National Research Centre "Kurchatov Institute"

PETERSBURG NUCLEAR PHYSICS INSTITUTE

Influence of pins with burnable poisons in the FA on peaking power factor of the reactor PIK

M.S. Onegin

6th International Serpent UGM
26 – 29 September 2016

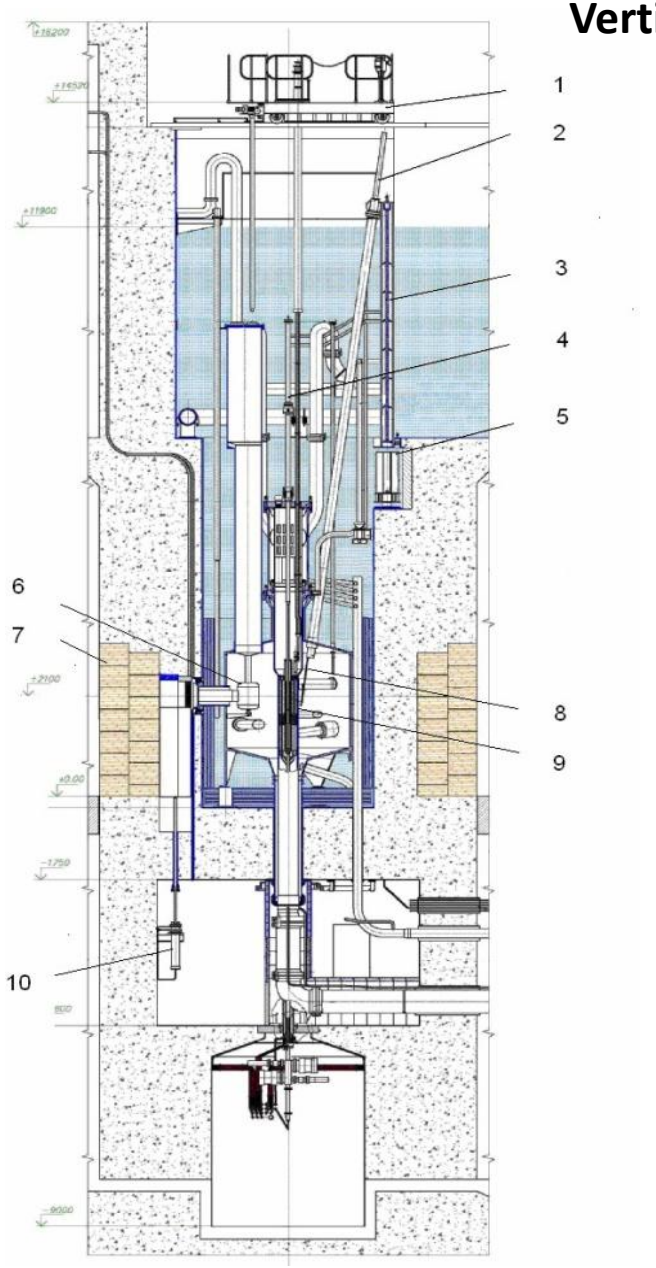
- Reactor PIK - introduction
- Modernization of the core – main reasons
- Redesign of FA - including of the burnable absorbers
- Calculation of the radial power distribution for the fresh core without and with burnable absorbers . Comparison.
- Calculation of the power distribution in the core after the burnup cycle.
- Summary and plans

Reactor PIK

2011 – Criticality reached
2013 – Construction finished
2014 – 2017 Licensing and neutron stations and installations construction
2018 – Power operation scheduled

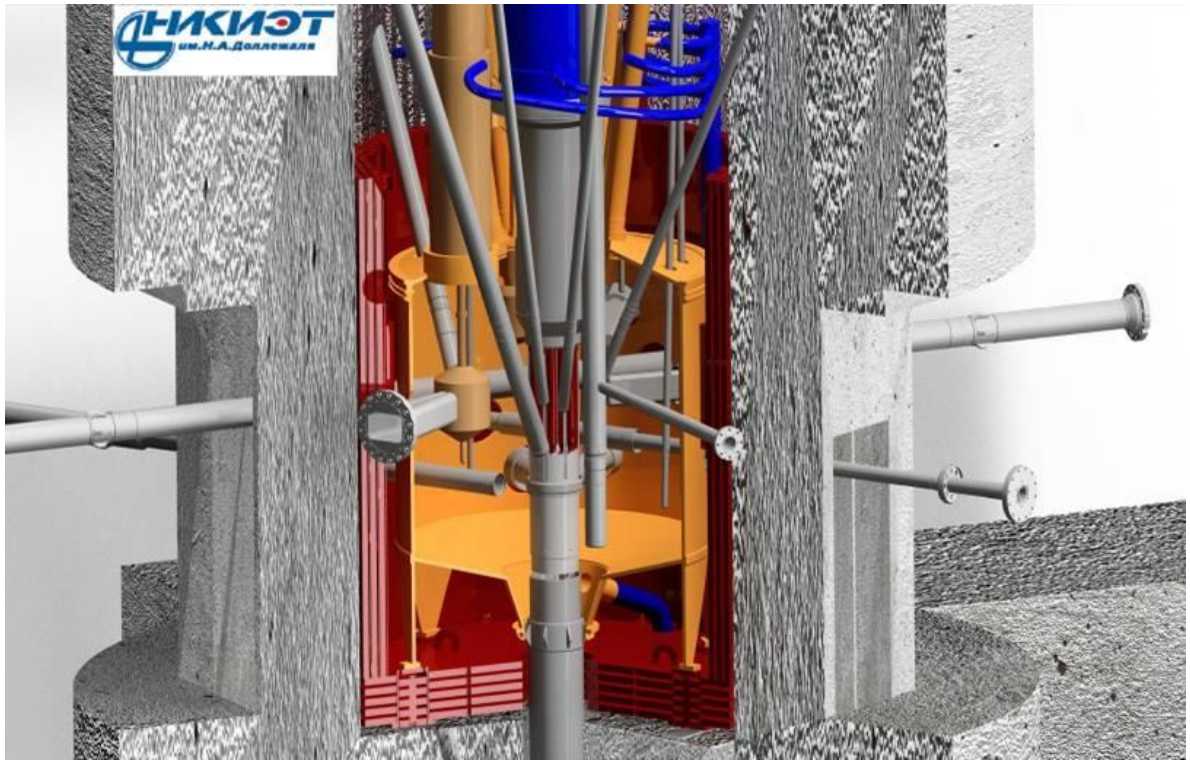
The maximum heat output	100 MW
Heat transfer agent	water
Reflector	heavy water
Number of horizontal experimental channels	10
Number inclined experimental channels	6
Number of vertical experimental channels	6

Vertical cut of reactor PIK



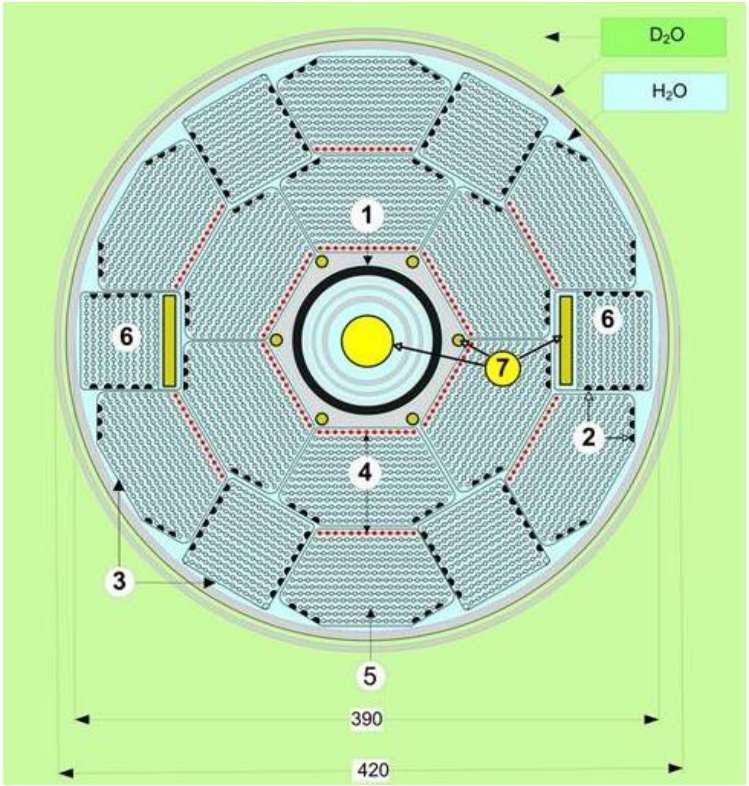
1. Fuel handling machine
2. Control rod disconnect driveline
3. Hydraulic lock
4. Central experimental channel
5. Transfer device cylinder
6. Cold neutron source
7. Biological shielding
8. Control rod
9. Reactor core
10. Driving gear of channel gate

3D model of reactor PIK



JSC “NIKIET” is the chief designer of the reactor.

