Frank Laboratory of Neutron Physics, JINR
ISINN, 22 – 26 May 2017, Dubna

A 15-year forward look at neutron facilities in JINR

V.L.Aksenov
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1. Aksenov V.L., Ananiev V.D., Komyshev G.G., Rogov A.D., Shabalin E.P. (2016) JINR P3-2016-90
2. E.P.Shabalin, G.G.Kamyshev, A.D. Rogov (2017) to be publ.
3. Aksenov V.L., Balagurov A.M., Pepelyshev Yu.N., Rogov A.D. (2016) JINR P13-2016-49
4. Aksenov V.L. (2017) JINR E3-2017-12

Principal question posed :

Which kind of neutron source could be more appropriate in Frank Lab. Neutron Physics after 2030 ?

Backgrounds for the question are as following:

1. Operating license for IBR-2 operation will be expired in 2032.
2. Some parameters of the IBR-2 are of inferior to that of SNS, J-Park, ESS.
3. Use of plutonium is in poor agreement with the convention on nonproliferation of nuclear weapon.

Pulsed neutron sources: in operation and advanced

	Moderator type	Peak differential neutron flux 10^{14} n/см^2/s/sr/ Ǻ	Peak neutron flux , 2π eqv. 10^{14} n/см^2/s	Fluence per pulse 10^{12} n/см^2/s	Time averaged flux 2π equivalent. 10^{14} н/см^2/с
IBR-2	Grooved, wide	**9**	58	0.28	**0.09**
	Grooved, height 4.5 см	12	77	0.37	0.12
J-Park	Coupled	10	65	0.2	0.3
ESS	Butterfly height 6 см	8	50	2.2	2.0
	Height 3 см	12	**75**	**3.4**	3.0
PIK, Russia	Stationary, D_2O moderator	1.6	12	-	12
DANS *)	**Grooved**	130	**800**	**4**	3.0

Principles of method to attack the problem :

- We should follow the highway of LNPh, that is fission based pulsed sources.
- Facility should be as economical as possible,
  - But : not to be inferior to the world leading neutron sources

Complexity of the current task –
too many parameters for optimization:

- Flux time averaged
- Peak flux
- Pulse duration
- Pulse frequency
- Background
- Economy
- Safety

Why do we need a new project of JINR neutron source?

1-st Generation
IBR
IBR + microtron

2-nd Generation
IBR-30 stoped in 2001
IREN under constr.
limited parameters

3-d Generation
IBR-2

LIU-30 was not realized

$$\overline{\Phi}_{th} < 10^{13}\,\frac{n}{cm^2 s}$$

Service life – until 2032

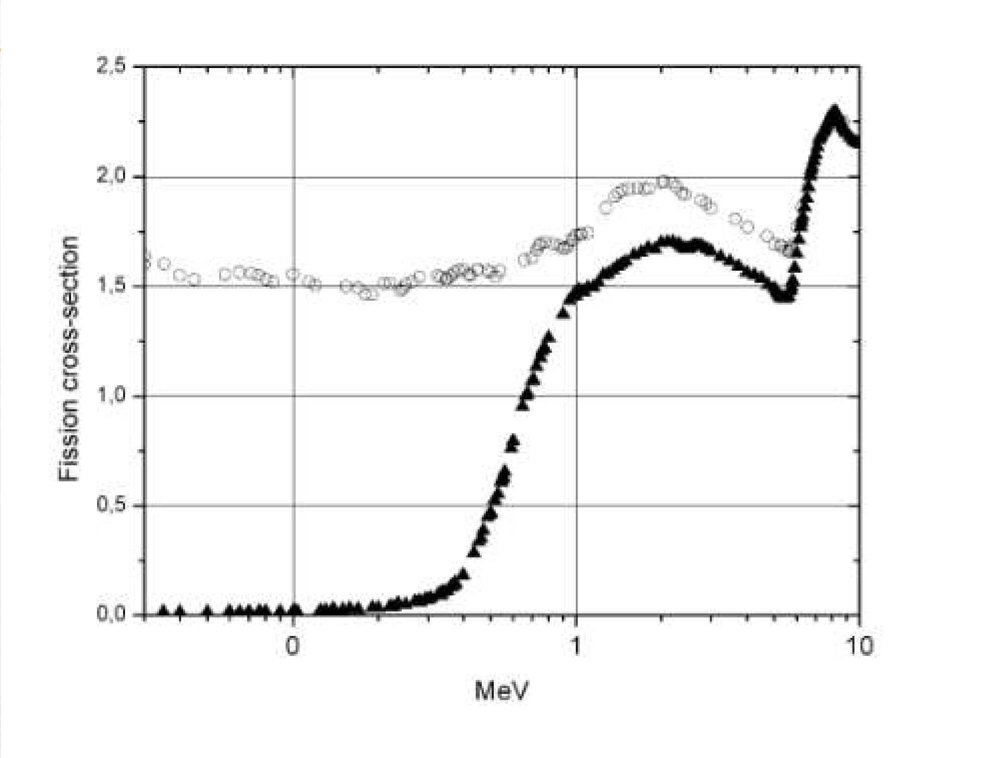
Resource of buildings and equipment – 2035 → a new building comple

Safety Agency permission for IBR-2 concept is problematic → a new concept is needed

Pulsed LNPh reactors and ESS

Parameter	Neptune reactor	Pu high flux reactor	IBR--2	ESS
Time averaged n/cм^2/s **Peak neutron flux**	**$1.0 \cdot 10^{14}$** **$4\ 10^{16}$**	**$3.5 \cdot 10^{13}$** **$7\ 10^{15}$**	**10^{13}** **$6 \cdot 10^{15}$**	**$(2 \div 4) \cdot 10^{14}$** **$(0.5 \div 1) \cdot 10^{16}$**
Thermal power	**15 MW**	**2 MW**	**2 MW**	**5 MW**
Pulse freguency	**10 Hz**	**10**	**5**	**14**
Pulse duration	**201 мкs**	**≥ 400 мкs**	**240 мкs**	**3 мs**
Background power	**3.2 %**	**7 - 8 %**	**7.5 %**	
Number of neutron beams	18-22	14	14	~20

Threshold fission



What’s profit of the threshold fissionable material?

