Neutronic and Thermal Hydraulic Assessment of Fast Reactor Cooling by Water of Super Critical Parameters

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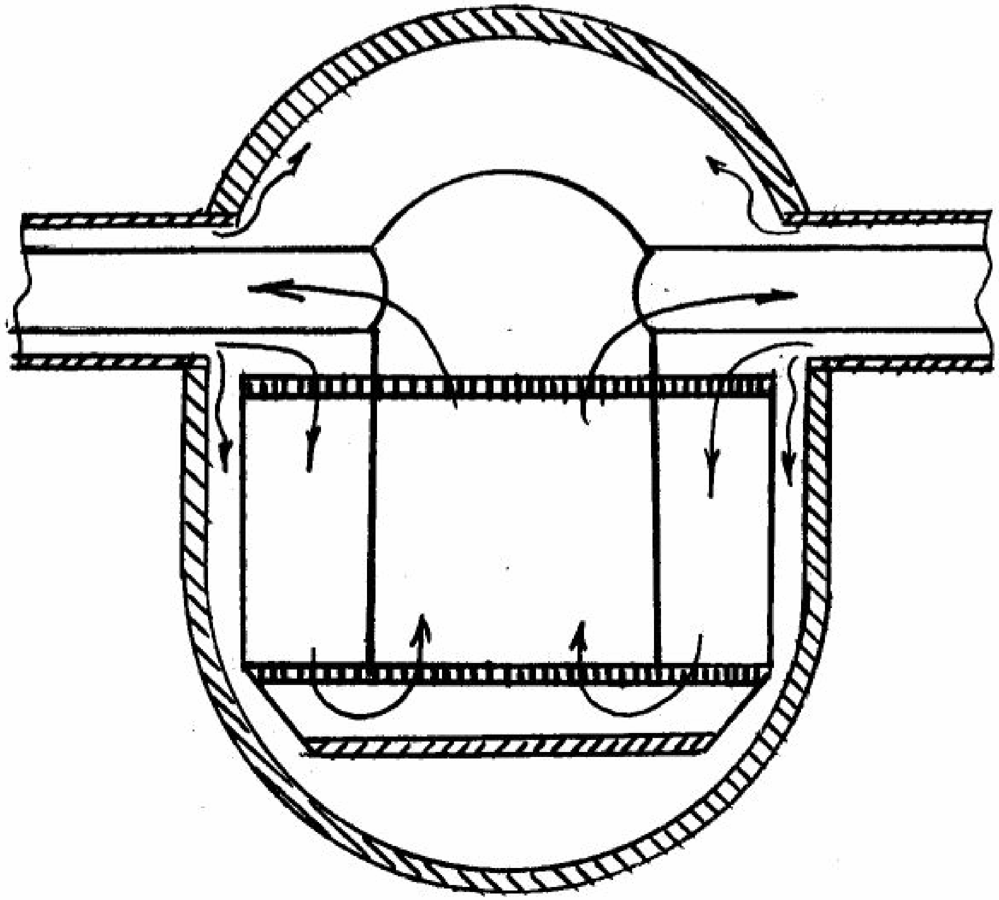
Objectives:

pre-design investigation of one-circuit reactor installation with
a fast-resonant spectrum of neutrons,
supercritical water coolant and
MOX fuel on the basis of weapon plutonium.
Specific feature of this reactor SCFR –2X is a double pass of coolant via the core
(the Supercritical Fast Reactor with the double pass of coolant).

