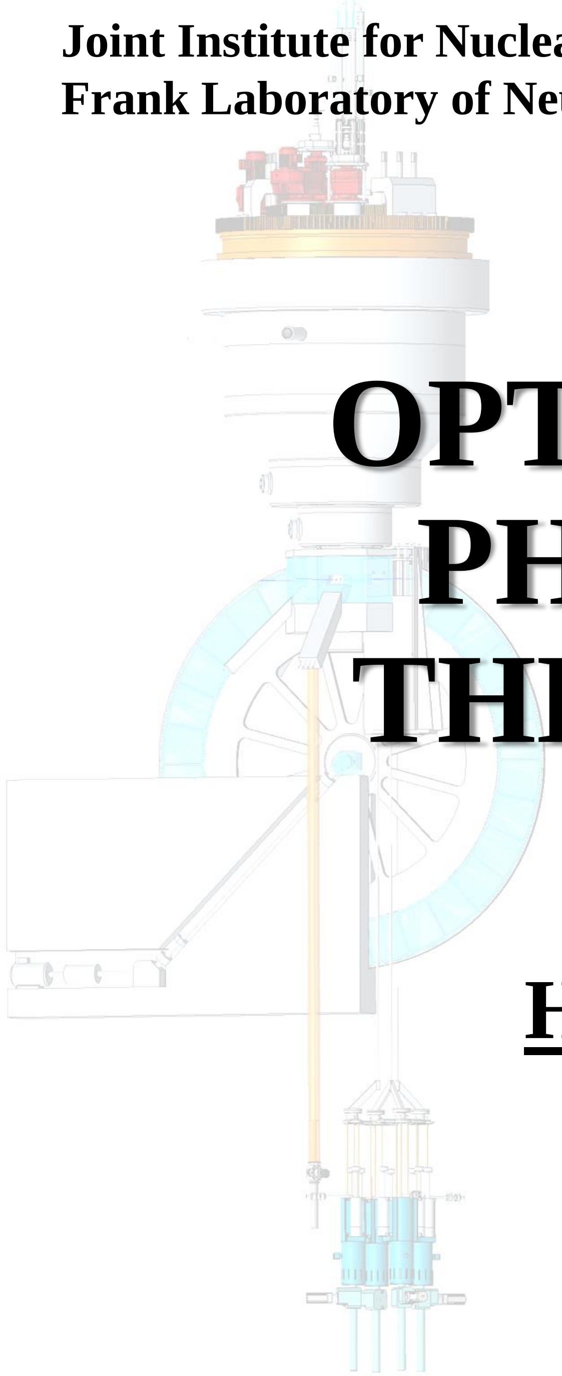
Joint Institute for Nuclear Research
Frank Laboratory of Neutron Physics



OPTIMIZATION OF NEUTRON PHYSICS PARAMETERS OF THE NEW PULSED NUCLEAR REACTOR NEPTUNE

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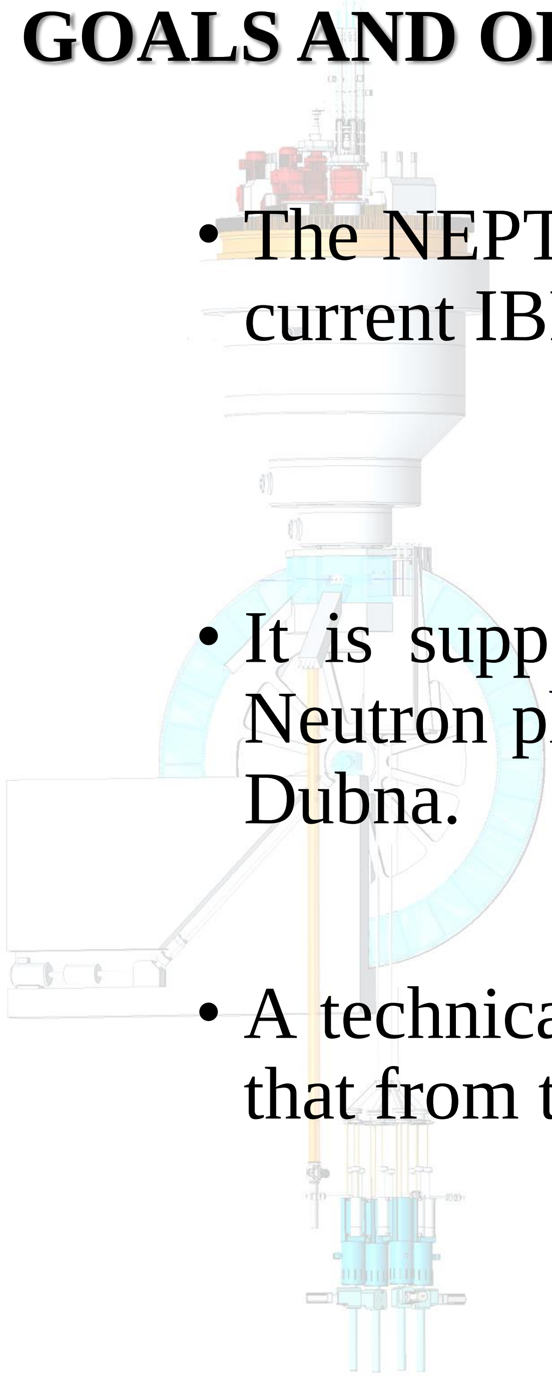
ISINN-30

Sharm Alsheikh - Egypt
2024

GOALS AND OBJECTIVES



- The NEPTUNE reactor is one of the proposed alternatives to replace the current IBR-2M reactor after it is out of service.

- It is supposed to work as a neutron source within the Laboratory of Neutron physics at the Joint Institute for Nuclear Research in the city of Dubna.

- A technical goal was set, to obtain an average neutron flux higher than that from the current IBR-2M reactor by one order of magnitude.

1- MAIN FEATURES OF THE REACTOR NEPTUN:

1. The proposed source will have a peak neutron flux up to $5 \times 10^{17}\ n/sec^{1}.cm^{2}$ and a time average flux density of up to $1.2\times 10^{14}\ n/sec^{1}.cm^{2}$ (in IBR – 2M: 0.7×10^{16} and 10^{13}).

2. Using the fission-threshold isotope Np-237 for the first time as a nuclear fuel, resulting in:

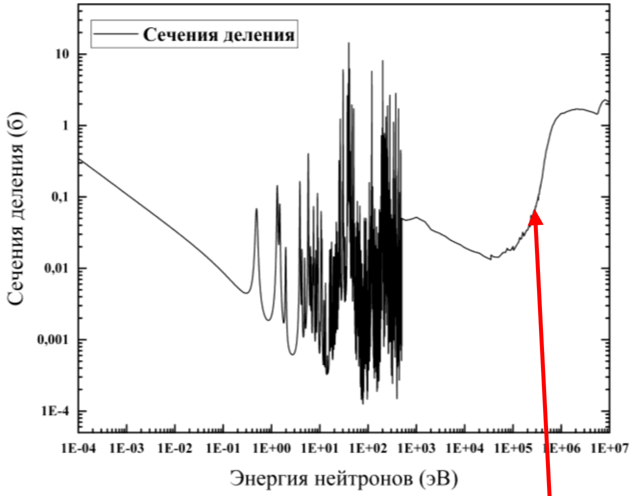
- The generation time of fast neutrons (***τ***) in the neptunium core is 5-7 times shorter than that in the core with plutonium (the task of having a short pulses of neutrons becomes easier).

- A low value of the effective delayed neutrons fraction (***β*-eff**) determines a low background power in the intervals between pulses (3-4 times less Pu).

- Possibility of using neutron moderating materials as a Reactivity Modulator (RM) or control rod (like hydride's metal **Ti**H_2, **Y**H_2).