1. Short neutron generation time

   10 ns versus ≥ 100 ns

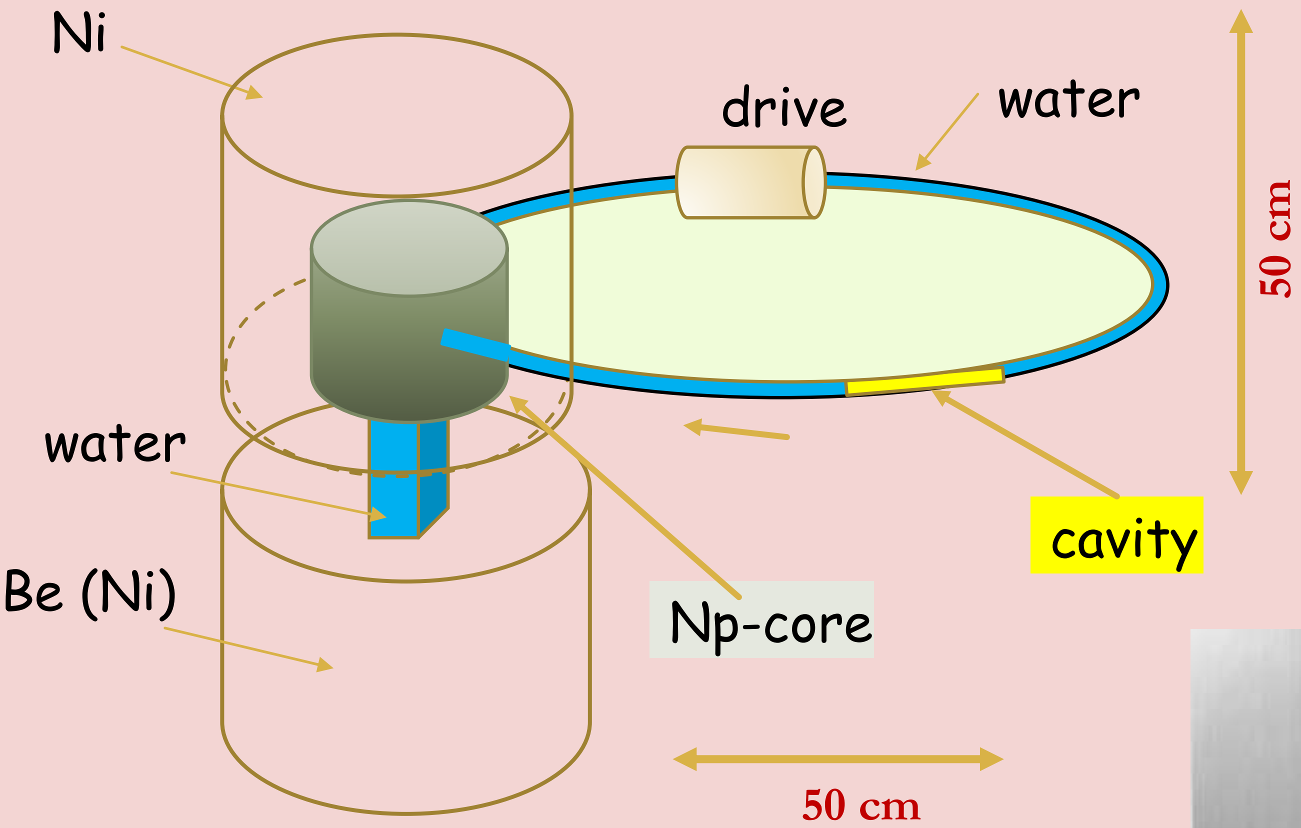
2. Deep reactivity modulation (from 2-3 % Keff up to 4-5%)

3. Delayed neutron fraction is smaller by 30%

These 3 merits provide shorter pulse duration (2-3 times) and lower background (2.5 times).

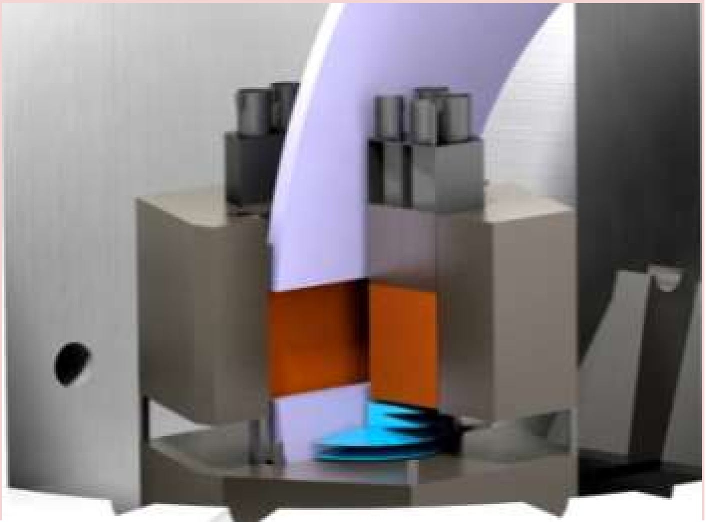
Pulsed plutonium reactor with the very parameters can’t be constructed, but superbooster.

PULSED Np-REACTOR ("NEPTUN")