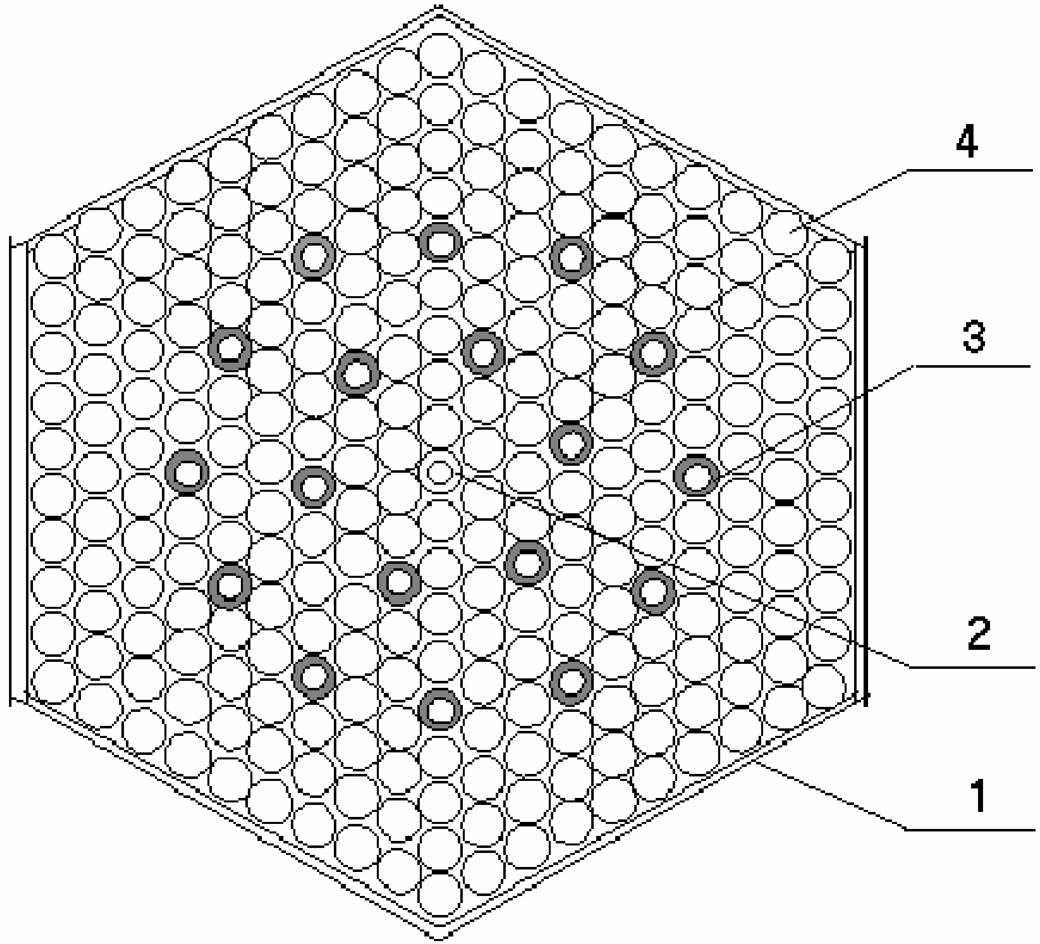
Characteristics of reactor installation and core of SCFR –2X

Reactor installation parameters	Value
Thermal power, MWt	3830
Electric power, MWt	1700
Coolant pressure, Mpa	25.0
Coefficient of efficiency, %	43.5
Coolant Temperature input / output ,°C	280/530
Coolant flow rate via reactor, tonn/hour	6750
Fuel element (FE) Clad material	Ni- alloy
Clad tube size, mm	∅10.7×0,55
Step of triangular fuel pin lattice, mm	12.0
Fuel	UO_2+PuO_2
Number of fuel pin in the FA, pieces	252
Number of covered FA in the core, pieces	241
Size of cover in a hexagonal lattice, mm	205
Material of FA cover	Ni-alloy
Thickness of FA cover, mm	2.25
Height of the core, m	4.05/3.38
Average power density in the core, Wt/cm^3	107
Average heat flux from fuel pin, Wt/cm	158

