The ADS-Troitsk project

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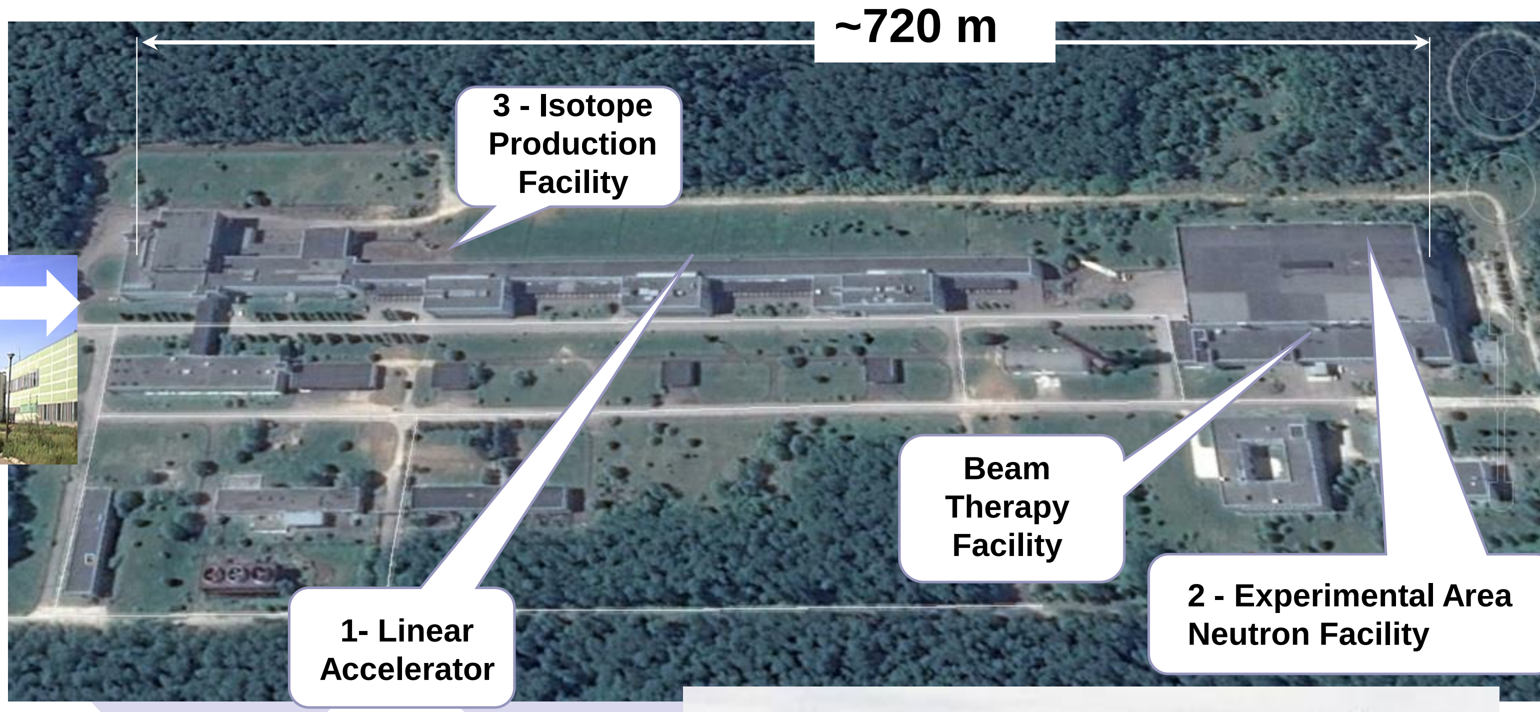
Outline

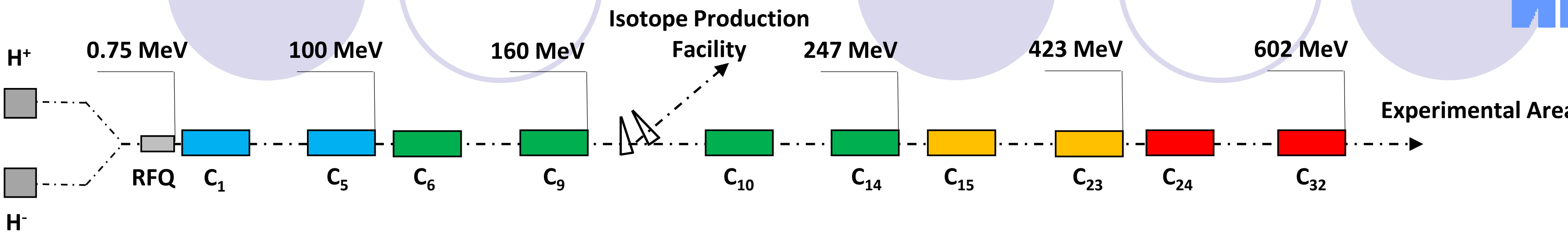
- Linac and experimental complex
- Pulse neutron sources and its infrastructure
- Development and modernization:
- The ADS proposal
- - Motivation
- - General features
  - Probable difficulties

View of INR facility (from Google map)



1. Linear Accelerator
2. Experimental Area
3. Isotope Production Facility

Linear Accelerator



Low energy part of accelerator

5 Drift Tube Tanks

Frequency – 198.2 MHz

Output energy- 100 MeV

High energy part of accelerator

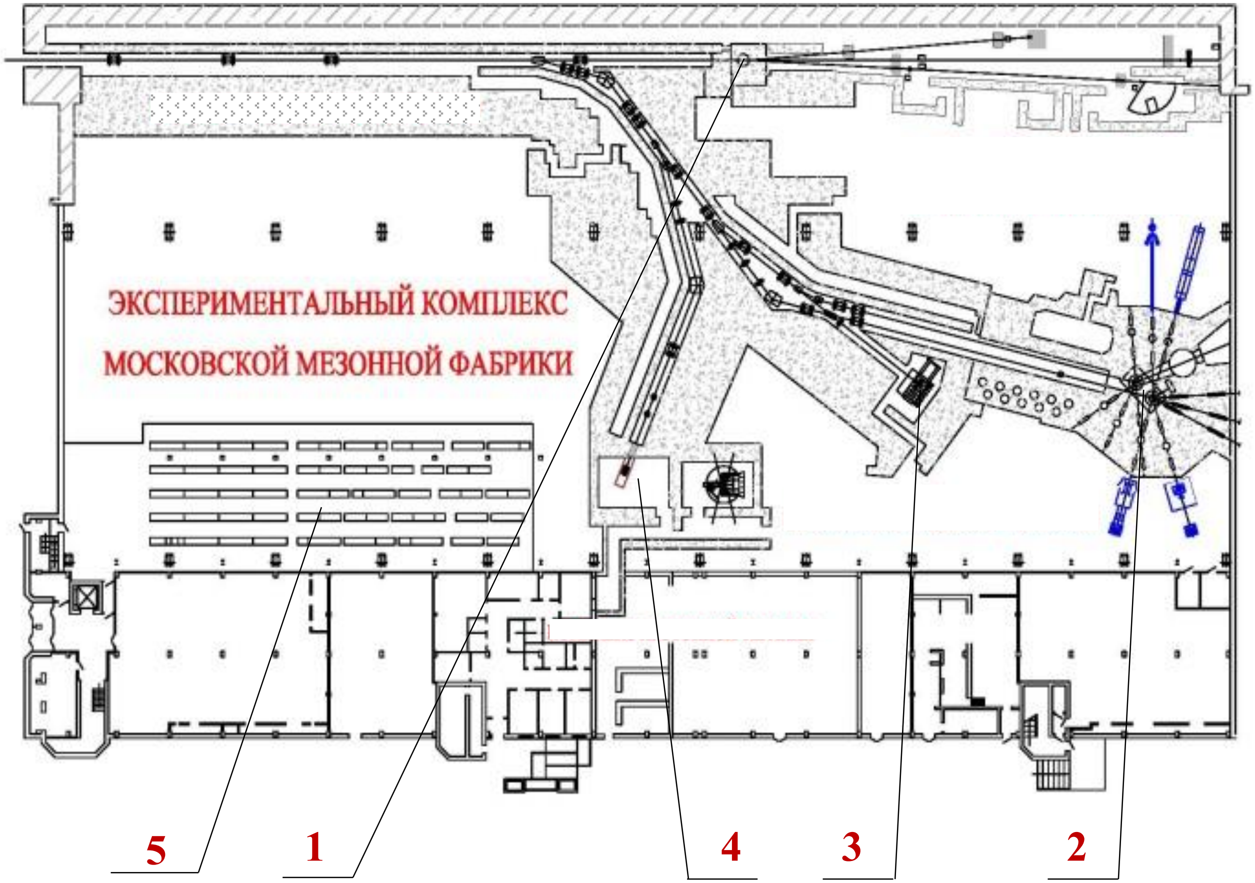
27 four-section Disk and Washer cavities

