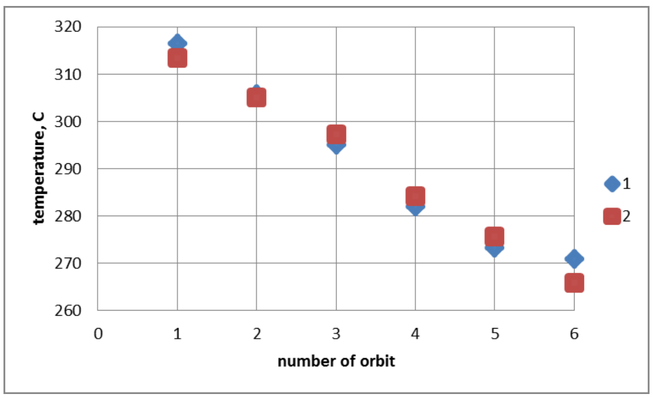

Fig. 9. Temperature vs orbit number for a fuel assembly with standard spacer grids, mode 1 (see Table 2): 1 - experiment, 2 – simulation

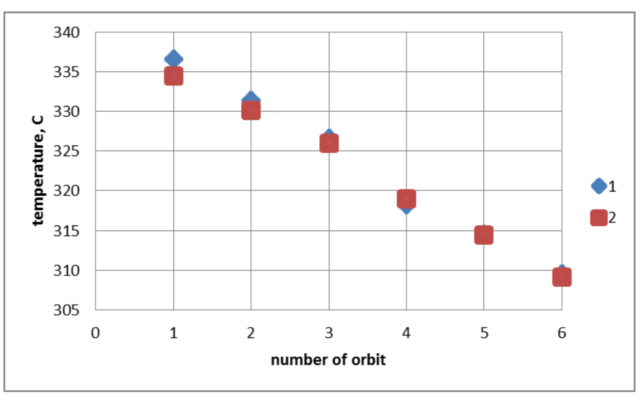

Fig. 10. Temperature vs orbit number for a fuel assembly with standard spacer grids, mode 2 (see Table 2): 1 - experiment, 2 – simulation

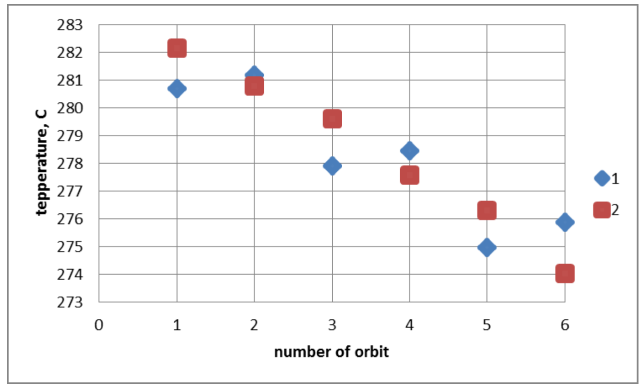

Fig. 11. Temperature vs orbit number for a fuel assembly with UDRI-type spacer grids, mode 4 (see Table 4): 1 - experiment, 2 – simulation

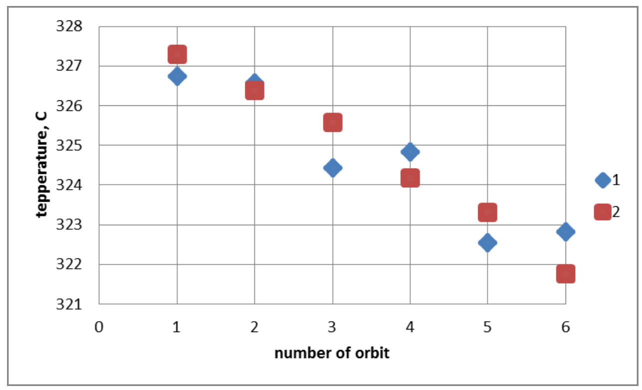

Fig. 12. Temperature vs orbit number for a fuel assembly with UDRI-type spacer grids, mode 2 (see Table 4): 1 - experiment, 2 – simulation