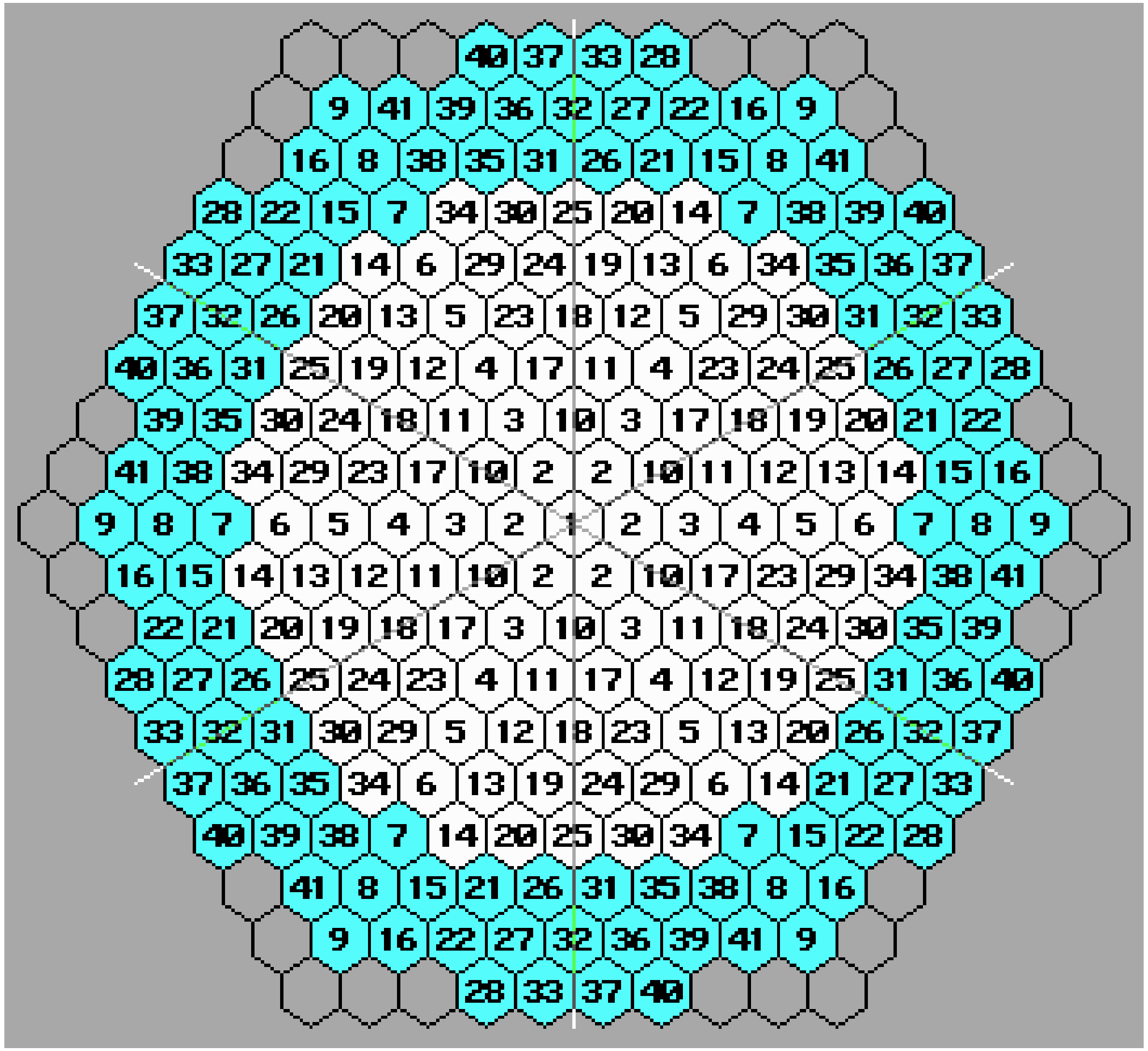
Scheme of reactor cooling



Fuel Assembly Cross-section: 1 - a cover of 2.25 mm thickness; 2 - the central tube with a size ∅10,7 mm × 1 mm; 3 - 18 directing tubes for absorber control rods in size ∅ 10,7 mm ×0,55 mm; 4 - 252 Fuel elements, clad tube size of ∅10,7 mm× 0,55 mm, with a step of 12 mm.



