5.2 STUDY OF TRANSIENT CONNECTED WITH WWER-1000 CLUSTER DROP WITH SUBSEQUENT WORKING OF AUTOMATIC POWER CONTROLLER

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ABSTRACT

Results of calculation study of transient connected with drop of WWER-1000 cluster of working group are presented. Transient was considered in the mode of automatic power control without forming of warning protection signal due to reaching of dropped cluster of core bottom. Calculations are shown that given transient can cause valuable distortion of power distribution in axial direction. At that main increase of pin power is occurred in upper part of the core, whereas power in lower part is almost not changed. The additional increase of power in the upper part of core makes conditions for initiation of DNB. This effect can be observed if in initial state axial power distribution is displaced in upper part of core nearby to rest of supported power clusters of working group. It is necessary to define conservatively with taking into account assumed working group efficiency – in which row from extracted clusters of working group the displacement of axial power in the upper part is possible. Probability of such displacement and its localization in plane of core must be properly analyzed. The work was performed in framework of orders BMU SR 2511 and BMU R0801504 (SR2611). The report describes the opinion and view of the contractor – SSTC N&RS - and does not necessarily represent the opinion of the ordering party - BMU-BfS/GRS and TÜV SÜD.

INTRODUCTION

Drop of one cluster causes decrease of neutron and thermal reactor power. In a WWER-1000 normal operation mode the automatic power controller should restore initial power of a reactor by a rising of regulating group upwards. However, the signal of preventive protection (PZ-2) is formed at achievement of dropped cluster of the core bottom, which imposes a prohibition on the rise of regulating group, therefore initial power of a reactor will not be restored. Presented below results of studies are received in the assumption, that owing to outage of system of group and individual operation of control and protection system (SGIU) the signal PZ-2 that imposes a prohibition for rise of regulating group will not be generated. Therefore after rod drop, the automatic power controller will restore initial value of reactor power. It leads to distortion of power distribution and as a consequence the fuel temperature increases in fuel pin of assemblies situated around raised control rods of regulating group.

RESULTS OF CALCULATION STUDIES

Drop of one cluster of 10th (regulating) group under gravity is initial event for considered mode; time of drop is 4sec. Numerical simulation is performed by DYN3D code [1]. Drop of one cluster of regulating group in cell №79 was considered. Initial position of regulating group was chosen under condition of achievement of rest CR of upper regulation limit (90%) and at that the maximal allowable level of power is achieved (104% with taking into account error of measurement and maintenance), i.e. scram actuation by exceeding of maximal power isn't occurred. To provide conservatism this mode is considered on rated level of power at beginning of fuel campaign (21st fuel campaign of 3rd unit of South-Ukraine NPP was chosen). It is caused by smaller negative feedback on fuel and moderator temperature at beginning of fuel campaign than at the end of campaign. Therefore in initial state the regulating group is deeper inserted and its extraction up to 90% will be caused more valuable distortion of axial power distribution. Furthermore smaller negative feedback will have less limiting influence on local power increase at a region of extracted CR. Fuel and moderator temperature reactivity coefficients are corrected by introduction of correction coefficients in parameterization dependencies for multiplication cross sections up to conservative values that defined by frame parameters.

With the help of corresponded preliminary calculations (as it was described above) it was defined that under maximal efficiency of regulating group 1.04% (according to table of frame parameters) position of control rods should correspond to 78% from core bottom. Efficiency of regulating group 1.04% was obtained by correction of absorption cross sections in thermal group for fuel assembly with inserted cluster.

Calculated parameters of reactor core in initial steady state before cluster drop for beginning of campaign are presented below in table 1.

Table 1 – Calculated parameters of reactor core in initial steady state before cluster drop

Parameter	**Value**
Reactor power, MW	3120 (maximal)
Coolant temperature at inlet of core,°C	292.3 (maximal)
Pressure over reactore core, MPa	15.4 (minimal)
Coolant flow rate, m^3/h	80000 (minimal)
Maximal radial pin power peaking factor, ($K_r \times K_{eng}$)	1.74
Position of regulating group, %	78
Reactivity coefficients on coolant temperature, $*10^5$ 1/(°K)	-12.32 (maximal)
Reactivity coefficients on coolant density, %/(g/cm^3)	3.46 (minimal)
Reactivity coefficients on fuel temperature, $*10^5$ 1/(°K)	-2.30 (maximal)
Efficiency of regulating group, %	1.04 (maximal)
Effective part of delayed neutrons, %	0.5 (minimal)

Analysis of acceptance criteria compliance is evaluated for most loaded fuel pins by use of "hot channels" of studied fuel assemblies. Relative power of most loaded pin amounts k_r=1.74 and is defined by maximum allowable peaking-factor of pin power (k_r^{lim} = 1.5) with taking into account engineering factor amounting 1.16. For given initial event a change of local powers, temperatures and DNBR are studied for fuel pins situated around of assembly

№85 with extracted cluster (on opposite part of core from dropped cluster) because the maximal increase of power will be observe in this region.

Fuel assemblies №84 and №70 are chosen for analysis that are situated in 1st and 2nd row from extracted from FA№85 cluster because the maximal increase of power will be observe in ones. In accordance with conception of WWER-1000 safety substantiation used by reactor design developer the safety assessment for different operation modes should be performed for three limiting axial profiles (figure1) that can be occurred in initial state of considered transient [2, 3]. To follow this conception three "hot channels" with presented at figure 1 initial axial power profiles are considered for each studied assembly.

