JOINT INSTITUTE FOR NUCLEAR RESEARCH

Research reactor "NEPTUN" status report

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Alushta
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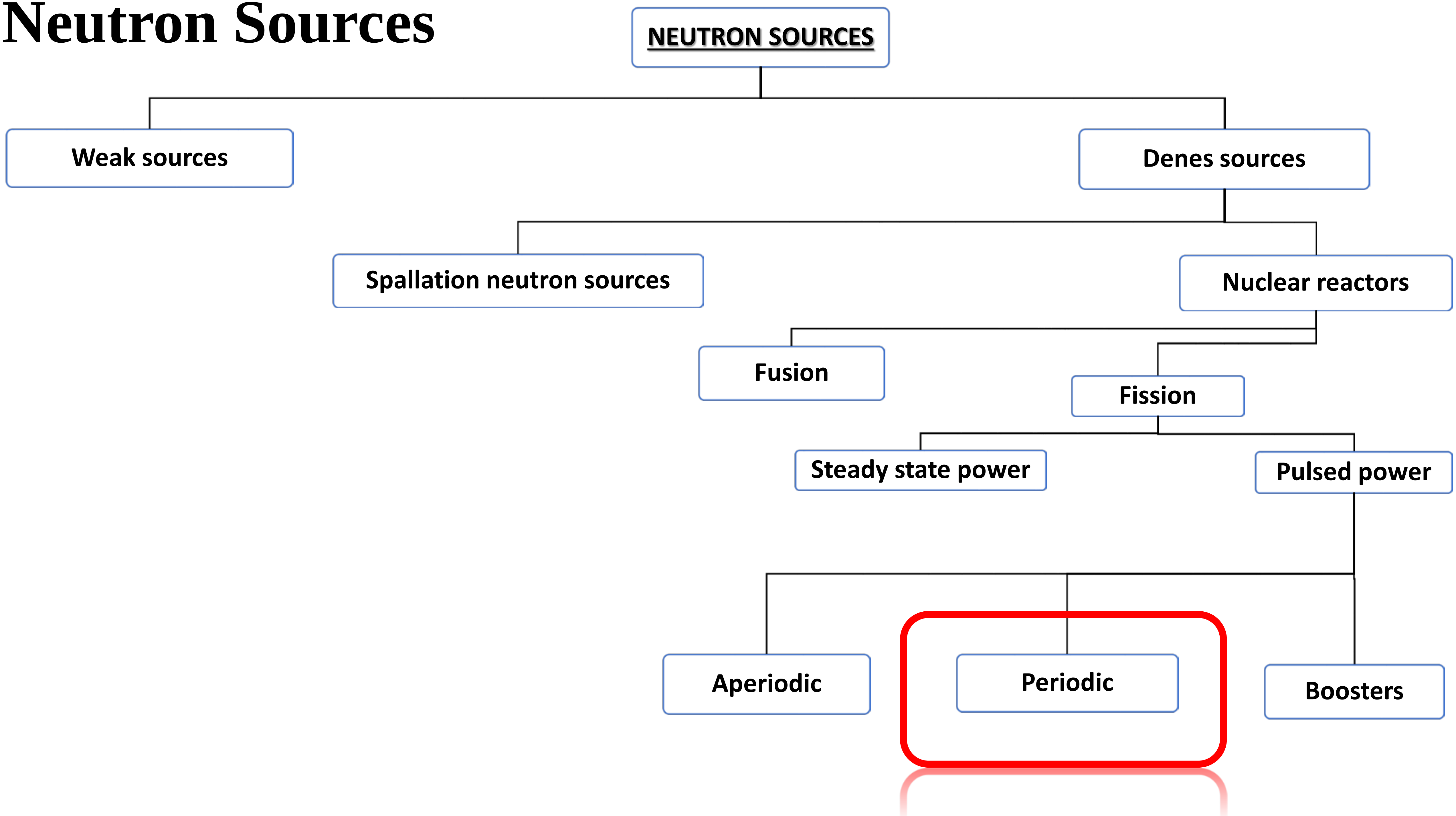
Neutron Sources

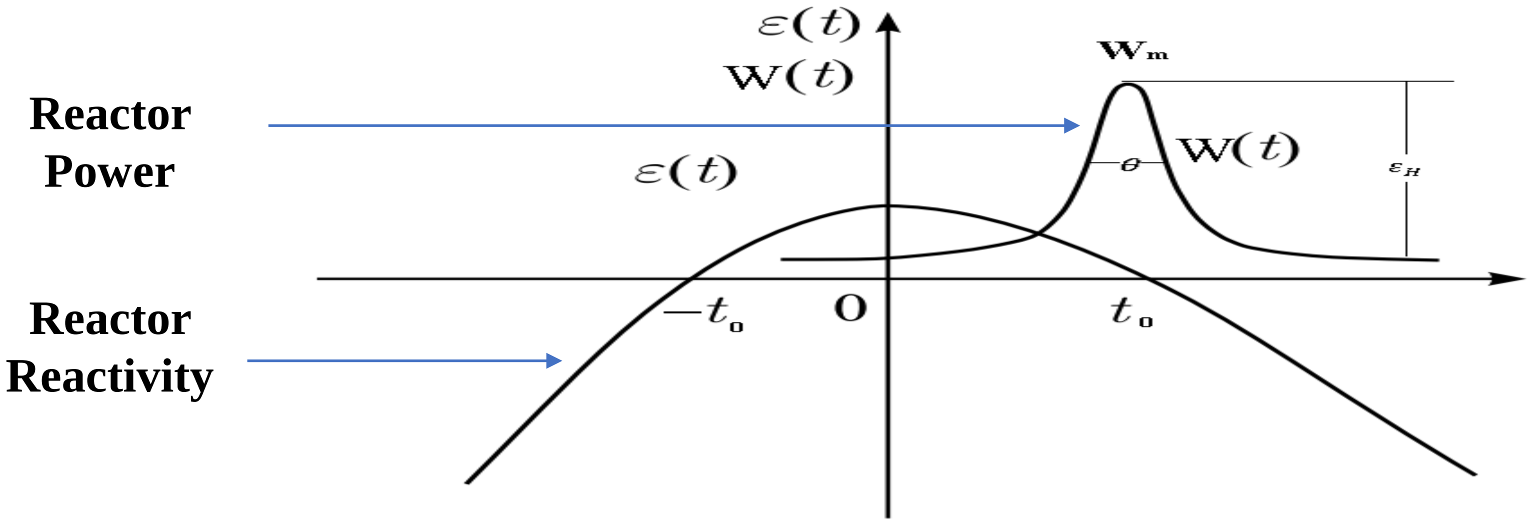


Neutron sources

B) Denes sources : 2- Periodic Pulsed power reactors:

- In 1955- in the Obninsk Pysical-Power institute (Russia), D. I. Blokhintsev suggested the idea of a periodic pulsed reactors with mechanically periodically reactivity modulation.
- To combines the best features of Aperiodic reactors (pulsed nature without any choppers – time of flight) and steady state power reactors (good enough fluence to neutron spectroscopy).