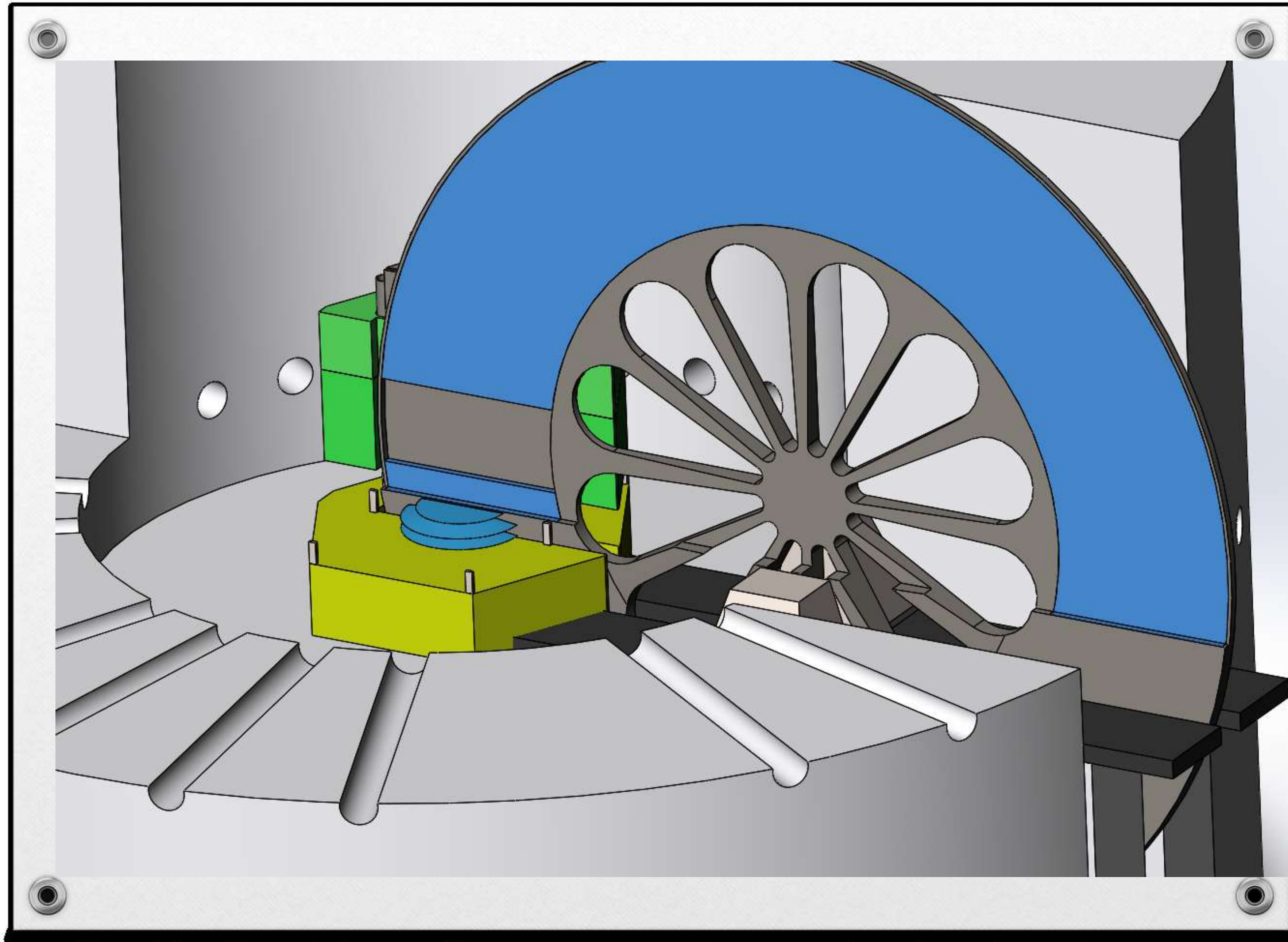
Three moderators:

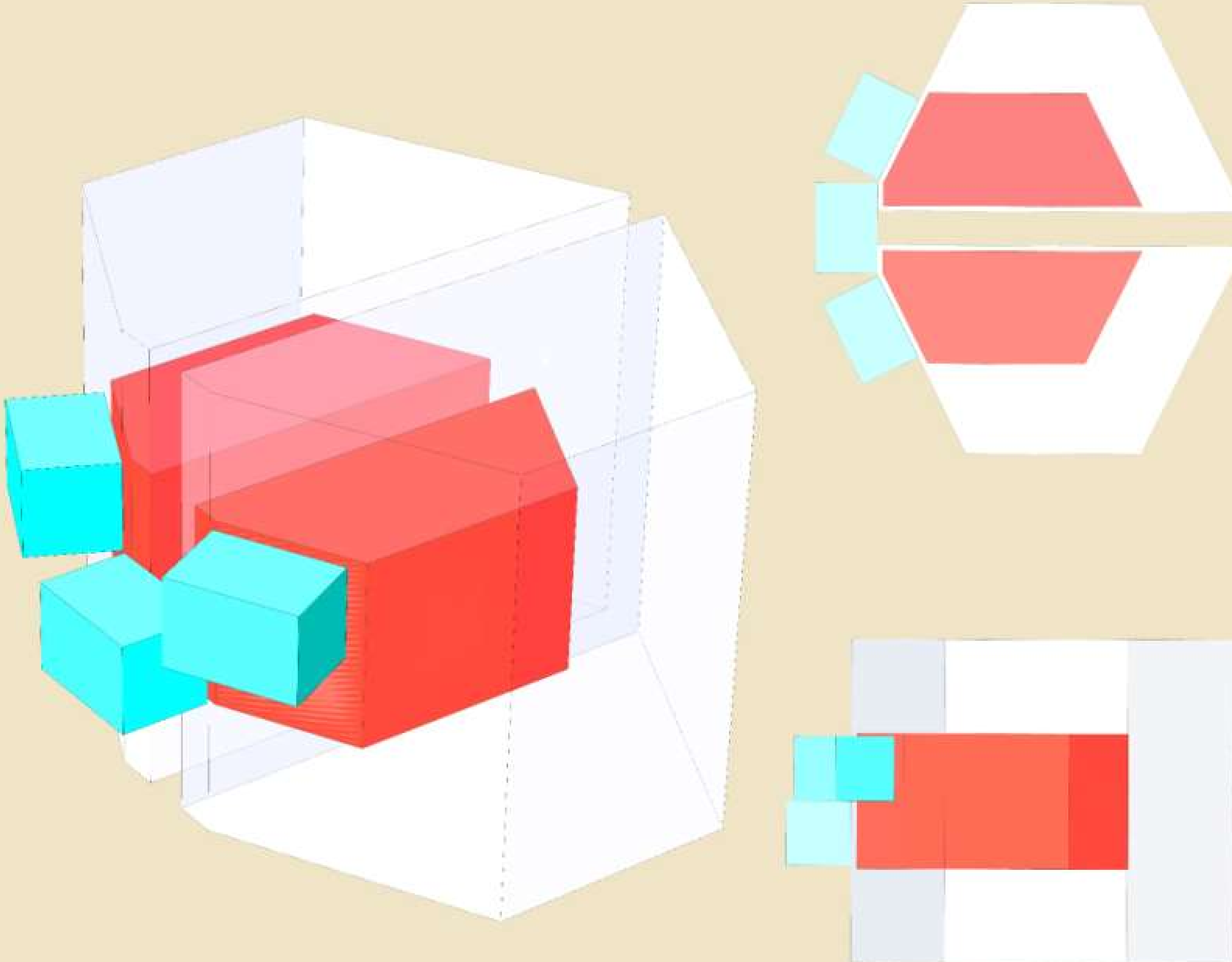
- * thermal } long pulse
- * cold } long pulse
- * poisoned: short pulse