- There is no reactivity effect from the fuel burnup (it is possible to work without additional fuel loading during the entire reactor cycle):

Np-237 (n absorption) → Np-238 (β-decay, (2.117 days) → Pu-238 (Fissionable material)



Fission cross section of Np-237

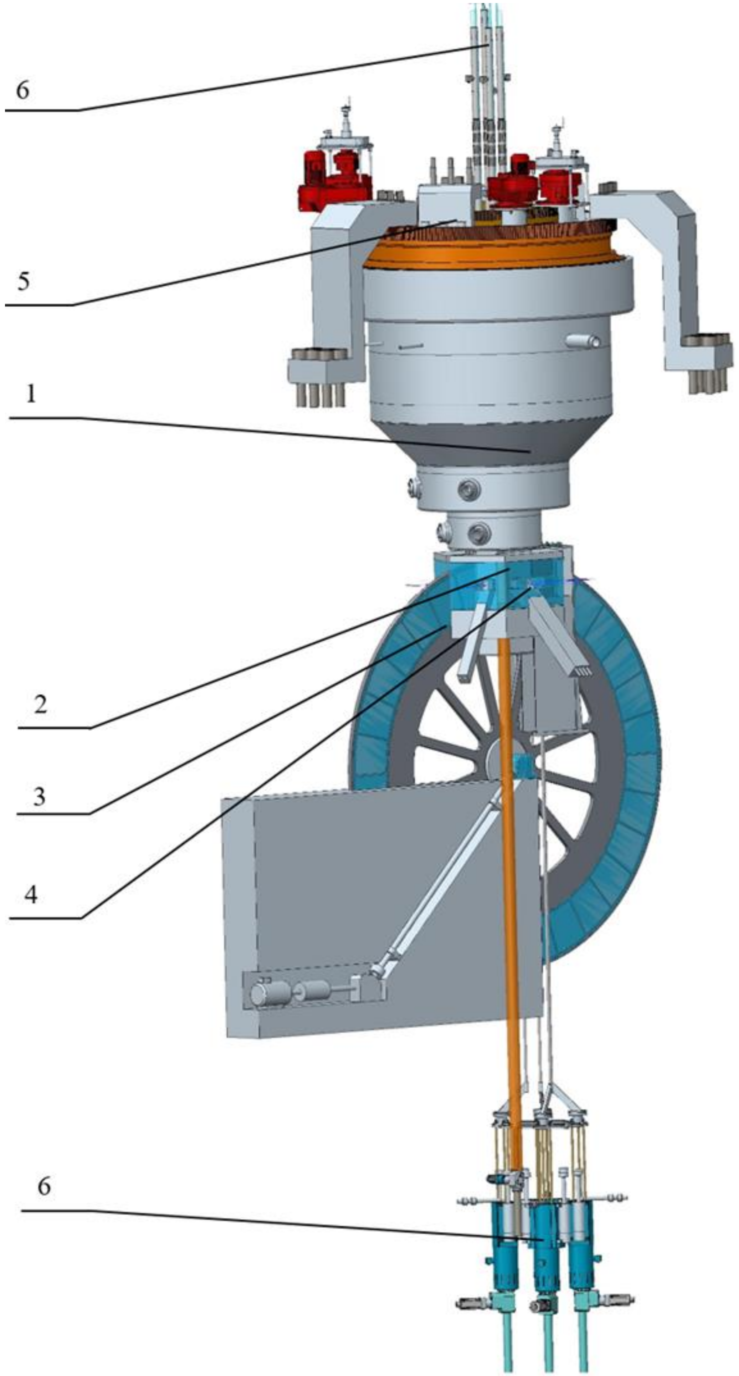
Fission threshold at 0,4 MeV

2-THE MAIN PARAMETERS OF THE REACTOR:

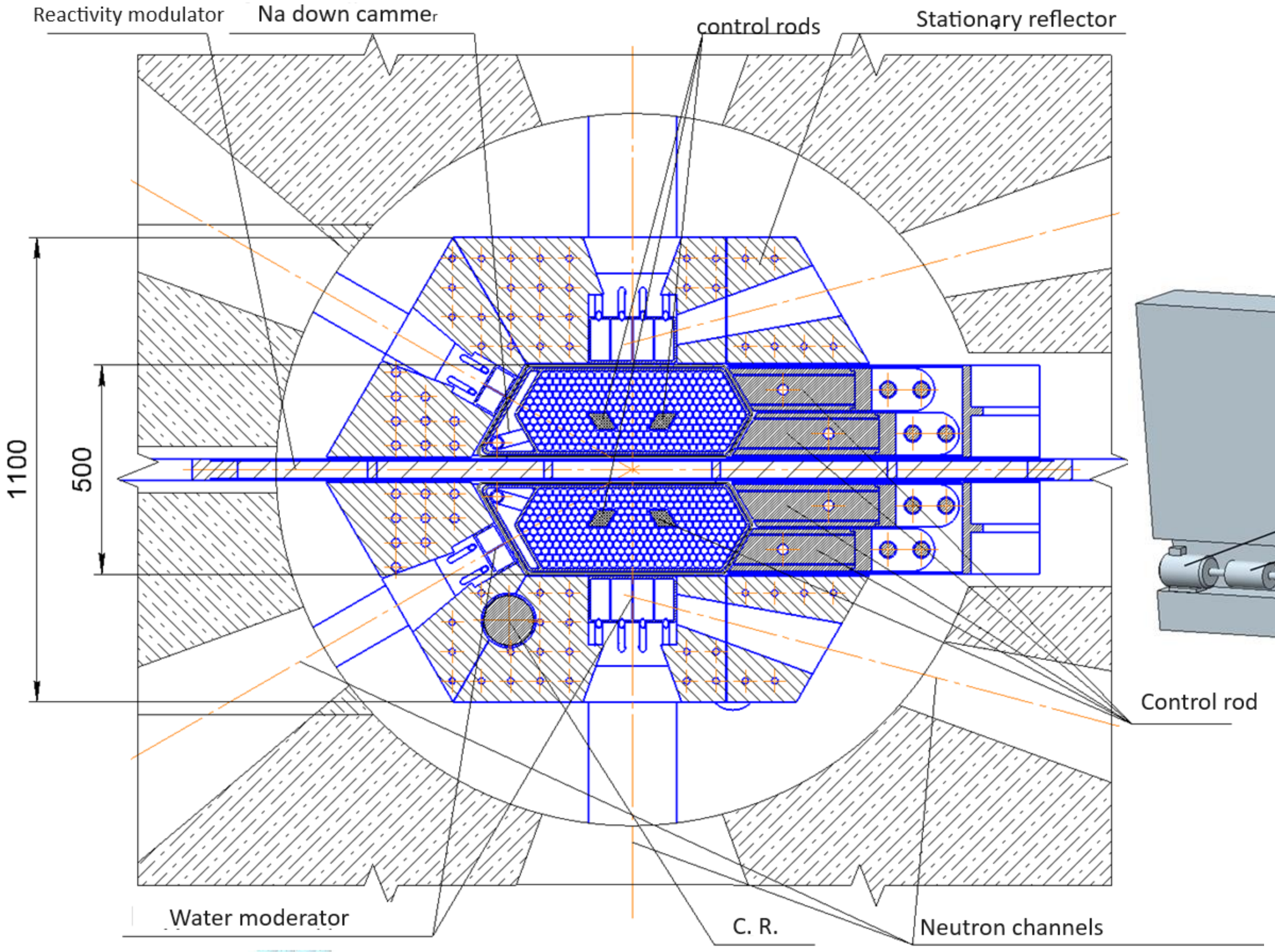
Parameter	Value
AVERAGE THERMAL POWER , MW	12 - 15
OPERATING MODE	pulsed
PULSE FREQUENCY, Hz	10
FUEL	NpN
CLADDING MATERIAL OF FUEL RODS	S.Steel
COOLER	Na
REFLECTOR	NICKEL ALLOY + BERYLLIUM
MODERATOR, PREMODERATOR	water, beryllium
COOLANT TEMPERATURE AT THE INLET TO THE CORE AND AT THE OUTLET, ^{0}C	290-390
PRESSURE DROP THROUGH THE CORE, Pa	$0{,}33\times10^5$
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$^{-2}\cdot$sec^{-1}	12
EFFECTIVE FRACTION OF DELAYED NEUTRONS	0,00131
GENERATION TIME OF THE SPONTANEOUS NEUTRONS , n,sec	8