Frequency 991 MHz

Output energy- 600 MeV

The main accelerator parameters

Parameter	Design	Obtained	February, 2017
Particles	p, H-minus	p, H-minus	p, H-minus
Energy, MeV	600	502	247
Pulse current, mA	50	16	15
Repetition rate, Hz	100	50	50
Pulse duration, μs	100	200	0.3÷200
Average current, μA	500	150	130



Experimental Area

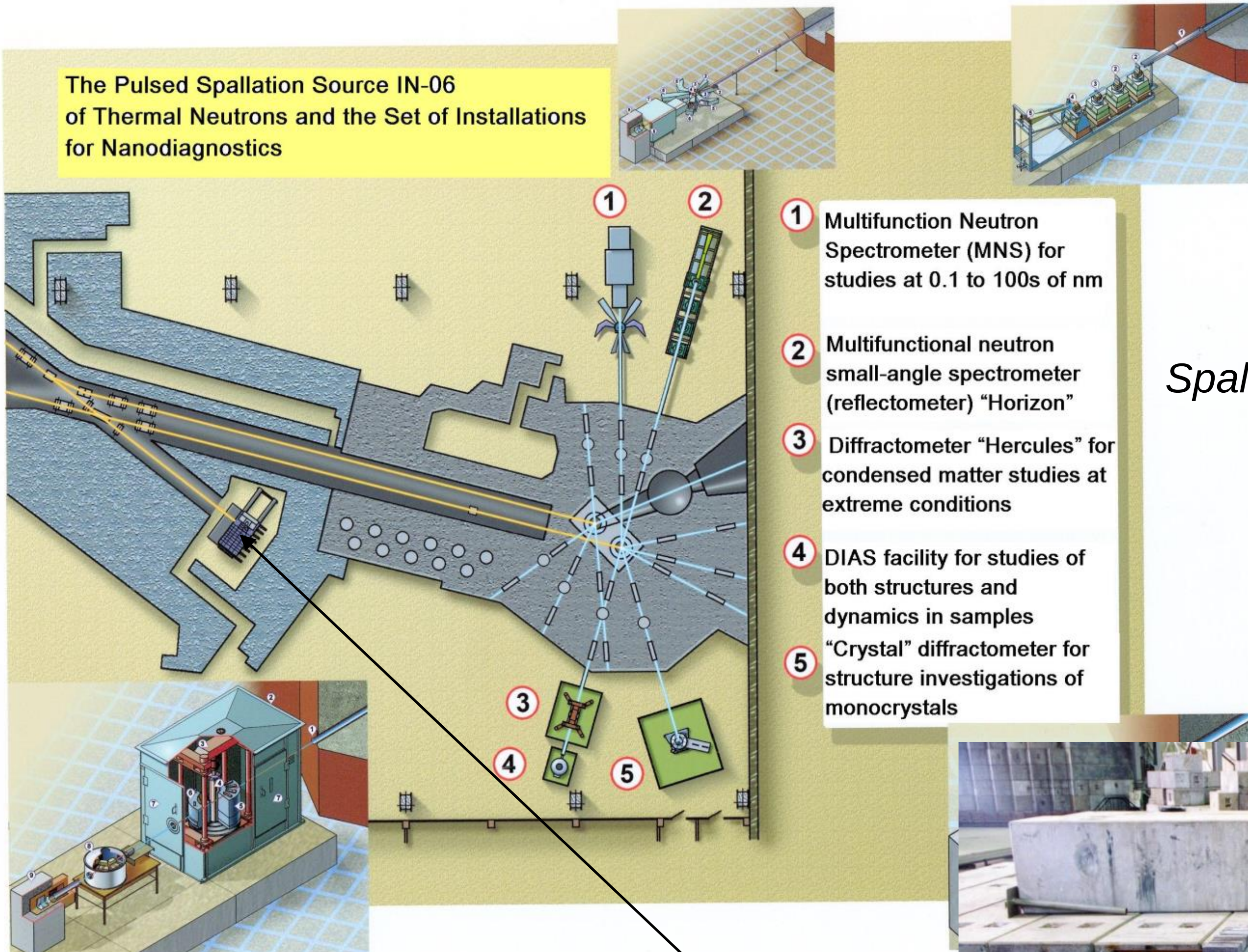
1 - RADEX facility - *Pulsed source of epithermal and resonance neutrons*