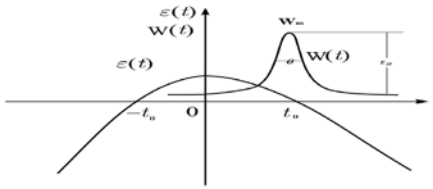
Dmitry Blokhintsev* *(1907-1979)



The course of reactivity and power of the reactor during the development of the power pulse

Neutron sources

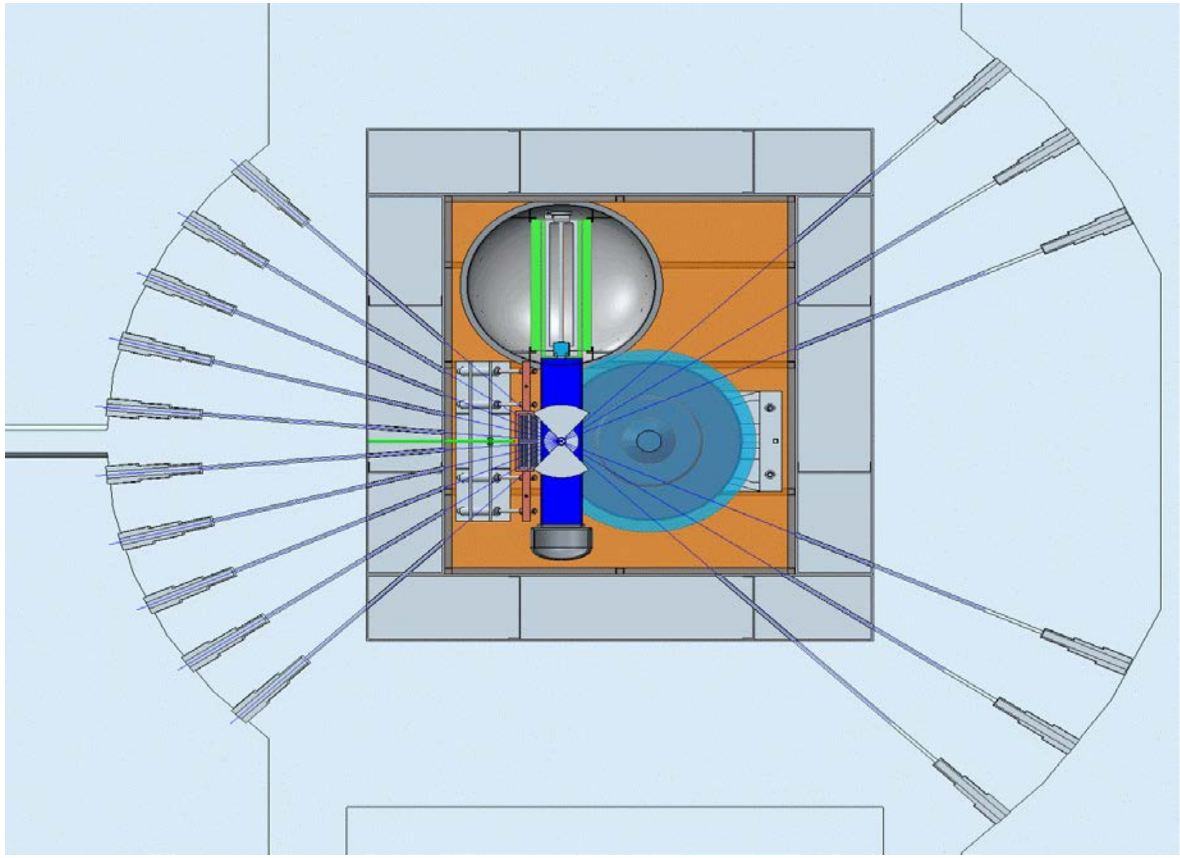
B) Denes sources : 2- Periodic Pulsed power reactors:



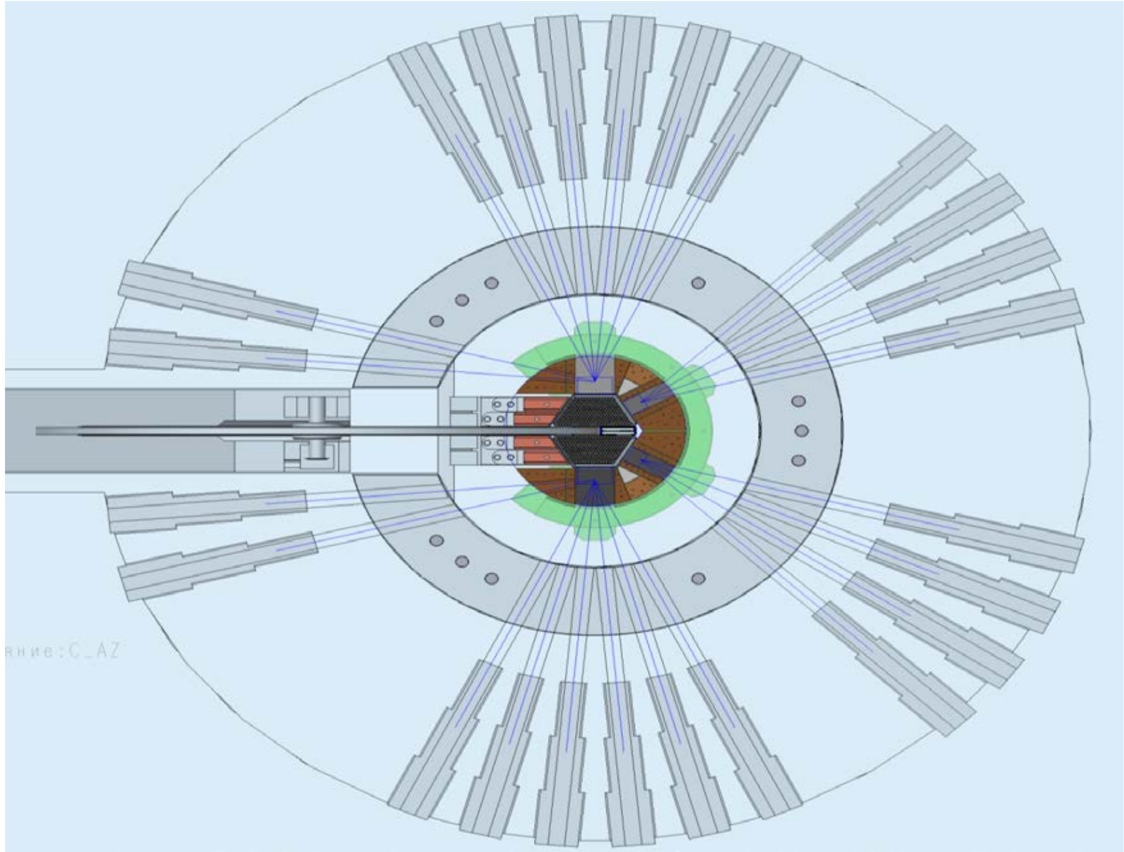
	IBR-1 1960 -1964 - 1968	IBR-30 1968-2001	IBR-2=> IBR-2M from 1984 г	Future Goal IBR-3 (NEPTUNE)
Average thermal power / Peak power	1-3-6 кWт / 25 MWt	20 кWт / 1000 MWt	4 MWт / 8300 MWt 2 MWт / 5200 MWt	12-15 MWт
Working regime	Reactor – Booster ($_{183}^{74}W$)-Microtron	Reactor – Booster ($_{183}^{74}W$)-Linear Resonance acc.	Booster – reactor ($_{183}^{74}W$)- Cf	Reactor
Fissile material	Pu-239 Metal-rods	Pu-239 Metal-rods	PuO_2	NpN
Reactivity modulator, frequency	U-235 5-50 Hz	U-235 0.1 - 100 Hz	Two Moveable reflector from Ni and Al 5-10-25-50 Hz	Neutron Moderator TiH_2+and void, 10 Hz
The half width pulse	30 / 3 μs	70 / 4 μs	240 μs	~200-μs
Average neutron flux at the surface of moderators, см²/ s,	~10^{10}	10^{11}	10^{13}	10^{14}

How can this goal ($10^{14}\ \frac{n}{cm^2.s}$) achieve????