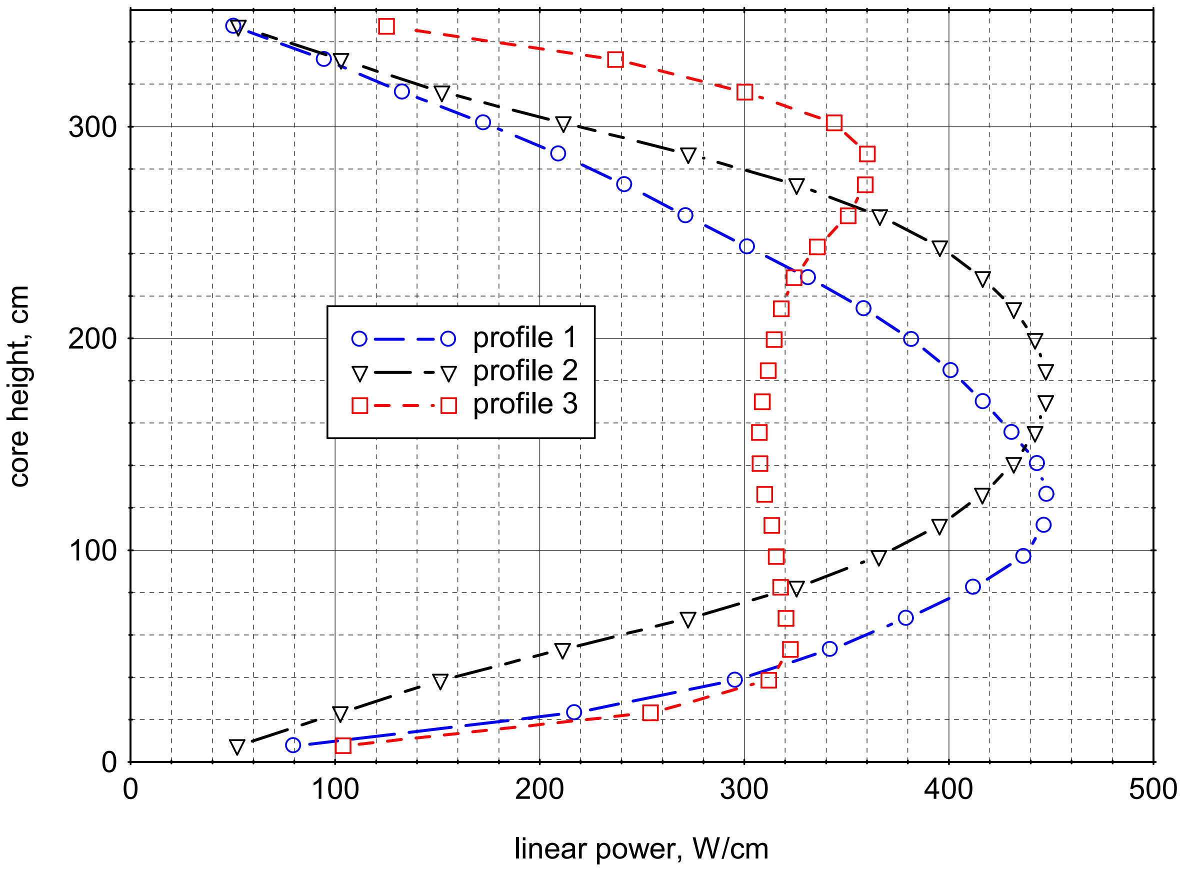

Figure 1 – Axial power profile of most loaded fuel pin accepted in studies

Calculation analysis of initial event related to cluster drop was performed for time interval 100sec without taking into account of action of operations staff. Calculation chronology for event of cluster drop is presented in table 2.

Calculation analysis showed that automatic power controller begins to extract five control rods of regulation group with speed 2cm/sec at time moment ≈0.6sec by a signal of power mismatch. Up to time moment ≈20.3sec control rods achieved upper regulation limit (90%) and are stopped. At that new steady state of reactor core is achieved that corresponds to rated level of power with taking into account error of measurement and maintenance (104%).

The valuable power surge in opposite sector of core from dropped cluster is the result of cluster drop and automatic power controller working off a signal of power mismatch. Thus relative power of studied fuel assembly in first row №84 (Kq) is increased from 1.20 up to 1.32 and for assembly in second row №70 from 1.17 up to 1.27 (figure 2).

Table 2- Chronology for event of cluster drop

Time, sec	Event
0.0	Initial event – beginning of cluster drop
0.6	Beginning of control rods of regulation group extraction
4.0	Achievement by dropped cluster of core bottom
~17÷18	DNB in “hot channels” of fuel assemblies of first row with initial axial power profile №3
20.3	Achievement by control rods of regulation group of upper regulation limit (90%)
20.3	Maximal value of reactivity 0.02$ (figure 11)
20.3	Maximal value of reactor neutron power – 3120 MW
~30	DNB in “hot channels” of fuel assemblies of second row with initial axial power profile №3
100	Maximal value of reactor thermal power – 3120 MW
100	Achievement of new maximal steady values of fuel and cladding temperatures