2 - Spallation neutron source IN-06 – *Pulsed source of thermal neutrons*

3 - LNS-100 spectrometer – *100 t lead slowing-down neutron spectrometer*

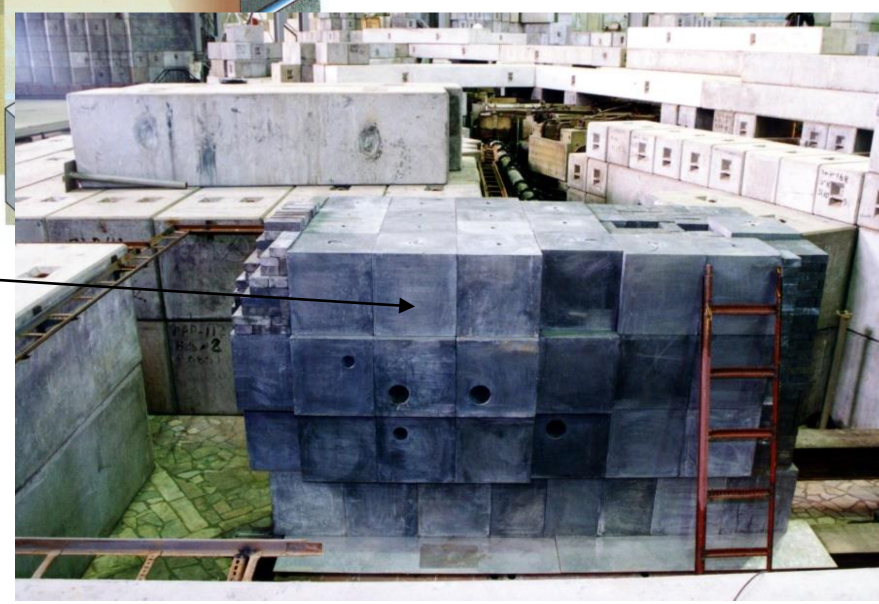
4 - Beam Therapy Complex

5 - Power supplies and support systems

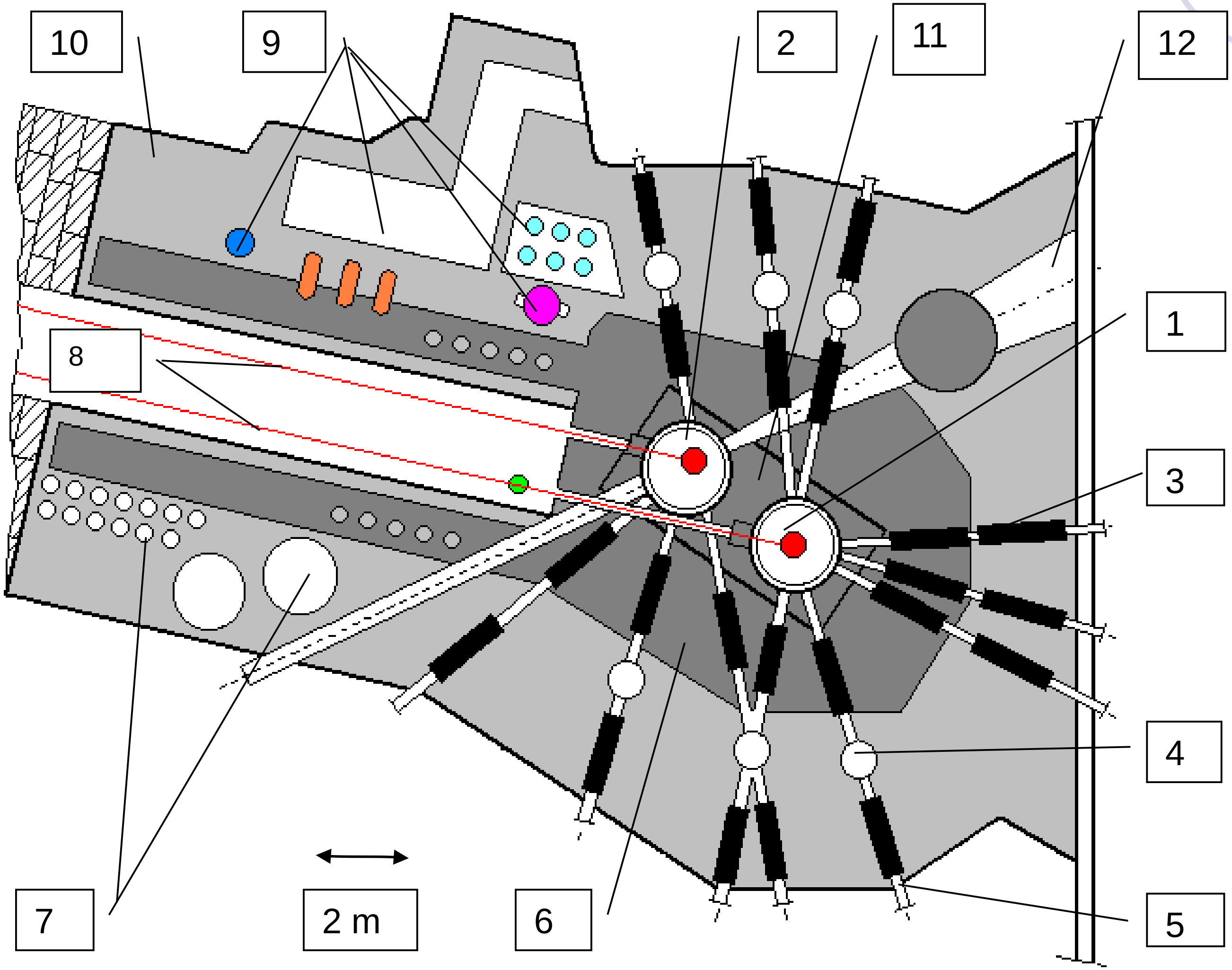


Spallation neutron source IN-06

100 t lead slowing-down neutron spectrometer

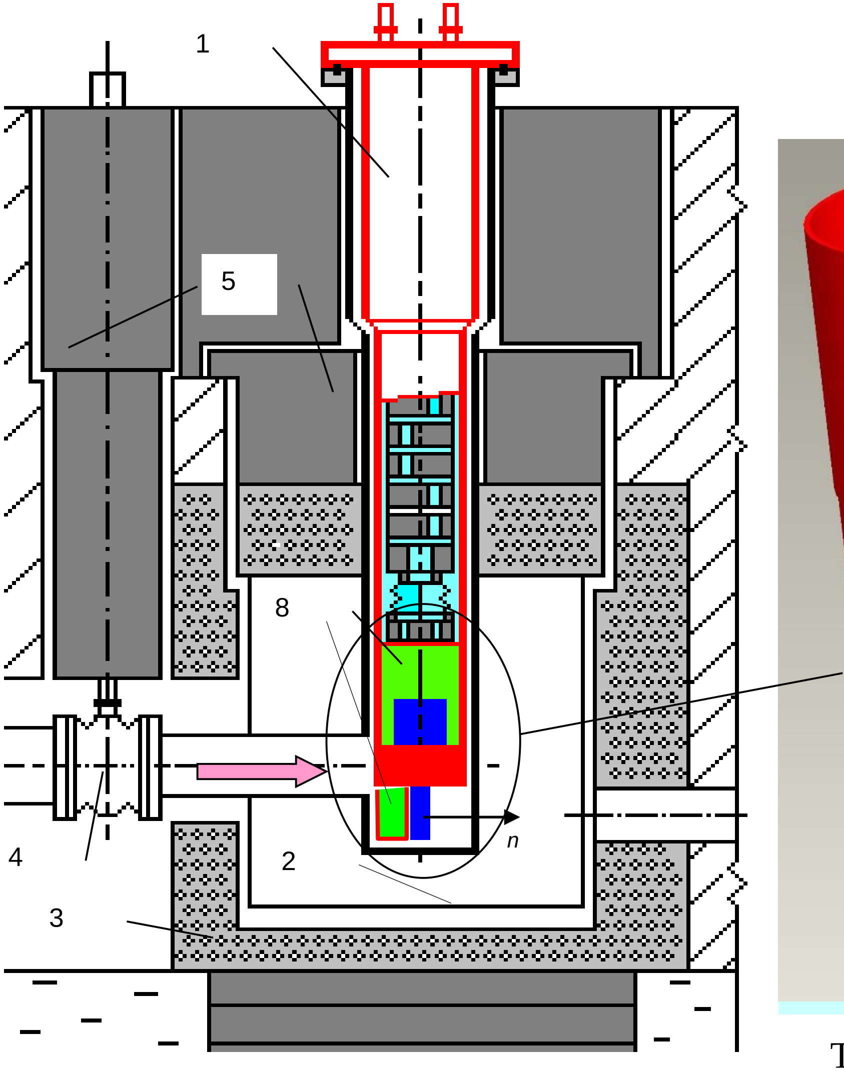


Infrastructure of the neutron sources assembly