- To achieve this goal, there were two ways, either continue to use Pu-39 as a nuclear fuel or consider a new fuel cycle (Np-as example).



Booster reactor based on Pu-239
16 neutron channel



Reactor based on Np-237
25 neutron channel

How can this goal ($10^{14}\ \frac{n}{cm^2.s}$) achieve???? **CONCLUSTION**

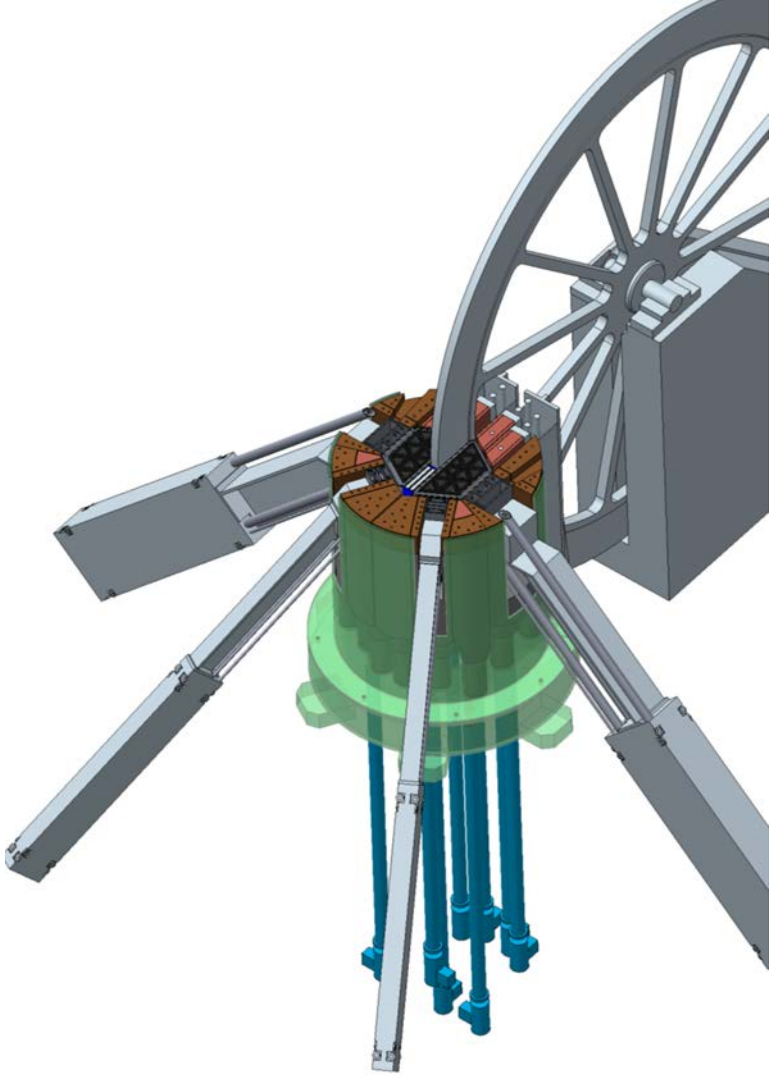
1- To obtain the proposed flux using Pu, accelerator must be used. This complicate the operation and raises the cost.
2- High efficiency of MR, allows to get a high pulse height in a very short time ---- very high peak flux.
3- The generation time of fast neutrons (τ) in the neptunium core is 7-10 times shorter than that in the core with plutonium (the task of having a short pulses of neutrons becomes easier).
4- A low value of the delayed neutrons fraction (β-eff) determines a low background power in the intervals between pulses (3-4 times less).
5- Possibility of using neutron moderating materials as a Reactivity Modulator (RM) (like high-temperature resistance - hydride's metal TiH_2, YH_2).
6- There is no reactivity effect from the fuel burnup (it is possible to work without additional fuel loading during the entire reactor cycle):

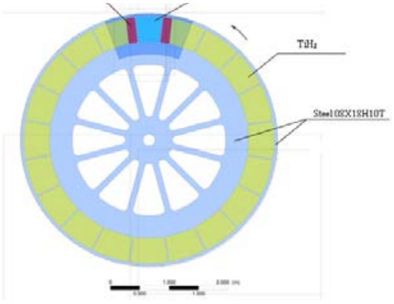
Np237 (n absorption) → Np238 (β-decay, (2.117 days) → Pu238 (Fissionable material)

Character	Reactor NEPTUNE	Booster-Reactor Pu-239
Average power, MWt	15	8,5
Control rod efficiency, %	2,39 (on the basis of n moderation)	4 (on the basis of neutron absorption)
MR efficiency, %	4,1	0,8
Average ther. flux, n/cm2.s	$1{,}0 \times 10^{14}$	$1{,}1 \times 10^{14}$
B-eff	0,0011	0,0024
Neutron generation time, ns	10	100

The main parameters of the reactor

Параметр	Значение
AVERAGE THERMAL POWER , MW	12 - 15
OPERATING MODE	pulsed
PULSE FREQUENCY, Hz	10
FUEL	NpN
CLADDING MATERIAL OF FUEL RODS	S.Steel ЧС-68
COOLER	Na
REFLECTOR	NICKEL ALLOY + BERYLLIUM
MODERATOR, PREMODERATOR	Hydrides, water, beryllium
COOLANT TEMPERATURE AT THE INLET TO THE CORE AND AT THE OUTLET, ^{0}C	290-390
PRESSURE DROP THROUGH THE CORE, Pa	$0{,}33\cdot10^{5}$
FLUENCE ON THE REACTOR SURROUNDING’S FOR 20,000 h, n / CM^{2}	$4{,}1\cdot10^{22}$
AVERAGE NEUTRON THERMAL FLUX AT THE SURFACE OF WATER MODERATOR, 2π- equivalent 10^{13} cm^{-2}·sec^{-1}	12
EFFECTIVE FRACTION OF DELAYED NEUTRONS	0,00131
GENERATION TIME OF THE SPONTANEOUS NEUTRONS , n,sec	10





THE MAIN NEUROTIC PROBLEMS THAT FACED REACTOR NEPTUNE, AND THE PROPOSALS TO SOLVE THEM.

- 1- The problem of non-stationary in reactor's power: with insertion a very small amount of reactivity to the reactor, the reactor power increases exponentially with time (the reactor is very sensitive to a very small amount of reactivity).