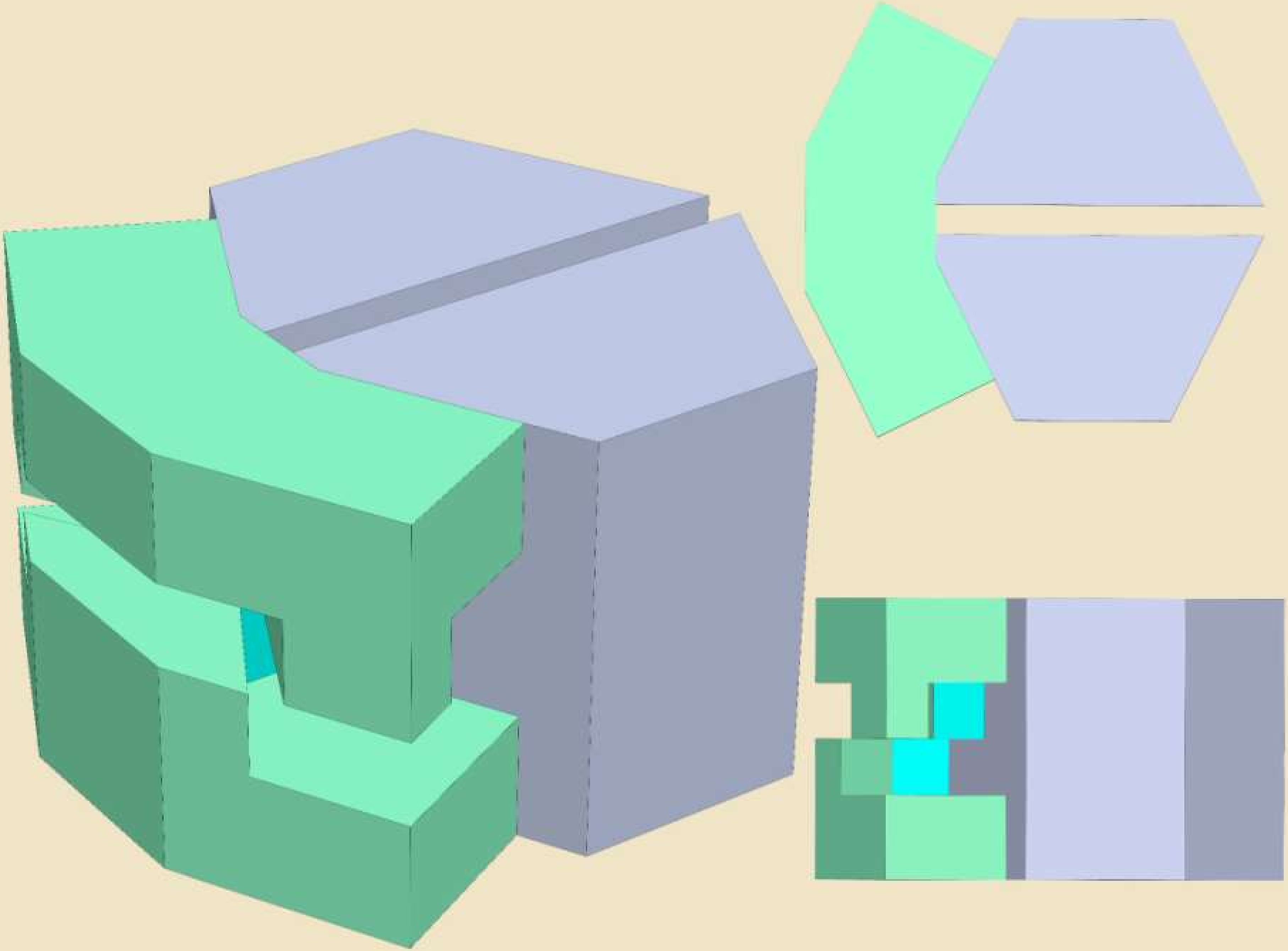


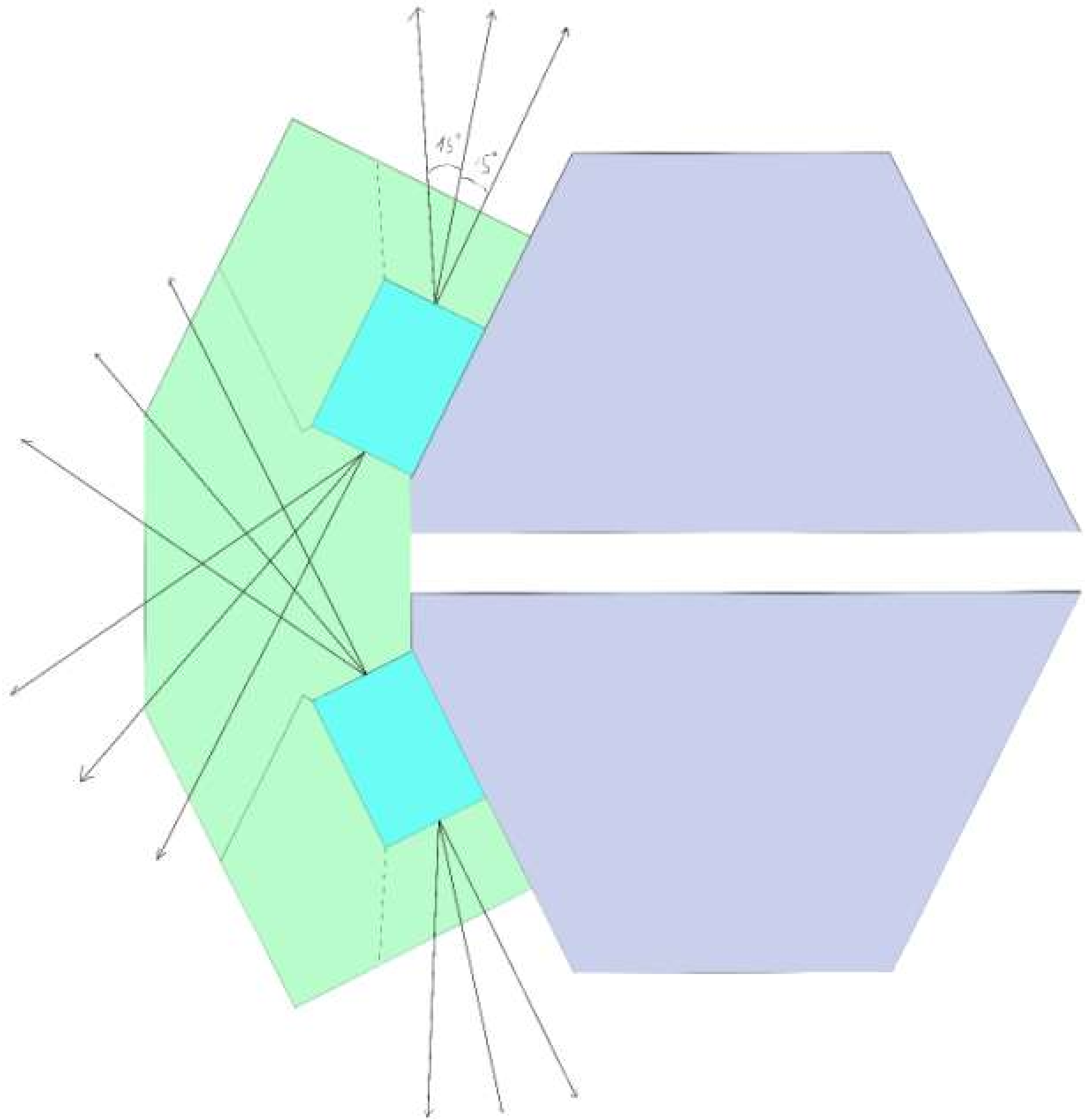
Computer model

E.P.Shabalin, G.G.Kamyshev, A.D. Rogov (2017) to be publ.