The relative divergence of the calculated temperatures from the experimental data was calculated via the following correlation:

$$\delta = \frac{\Delta T_e - \Delta T_c}{\overline{\Delta T}} \cdot 100\% \ , \qquad (6)$$

$\Delta T_e = T_{exp} - t_{in}$ –experimental coolant heating value for a subchannel, ^oC;
$\Delta T_c = T_{calc} - t_{in}$ –calculated coolant heating value for a subchannel, ^oC;
T_{exp} - experimental coolant temperature for a subchannel, ^oC;
T_{calc} - calculated coolant temperature for a subchannel, ^oC;
t_{in} – inlet coolant temperature;
$\overline{\Delta T}$ - average coolant heating for a FA (calculated value), ^oC.

The average deviations of the calculated data (obtained using the subchannel code) from the experimental values were calculated via the following formula:

$$\Delta = \frac{\sum_{i=1}^{N} \delta_i}{n} , \tag{7}$$

The root-mean-square deviations of the calculated temperatures from the experimental data were calculated via the following correlation:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (\delta_i - \Delta)^2}{n-1}} , \tag{8}$$

Mean absolute errors and root-mean-square deviations for the experiments with fuel assemblies with standard and UDRI-type spacer grids are given in Table 6.

TABLE 6. Mean absolute errors and root-mean-square deviations vs coefficient for a specific spacer grid type (K_G) for fuel assemblies with spacer grids of different types.

Grid type	Δ	δ
SG	0.6	3.5
UDRI	0.3	3.2

According to the calculation results obtained in the present study, the SC-INT code is suitable for the calculations of the parameters of coolant in the FA subchannels with the accuracy close to that for measuring instruments implemented for test facilities and NPPs.

VI. CONCLUSION

This report represents the results of validation of the SC-INT code against experimental data on the mixing of coolant flowing through 37-rod fuel assemblies equipped with both standard spacer grids and heat exchange intensifying spacer grids The detailed information on the test facility 'KS' (NRC 'Kurchatov Institute') and experimental data obtained by means of it are given. 106 experimental points were obtained for two fuel assemblies which were compared with the data calculated via the SC-INT code. The experimental results suggest that installation of intensifying spacer grids in FAs results in considerable temperature distribution flattening.

The models for convective and turbulent coolant mixing described in the present report were introduced into the SC-INT code. This allows temperature distribution analysis to be complemented with the effects of heat exchange intensifying spacer grids on coolant mixing.

In case of fuel assemblies without intensifying spacer grids the mean absolute error of heating values for the subchannels is Δ= 0.6% with the root-mean-square deviation σ = 3.5% of the average heating in the FA.

As to fuel assemblies with UDRI-type intensifying spacer grids the mean absolute error of heating values for the subchannels is Δ= 0.3% with the root-mean-square deviation σ = 3.2%.

The results of the experimental studies carried out can be used for validation of different computer codes.

NOMENCLATURE

NPP = Nuclear power plant
ISG = Heat exchange intensifying spacer grid
RU = Reactor unit
HPL = High-pressure loop
MCP = Main circulating pump
FA = Fuel assembly
SG = Spacer grid
UDRI = General-purpose heat exchange intensifying spacer grid
DC = Drag coefficient
k_r = Radial power peaking factor
N = Mode number in accord with the set order
P = Pressure at the fuel assembly heating zone outlet, MPa
T_{in} = Inlet coolant temperature, °C
W = Power supplied to the test facility, kW
T1 - T6 = Coolant temperatures averaged over the orbits, °C
CFD = Computational fluid dynamics
K_{mix} = Mixing coefficient for a spacer grid of n-type
δ = Relative divergence
Δ = Mean absolute error
σ = Root-mean-square deviation

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