Solution

- Increasing the value β-pulsed, through increasing the :

A. The fast neutron generation time, by insert a high enriched U or Pu in reactor core;

B. Increasing the linear velocity of MR from 64 to 100 m/s.

$$\frac{Q_n}{Q_0} = e^{\left(\frac{\Delta\rho}{\beta_{puls}}\right)} \qquad (1)$$

$$\theta_{effective} \cong \left(\frac{\tilde{\tau}}{\alpha V^2}\right)^{\frac{1}{3}} \qquad (2)$$

$$\beta_{puls} \cong 0.5 \left(\propto V^2 \tilde{\tau}^2\right)^{\frac{1}{3}} \qquad (3)$$

$$T = \frac{\frac{\gamma_1}{\alpha_1}+\frac{\gamma_2}{\alpha_2}}{\Delta K} - \gamma_1\tau_2 = \frac{\gamma_1\tau_1 + \gamma_2\tau_2}{\Delta K} - \gamma_1\tau_2 = \frac{\tilde{\tau}}{\Delta K} - \gamma_1\tau_2 \qquad (4)$$

where;

$\theta_{effective}$: pulse duration, Q : pulse energy power

α : The coefficient of parabola for RM perturbation curve

V : Linear velocity of RM ,

$\tilde{\tau}$: Average neutron generation time,

β_{pulse} : Impulse delayed neutron fraction,

T : Reactor period.

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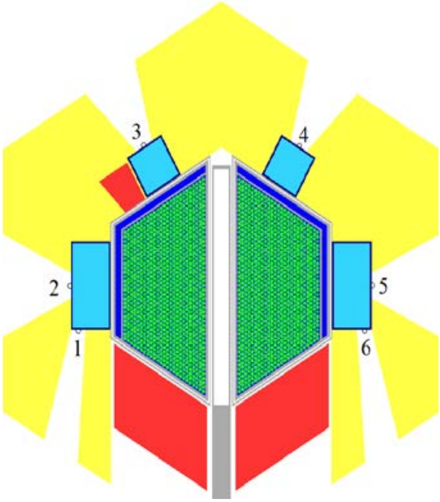
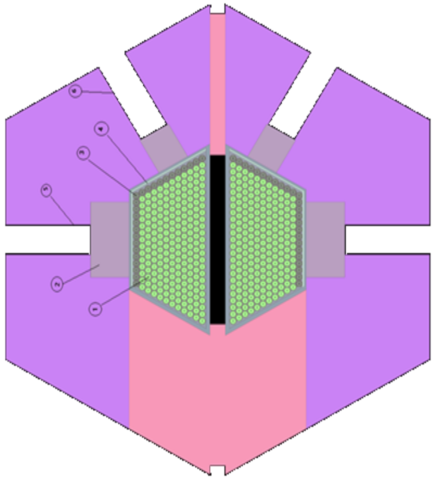
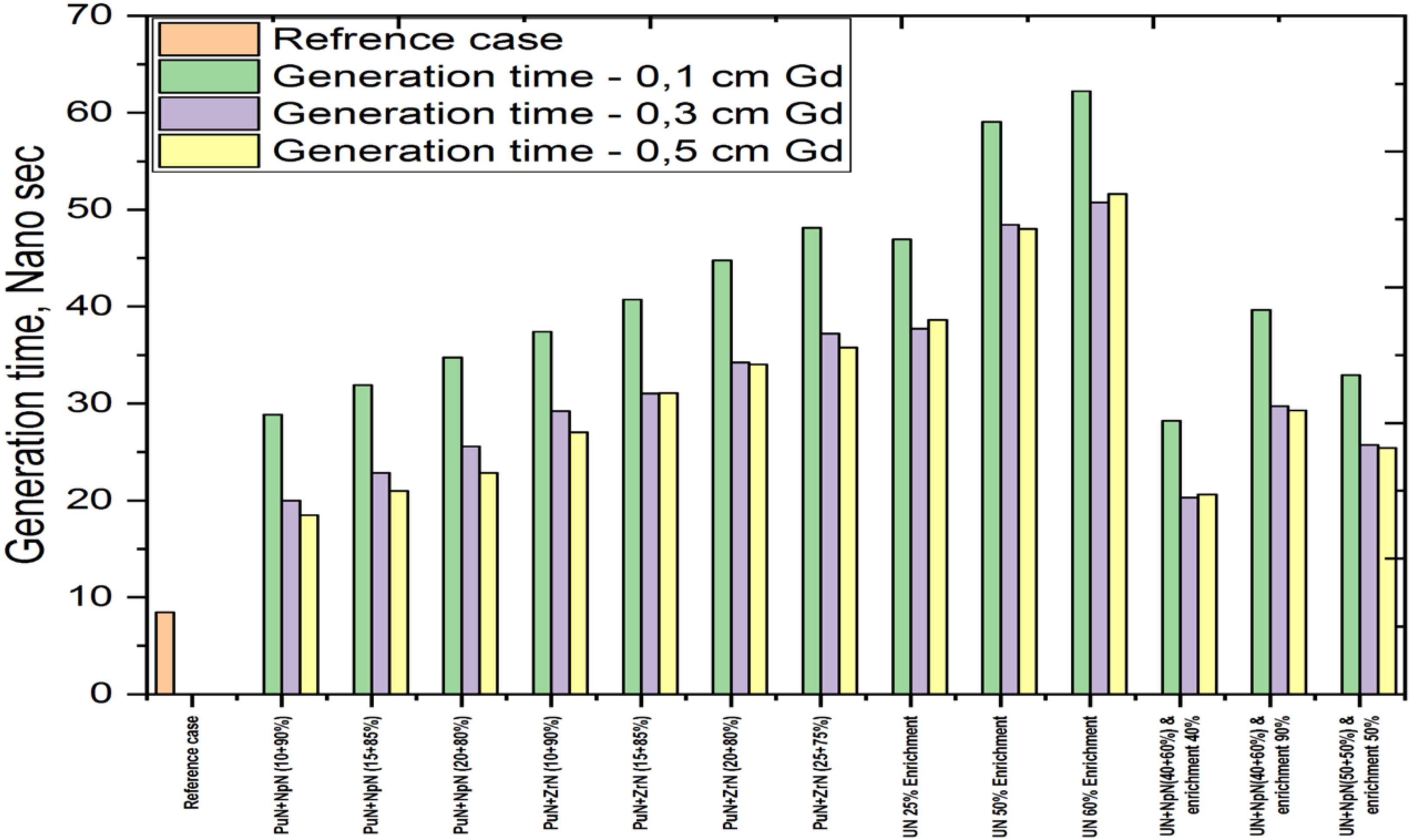
1- The problem of non-stationary in reactor's power:







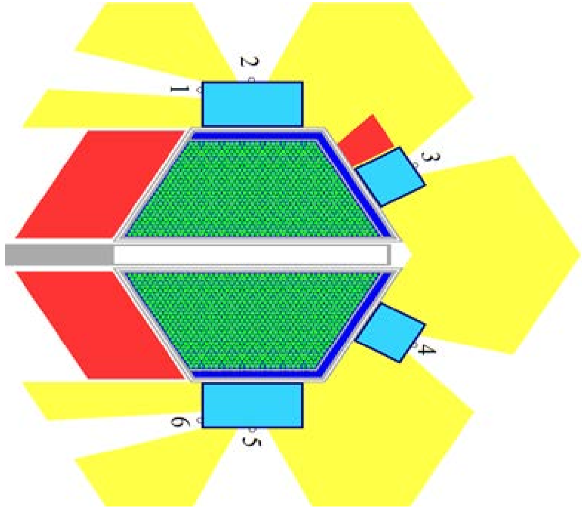
THE MAIN NEUROTIC PROBLEMS THAT FACED REACTOR NEPTUNE, AND THE PROPOSALS TO SOLVE THEM.