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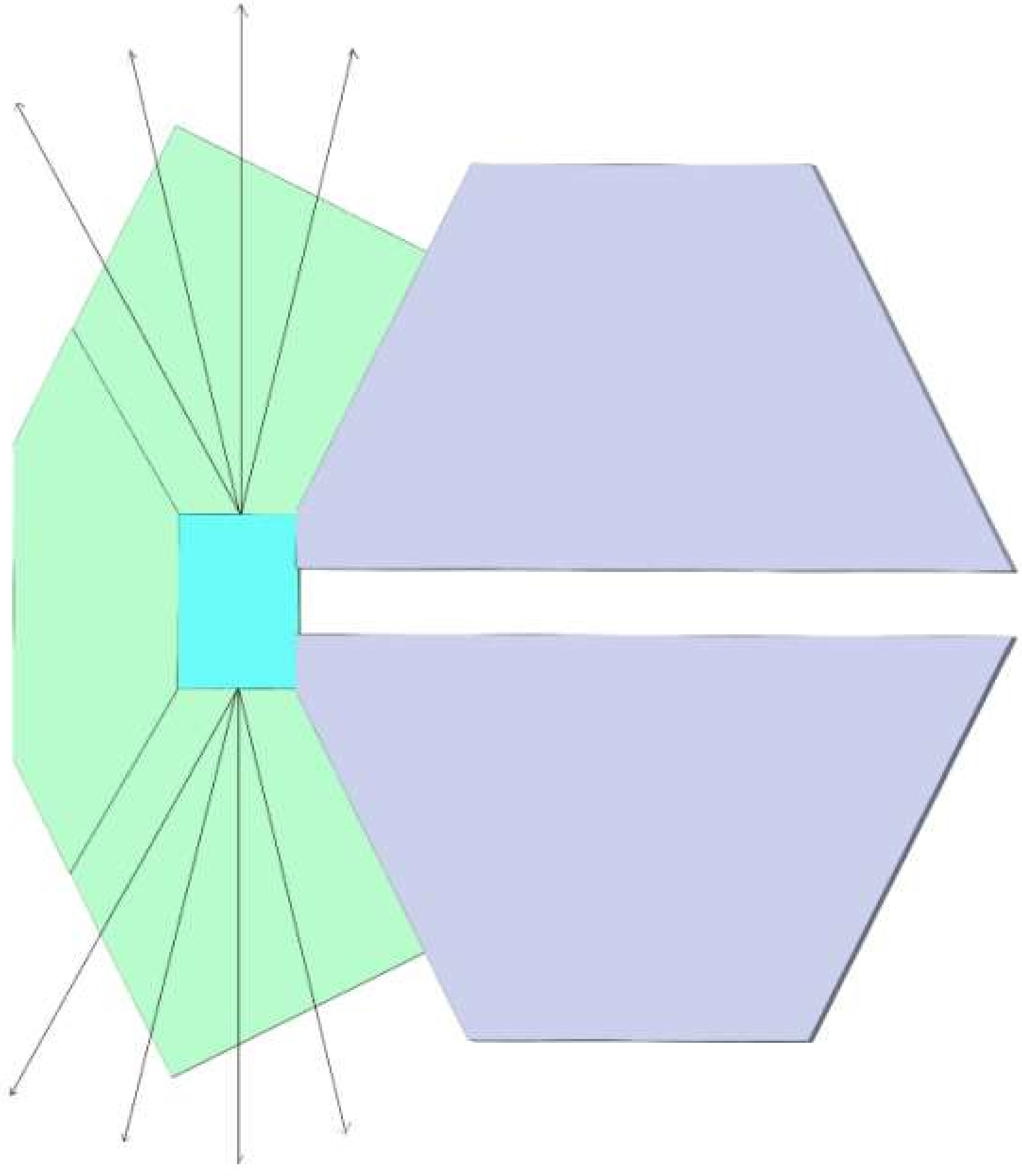

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Time averaged n/cm^2/s Peak neutron flux	$1.0 \cdot 10^{14}$ $4\ 10^{16}$	$3.5 \cdot 10^{13}$ $7\ 10^{15}$	10^{13} $6 \cdot 10^{15}$	$(2 \div 4) \cdot 10^{14}$ $(0.5 \div 1) \cdot 10^{16}$
Thermal power	15 MW	2 MW	2 MW	5 MW
Pulse freguency	10 Hz	10	5	14
Pulse duration	201 MKS	≥ 400 MKS	240 MKS	3 MS
Background power	3.2 %	7 - 8 %	7.5 %	
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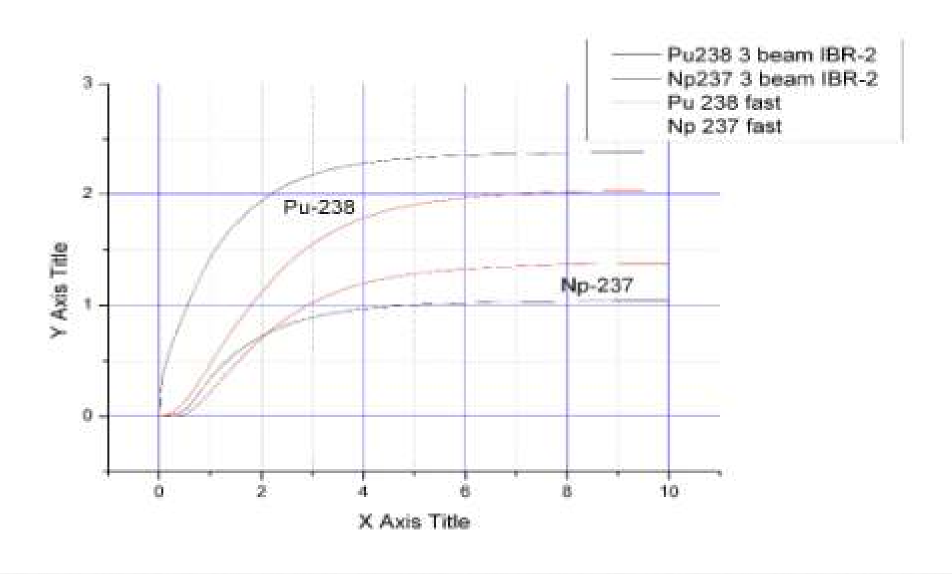
Pu-238 production:
Positive reactivity effect!