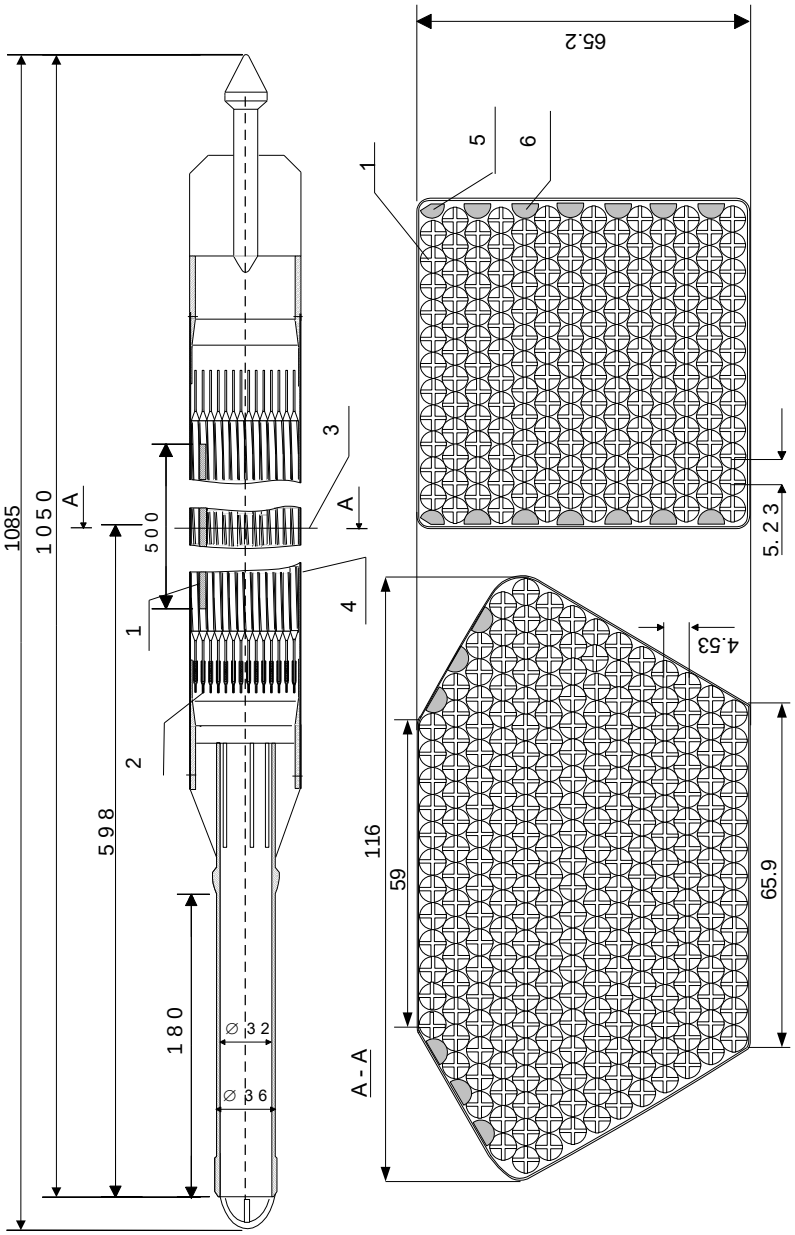
PIK core

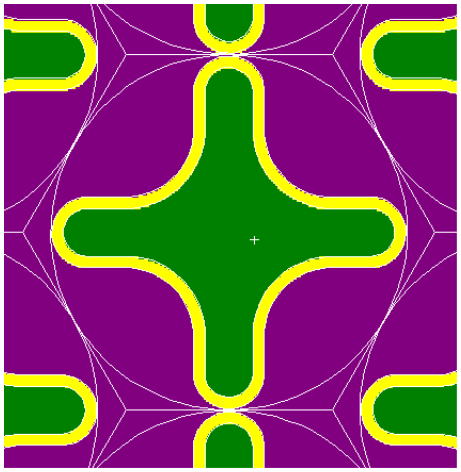


1. Hafnium central control rod
2. Water displacers
3. Fuel assemblies Zr case
4. Profiled Fuel elements
5. Fuel elements
6. Fuel assemblies with irradiation volumes
7. Volumes for samples irradiation

Heat-transfer agent – light water
Presser – 50 bar
Inlet temperature – 50 °C
Outlet temperature – 90 °C
Inlet water velocity – 10 m/s
Power heat load – 2 MW/l (mean)
density 6.6 MW/l (max)