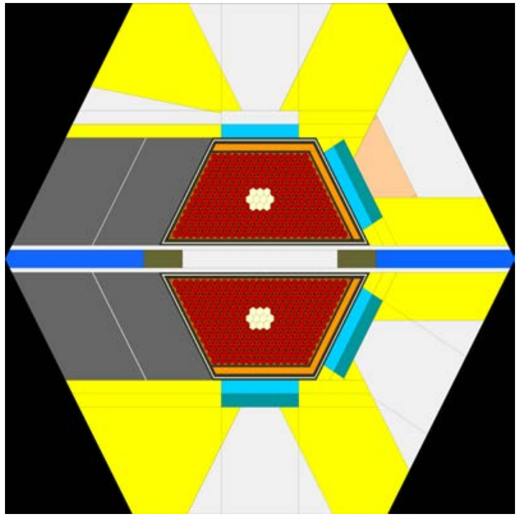
2- The problem of low efficiency of reactor rods:

Solution

Insert control rod (CR) inside the reactor (as a result of calculations it was decided to use for the first time moderator material as a CR instead of neutron absorber) to increase there efficiency from 2,39 to 3,7% to maintain a safe reactor operation with company life time.

As a result the power production was increased in each fuel rod, so the height of fuel column increased by 30 mm to reduce the power density production in fuel rods.



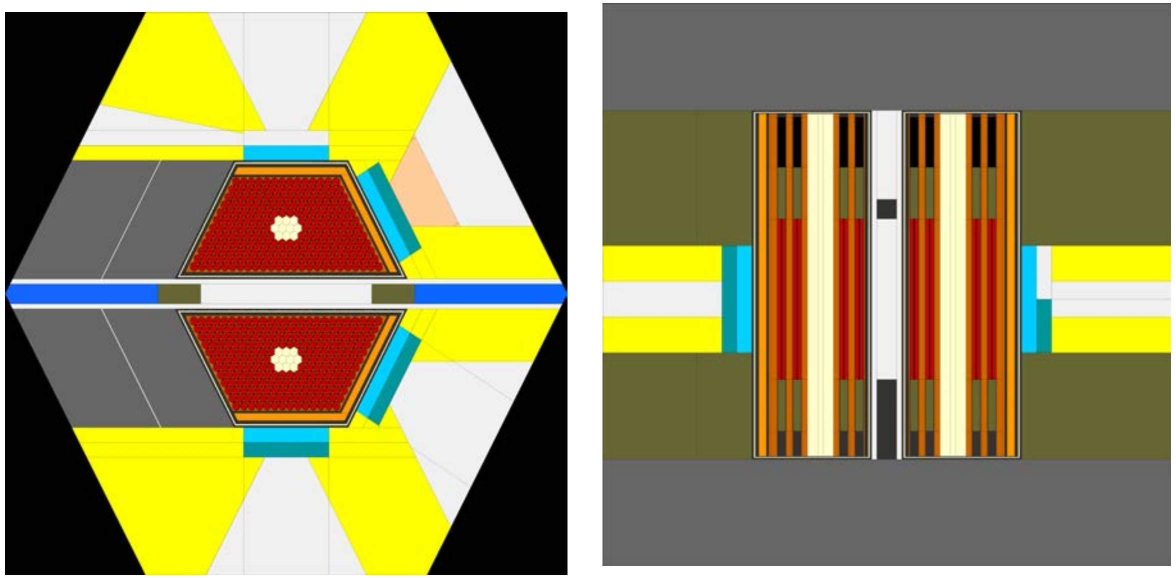


THE MAIN NEUROTIC PROBLEMS THAT FACED REACTOR NEPTUNE, AND THE PROPOSALS TO SOLVE THEM.

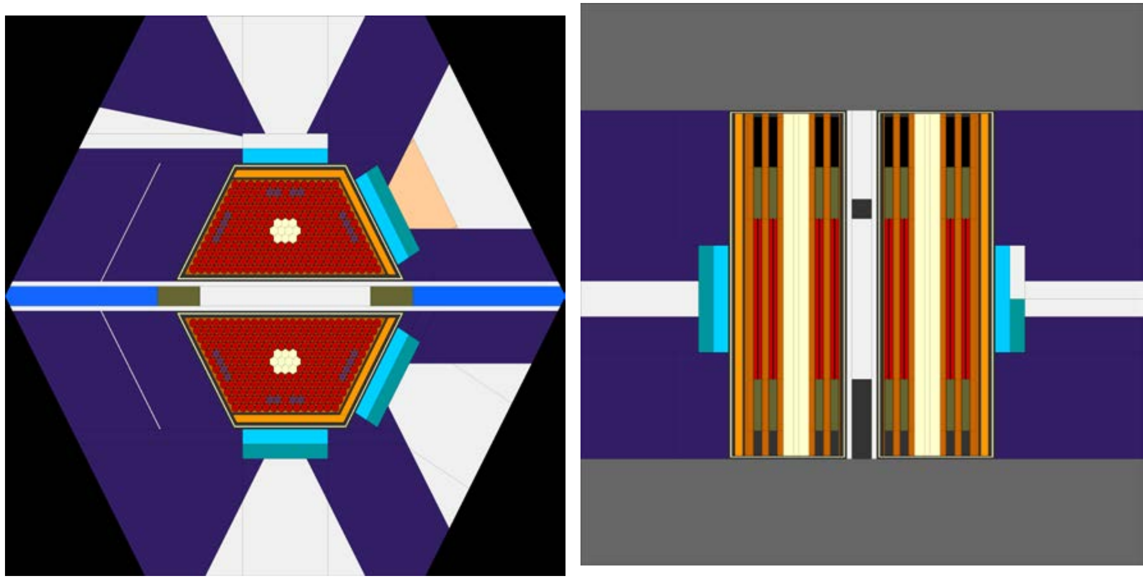
3- The problem of using high enriched U (90%) to increase the generation time: nonproliferation laws prohibit the use of enriched U higher than 20% in research reactors.

Solution

- **Using a new reflector made from Pb-208 instead of Be and Ni.**
- **This will increase the generation time through a deep penetration of neutrons into the reflector and long return to the core with high probability and the other part through the fission in low enriched U.**