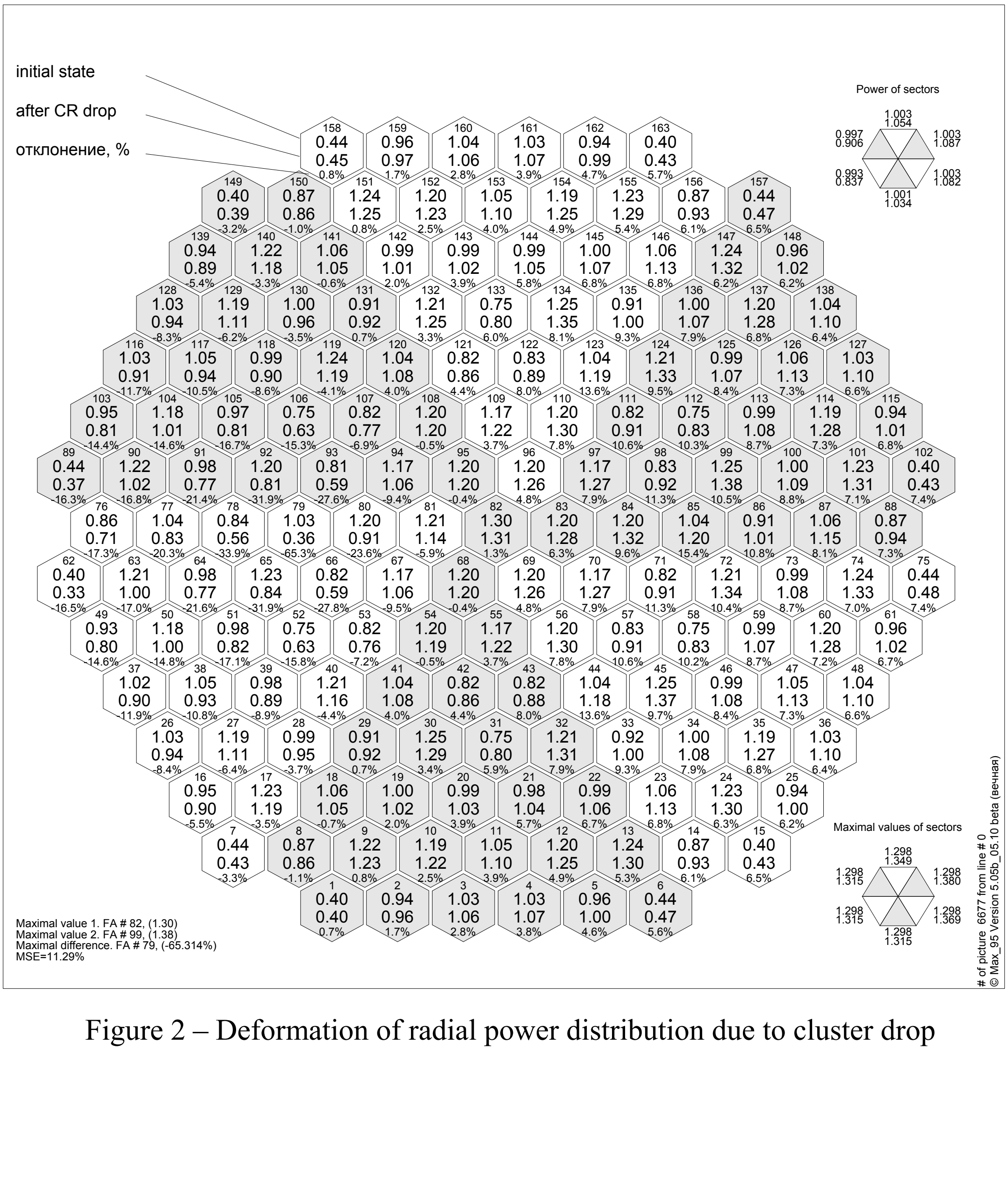

Figure 2 – Deformation of radial power distribution due to cluster drop

Difference of initial 1st, 2nd and 3rd axial power profiles in “hot channels” of studied assemblies (that are situated in 1st and 2nd rows from FA№85 with extracted cluster) from power distributions at the end of transient are presented at figures 3÷5.

Results of calculations are showed that DNB can be occurred depending on initial axial profile both for pins in FA№84 out of 1st row from extracted cluster and FA№70 out of 2nd row (figures 6, 7).

Cause of DNB occurrence is related to valuable increase of local power that takes place in upper part of reactor core while in lower part it’s almost unchangeable (figures 3÷5).

Above presented figures are shown that the more displaced upward initial power profile in studied assembly and closer situated assembly to extracted cluster for power maintenance lead to more probable DNB occurrence. DNB begin both for assemblies out of 1st row and out of 2nd row only in case of valuable displacement of maximum power into upper part of rector core for “hot channel” in initial state (profile 3). DNB doesn’t occur for the rest of power profiles. If DNB begin at time moment ≈17÷18sec for assemblies out of 1st row (figure 6) then for one’s out of 2nd row DNB begin later (≈30sec, figure 7). At that the maximal values of fuel and cladding temperatures are achieved also for calculation case with initial 3rd axial power profile. At that case the maximal cladding temperature of “hot channels” of assembly out of 1st row (№84) and 2nd row (№70) amounted accordingly 815°C and 672°C (figure 8). In case of initial 1st and 2nd axial power profiles the maximal cladding temperature doesn’t exceed 351°C.