Construction of reactor Neptune:

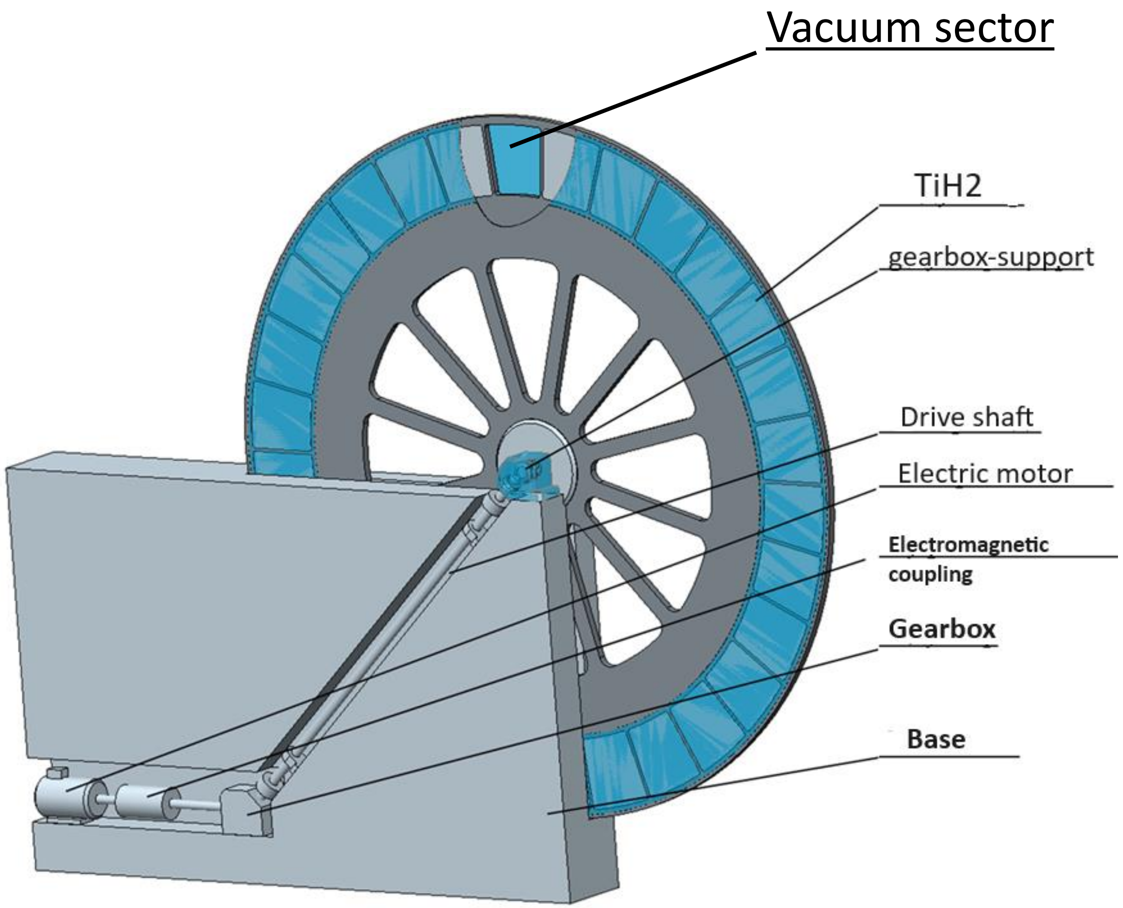
1 – reactor;
2 – stationary reflector;
3 – reactivity modulator;
4 – moderator;
5 – cooler storage;
6 – control rod



Reactor core and reactivity modulator

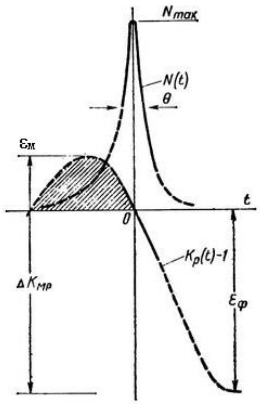


Vertical section of the original reactor design



- Rotation frequency 10 Hz;
- Disc outer diameter 3720 mm;
- Window height 440 mm.

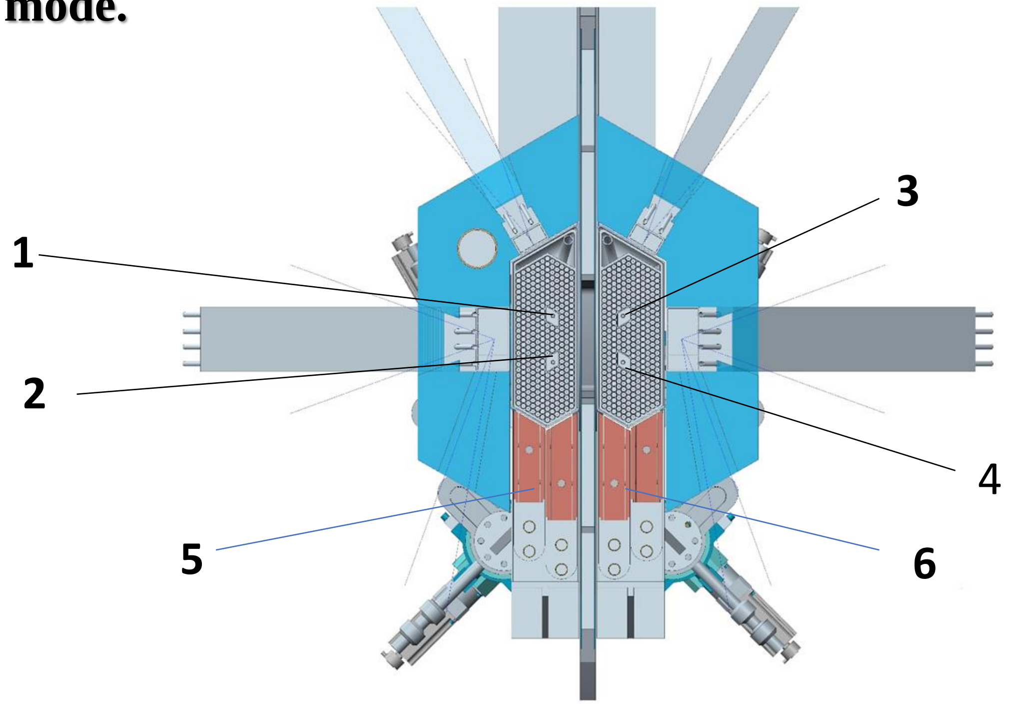
A 3D drawing showing the main parts of the interactive modulator



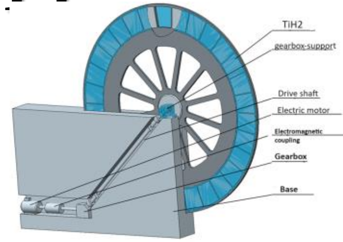
4- REACTOR CONTROL SYSTEM:

- Reactor control system consists of 3 groups:
  1- automatic control system;
  2- burnup balancer system;
  3- emergency shutdown system.
- The first and second systems are located around the reactor core and act as a neutron reflector (Ni blocks).
- The third system is located inside the reactor core and consists of blocks that are either neutron moderators (TiH_2 or YH_2) or neutron absorbers (B_4C).
- According to the regulations governing the operation of research reactors stipulate that: the control system must provide a subcriticality of 2% (Keff=0.98) in the temporary shutdown mode.