Reflector --- Ni + Be



Reflector --- Pb-208

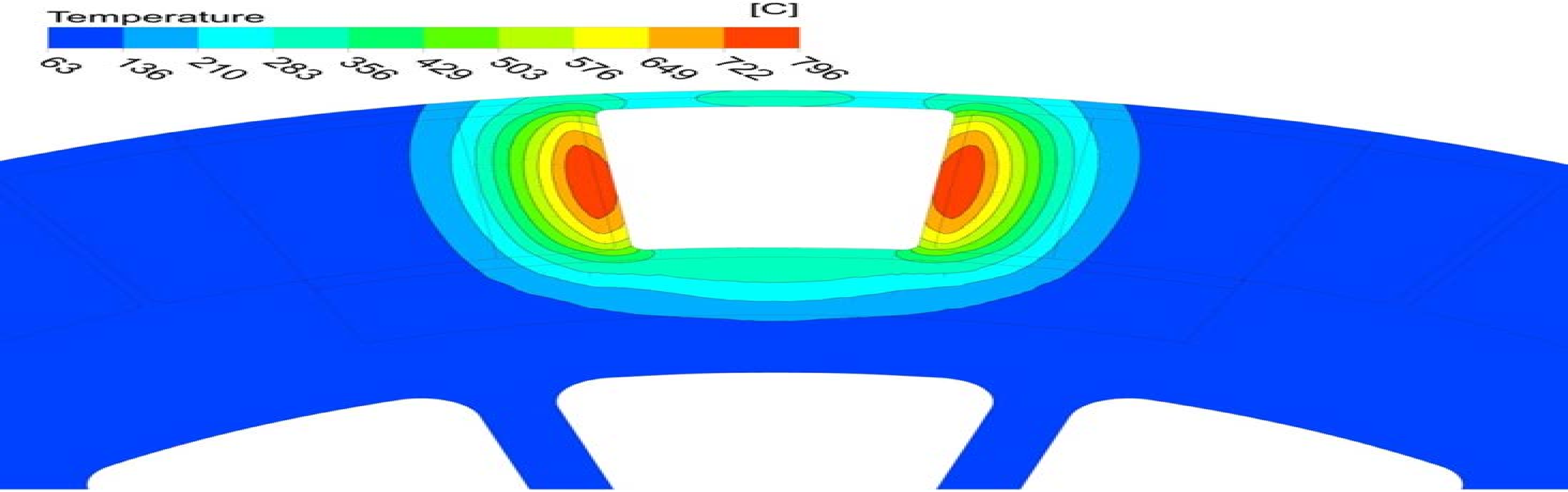
THE MAIN NEUROTIC PROBLEMS THAT FACED REACTOR NEPTUNE, AND THE PROPOSALS TO SOLVE THEM.

3- The problem of using high enriched U (90%) to increase the generation time:

	K-эфф	Max. efficiency of RM	Generation time, ns
1- initial solution	1,0143	1,49%	9,97154
2- U(5%)N 100% + 0% NpN	1,00242	1,65%	33,3602
3- U(5%)N 25% + NpN 75%	1,01631		13,3972
4- U(5%)N 50% + NpN 50%	1,01124		16,6921
5- U(5%)N 75% + NpN 25%	1,01326		15,5914
6- U(10%)N 25% + NpN 75%	1,01669		15,227
7- U(10%)N 50% + NpN 50%	1,01239		20,8807
8- U(10%)N 75% + NpN 25%	1,00844		28,7854
9- U(15%)N 25% + NpN 75%	1,0173		16,3718
10- U(15%)N 50% + NpN 50%	1,01368		23,2121
11- U(15%)N 75% + NpN 25%	1,01007		32,2773
12- U(20%)N 25% + NpN 75%	1.01805		19.3032
13- U(20%)N 50% + NpN 50%	1.01491		26.7414
14- U(20%)N 75% + NpN 25%	1.01173		35.7730

THE MAIN NEUROTIC PROBLEMS THAT FACED REACTOR NEPTUNE, AND THE PROPOSALS TO SOLVE THEM.

4- Reduced heat load on Ti**H2** in the MR: The slide shows that the temperature of titanium TiH2 at the edges of the empty sector reaches 700 degrees, and it is known that the use of TiH2 is limited to a temperature of 500 degrees. After that, the hydrogen content in it decreases. Reducing the thermal load on titanium hydride leads to a significant extension of the service life of the reactivity modulator.

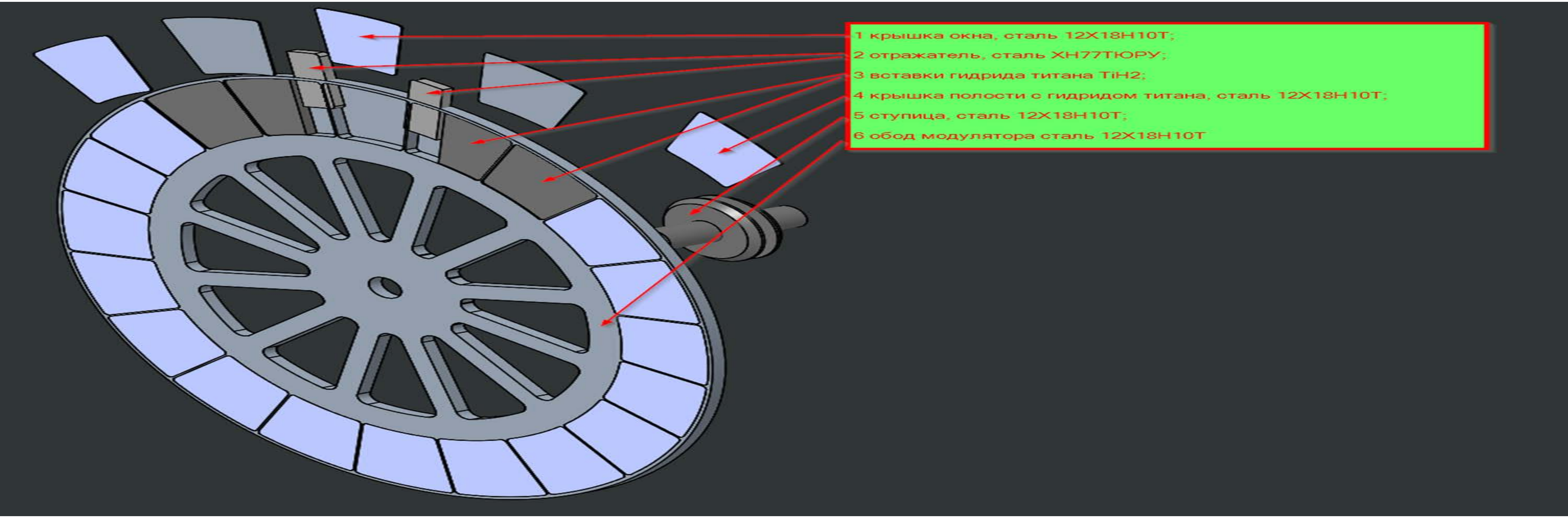


THE MAIN NEUROTIC PROBLEMS THAT FACED REACTOR NEPTUNE, AND THE PROPOSALS TO SOLVE THEM.

4- Reduced heat load on Ti**H2** in the MR:

Solution

- it is proposed to install additional nickel reflectors on the border of the empty sector and the sector with titanium hydride.