FA of reactor PIK





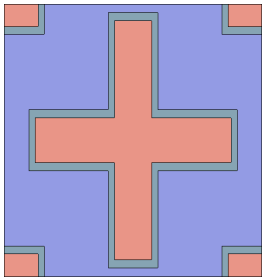
S_{cell} = 23.688 mm^2

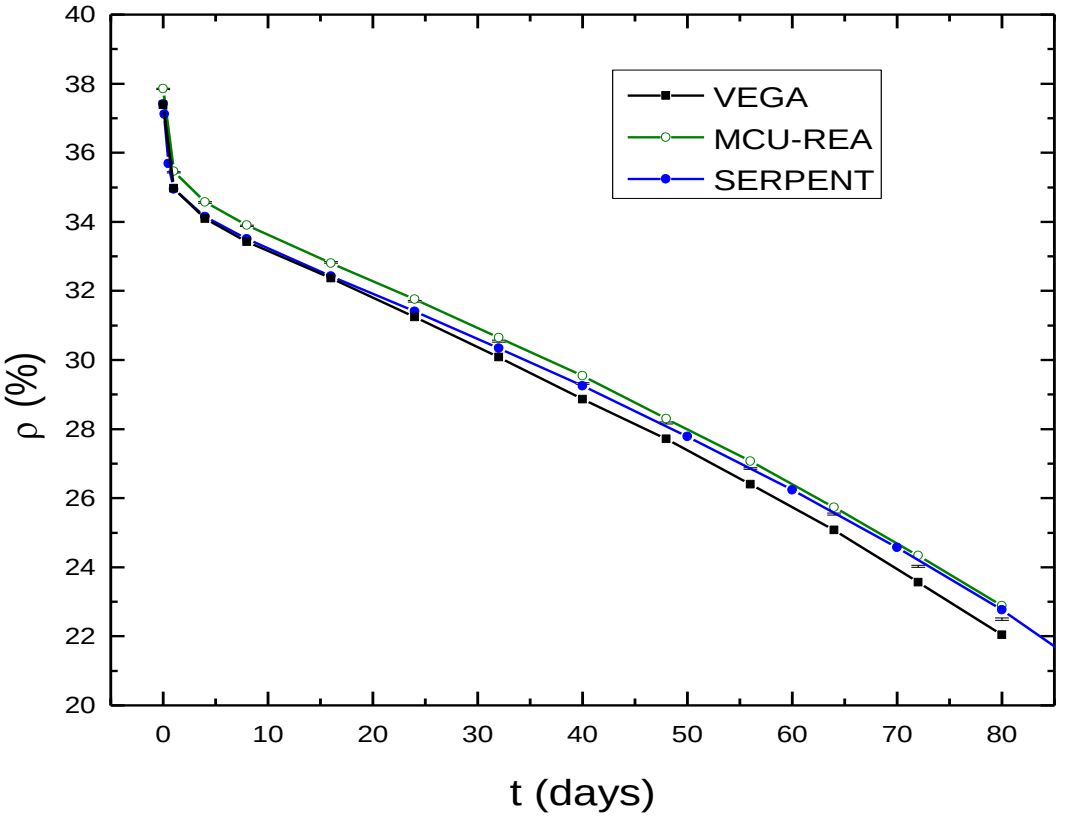
S_{pin} = 10.15 mm^2

S_{meat} = 7.23 mm^2

Hexagonal lattice with 5.23 mm pitch

Burn up of the infinite lattice of pins

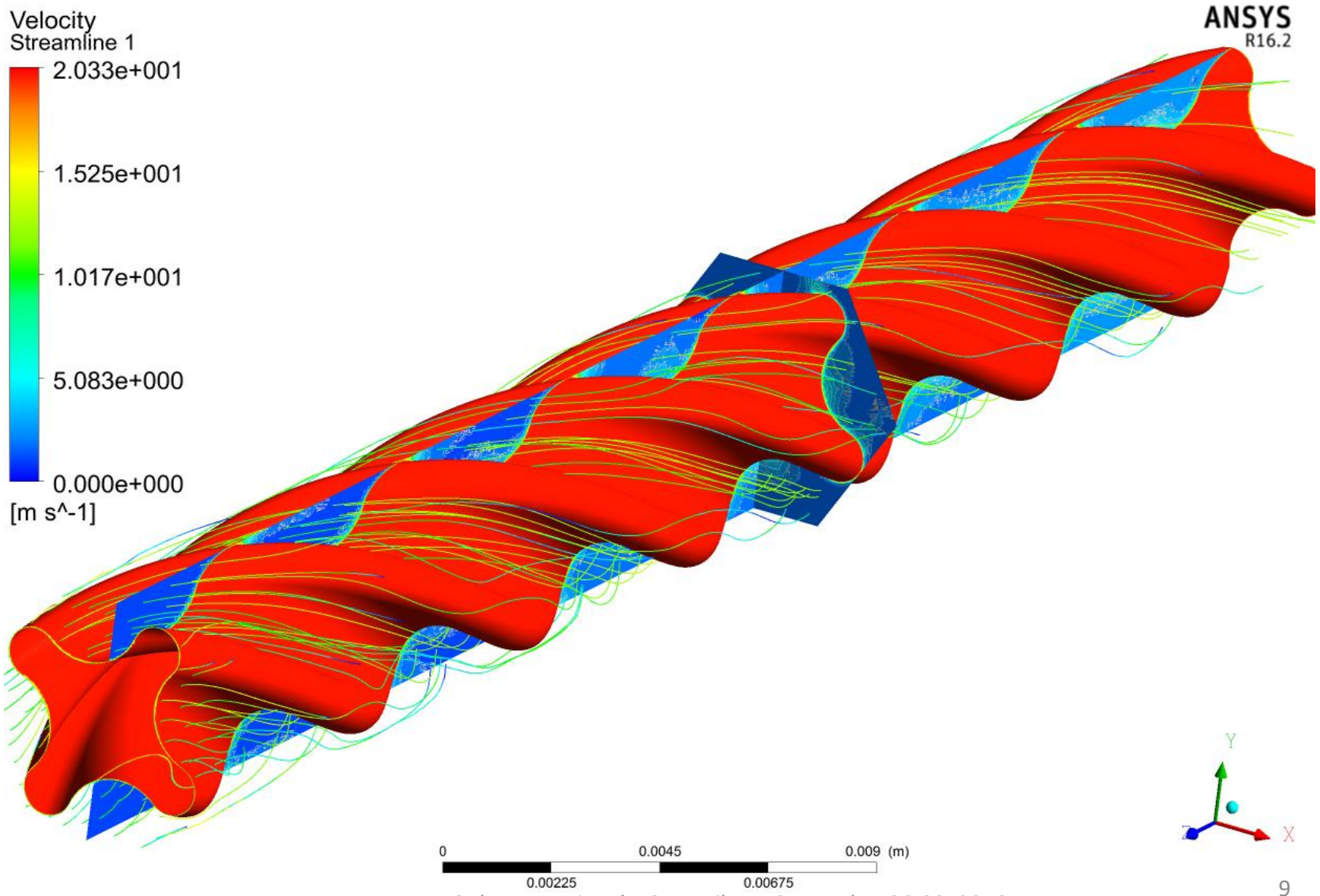




List of FP isotopes taken into account in burn up calculation:
Kr-83, Mo-99, **Tc-99**, Ru-101, Rh-103, **Rh-105**, Ag109, I-135, **Xe-131**, **Xe-135**, **Cs-133**, Cs-134, Cs-135, Cs-137, Ba-140, La-140, **Nd-143**, **Nd-145, Pm-147**,148,149,148m, **Sm**-147,**149**,150,**151**,**152**, Eu-153,154,155,156, Gd-152,154,155,156,157,160,

Important isotopes wasn't included in the list: Ce-141, Nd-147, Pr-143, Xe-133

The twist pins have 300 mm step



The main objectives to use the burnable pins in FA are:

- To reduce the initial amount of reactivity
- To reduce the non uniformity of energy release in the core

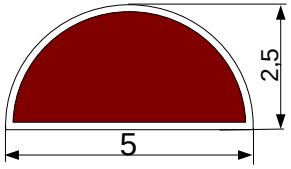
The main requirements to the burnable pins are:

- The nuclide which is used for poisoning in these pins should burn up completely during the operational cycle of the reactor .

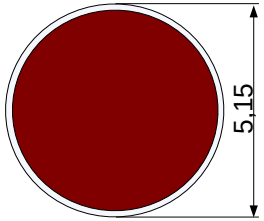
- Its geometry shouldn't disturb essentially the flow of the moderator in the FA.

We have chosen the Gd_2O_3 in ZrO_2 matrix as a poison.