Control block (C.B.)	Worth (effect) of C. B. % Material of inside core C.B.	
	YH_2	B_4C
1 (1+2)	0.94 (2.0)	0.75(1.6)
1+2+3+4	4.0	3.2
5	0.53	0.54
5+6	1.04	1.1



5- THE PROBLEM OF HIGH THERMAL LOAD IN TIH_2 IN THE REACTIVITY MODULATOR (RM):

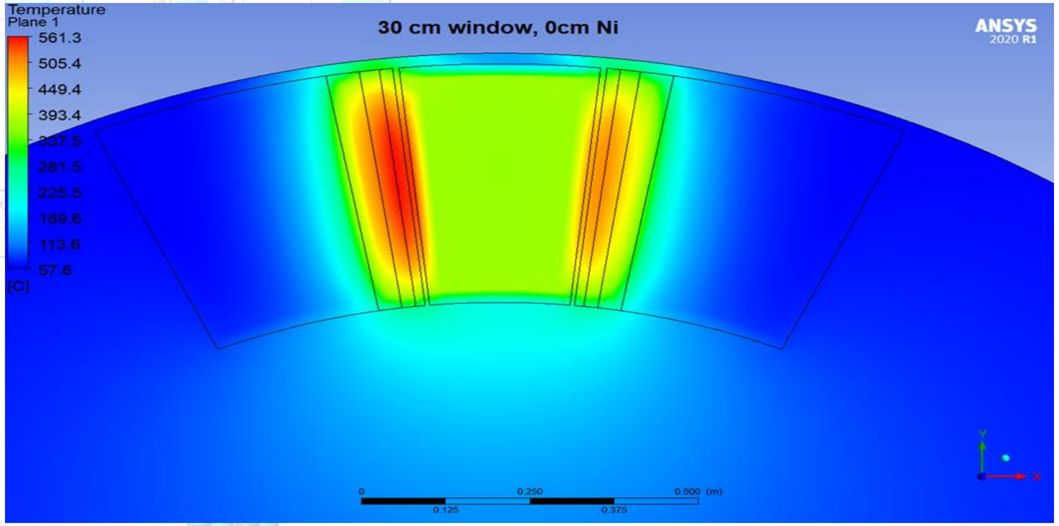


- Technical problem:

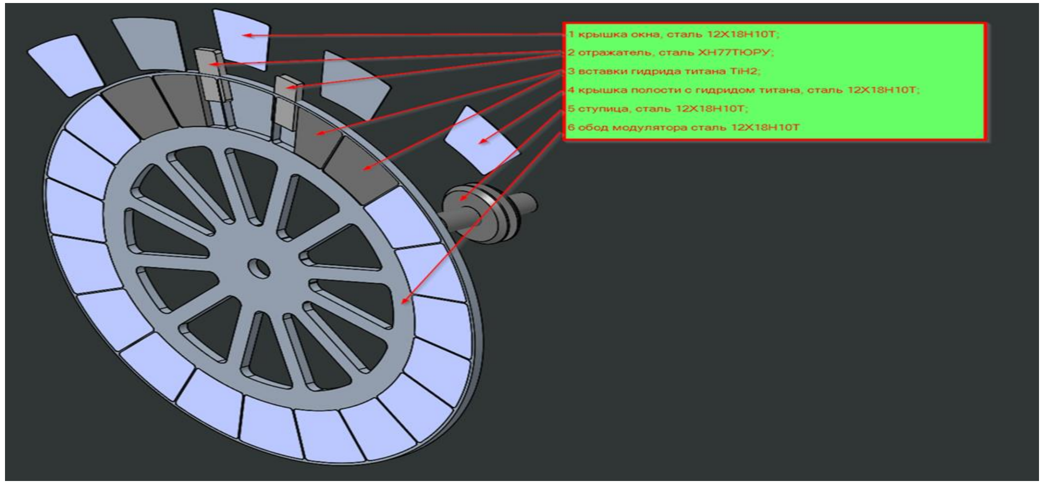
- The temperature of TiH2 near the empty sector reaches **560** degrees.
- It is known that the use of TiH2 is limited to a temperature of **400** degrees. After that, the hydrogen content in TiH2 decreases and the effectivity of RM decreases.

- Technical solution:

- It is suggested to install additional nickel reflectors on the border of the empty sector and sectors containing TiH2.
- Both the width of the vacuum sector (30,35,40,45 cm) and the width of the of added Ni plate (0,5,10) have been changed, and the energy absorbed in TiH2 was calculated for each variant.

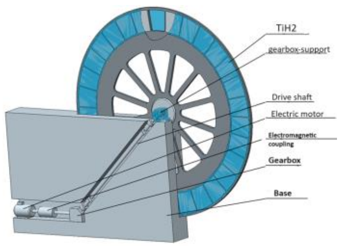


Temperature distribution in TiH2 near the vacuum sector.



Addition Ni reflectors between the vacuum sector and TiH2 sectors

5- THE PROBLEM OF HIGH THERMAL LOAD IN TIH_2 IN THE REACTIVITY MODULATOR (RM):

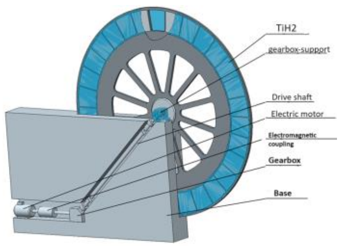


- The obtained results:

Dependence of the maximum absorbed heat in TiH2 (W/cm3), on changes in the vacuum width and Ni thickness

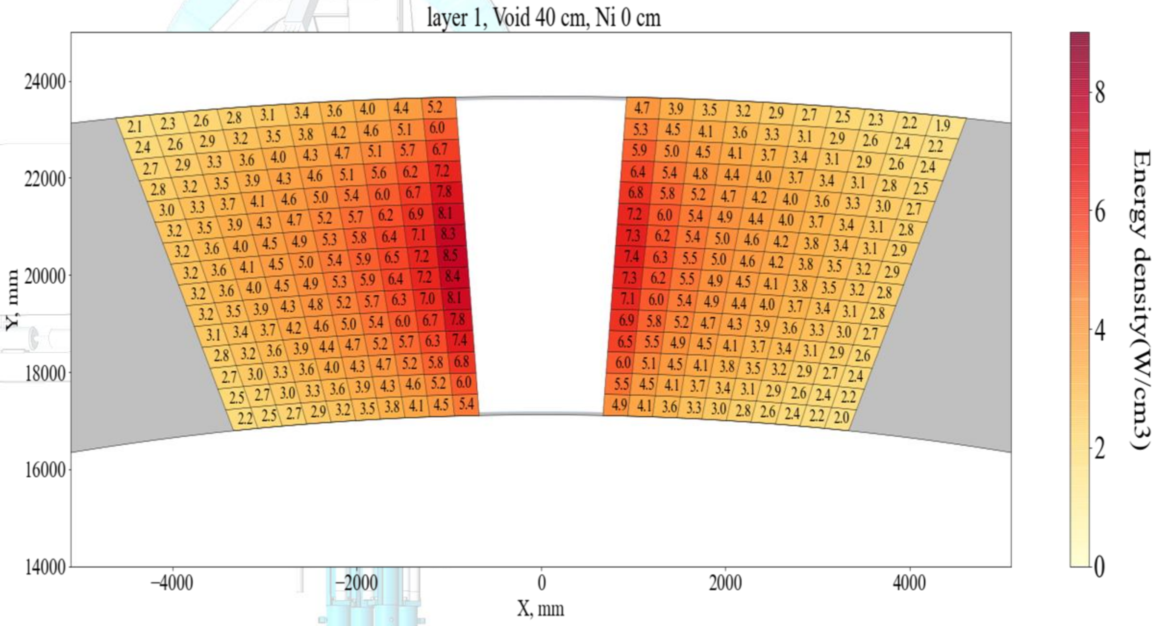
	Maximum absorbed heat in TiH2, W/cm3							
	0 cm Ni			5 cm Ni			10 cm Ni	
	Right	left		Right	left		Right	left
30 cm vacuum	9,65634	10,5207		6,66692	7,75357		4,48174	5,43119
35 cm vacuum	8,5089	9,52174		5,55672	6,59312		3,82486	4,4615
40 cm vacuum	7,41187	8,45502		4,71953	5,61119		3,22433	3,61275
45 cm vacuum	6,3444	7,32191		4,00864	4,68787		2,59712	2,93969