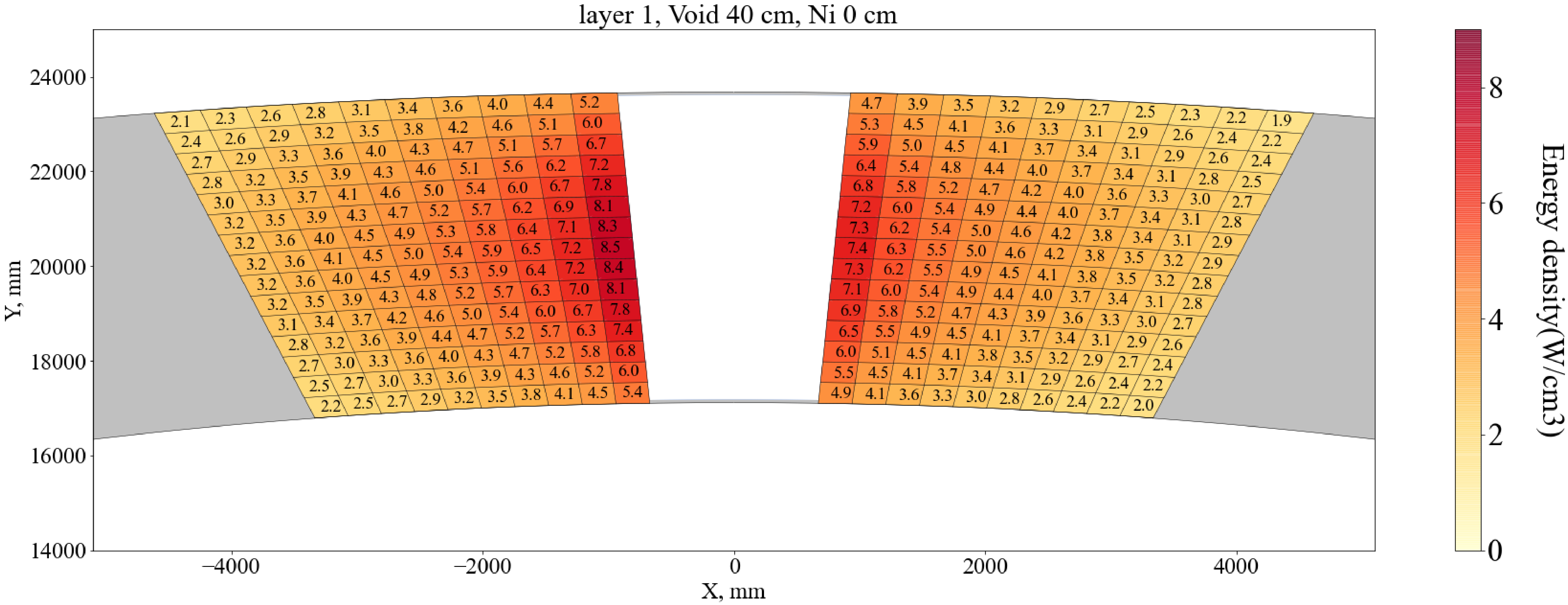


Зависимость максимального удельного тепловыделения в диске модулятора (Вт/см3), максимального эффекта смещения модулятора (%) и α – параметра (см-2) от изменения ширины вакуума и толщины Ni

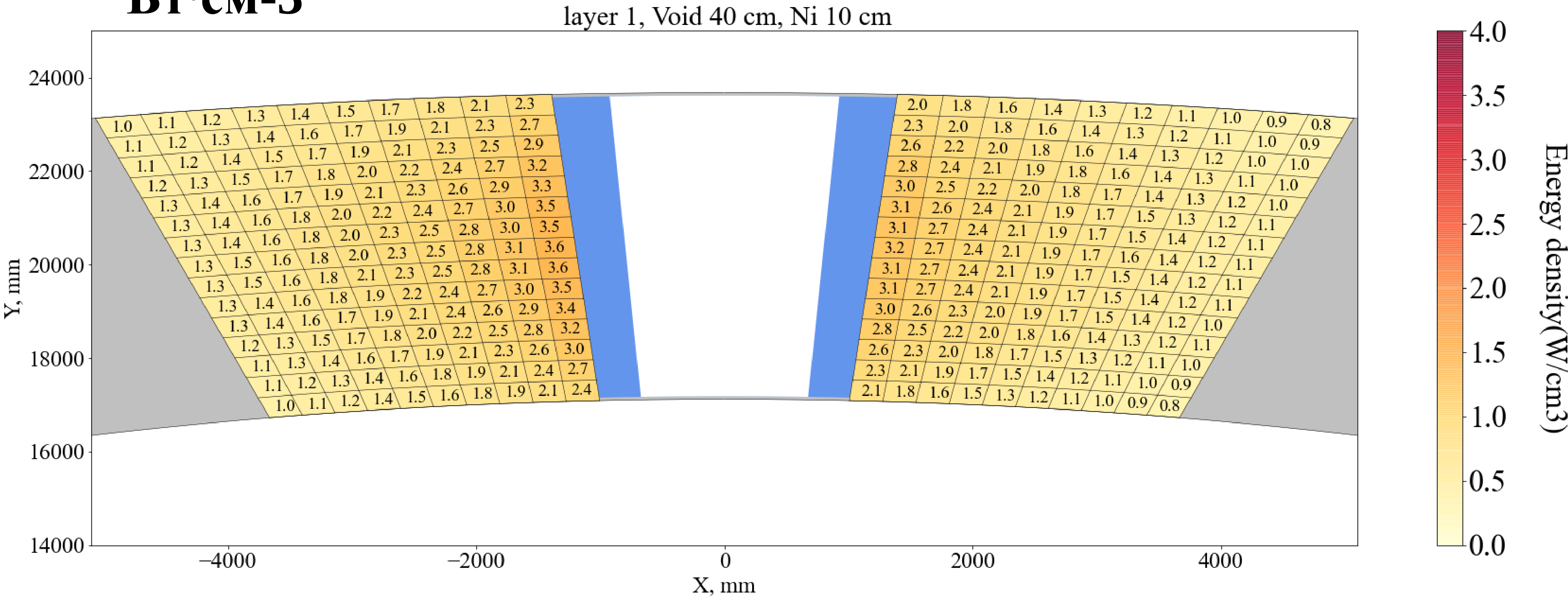
	Максимальный удельная тепловыделения , Вт/см3							
	0 cm Ni			5 cm Ni			10 cm Ni	
	Справа	Слева		Справа	Слева		Справа	Слева
30 cm вакуум	9,65634	10,5207		6,66692	7,75357		4,48174	5,43119
35 cm вакуум	8,5089	9,52174		5,55672	6,59312		3,82486	4,4615
40 cm вакуум	7,41187	8,45502		4,71953	5,61119		3,22433	3,61275
45 cm вакуум	6,3444	7,32191		4,00864	4,68787		2,59712	2,93969

	30 cm Вакуум, 0 см Ni	30 cm Вакуум, 5 см Ni	30 cm Вакуум, 10 см Ni		35 cm Вакуум, 0 см Ni	35 cm Вакуум, 5 см Ni	35 cm Вакуум, 10 см Ni		40 cm Вакуум, 0 см Ni	40 cm Вакуум, 5 см Ni	40 cm Вакуум, 10 см Ni		45 cm Вакуум, 0 см Ni	45 cm Вакуум, 5 см Ni	45 cm Вакуум, 10 см Ni
Максимальный эффект смещения модулятора, %	6,29%	7,13%	7,50%		6,73%	7,37%	7,59%		7,01%	7,46%	7,61%		7,17%	7,48%	7,59%
α -параметр, см-2	1,37E-04	1,24E-04	9,82E-05		1,21E-04	9,88E-05	6,81E-05		9,01E-05	6,04E-05	3,85E-05		5,40E-05	2,92E-05	1,28E-05