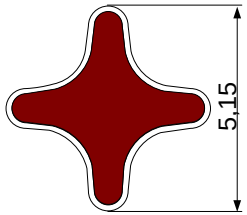
Forms of burnable pins cross section



Semi-cylinder



Cylinder



Cross

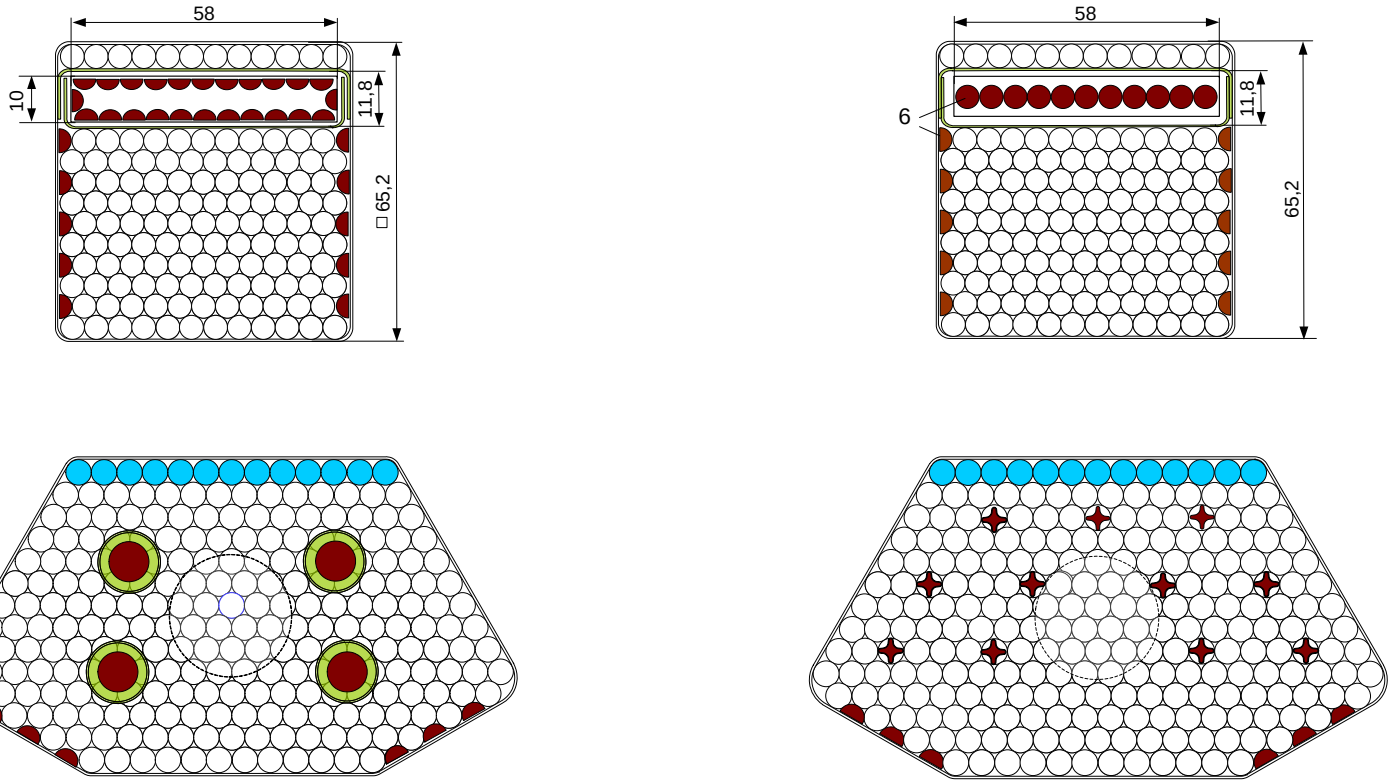
We have considered three different forms of burnable pins cross section.

The most preferred form – cross form. But it is the most difficult for production.

Cylinder form – is the easiest form for production. But the poison in the pins of these form burns up slowliest.

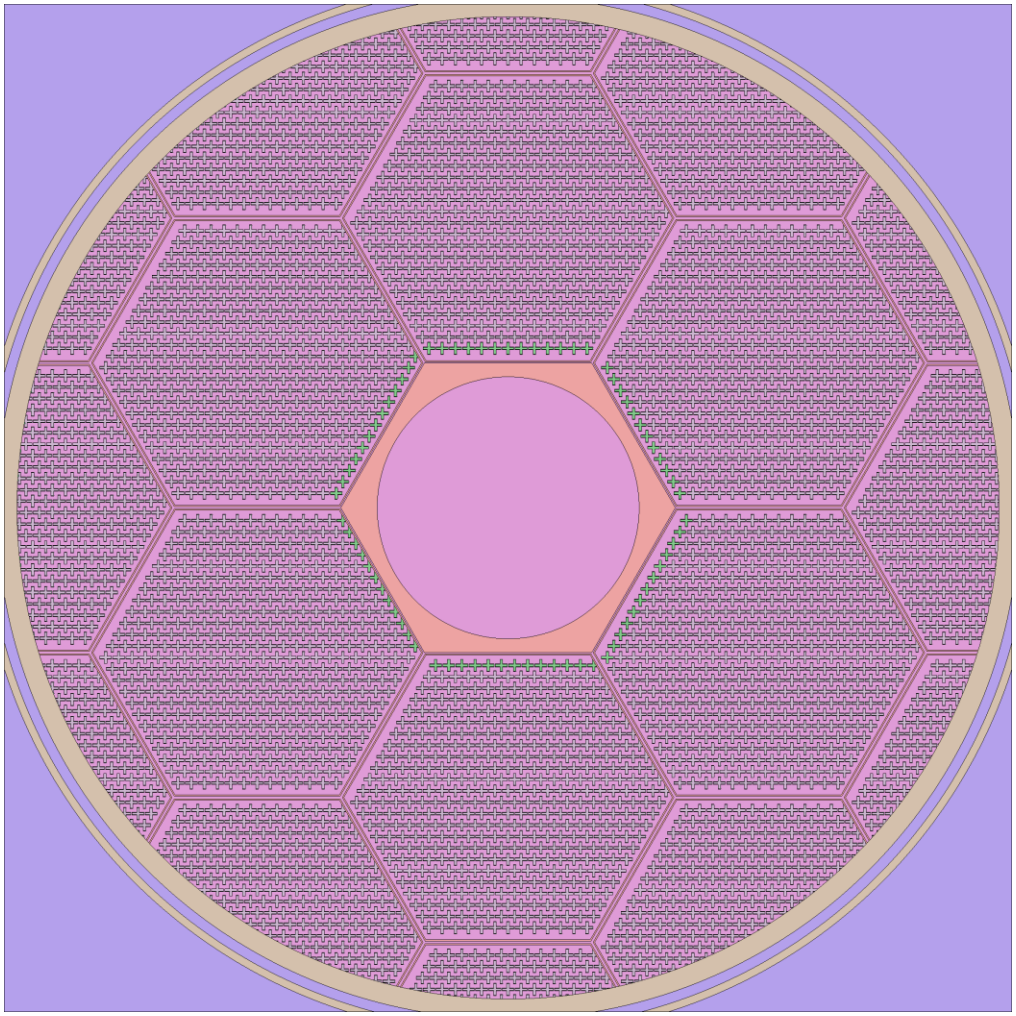
The amount of gadolinium in the semi-cylinder pin can vary from 0.7 g up to 2.8 g.
The amount of gadolinium in the cross can vary from 0.73 up to 2.2 g.
(density of gadolinium can vary from 0.184 g/cm^3 up to 0.55 g/cm^3.)