5- THE PROBLEM OF HIGH THERMAL LOAD IN TIH_2 IN THE REACTIVITY MODULATOR (RM):

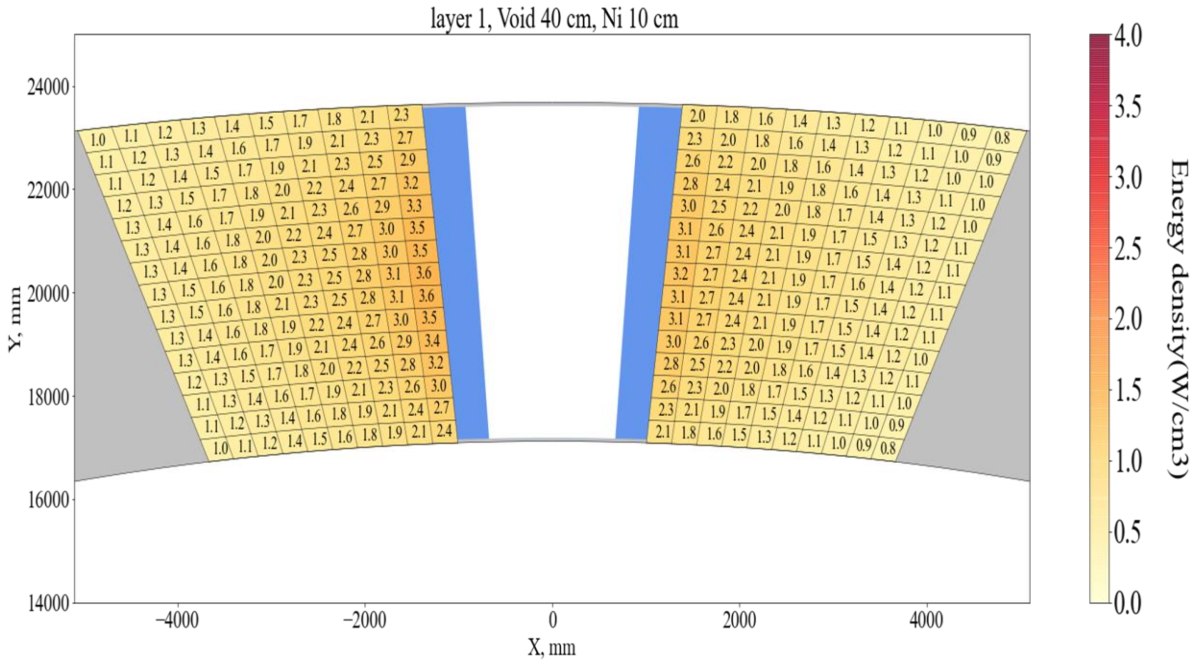


- The obtained results:

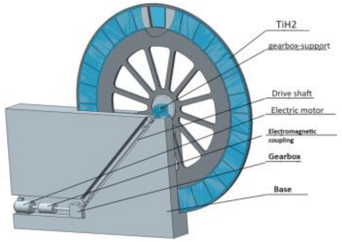
Absorbed heat in TiH2 without installing an additional Ni reflector, W·cm-3



Absorbed heat in TiH2 with installing 10 cm Ni reflector, W·cm-3

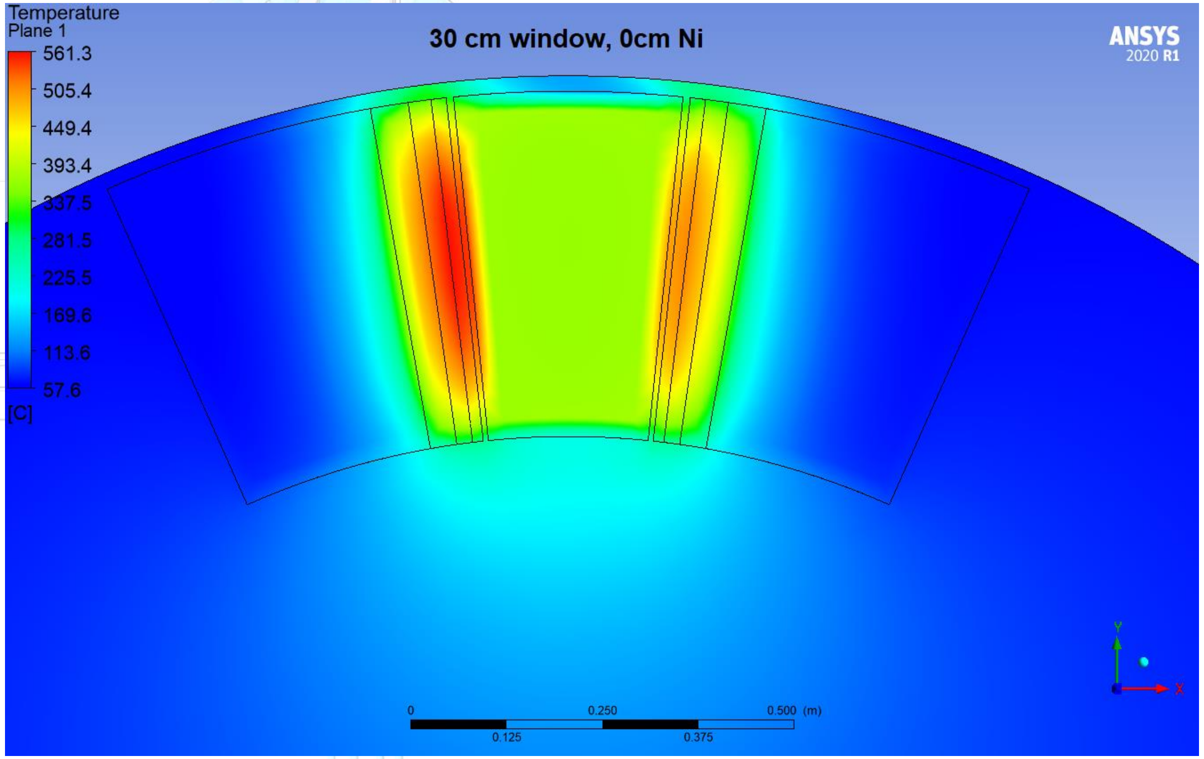


5- THE PROBLEM OF HIGH THERMAL LOAD IN TIH_2 IN THE REACTIVITY MODULATOR (RM):