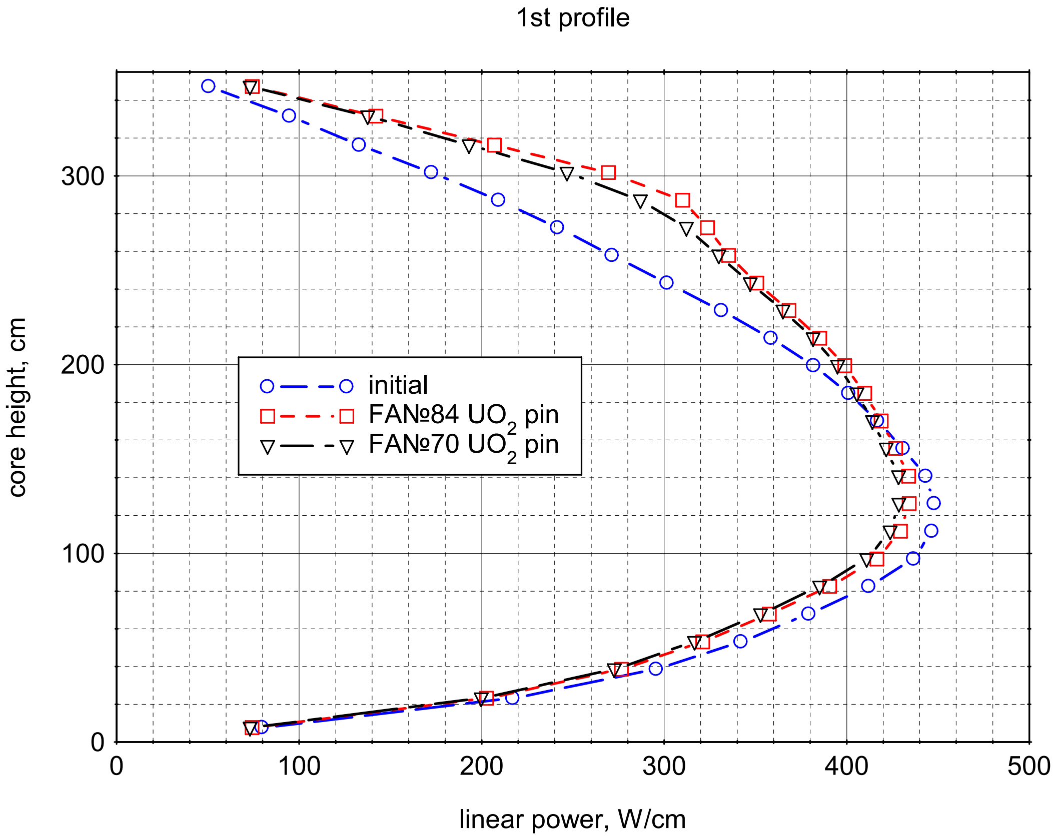

Figure 3 – Change of axial power distribution in “hot channels” (1st initial axial profile)

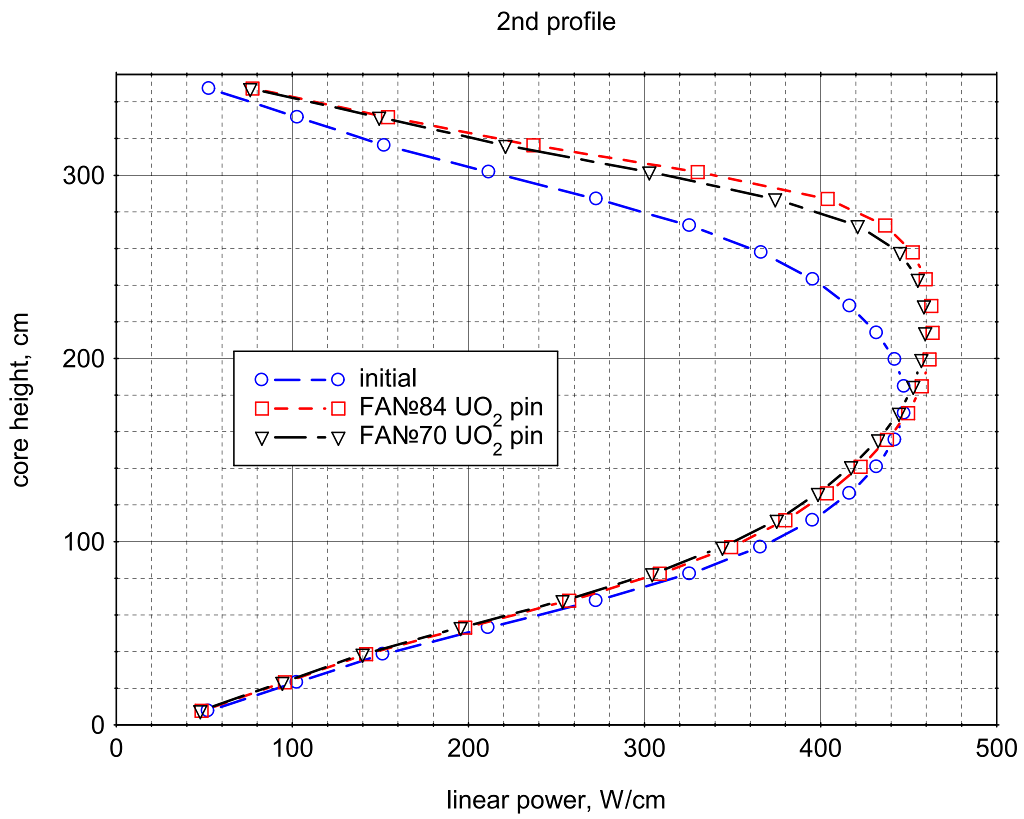

Figure 4 – Change of axial power distribution in “hot channels” (2nd initial axial profile)