FA with burnable pins



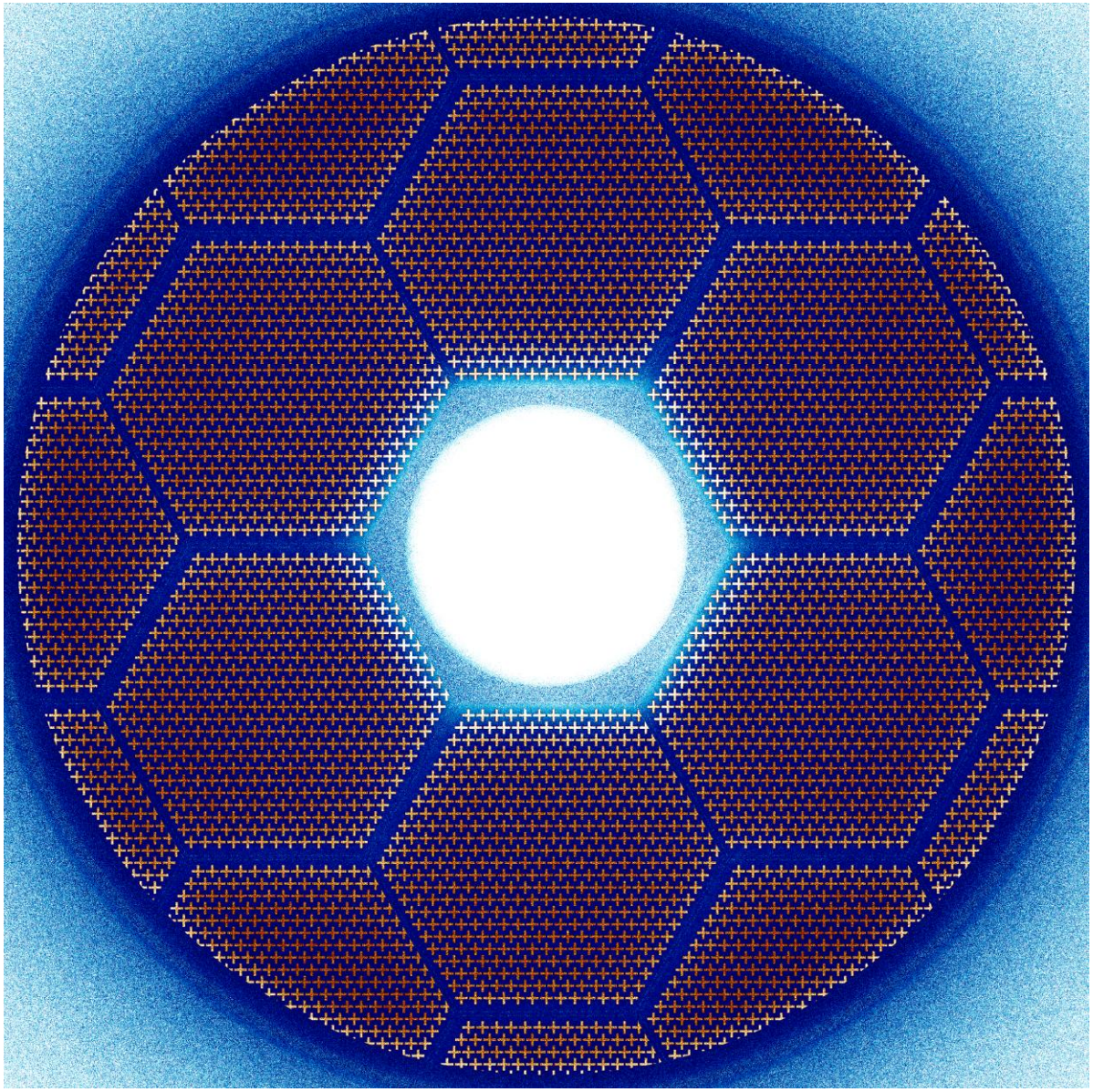
We have considered different constructions of FA with burnable pins. The most promising solution is to install cross burnable pins into the hexagonal FA. In this case we leave free space in the square FA for surveillance specimens and irradiated samples. Using of cross burnable pins doesn't change the hydrodynamics of the core.

Serpent model of the core (horizontal layout)



The PIK core in the model was filled with FA of hexagonal form.
The first layer of pins near the water trap is profiled (48%) to reduce the energy release here.

Fresh zone (flux distribution)



Power distribution in the FA near the water trap (without burnable poison pins)