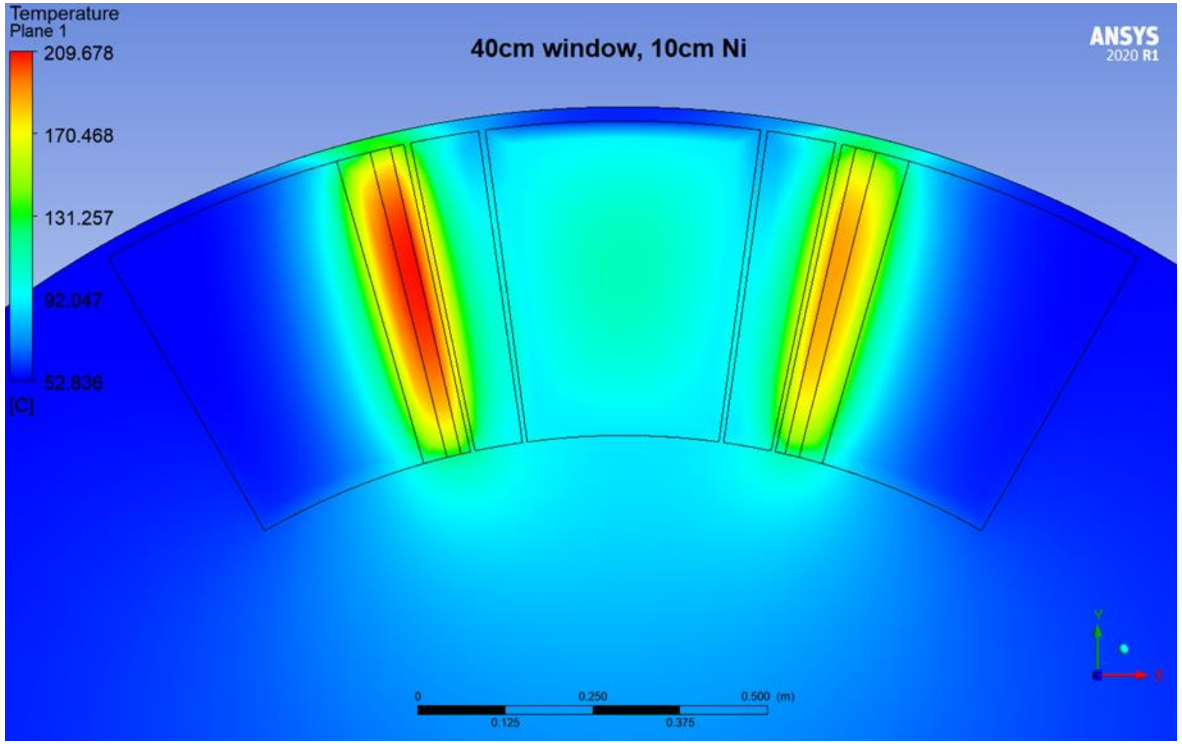


- The obtained results:

Temperature distribution in TiH2 without installing an additional Ni reflector, W·cm-3



Temperature distribution in TiH2 with installing 10 cm Ni reflector, W·cm-3



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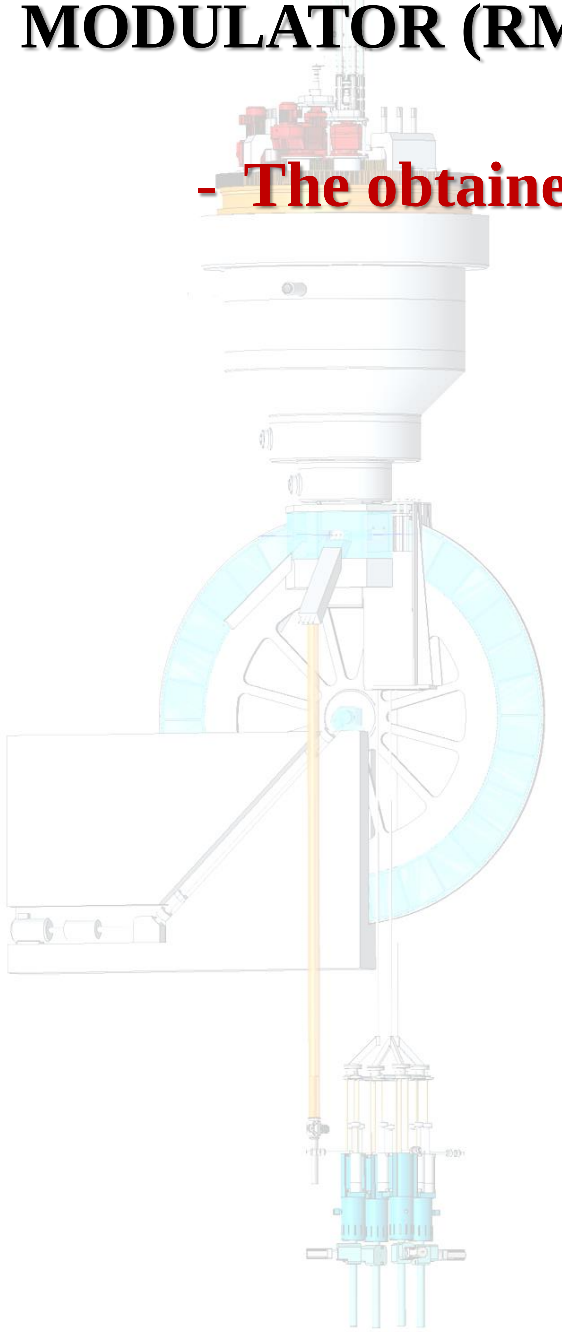
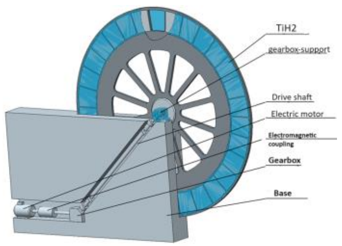
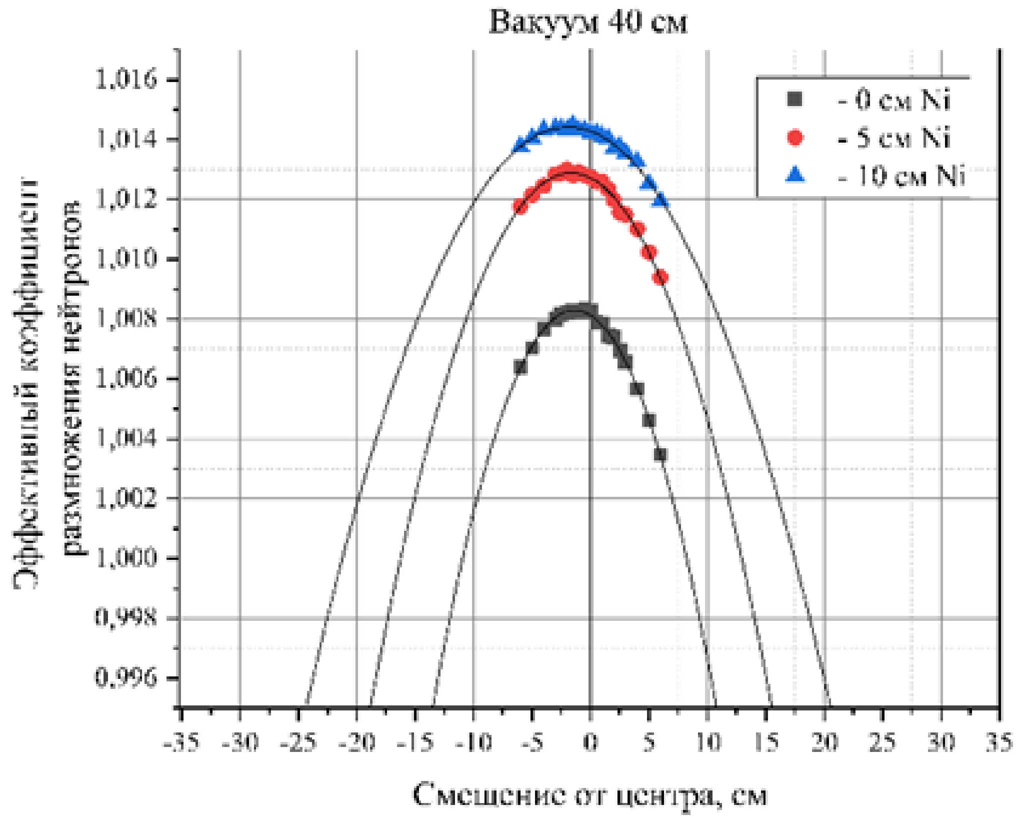