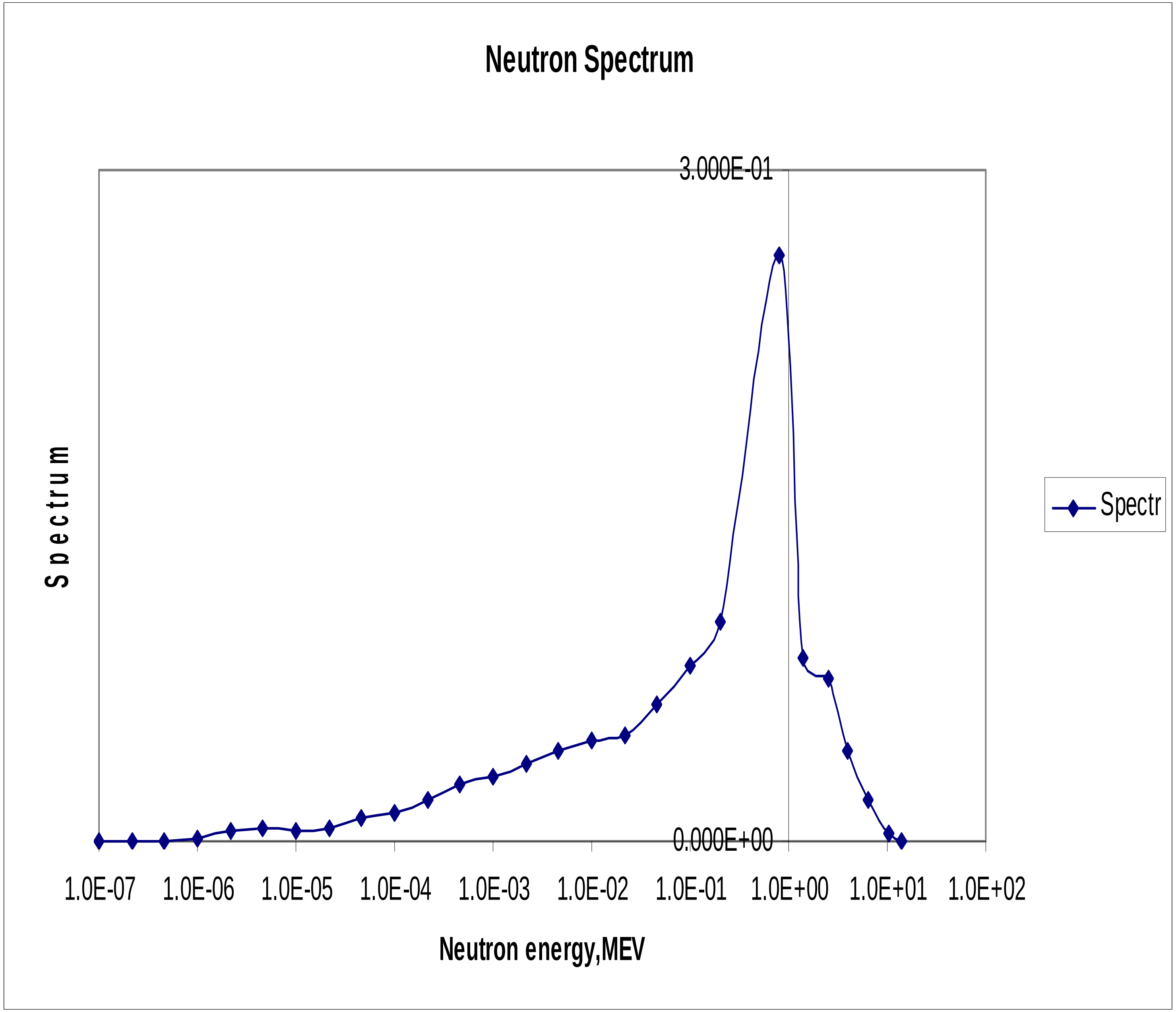
Fuel loading configuration



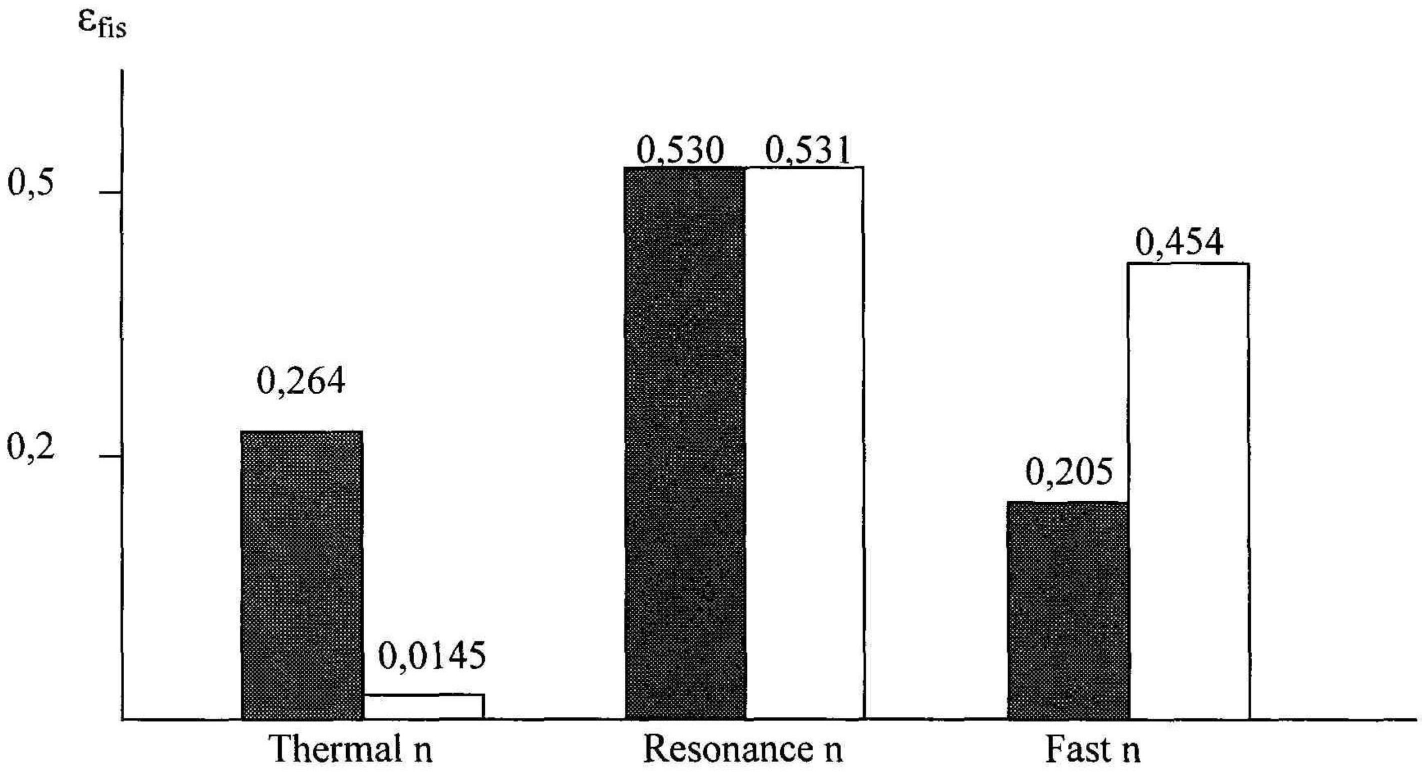
40 37 33 28
9 41 39 36 32 27 22 16 9
16 8 38 35 31 26 21 15 8 41
28 22 15 7 34 30 25 20 14 7 38 39 40
33 27 21 14 6 29 24 19 13 6 34 35 36 37
37 32 26 20 13 5 23 18 12 5 29 30 31 32 33
40 36 31 25 19 12 4 17 11 4 23 24 25 26 27 28
39 35 30 24 18 11 3 10 3 17 18 19 20 21 22
41 38 34 29 23 17 10 2 2 10 11 12 13 14 15 16
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9
16 15 14 13 12 11 10 2 2 10 17 23 29 34 38 41
22 21 20 19 18 17 3 10 3 11 18 24 30 35 39
28 27 26 25 24 23 4 11 17 4 12 19 25 31 36 40
33 32 31 30 29 5 12 18 23 5 13 20 26 32 37
37 36 35 34 6 13 19 24 29 6 14 21 27 33
40 39 38 7 14 20 25 30 34 7 15 22 28
41 8 15 21 26 31 35 38 8 16
9 16 22 27 32 36 39 41 9
28 33 37 40