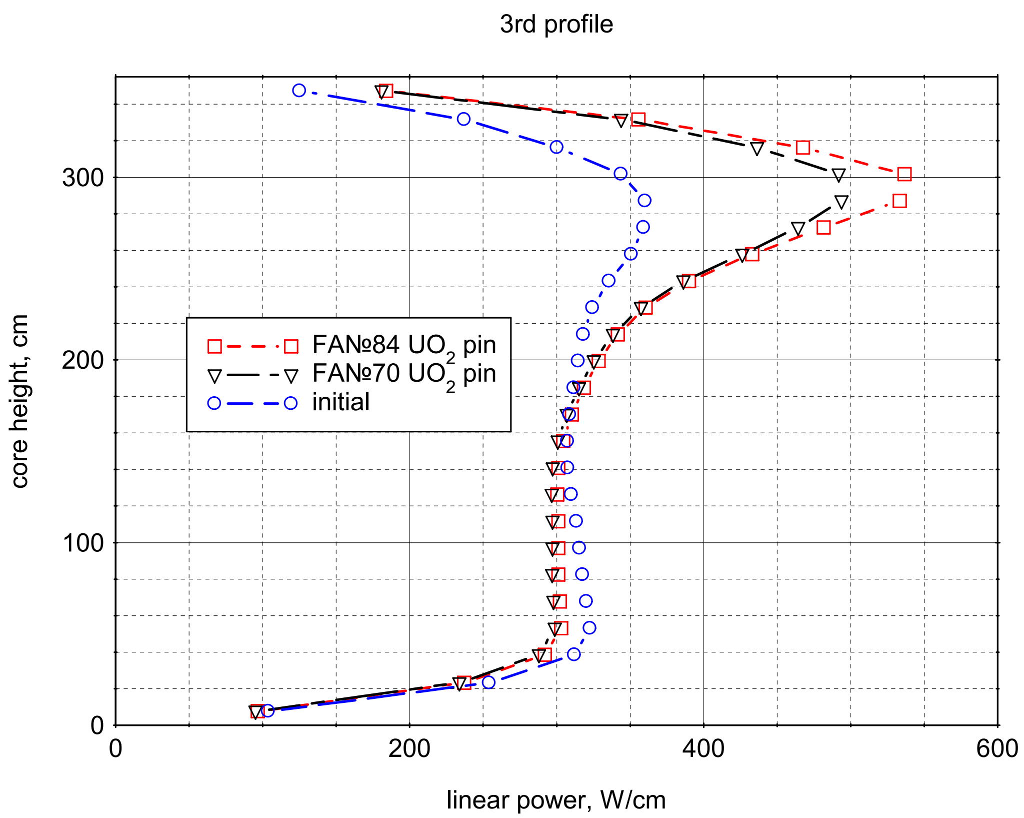

Figure 5 – Change of axial power distribution in “hot channels” (3rd initial axial profile)

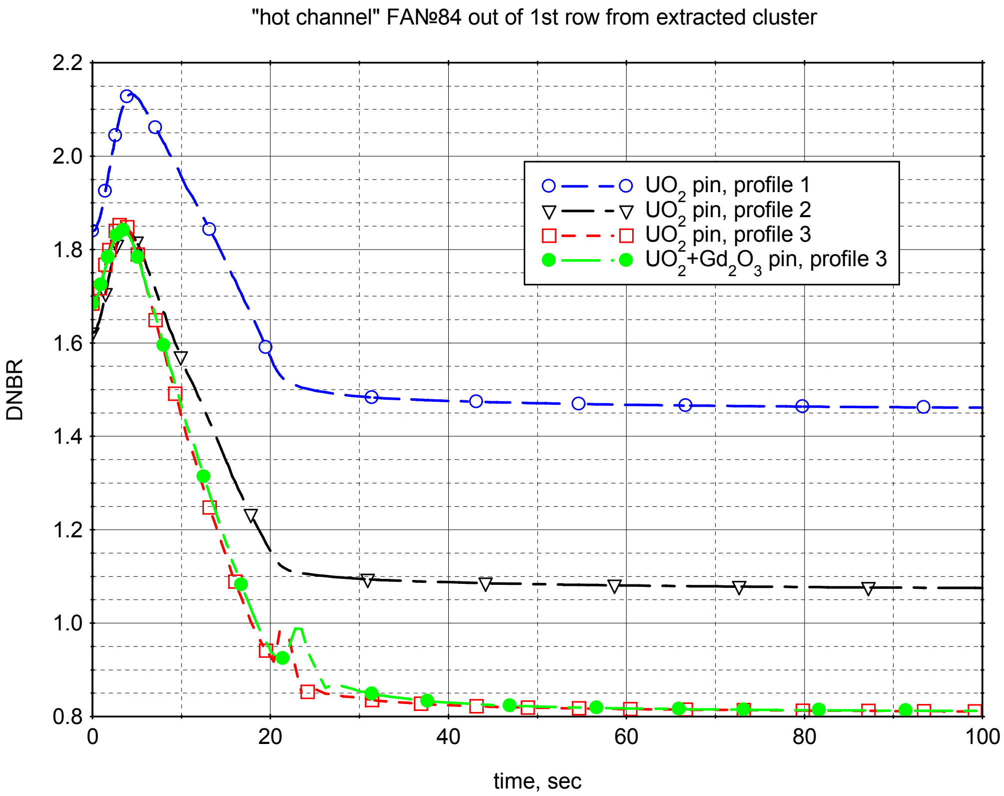

Figure 6 – Change of minimal DNBR for "hot channel" FA№84 out of 1st row from extracted cluster for 3rd initial axial power profiles

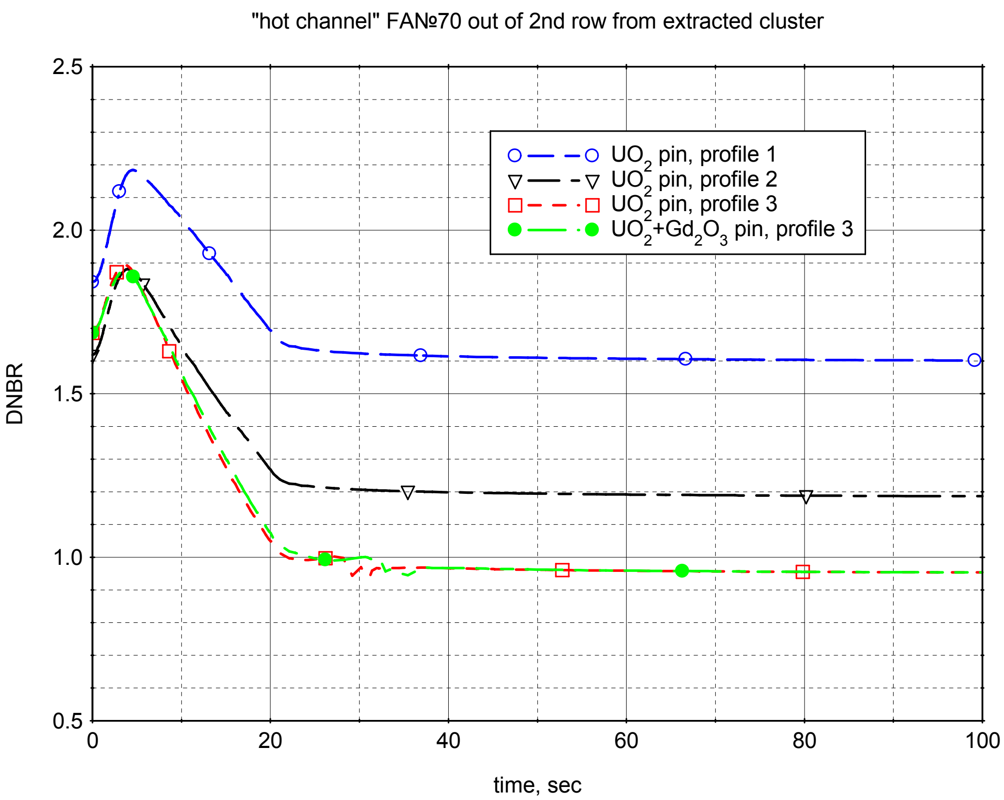

Figure 7 – Change of minimal DNBR for "hot channel" FA№70 out of 2nd row from extracted cluster for 3rd initial axial power profiles