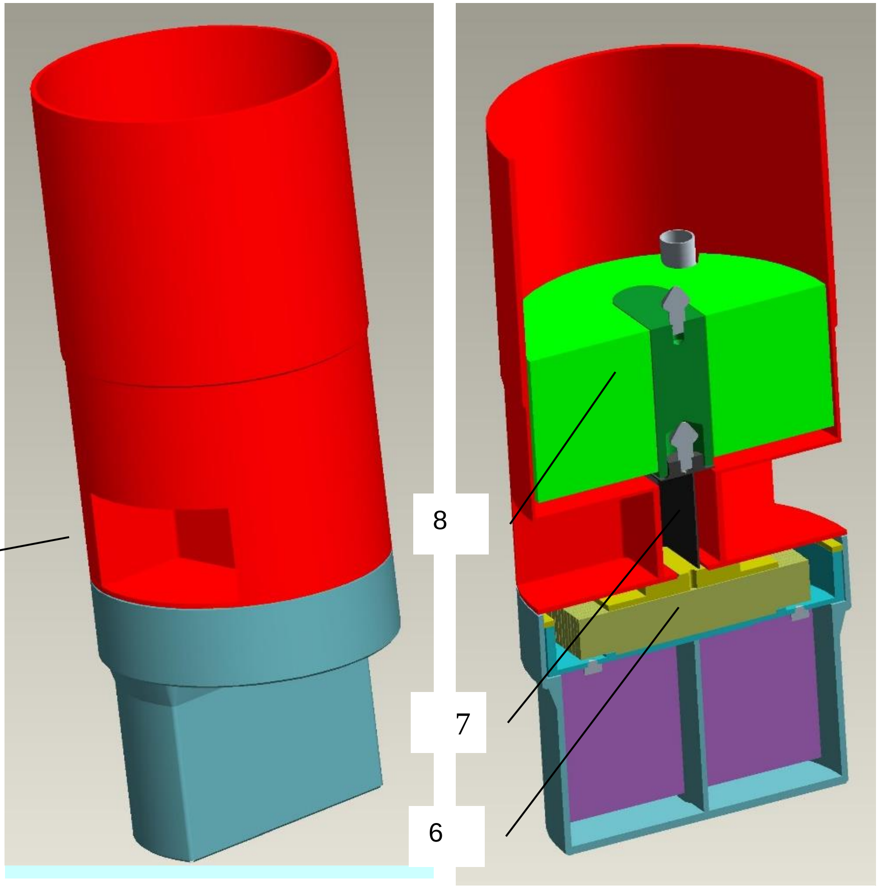


1 – cell of the neutron source,
2 - cell of ADS stand,
3 – neutron gates,
4 – vertical channels,
5 – neutron guides,
6 – iron shield,
7 – storages of modules,
8 – proton guides,
9 – equipment of the first water loop,
10 – heavy concrete shield,
11 – heat shield,
12 – the wide aperture channel.

Scheme of the pulsed neutron source with a new module



Position of a target module in the neutron source and the arrangement of basic elements