PETERSBURG NUCLEAR PHYSICS INSTITUTE

1.33

1.34

1.36 1.07

1.40 1.07

1.46 1.07 0.96

1.58 1.13 0.97

1.82 1.16 0.98 0.89

2.41 1.25 0.99 0.91

2.19 1.48 1.06 0.93 0.86

2.11 1.14 0.94 0.89

2.11 1.40 1.00 0.90 0.87

2.06 1.10 0.92 0.86

2.11 1.33 0.97 0.88 0.86

2.05 1.08 0.91 0.86

2.14 1.35 0.98 0.88 0.84

2.05 1.07 0.92 0.86

2.16 1.34 0.96 0.87 0.86

2.06 1.07 0.90 0.85

2.17 1.36 0.95 0.87 0.85

2.03 1.07 0.91 0.86

2.15 1.36 0.94 0.88 0.85

2.05 1.08 0.89 0.85

2.15 1.34 0.97 0.87 0.85

2.02 1.09 0.89 0.86

2.12 1.36 0.97 0.87 0.84

2.03 1.10 0.91 0.86

2.09 1.34 0.96 0.88 0.86

2.05 1.10 0.92 0.87

2.10 1.39 0.98 0.90 0.87

2.11 1.16 0.94 0.87

2.16 1.46 1.05 0.93 0.90

2.40 1.26 1.00 0.91

1.84 1.14 0.96 0.89

1.57 1.09 0.96

1.48 1.08 0.94

1.41 1.05

1.37 1.06

1.35

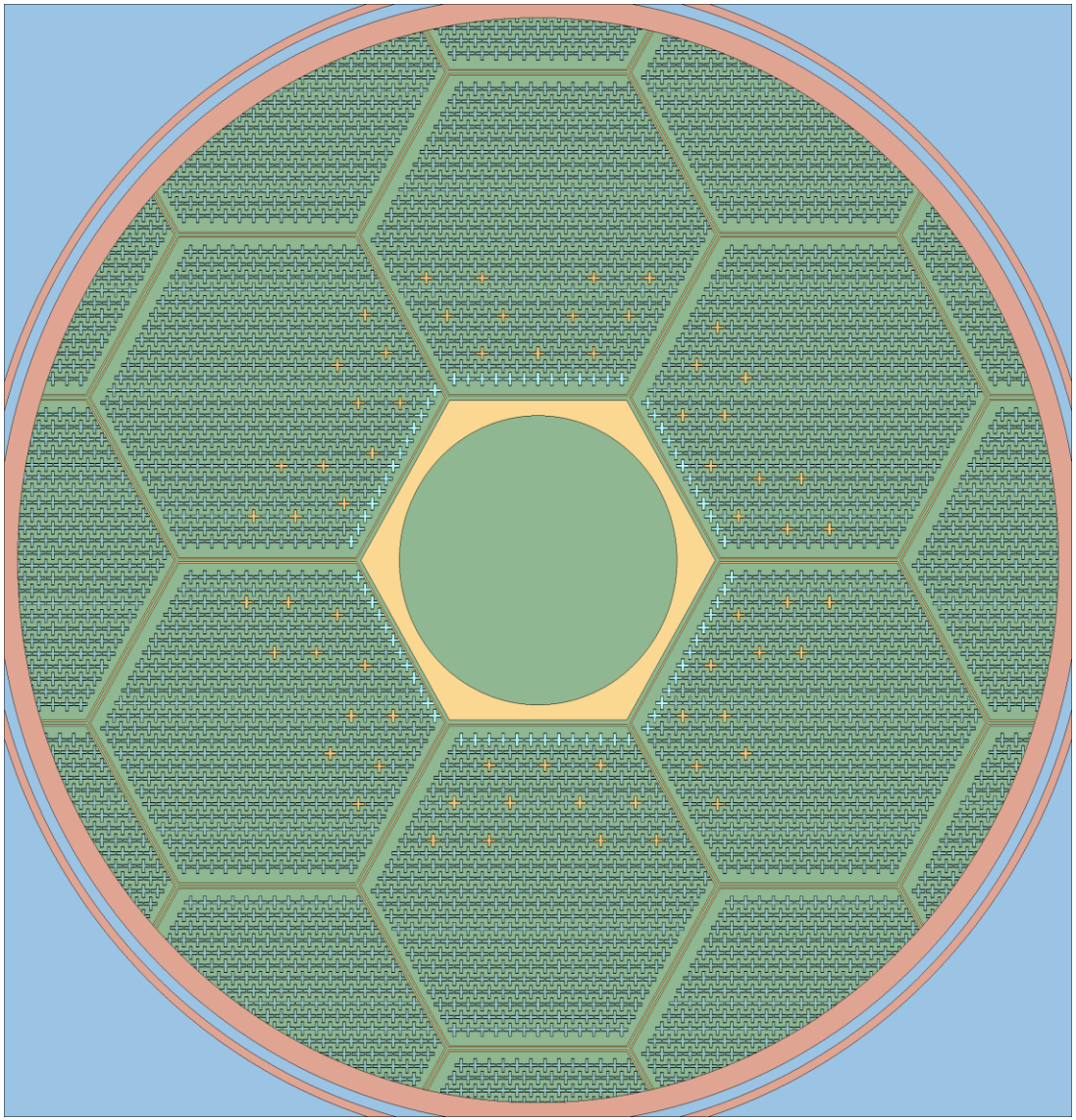
1.34

$$\bar{k}_{r,1} = 1.54$$

$$\bar{k}_{r,2} = 1.49$$

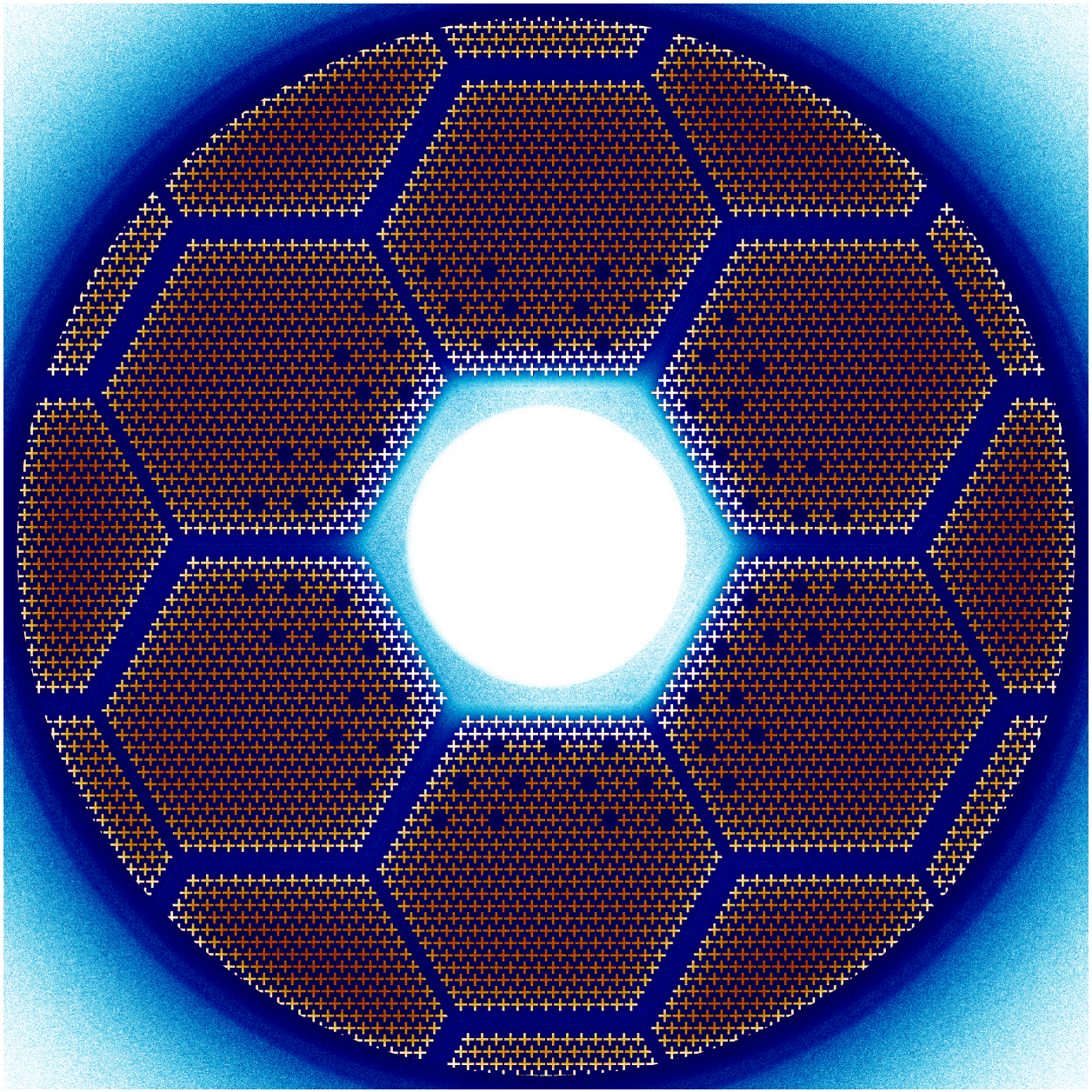
$$\bar{k}_{r,3} = 1.51$$

Serpent model of the core with burnable pins (horizontal layout)



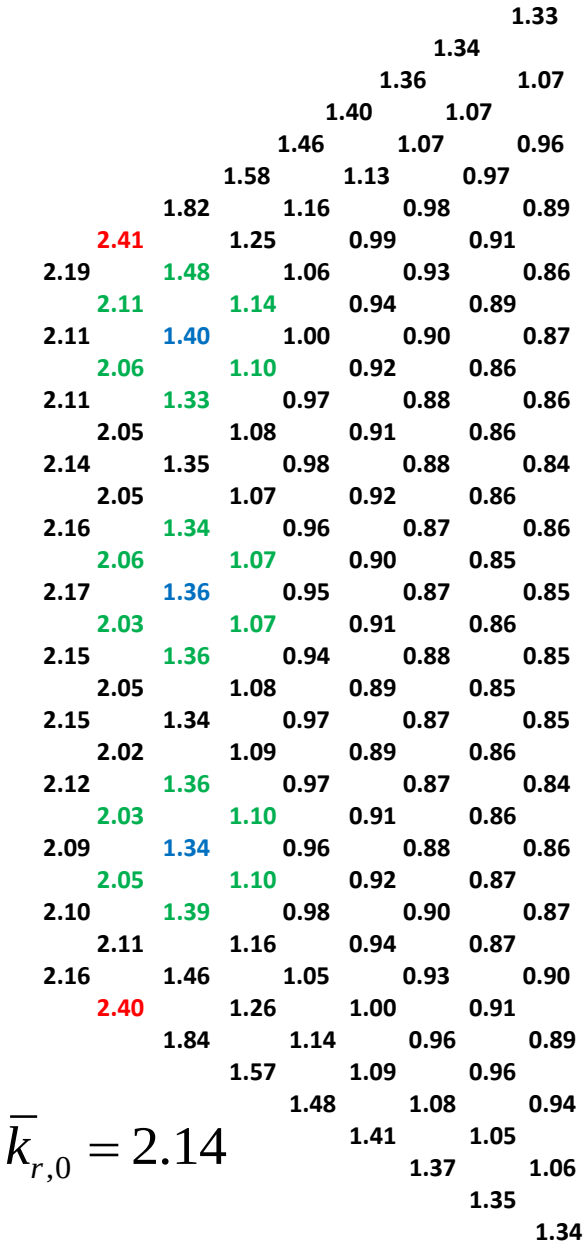
Part of the pins in the FA was replaced with cross form burnable pins.
The main goal of this investigation was to fix the concentration of gadolinium in the pins and to investigate how these burnable pins influences on the heat load pattern.