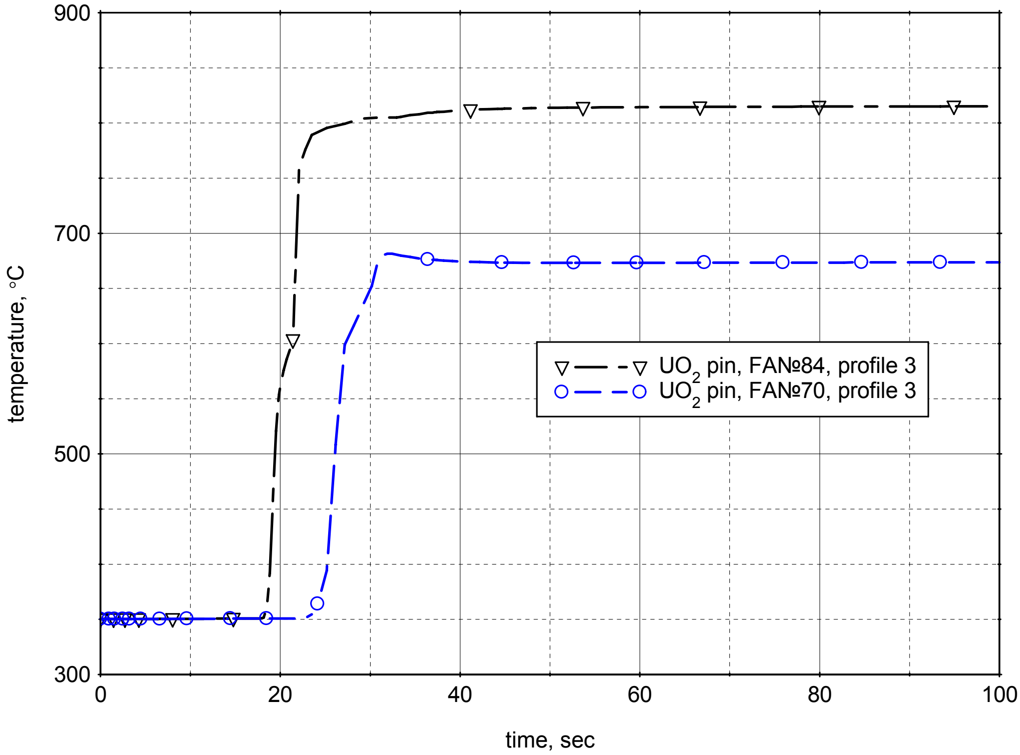

Figure 8 – Change of maximal cladding temperature in "hot channels" of FA№84 and №70

Maximal fuel temperatures in UO_2 and UO_2+Gd_2O_3 pins are realized also for 3rd limiting power profile with maximum in upper part of rector core (figures 9, 10). Their maximal values for fuel assemblies out of 1st and 2nd rows amounted accordingly 2160°C and 2062°C for UO_2 pin, and 2370°C and 2212°C for UO_2+Gd_2O_3 pin. At that the calculated values of increase in fuel temperature for UO_2 pin and UO_2+Gd_2O_3 pin of assemblies out of 1st and 2nd rows are quite valuable and amount accordingly: 540°C and 400°C for UO_2 pin, and 630°C and 430°C for UO_2+Gd2O_3 pin.