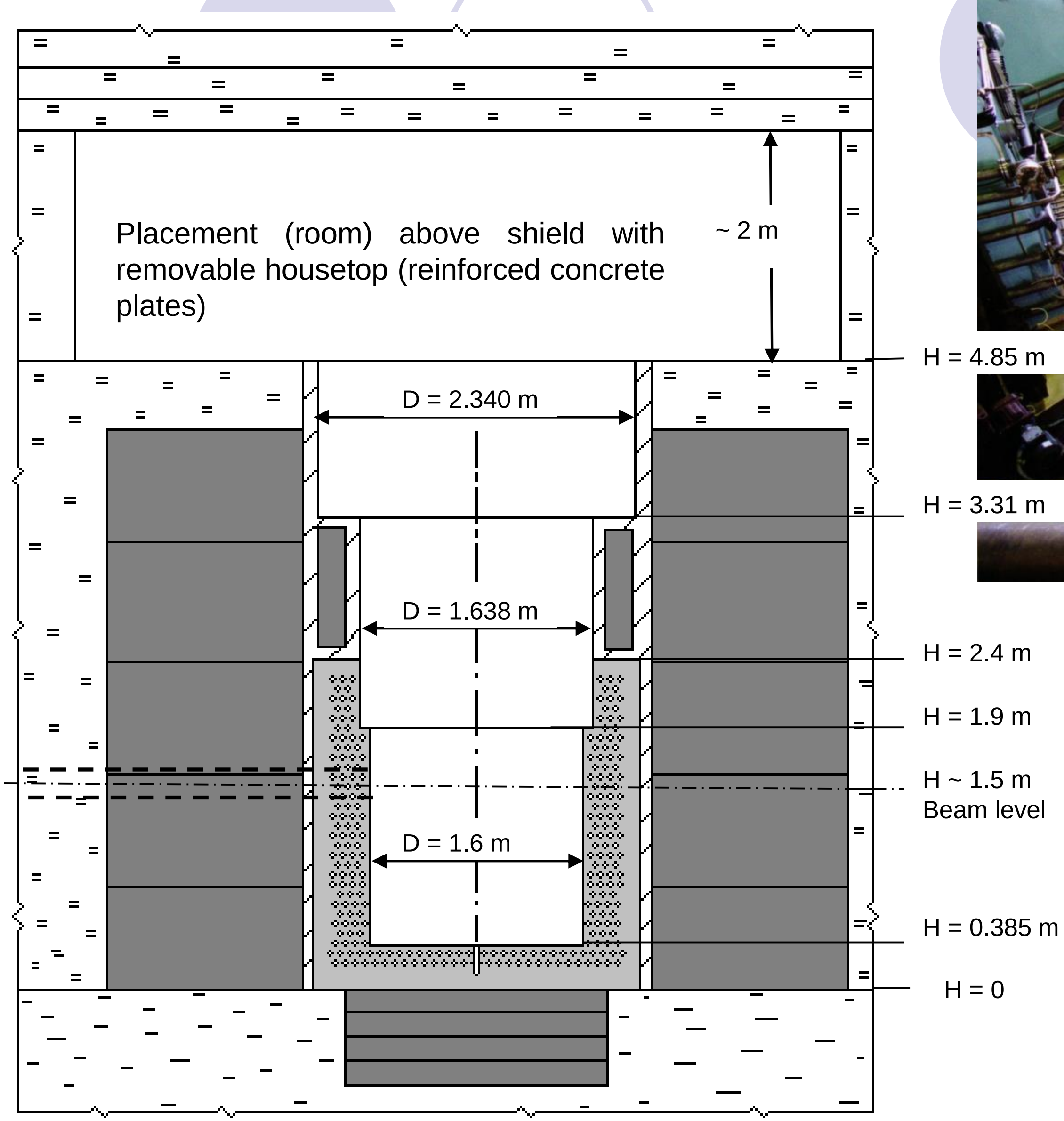


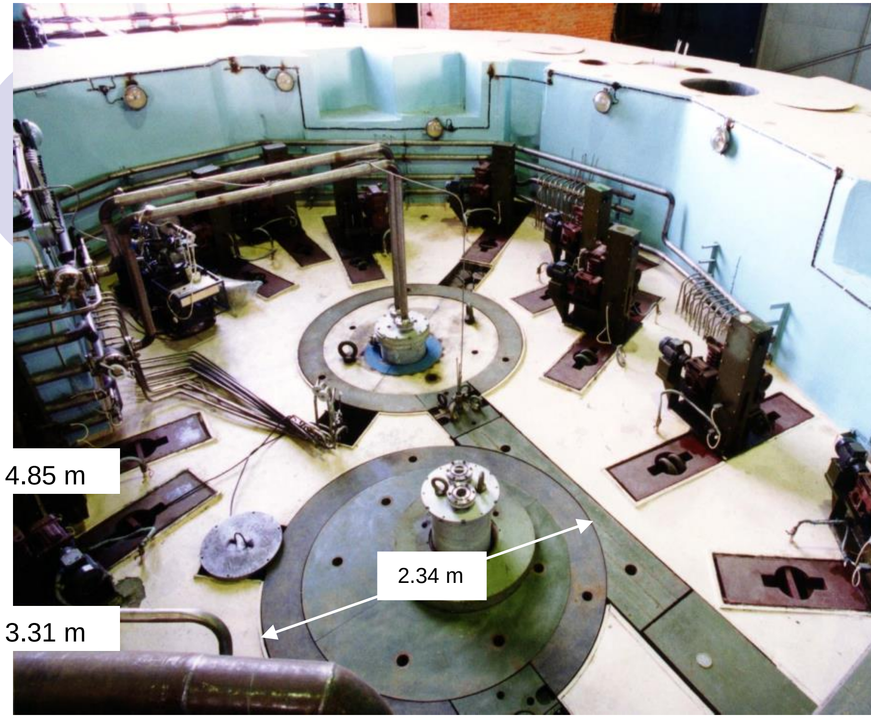
The enlarged lower part of the module containing a target, moderators and reflectors, cut of the lower part of the module.

Pulsed source of thermal neutrons

Pulsed source of thermal neutrons is located in the first box of radiation shield and is intended for research in condensed matter physics.

The design of the neutron source is flexible and allows to use modules with different targets and moderators to carry out full replacement of all equipment of the central part for modernization of the source.





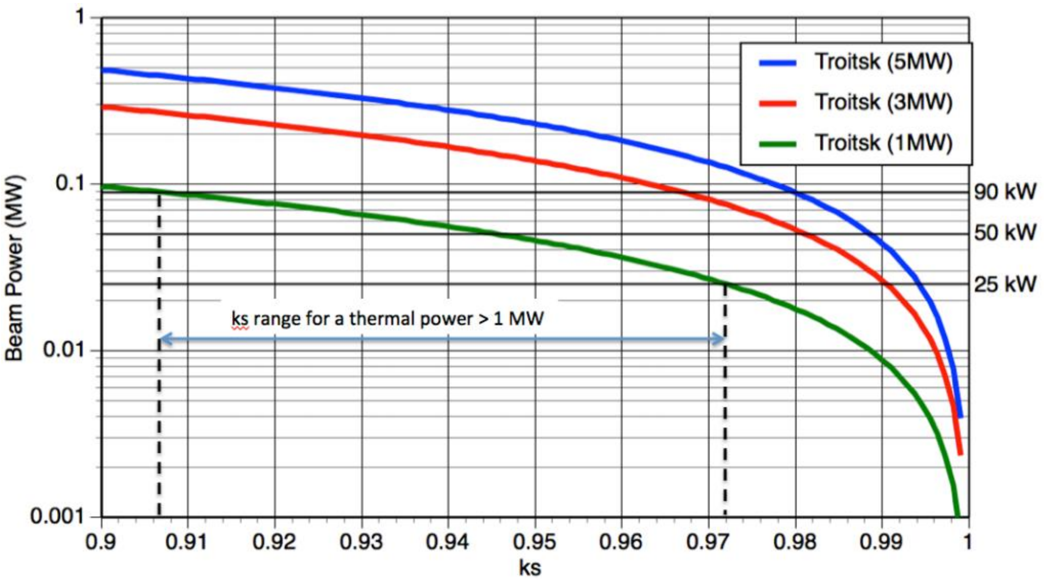
The scheme of the second cell in the shield and its basic sizes

Development and modernization of neutron sources

- Installation of the a beryllium reflector in all volume of the gas tank
- Creation of targets with increased neutron yield per proton. Possibility of using of the target based on ^{237}Np is studied.
- Placing of the second neutron source or ADS in the free boxing of the shield is planned.

The main accelerator tasks to be solved

1. Increasing of energy up to 250-350 MeV
2. Increasing of beam intensity
   - Beam pulse current: 15 mA (limit)
   - Beam pulse duration: 200 μs (limit)
   - Beam pulse repetition rate: increasing from 50 Hz to 100 Hz
3. Development, fabrication and replacement of the first DAW cavity (100÷113 MeV)
4. Installation of new beam line to the second compartment of neutron source.
5. Others



With the achievable accelerator parameters the 1 MW line (green) looks realistic.

Expected maximal power of Research ADS depend upon proton current – I_P, multiplication coefficient – M, proton energy – E_P and type of target.

Average proton current I_P (μA)	Multiplication M (k_{eff})	Average power of blanket, P (MW), for proton 300–600 MeV							
		W (plates)				Natural uranium target with rod elements			
		300	400	500	600	300	400	500	600
100	20 (0.95)	0.73	1.16	1.66	2.08	1.02	1.62	2.29	2.91
	50 (0.98)	1.80	2.90	4.15	5.20	2.55	4.05	5.70	7.30
150	20 (0.95)	1.10	1.75	2.50	3.12	1.54	2.44	3.44	4.36
	50 (0.98)	2.75	4.40	6.25	7.80	3.85	6.10	8.60	10.9
200	20 (0.95)	1.47	2.32	3.32	4.16	2.05	3.25	4.58	5.82
	50 (0.98)	3.65	5.80	8.30	10.4	5.15	8.10	11.5	14.6
250	20 (0.95)	1.83	2.91	4.16	5.20	2.57	4.06	5.72	7.28
	50 (0.98)	4.60	7.30	10.4	13.0	6.40	10.2	14.3	18.2
300	20 (0.95)	2.19	3.5	5.00	6.24	3.08	4.86	6.86	8.74
	50 (0.98)	5.45	8.75	12.5	15.6	7.70	12.2	17.2	21.9
Neutron yield, Y (n/p)		~ 3.5	~ 5.6	~ 8	~ 10	~ 4.9	~ 7.8	~ 11	~ 14
Proton range – R, cm		~ 5.2	~ 9.2	~ 13	~ 17				
Target diameter - D ~ 1.3R,		~ 8	~ 13	~ 17	~ 21				
Importance of the primary neutrons, $\omega \approx 1.3$									

Demo ADS - motivations and goals

The possibility to create ADS demonstration facility with a minimal investment, looks as at least one order of magnitude cheaper than any alternative projects.

The study of different configurations of the blankets and testing of structural elements by research ADS

The use of this stand as the second neutron source for condensed matter physics.