Fresh zone with burnable pins (flux distribution)



Power distribution in the FA near the water trap

PETERSBURG NUCLEAR PHYSICS INSTITUTE

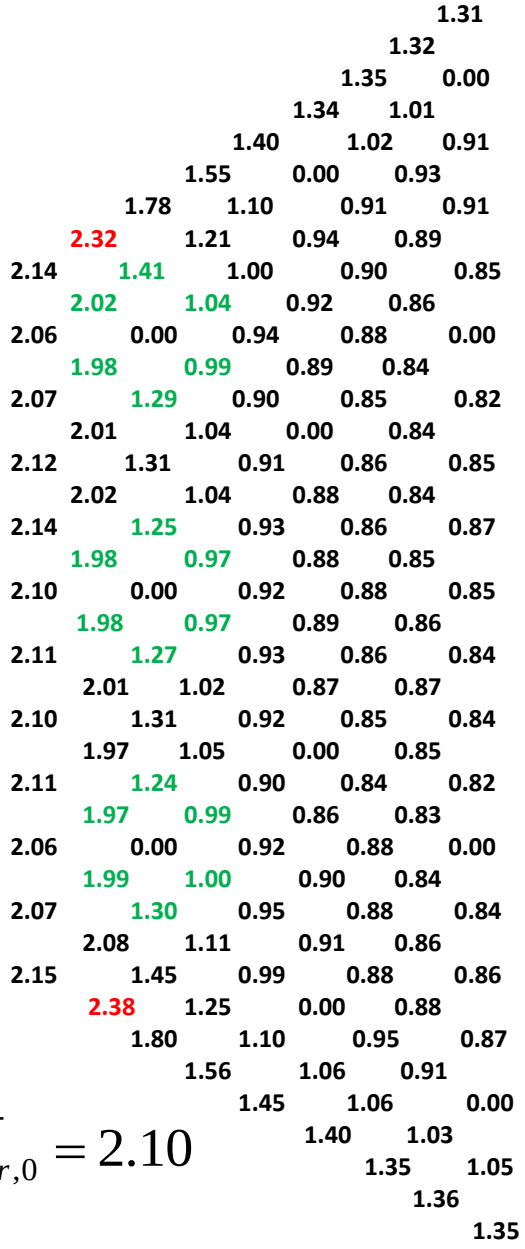


$\bar{k}_{r,0} = 2.14$

$\bar{k}_{r,1} = 1.54$

$\bar{k}_{r,2} = 1.49$

$\bar{k}_{r,3} = 1.51$



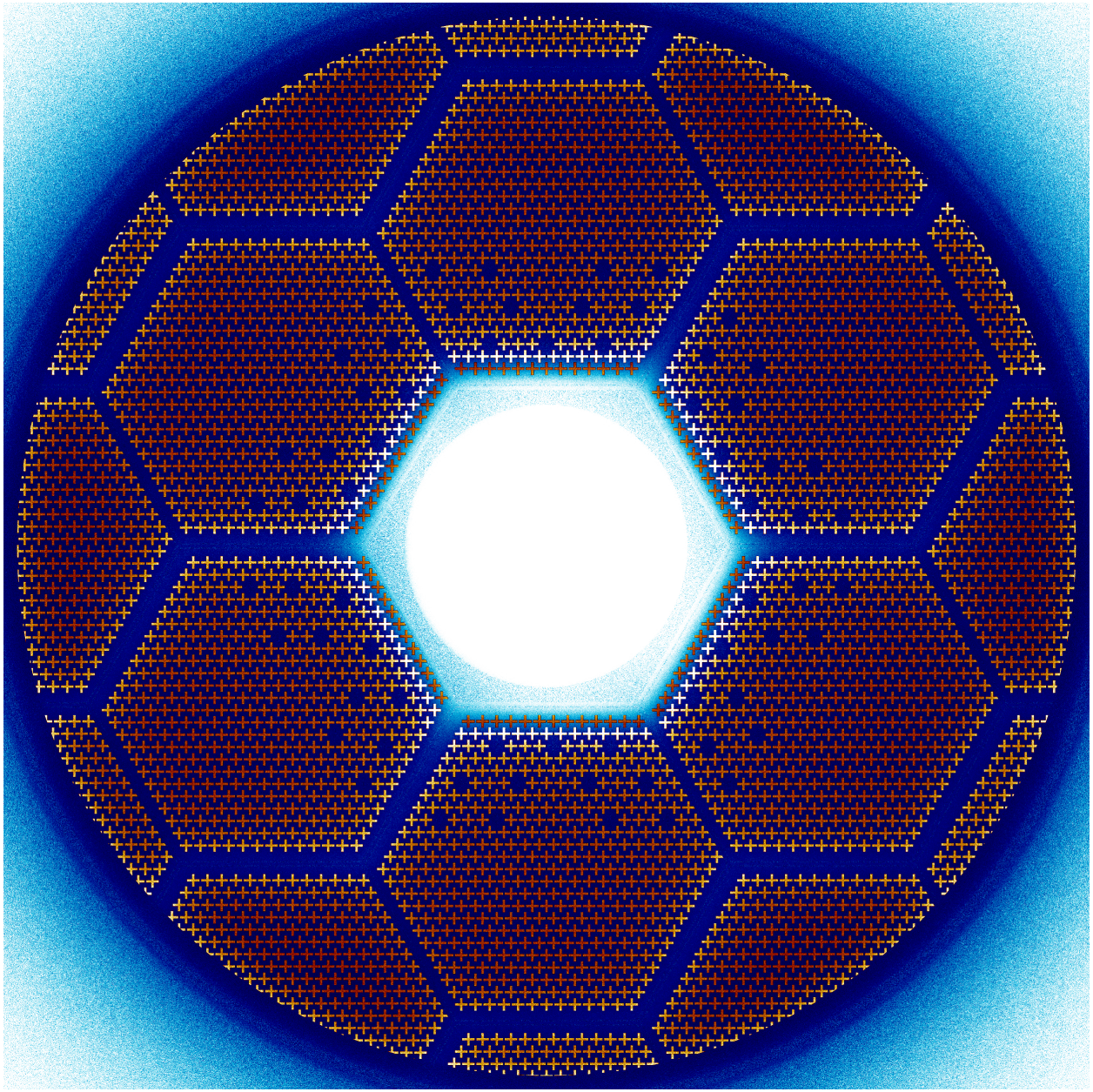
$\bar{k}_{r,0} = 2.10$

$\bar{k}_{r,1} = 1.46$ (-6%)

$\bar{k}_{r,2} = 1.40$ (-6%)

$\bar{k}_{r,3} = 1.42$ (-6%)

Burnt zone with burnable pins (flux distribution)



Power distribution in the FA near the water trap

PETERSBURG NUCLEAR PHYSICS INSTITUTE

1.31
1.32
1.35 0.00
1.34 1.01
1.40 1.02 0.91
1.55 0.00 0.93
1.78 1.10 0.91 0.91
2.32 1.21 0.94 0.89
2.14 1.41 1.00 0.90 0.85
2.02 1.04 0.92 0.86
2.06 0.00 0.94 0.88 0.00
1.98 0.99 0.89 0.84
2.07 1.29 0.90 0.85 0.82
2.01 1.04 0.00 0.84
2.12 1.31 0.91 0.86 0.85
2.02 1.04 0.88 0.84
2.14 1.25 0.93 0.86 0.87
1.98 0.97 0.88 0.85
2.10 0.00 0.92 0.88 0.85
1.98 0.97 0.89 0.86
2.11 1.27 0.93 0.86 0.84
2.01 1.02 0.87 0.87
2.10 1.31 0.92 0.85 0.84
1.97 1.05 0.00 0.85
2.11 1.24 0.90 0.84 0.82
1.97 0.99 0.86 0.83
2.06 0.00 0.92 0.88 0.00
1.99 1.00 0.90 0.84
2.07 1.30 0.95 0.88 0.84
2.08 1.11 0.91 0.86
2.15 1.45 0.99 0.88 0.86
2.38 1.25 0.00 0.88
1.80 1.10 0.95 0.87
1.56 1.06 0.91
1.45 1.06 0.00
1.40 1.03
1.35 1.05
1.36
1.35