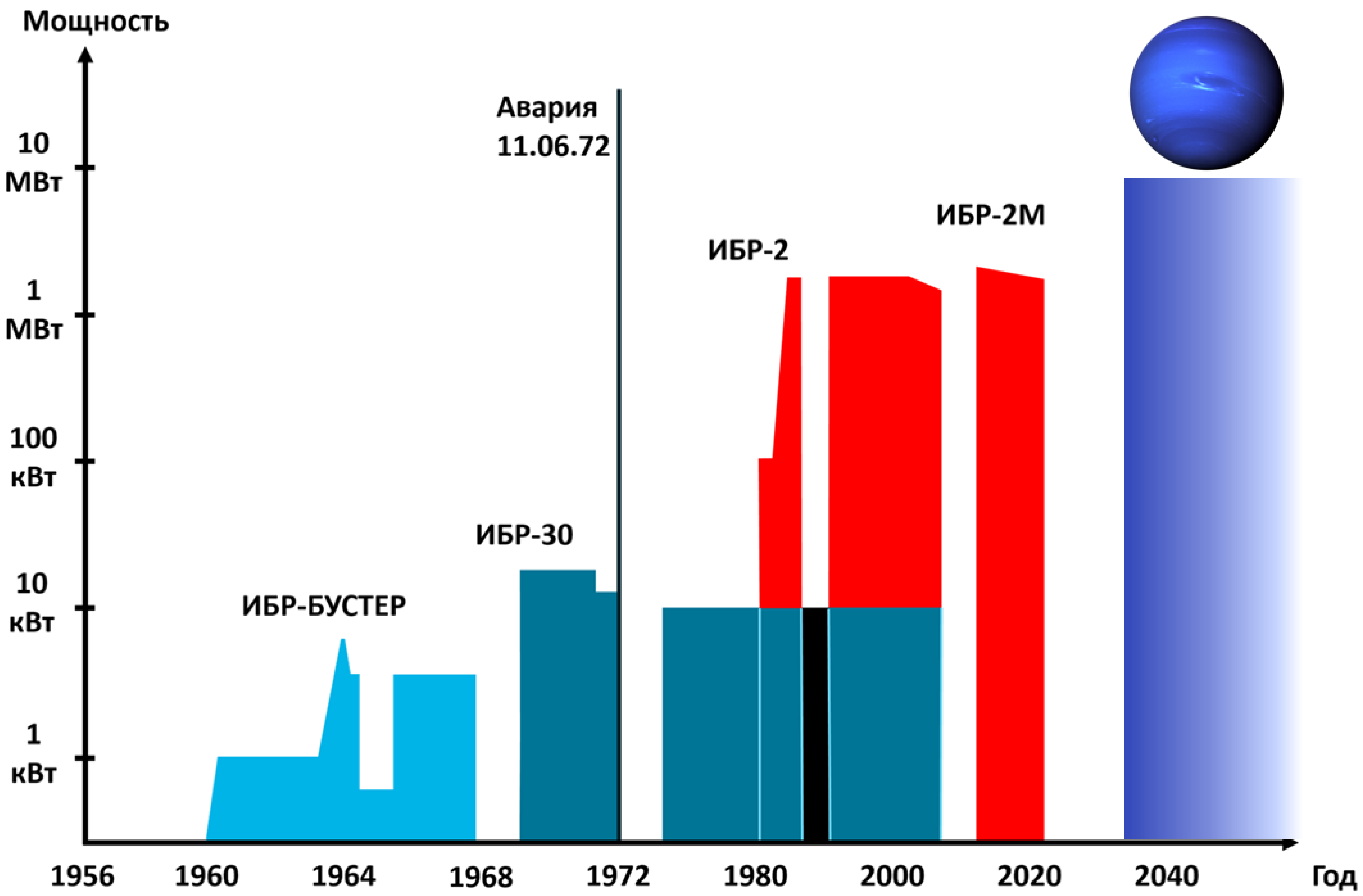
Удельные тепловыделения в диске модулятора без установки дополнительного никелевого отражателя, Вт·см-3



Удельные тепловыделения в диске модулятора с установкой 10 см дополнительного никелевого отражателя, Вт·см-3



Thank you
Any questions?


Мощность
10
МВт
1
МВт
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кВт
10
кВт
1
кВт
Авария
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ИБР-БУСТЕР
ИБР-30
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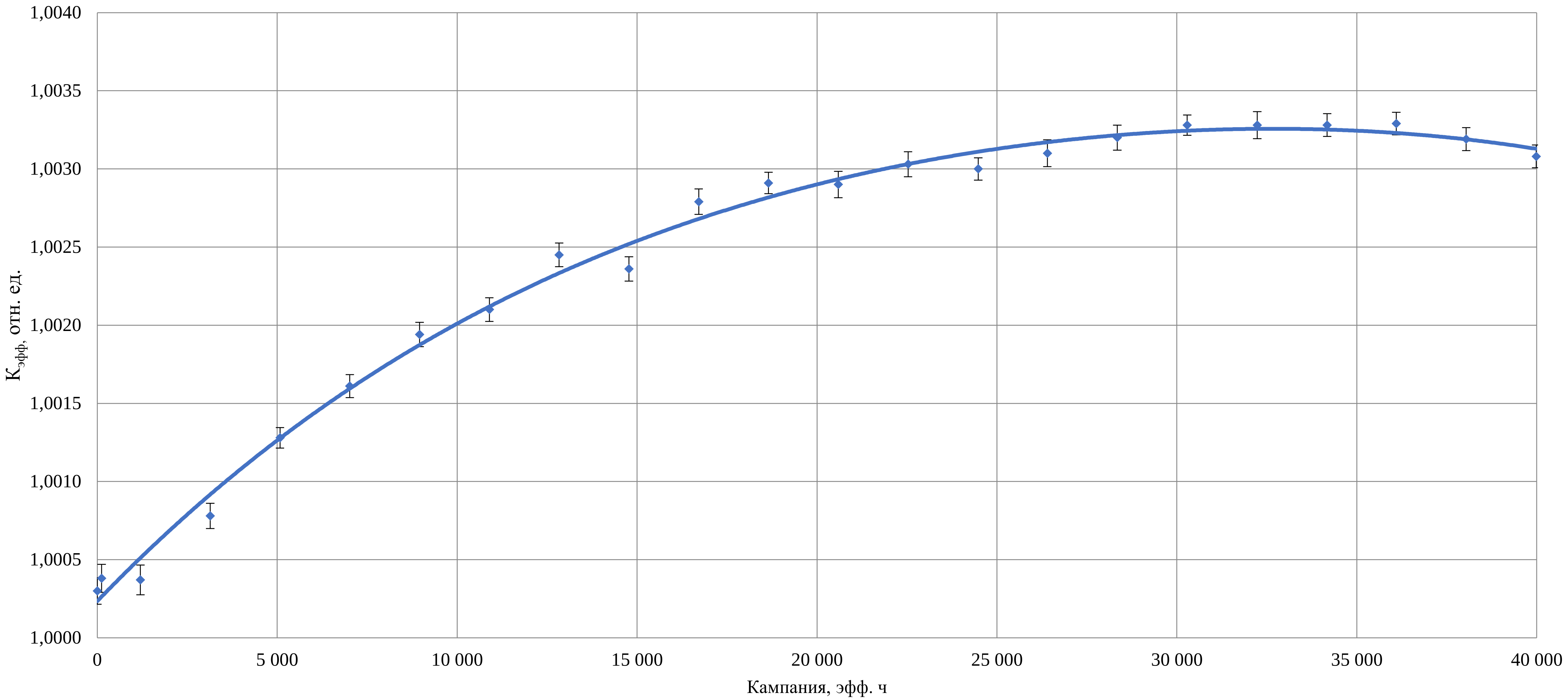

Change of K-eff with reactor company time