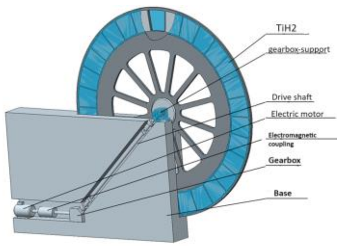


- The obtained results:

Reactivity course for options: vacuum window width 40 cm



5- THE PROBLEM OF HIGH THERMAL LOAD IN TiH_2 IN THE REACTIVITY MODULATOR (RM):

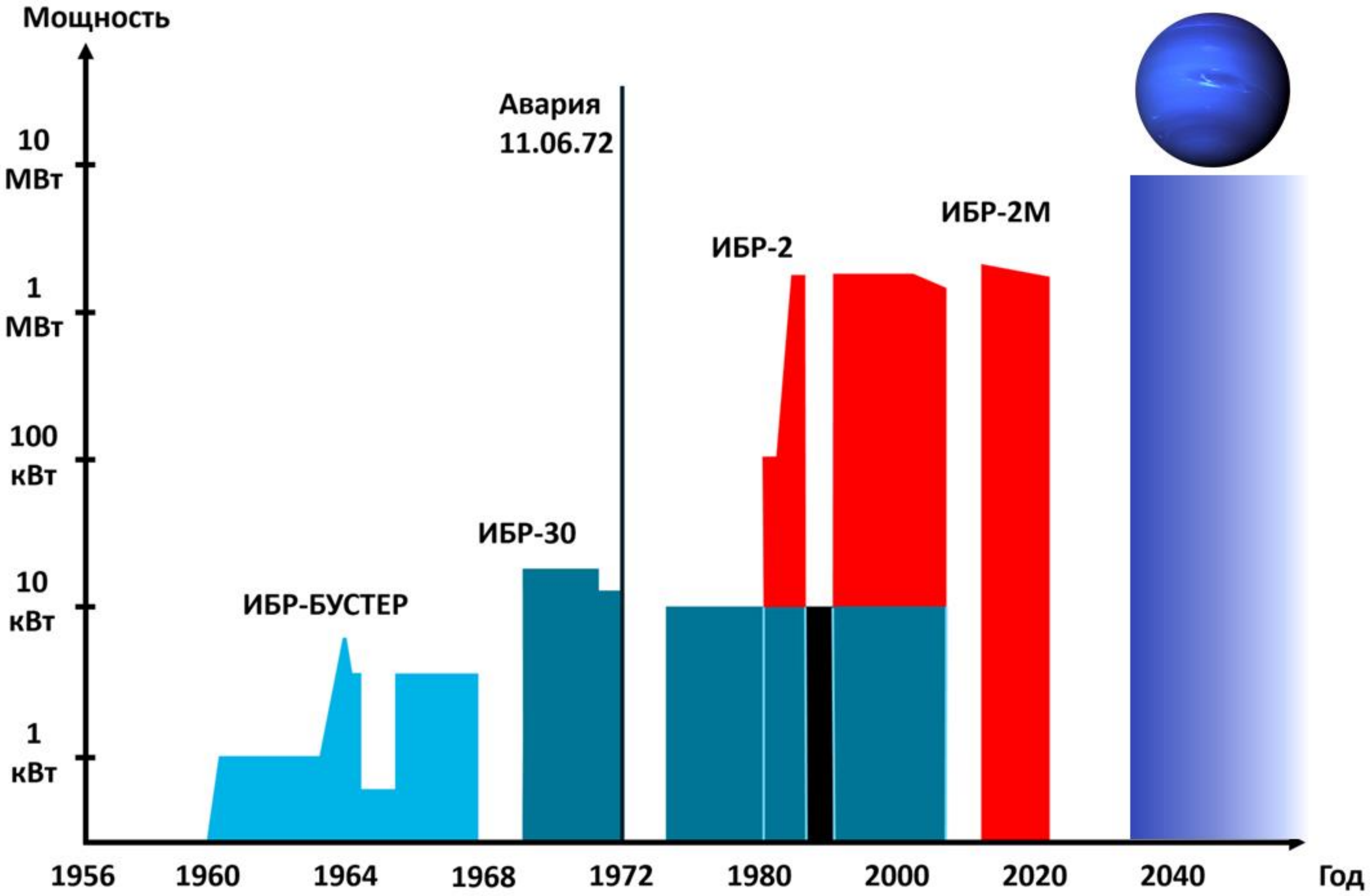


- The obtained results:

Dependence of the maximum modulator effect (%) and α - parameter (cm-2) on changes in the vacuum width and Ni thickness

	30 cm vacuum, 0 см Ni	30 cm vacuum, 5 см Ni	30 cm vacuum, 10 см Ni		35 cm vacuum, 0 см Ni	35 cm vacuum, 5 см Ni	35 cm vacuum, 10 см Ni		40 cm vacuum, 0 см Ni	40 cm vacuum, 5 см Ni	40 cm vacuum, 10 см Ni		45 cm vacuum, 0 см Ni	45 cm vacuum, 5 см Ni	45 cm vacuum, 10 см Ni
Maximum modulator effect , %	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 -parameter, 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

Thanks for attention.
Any questions??