$\bar{k}_{r,0} = 2.10$

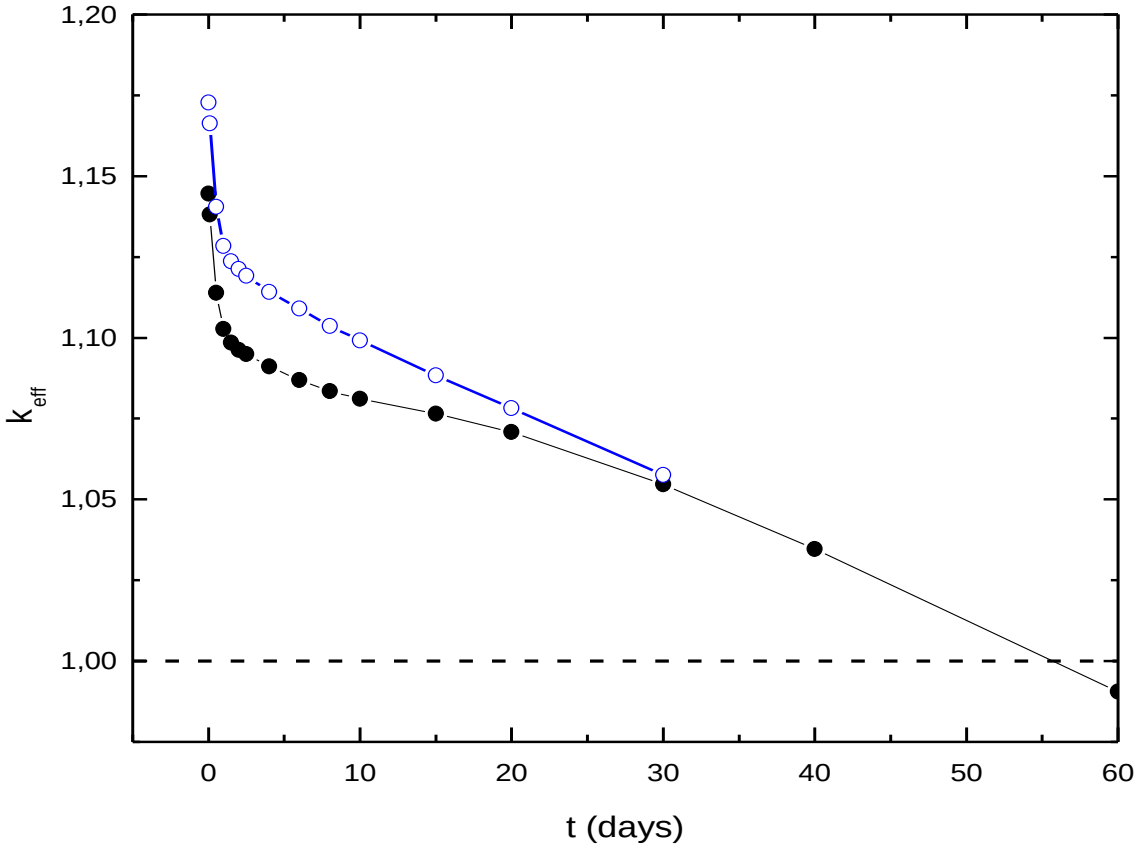
$\bar{k}_{r,1} = 1.46$

$\bar{k}_{r,2} = 1.40$

$\bar{k}_{r,3} = 1.42$

1.37
1.41
1.40 0.00
1.50 1.14
1.55 1.17 1.05
1.66 0.00 1.02
1.93 1.26 1.06 0.95
2.60 1.36 1.10 0.97
0.96 1.67 1.12 0.98 0.94
2.44 1.32 1.04 0.95
0.95 0.00 1.10 0.94 0.00
2.43 1.29 1.00 0.95
0.96 1.56 1.09 0.95 0.90
2.39 1.18 0.00 0.91
0.95 1.52 1.07 0.94 0.86
2.39 1.18 0.97 0.88
0.96 1.57 1.03 0.90 0.85
2.41 1.23 0.95 0.87
0.97 0.00 1.04 0.90 0.84
2.40 1.26 0.95 0.88
0.98 1.56 1.03 0.90 0.85
2.38 1.19 0.98 0.88
0.97 1.49 1.07 0.94 0.86
2.33 1.18 0.00 0.89
0.95 1.55 1.05 0.95 0.88
2.41 1.24 0.99 0.92
0.95 0.00 1.08 0.93 0.00
2.38 1.26 0.99 0.93
0.93 1.60 1.06 0.94 0.90
2.37 1.25 1.04 0.94
0.94 1.61 1.15 0.99 0.92
2.58 1.32 0.00 0.96
1.91 1.22 1.05 0.97
1.63 1.20 1.02
1.50 1.12 0.00
1.44 1.12
1.39 1.11
1.36
1.34

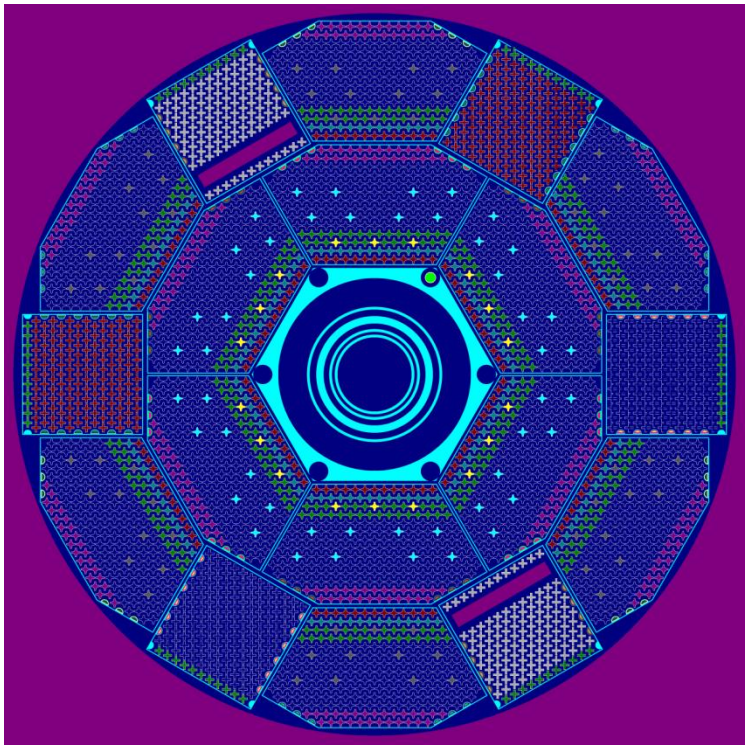
Burn up of the core (Serpent calculations)

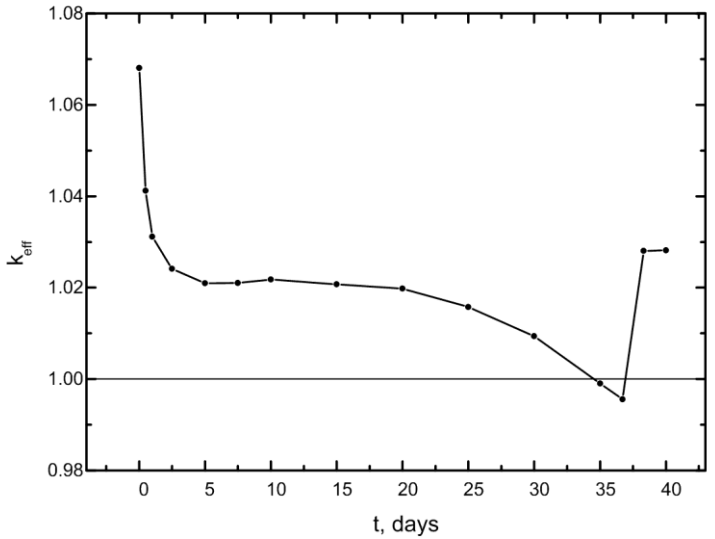


Open circles – without burnable pins
Closed circles – with burnable pins

Duration – 55 days

Operational cycle for the real core with burnable pins (MCU code)





Duration – 35 days. The reducing of the reactivity during transition to worm state of the core; the influence of the surveillance specimens and neutron channels were taken into account.

Thank you for the attention!