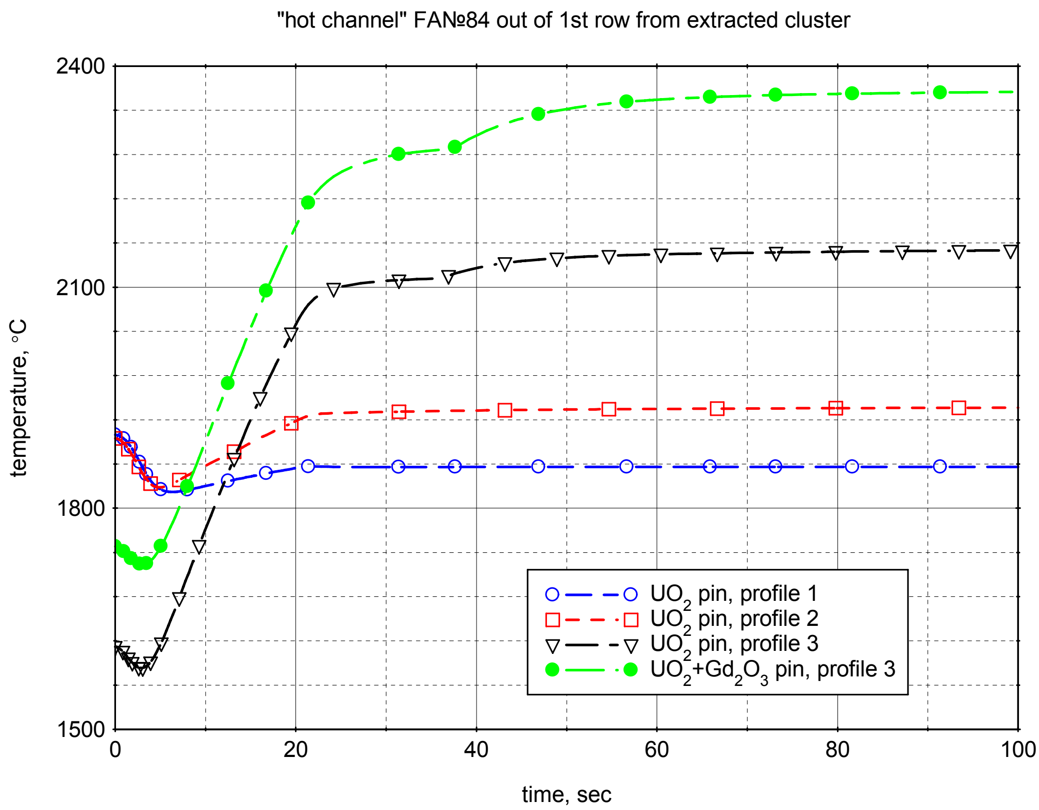

Figure 9 – Change of maximal fuel temperature for "hot channel" FA№84 out of 1st row from extracted cluster for different initial axial power profiles

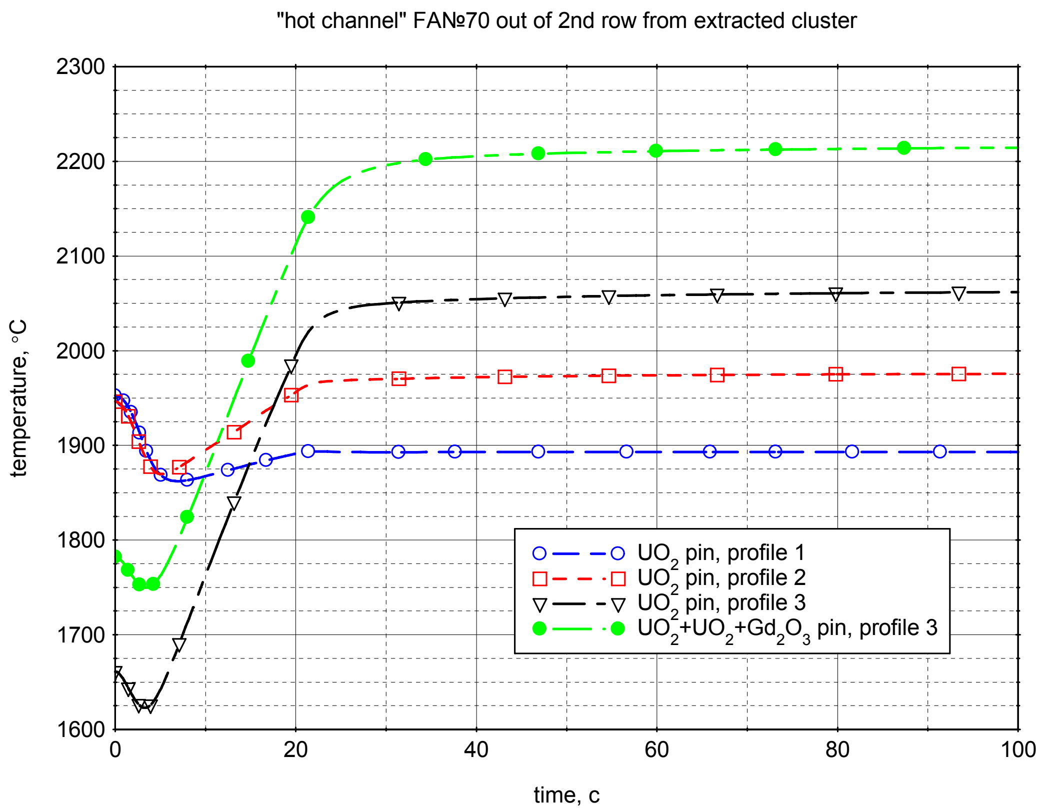

Figure 10 – Change of maximal fuel temperature for "hot channel" FA№70 out of 2nd row from extracted cluster for different initial axial power profiles

If in initial state axial power profile №1 takes place then the decrease of maximal fuel temperature will be occurred in comparison to initial state for given transient. This can be explained by the smoothing of axial power distribution along “hot channel” height and by the decrease of maximal linear power (figure 3) that caused by the extracting of control rods of regulating group. In case of axial power profile №1 (figure 3) the displacement of neutron field in upper part of core due to automatic power controller caused increase of maximal linear neutron power in comparison to initial maximal value on ≈12W/cm and ≈15W/cm accordingly for assemblies out of 1st and 2nd rows. At that the observed increase of fuel temperature is insignificant and amounts ≈50°C.

Results of analysis of transient related to cluster drop show that neutron and thermal powers were changing slow at regulation group extract, at that thermal power insignificantly lag behind neutron power and they are coincided at the end of transient (figure 11). Also taking into account that the scram doesn’t actuated in given transient the assessment of acceptance criteria compliance was performed also on base of calculations of steady state with the dropped cluster. Results of calculation of steady state with the dropped cluster are presented at table 3 (calculation are performed for 26 axial layers - 24 along core and one on lower and upper reflector).