Thermal-hydraulic parameters used in the FA calculation model on the direction of coolant path

Lengths of parts (on a course of the coolant), cm	Coolant density, g/cm^3	Temperature, °C		
		Coolant	Clad	Fuel
	Periphery part			
108	0.76	290	300	600
120	0.68	340	352	720
80	0.45	370	385	860
68	0.3	388	405	990
	Central part			
68	0.2	403	430	1000
80	0.15	420	465	1050
120	0.12	450	530	1100
108	0.095	513	575	1080


Neutron Spectrum
3.000E-01
0.000E+00
Spectrum
Spectr
1.0E-07
1.0E-06
1.0E-05
1.0E-04
1.0E-03
1.0E-02
1.0E-01
1.0E+00
1.0E+01
1.0E+02
Neutron energy,MEV

the Relative contribution (έfis) for neutrons of different energy groups in total amount of fission on the inlet (■), and outlet (□) part of the core



Physical characteristics of a fuel cycle at various scheme of heat-removal

Characteristics	Value	
	One-pass	Two-pass
Initial load of weapon-grade Pu into the core, tones	15.68	9.47
Loading of the mixed fuel in one FA, kg	598	560.6
Loading weapon Pu in one FA, kg	67.88	39.3
Part of FA overloads	1/5	1/5
Excess Reactivity reserve on campaign, %	1.5	1.26
Duration of an inter reloading interval , eff. Days	250	300
Amount of FA types /fuel of different enrichment in the core	4/16	1/1
Average energy release of discharge FA, MWt*day/kg. H.n	33.3	39.79
Maximal peaking factor of power density by FA /by the core volume	1.22/2.33	1.46/2.19
Loading of fissile isotopes ^{235}U, ^{239}Pu, ^{241}Pu, tones/year	2.65	2.34 (Weapon Pu = 1.89)
Discharge of fissile isotopes tones/year	2.48	2.18
Breeding ratio	0.936	0.933
Void reactivity effect in the beginning / end campaign, %	0.2/0.562	-5.88/-3.64
Reactivity coefficient for N = $N_{nominal}$ on the beginning / end of an interreloading interval: $\partial\rho/\partial\gamma\cdot10^{-2}$, cm^3/kg $\partial\rho/\partial T_T\cdot10^{-4}$, 1/°C $\partial\rho/\partial T_{fuel}\cdot10^{-5}$, 1/°C $\partial\rho/\partial S_{\text{п}}\cdot10^{-4}$, 1/% steam	1.64/-0.548 -1.09/0.646 -1.85/-1.77 -	8.03/5.20 -2.40/-1.9 -1.50/-1.45 -6.0/-4.0

Overcriticality and required number of control rods for its compensation

State	ΔΚ, %	$N_{\text{FA with CR}}$
N_{nom}	1.26	12
Minimally controlled level	7.265	120
Void	-2.26	–
Cold	13.679	216

Conclusions

- The suggested double-pass scheme of coolant circulation with supercritical pressure in water-cooled reactors with fast - resonant and thermal spectra of neutrons allow us to realize some advantages in comparison with another similar projects of NPPs. At realization of the specified scheme of coolant circulation we got such an advantages as:
- - temperature difference at which FA constructive elements are working decrease in 2 times;
- - Required core non-uniformity of energy release distribution could be ensured without complex profiling of fuel enrichment;
- - the coolant heating via height on the core upcoming site decreases in 2 times that will result in reduction of non-uniformity in coolant temperature distribution between FA;
- - Negative feedback on key parameters are ensured to be negative: to temperature and density of the coolant, temperature of fuel, void effect (without use of additional measures – such as blanket introduction , solid moderator for a reactor with a fast spectrum of neutrons);
- - Only small excess of reactivity is required on burn-up and the most difficult modes of operation (flooding by cold water), and this excess can be provided by regular means - an arrangement of absorbing control rods in 2/3 FA.

Thank you for attention