Np-237 + n = Np-238 (> 1.1/ fission), β^-, $T_{1/2}$ = 2.1 *d*

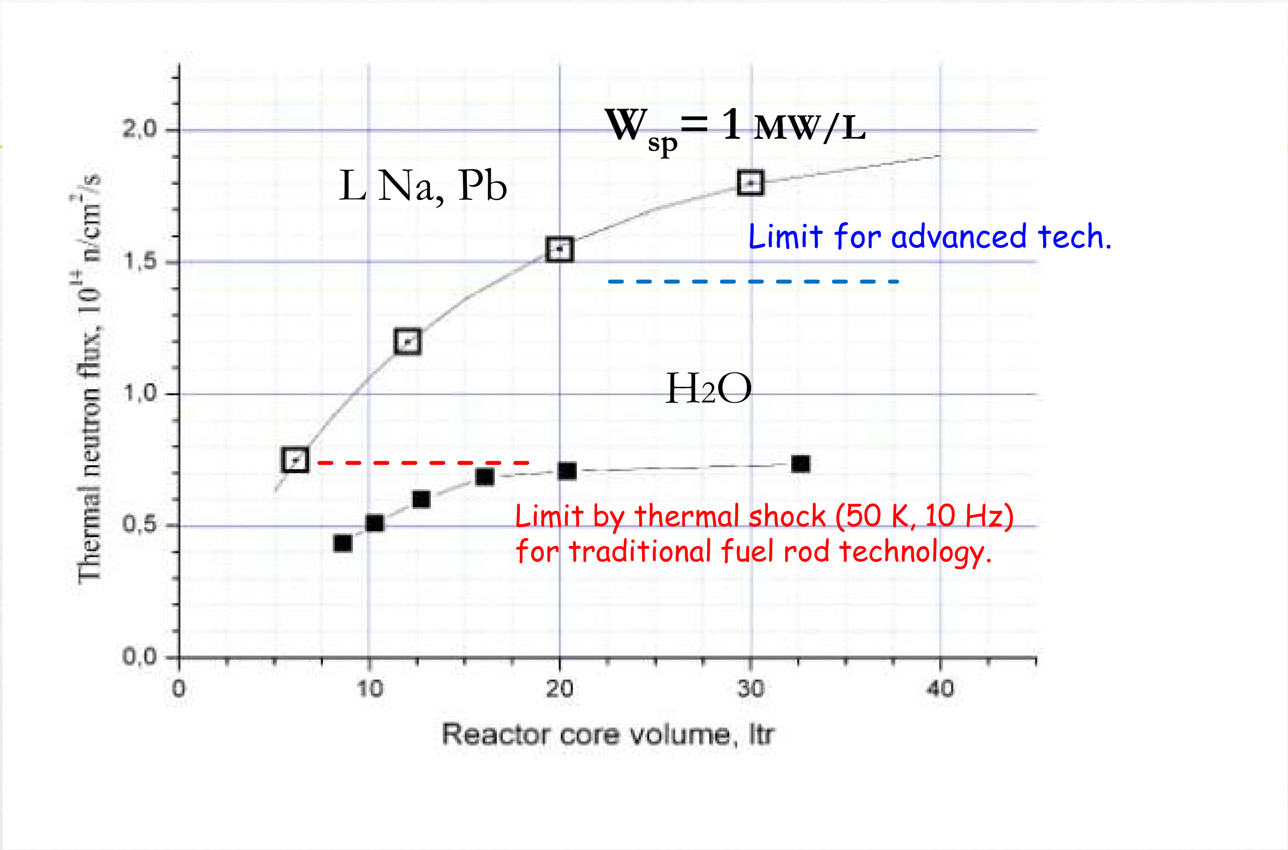
↓

Pu-238 – fissionable nucleus



Burn-up reactivity effect is positive, ~ +1% ΔK /1% burn-up

Neutron flux versus reactor core volume
(MCNP, Wsp = 1 MW/ltr)



Cascade Booster Razmnozhitel (multiplayer)