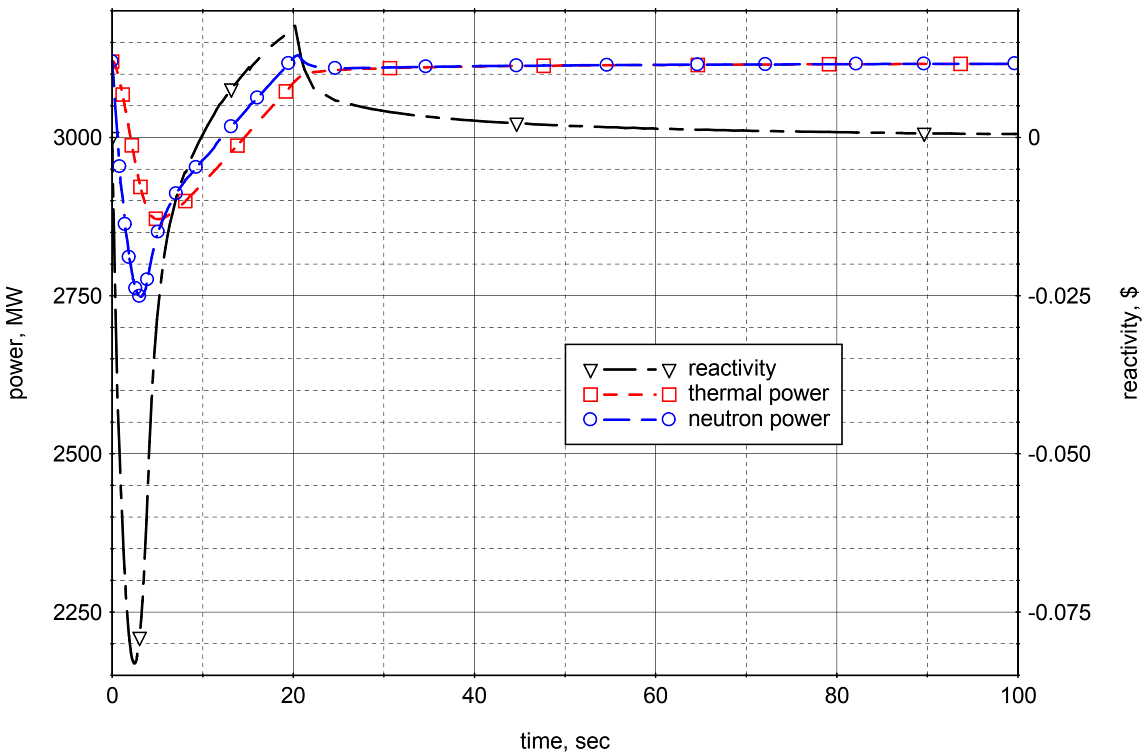

Figure 11 – Change of reactivity, neutron and thermal power during transient

The obtained with use of steady state and dynamical versions of DYN3D results showed good agreement. Therefore the using of steady state calculations is acceptable for analysis of transient with slow movement of control rods.

Table 3 – Change of most loaded UO_2 and UO_2+Gd_2O_3 pins due to cluster drop

Parameter	State	
	Initial	After cluster drop
Position of regulation group, cm	278	319
Position of dropped CR, cm	278	0
Reactor power, MW	3120	3120
Relative FA power / №FA	1.20/84 1.17/70	1.32/84 1.27/70
Parameters of most loaded UO_2 and UO_2+Gd_2O_3 pins		
Maximal linear power / № layer, W/cm		
profile 1 FA№84	448 / 9	434 / 9
profile 2 FA№84	448 / 12	464 / 15
profile 3 FA№84	360 / 20	539 / 21
profile 1 FA№70	448 / 9	428 / 9
profile 2 FA№70	448 / 12	460 / 15
profile 3 FA№70	360 / 20	495 / 20
Maximal fuel temperature of UO_2 pins (minimal gas gap conductivity) /№layer, °C		
profile 1 FA№84	1898 / 9	1855 / 9
profile 2 FA№84	1898 / 12	1938 / 15
profile 3 FA№84	1611 / 20	2126 / 21
profile 1 FA№70	1951 / 9	1892 / 9
profile 2 FA№70	1951 / 12	1977 / 15
profile 3 FA№70	1660 / 20	2066 / 20
Maximal fuel temperature of UO_2+Gd_2O_3 pins (minimal gas gap conductivity) /№layer, °C		
profile 3 FA№84	1747 / 20	2381 / 22
profile 3 FA№70	1781 / 20	2219 / 20
Minimal DNBR (maximal gas gap conductivity) /№layer		
profile 1 FA№84	1.84 / 17	1.47 / 21
profile 2 FA№84	1.62 / 19	1.07 / 21
profile 3 FA№84	1.69 / 23	**<1/ 22**
profile 1 FA№70	1.84 / 17	1.61 / 20
profile 2 FA№70	1.62 / 19	1.18 / 21
profile 3 FA№70	1.69 / 23	**<1/ 23**
Maximal cladding temperature (maximal gas gap conductivity) /№layer, °C		
profile 1 FA№84	351.0/ 9	351.0/ 9
profile 2 FA№84	350.9 / 12	350.9 / 13
profile 3 FA№84	350.4 / 19	816.1 / 22
profile 1 FA№70	351.0/ 9	351.0/ 9
profile 2 FA№70	350.9 / 12	350.9 / 13
profile 3 FA№70	350.4 / 19	672.7 / 23

CONCLUSIONS

The initial event related to cluster drop is categorized as anticipated transient and compliance of acceptance criteria (DNB absence) is confirmed in safety analysis report [4]. But results of performed studies showed that compliance of acceptance criteria on DNB absence isn't confirmed in case of 3rd limiting axial power profile.

Main cause of difference of presented and earlier obtained results next: deformation of axial power profile in area of extracted cluster didn't take into account at using point kinetic model, and the displaced in upper part of core conservative (3rd limiting) axial power profile didn't take into account at using spatial kinetic model. Performed studies showed that main increase of local power is occurred in upper part of core whereas maximal linear power is almost unchangeable in lower part. Additional increase of power in upper part of "hot channels" leads to conditions for initiation of DNB.

It is obvious that excess conservatism has a place in considered transient. Namely superposition of such conservative assumptions as big efficiency of partially inserted working group of control rods and realization of most loaded fuel pin with displaced in upper part of core limiting axial profile that situated near to FA with inserted cluster. For correct performing of conservative analysis of this transient it's necessary to substantiate possibility of realization limiting axial profiles in the nearest rows from FA with partially inserted cluster in different operation modes.

LIST OF NOMENCLATURE

CR	- control rod;
DNB	- departure from nucleate boiling;
FA	- fuel assembly;
NPP	- nuclear power plant;
PZ-2	- preventive protection;
SGIU	- system of group and individual operation of control and protection system.

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