Мощность
10
МВт
1
МВт
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10
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кВт
Авария
11.06.72
ИБР-БУСТЕР
ИБР-30
ИБР-2
ИБР-2М
1956
1960
1964
1968
1972
1980
2000
2020
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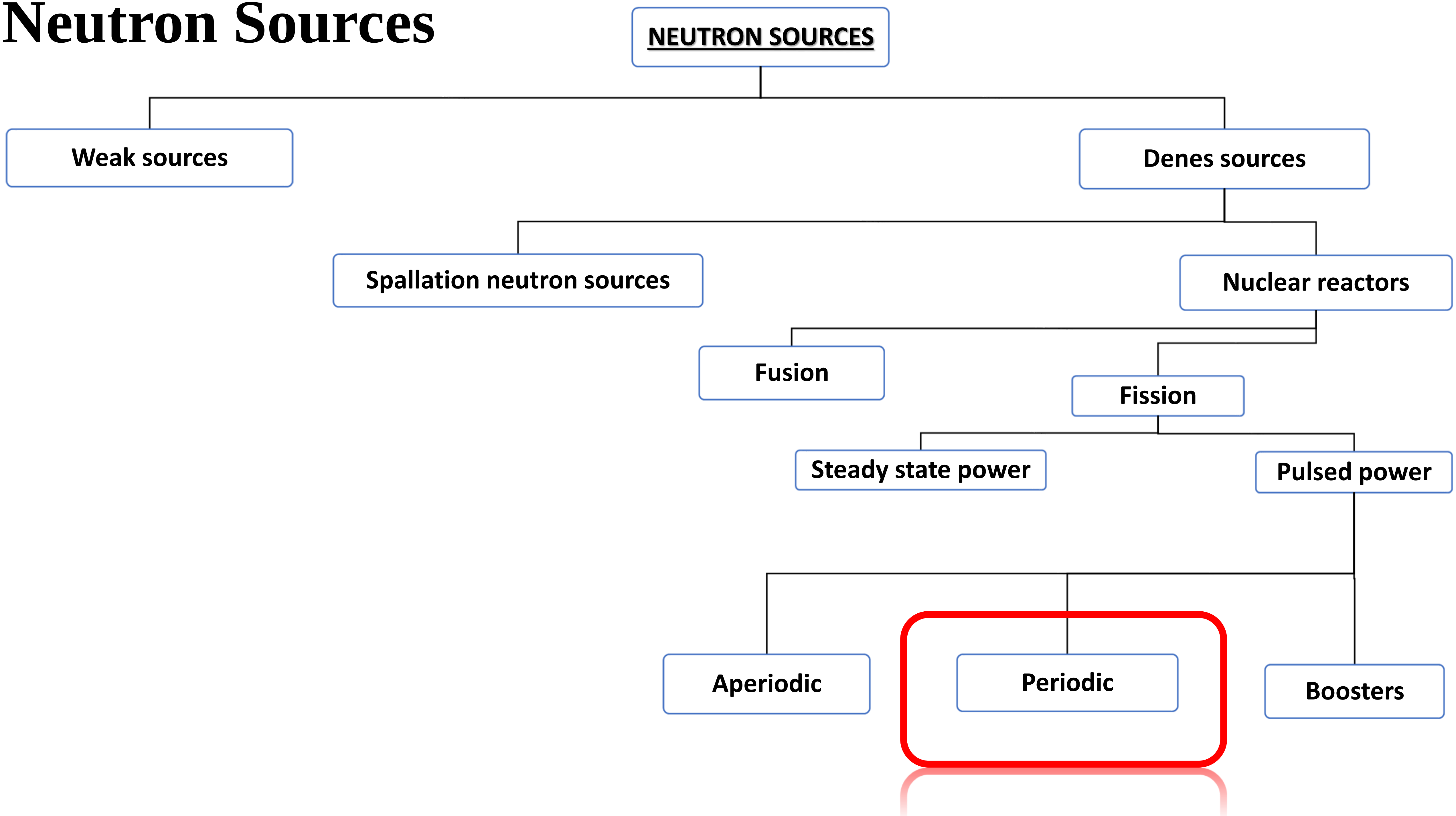
Год

Neutron Sources



Neutron sources

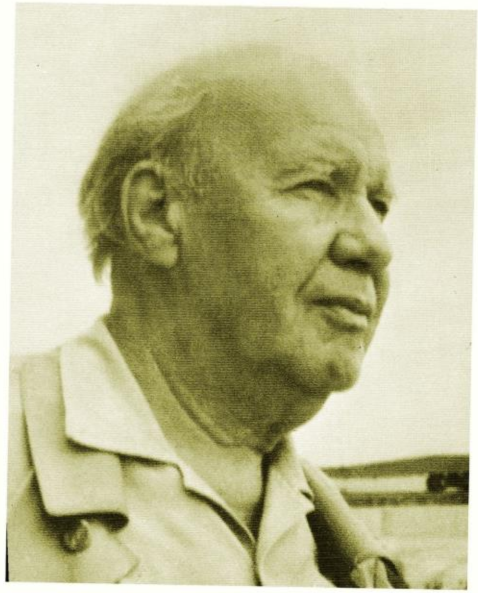
B) Denes sources : 2- Periodic Pulsed power reactors:

	IBR-1 1960 - 1968	IBR-30 19	IBR-2 с 1984 г	IBR-3 (NEPTUNE)
Thermal power	1- 3 кWт	20 кWт	2 MWт	12-15 MWт
Fissile material	Pu-239 metal	Pu-239 metal	PuO_2	Np-237, NpN
Reactivity modulator, frequency	U-235 5-50 Hz	U-235 0.1 - 10 Hz	Moveable reflector from Ni 5-25 Hz	TiH_2+and void, 10 Hz
The half width pulse	40 µs	70 µs	240 µs	~260-µs
Neutron flux at the surface of moderators, см^2/ s,	$\sim 10^{10}$	10^{11}	10^{13}	10^{14}

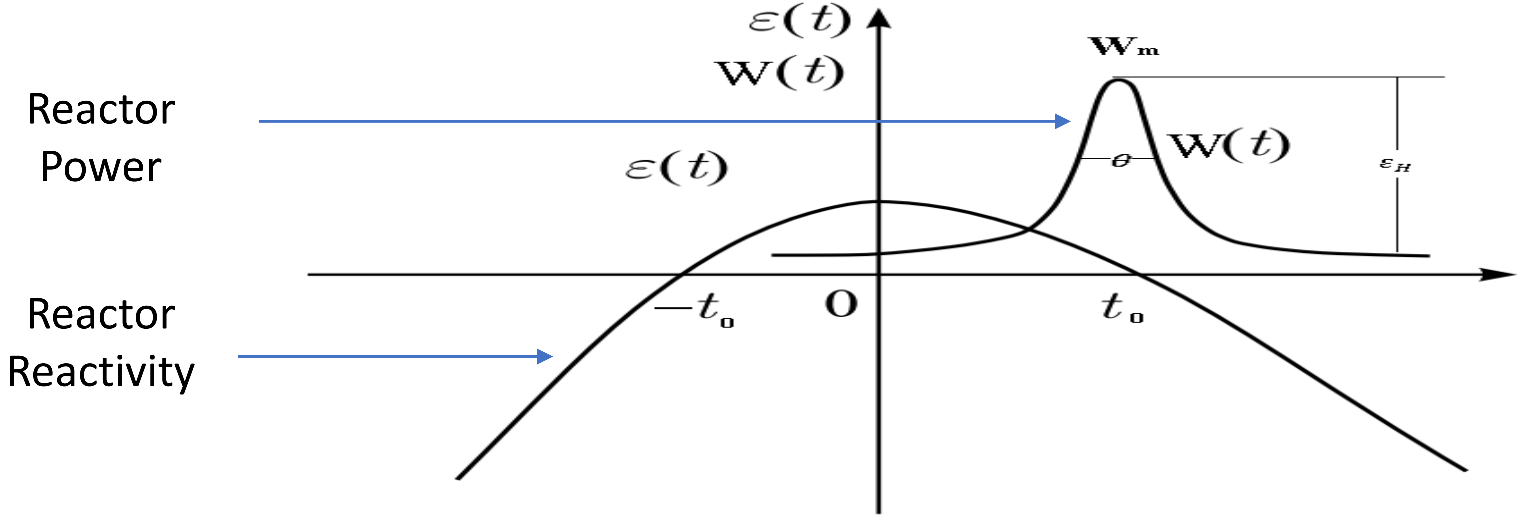
Neutron sources

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).
-

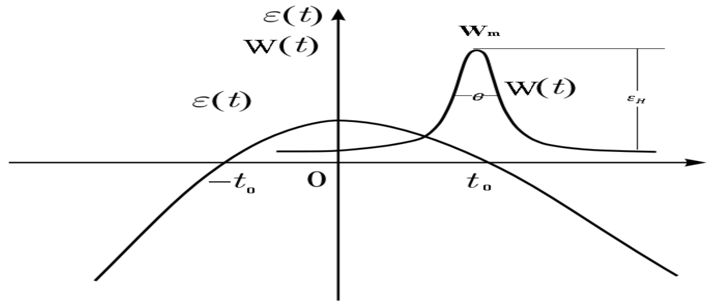


Dmitry Blokhintsev* *(1907-1979)



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

4- REACTOR CONTROL SYSTEM:



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