Troitsk-ADS

Technical assumptions

Minimum guaranteed beam power: 25 kW, average beam power 50 kW, and maximum beam power 75 kW, all at a beam energy of 247 MeV – but 300 MeV should also be possible;

In order to guaranteed that a thermal power of 1 MW can be reached, k will have to reach 0.972, and in general during operation **k will be varied from 0.9 up to the maximum value of 0.98**, to characterize the core to accelerator coupling over the largest k range;

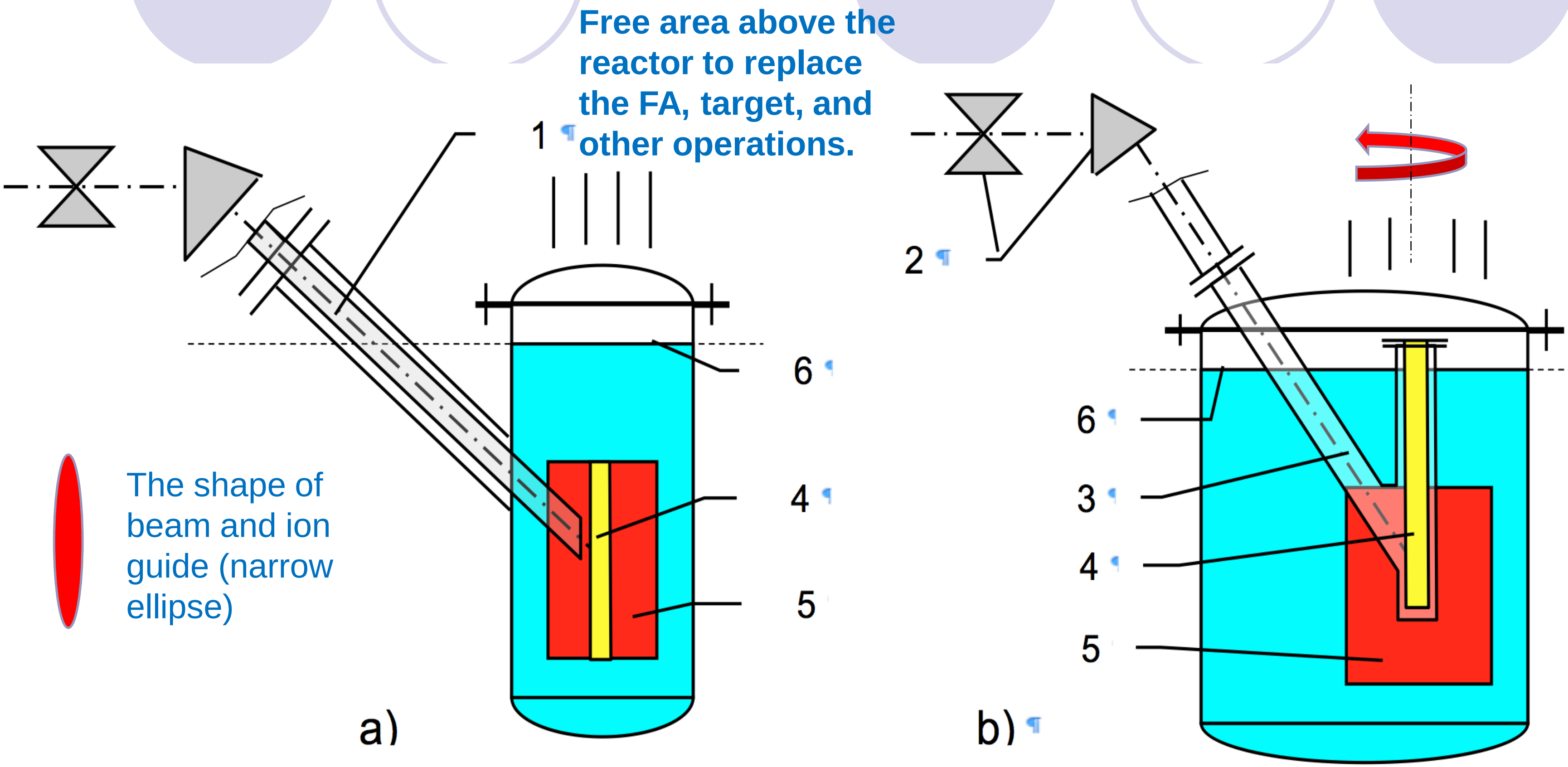
As the beam power is relatively small, the target will be **a solid target, most likely tungsten, water-cooled**. This is a simplification and a significant saving on the cost;

The maximum thermal power could reach 3MW (at 75 kW beam power), therefore the cooling of the core should allow for this.

Main engineering problems

- Creating a long-lived target modules with high yield of neutrons
- Entering powerful proton beam in ADS
- Creating ADS configurations with natural internal safety

Possible solutions - Increasing the cross sectional area of the beam and the rotation of target around its axis



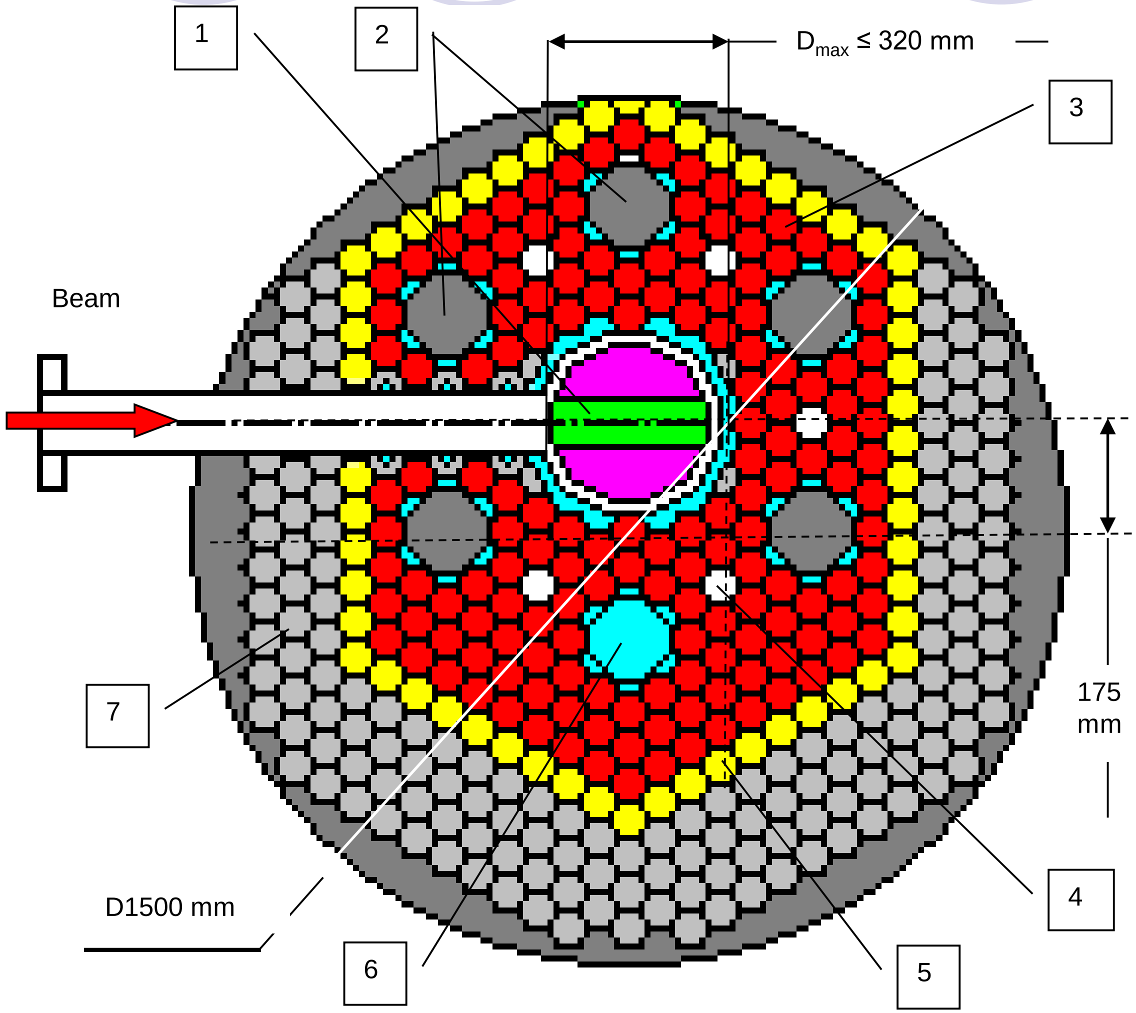
Schematic of the input of a proton beam diagonally (sideways from above): (a) with separate cooling window on the removable portion of the ion guide; (b) with placement of target module inside vacuum chamber that is connected with the proton guide.
(1) Removable part of proton guide; (2) vacuum shut-off gate and beam-bending magnet; (3) vacuum chamber; (4) target module; (5) blanket; (6) water level in body after breakdown of window or target module