COBRA

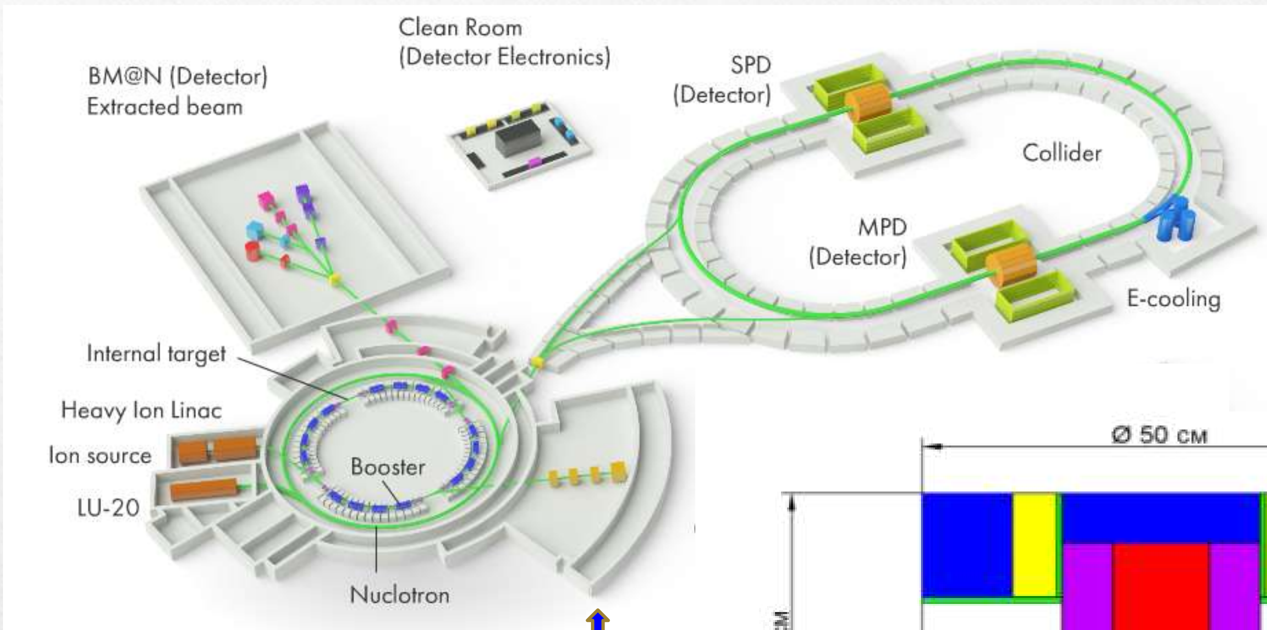
proton accelerator

$E_p \geq 0.6$ GeV,

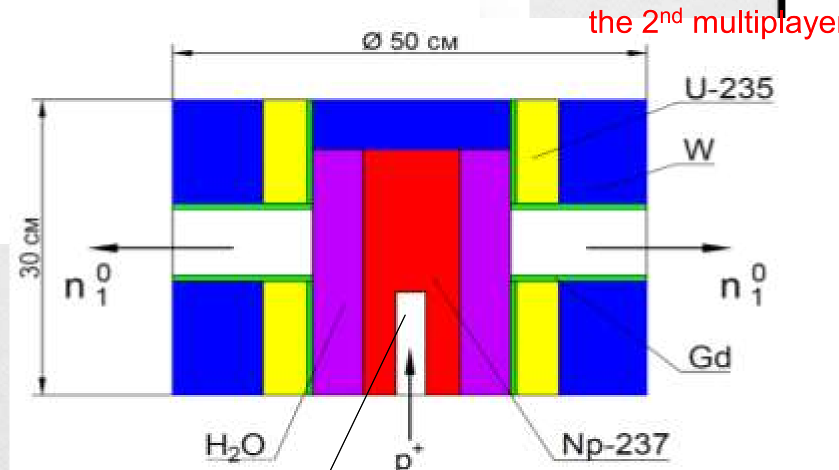
$I \geq 0.1$ mA, $\nu = 10\ s^{-1}$, $\Delta t_p = 100 \div 200\ \mu s$

neutron generating target + cascade subcritical assembly

NICA Complex



Target Station



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Dubna Advanced Neutron Source (DANS)

- innovative approach for a novel type of neutron facility
- dedicated target stations with pulse structures adapted to specific instruments
- high nuclear safety and relatively low cost
- muons, isotopes, irradiation for biology and medicine

proton accelerator $E_p \geq 0.6$ GeV, $I \geq 0.1$ mA, $\nu = 10\ s^{-1}$, $\Delta t_p = 100 \div 200\ \mu s$

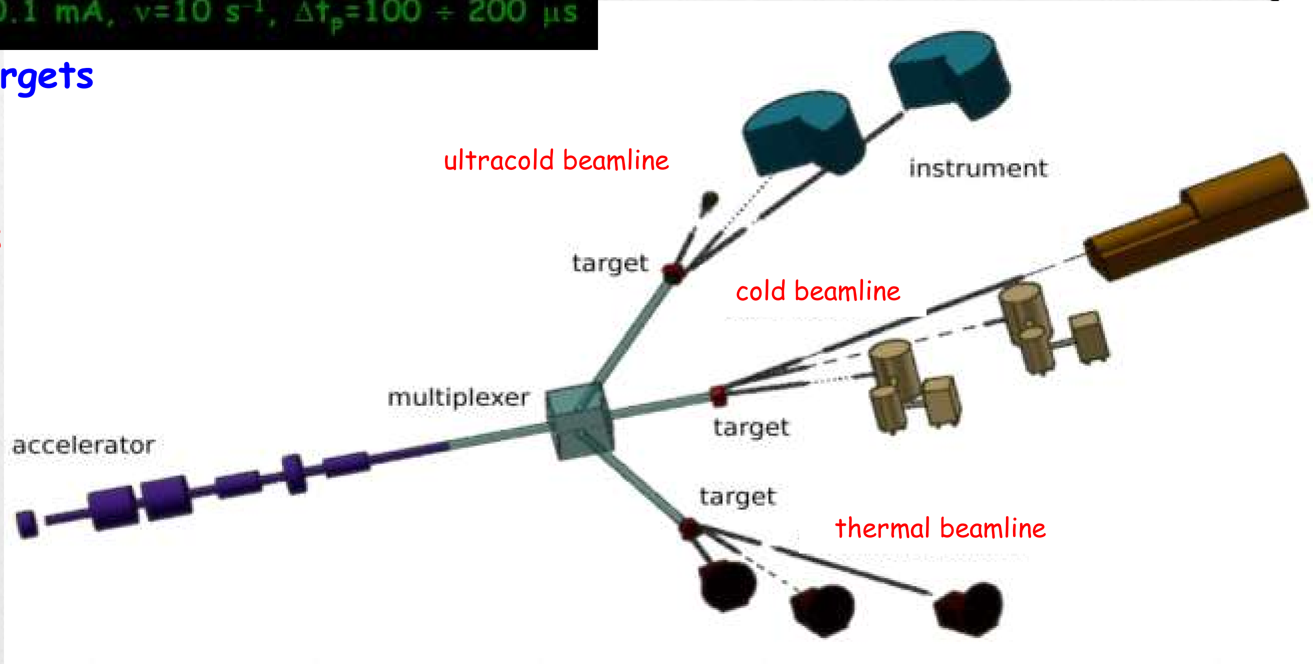
+ neutron generating targets

Three target stations:

*** thermal**

*** cold**

*** ultracold**



Aksenov V.L. (2017) JINR E3-2017-12

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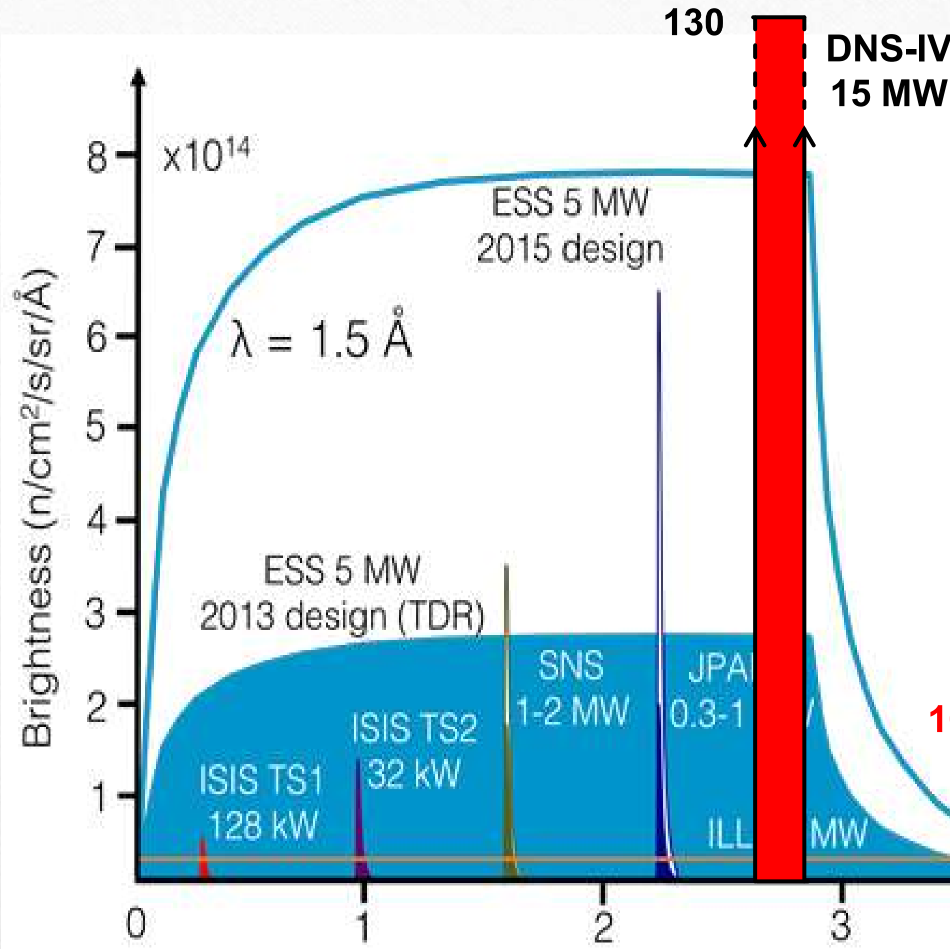
Dubna Neutron Source of fourth generation (DNS-IV) vs. other sources



	Brightness, peak × 10^{14}	Flux density, time aver.	Flux density, peak
IBR-2 10 MEu	9	0.1	58
ESS 2000 MEu	8	2	75
PIK 200 MEu	2	10	10
DNS-IV 100÷600 MEu	130	3	800

Data $\times 10^{14}\ [n \cdot cm^{-2} \cdot s^{-1}]$

Single-pulse source brightness as a function of time at wavelenght of 1.5 A at ESS, ILL, SNS, J-PARC and ISIS Target Stations 1 and 2. In each case, the thermal moderator with the highest peak brightness shown. (Source: ESS)

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CONCLUSIONS

1. New Accelerator Driven Subcritical Systems are under consideration in FLNP JINR for realization after 2032

2. New Pulsing Reactor (long and short pulse) is under consideration

3. Nuclear Physics Programme for Research and Instrumentation needs discussions

4. GNEIS, IREN, IBR-2 are available for nuclear physics

There are TWO most important factors responsible for a value

1) *neutron intensity* , *n/s* – for a low-sized source,
i.e. accelerator

or *spatial density of neutron generation*, $n/cm^3/s$ –
- for big-sized source, i.e. nuclear r

2) Mutual arrangement of source and neutron moderator (targ
station geometry)

What's bad with the IBR-2?

1) Rather low thermal neutron flux (2π-eqv., time averaged, flat water moderator) - 5 10^12 n/sq. cm/s , whereas in SNS – 10^14, in future ESS - 4 10^14 .

2) Neutron background is inconveniently high – 7.5 - 8 % of time averaged flux.

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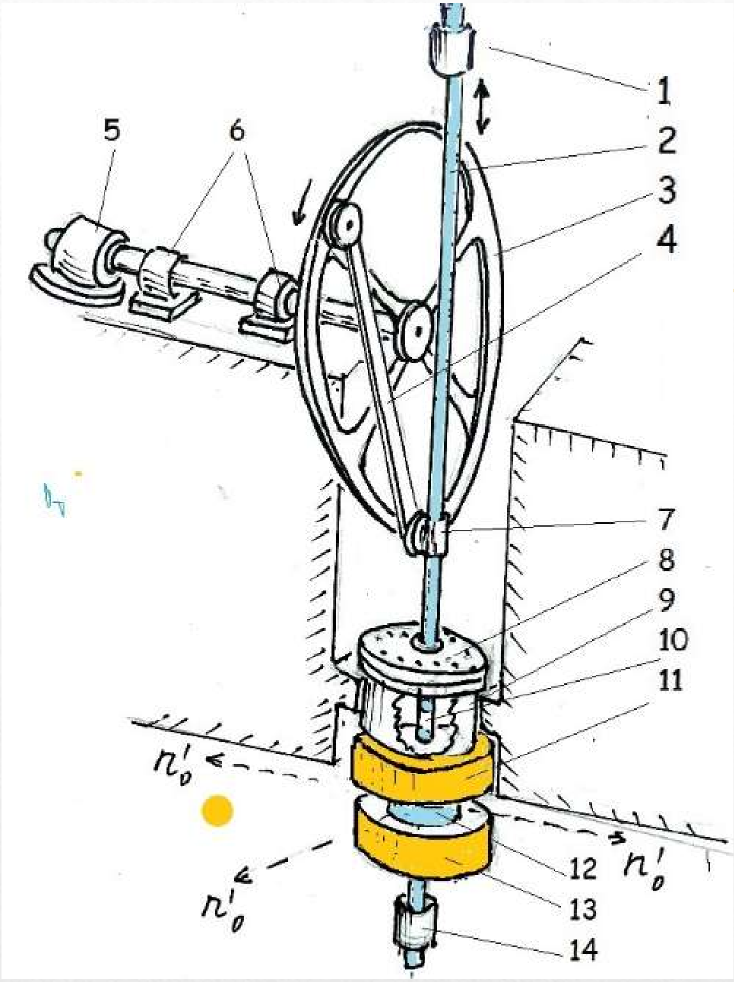
3) Nuclear weapon fissionable isotope is employed.

What to do to improve the characteristics?

Neptune,
the periodically pulsed reactor



conception design

IBR-2 *is still the brightest pulsed neutron source, but…*

- In the course of one third of centure (since 1984) the IBR-2 reactor has been and still is one of the most intense high-flux sources of thermal neutrons in the world for the investigations on extracted beamlines:
- Peak thermal neutron flux - $6 \cdot 10^{15}$ n/cm^2/s

  (at J-Park up-to-the date - $2 \cdot 10^{15}$)
- Time averaged neutron flux - 10^{13} n/cm^2/s

  (just the same as J-Park).
- *ESS will overcome them (~10^{16} and $\geq 10^{14}$)*