The main physical and technical requirements to demo ADS

The research ADS should provide:

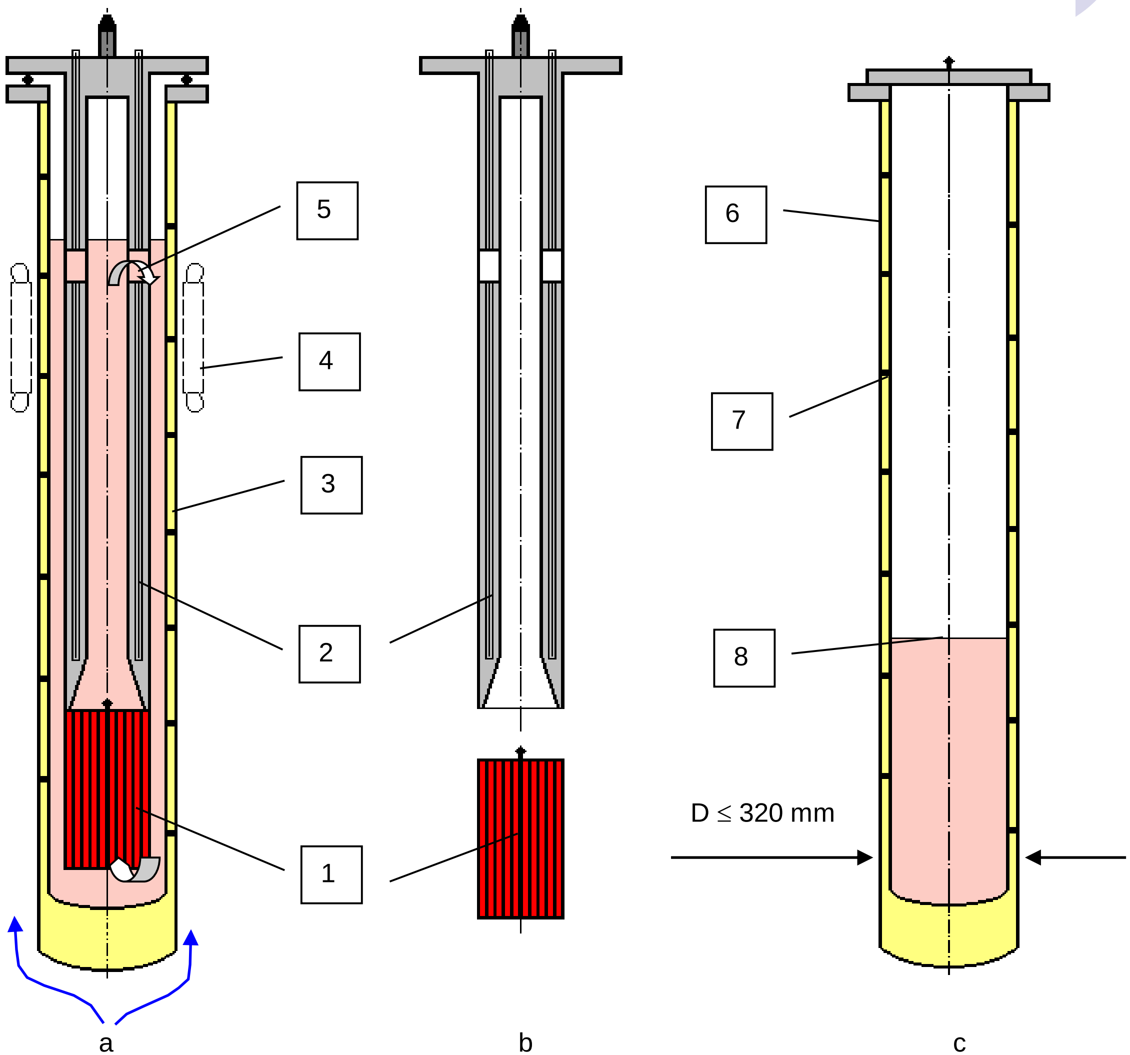
- Fast enough and convenient blanket reprocessing, target change and assembling of the other ADS configurations.
- The study of different fuel compositions with different contents of MA, Th...
- Fast access to the experimental channels of the blanket, the safe extraction of the irradiated heat-generating-assemblies.
- Fast core spectrum for the minor actinides burning.
- Thermal neutron spectrum for transmutation of long live fission products and for work of neutron guides.
- Stability of ADS elements to spontaneous interruptions of accelerator proton current (thermal shock).

One of the possible conceptual scheme of Research ADS with natural safety



1 –target module;
2 – hermetical PbBi capsules with high enriched fuel and minor actinides;
3 – the cassettes of the water-cooled part of blanket with MOX fuel (~ 25% enr.);
4 – the module of controlled systems;
5 – decoupler (if it is required);
6 – traps of thermal neutrons (moderator) can construct in any place ;
7 – reflector.

Conceptual scheme of PbBi capsule



a – collected capsule,
b – cassette with fuel elements and displacer (removable elements),
c – body of capsule with Pb-Bi after removal of fuel cassette and displacer.
1 – cassette wit fuel;
2 – spreader of up-going and down-going flows with build-in heaters, the displacer of liquid metal and holder of fuel cassette;
3 - binary body; 4 – EM pump;
5 – direction of liquid metal flow;
6 – gas gap (~1 mm) of the heat barrier;
7 – spacer;
8 – level of liquid metal after removal of displacer and fuel cassette.

Functions of the basic elements

Module cooling is performed by water of the first loop through the lateral surface.

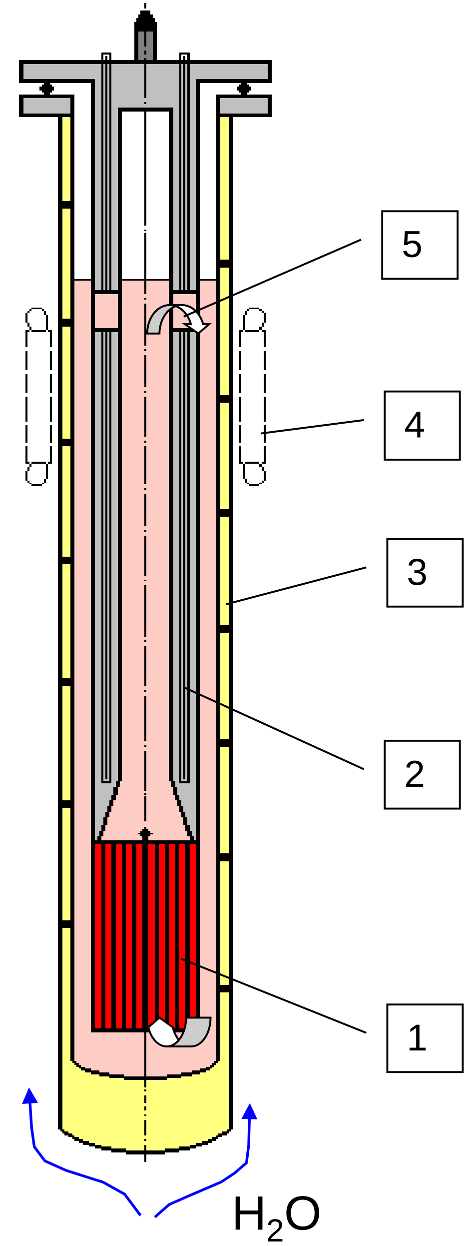
The inset should have double wall to maintain temperature regime and to be safety.

There is also a gas gap ~ 1 mm which acts as a heat barrier.

Each inset is equipped by its own heater (2) for:

- prescribed temperature level support and variation;
- preliminary melting of PbBi and heating of all ampoule after its delivery and its fixing in working position;
- partly compensation of the PbBi temperature decrease and for prevention its freezing caused by automatic increase of current loading in the case of accidental accelerator failure or beam loss.

Apart from these, an inset can have its own electromagnetic pump (4). It permits to vary temperature and velocity of PbBi coolant.



Some technical aspects of safety

Presuppose that:

- The PbBi modules will be manufactured and tested in IPPE (Obninsk ~ 70 km from Troitsk),
- PbBi modules can operate without support systems of coolant within ~ 2 years (findings of IPPE)
- The safety transportation of PbBi modules with fuel elements is carried out in the solid state (Obninsk → Troitsk → Obninsk, for post irradiation study).

Localization of flaw in SS casings (solidification of PbBi leakage by cold water) under operation of PbBi module is possible.

Probable use of the fuel elements of the IBR-2M (Periodically Fast Pulsed Reactor – JINR, Dubna) as a prototype. This elements has specific character for preventing levitation of the fuel pills under the heat shock.

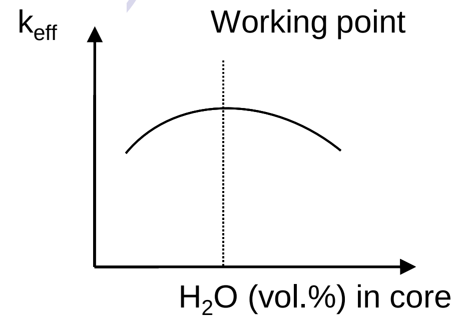
Some physical features of the ADS stand and the fast water cooled blanket

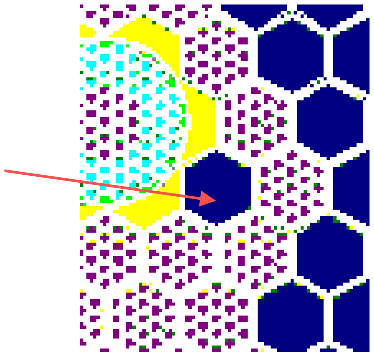
- High sensitive to density of water. Decrease density of water including boiling and full loss makes assembly deep subcritical.
- Water cavity (it appears after replaced a fuel cassette or PbBi capsule - refuelling) is the source of thermal neutrons. It is big positive effect of reactivity can makes assembly above-critical.
- Using of hafnium alloy for covering the fuel assemblies (cassettes) allows to exclude the positive effect of reactivity at replacement fuel assemblies and PbBi - insertions under water layer.

Nuclear safety and the other features

This two effects (the high sensitivity of the blanket to the concentration of water and the using of hafnium for the covering of fuel assemblies***) allow:***

- to make the blanket with intrinsic safety
- to change configuration of fast blanket and replace the irradiated fuel assemblies and modules (target and PbBi) under a water layer as in the swimming pool-type thermal reactors;
- to create traps of thermal neutrons and moderators in any place of fast blanket;
- To create the effective control and safety systems on base neutron traps in any place of fast blanket. This can be the hollow displacers of water moving and floating by Archimed force.

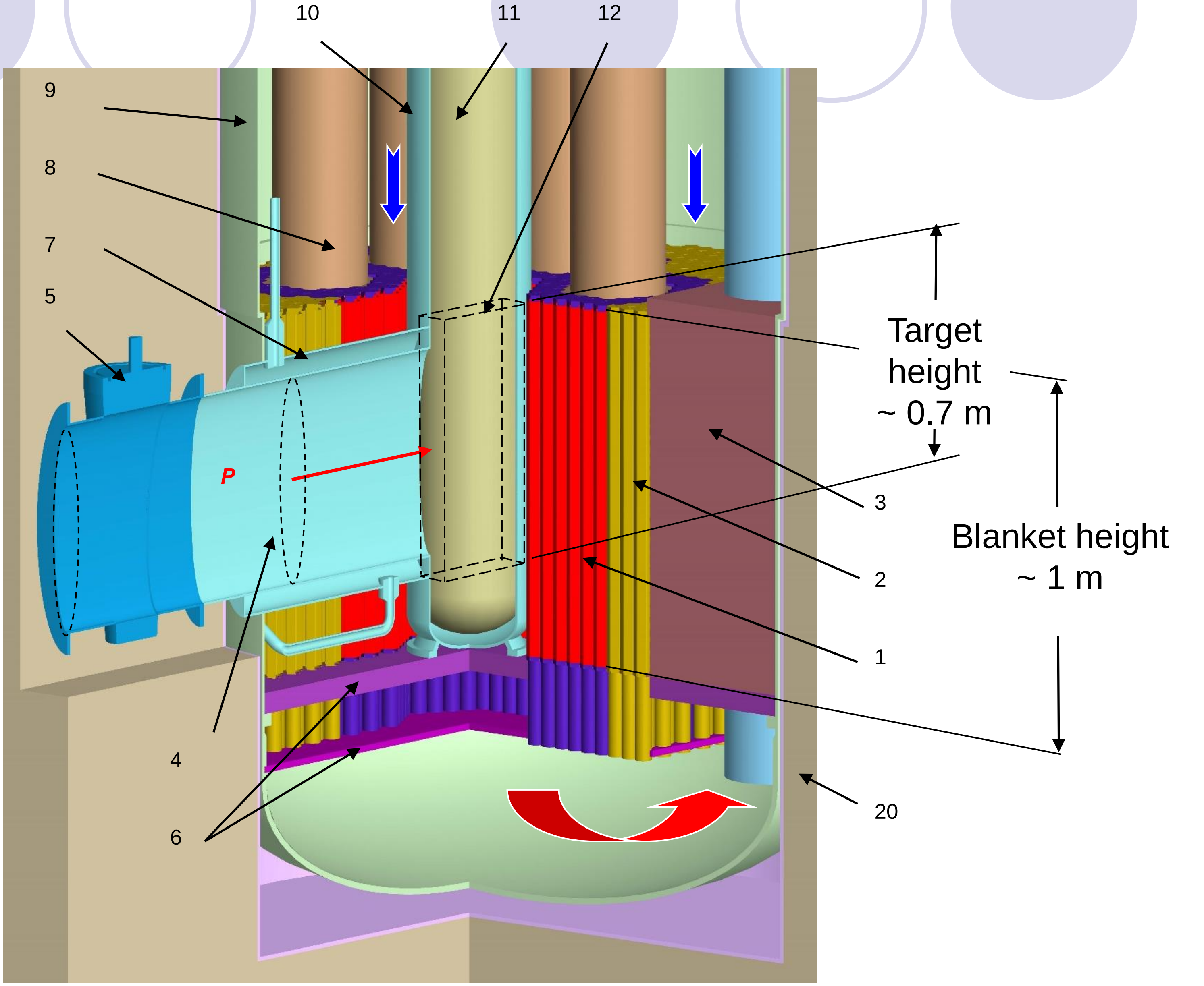




Research ADS and Pulsed Neutron Source

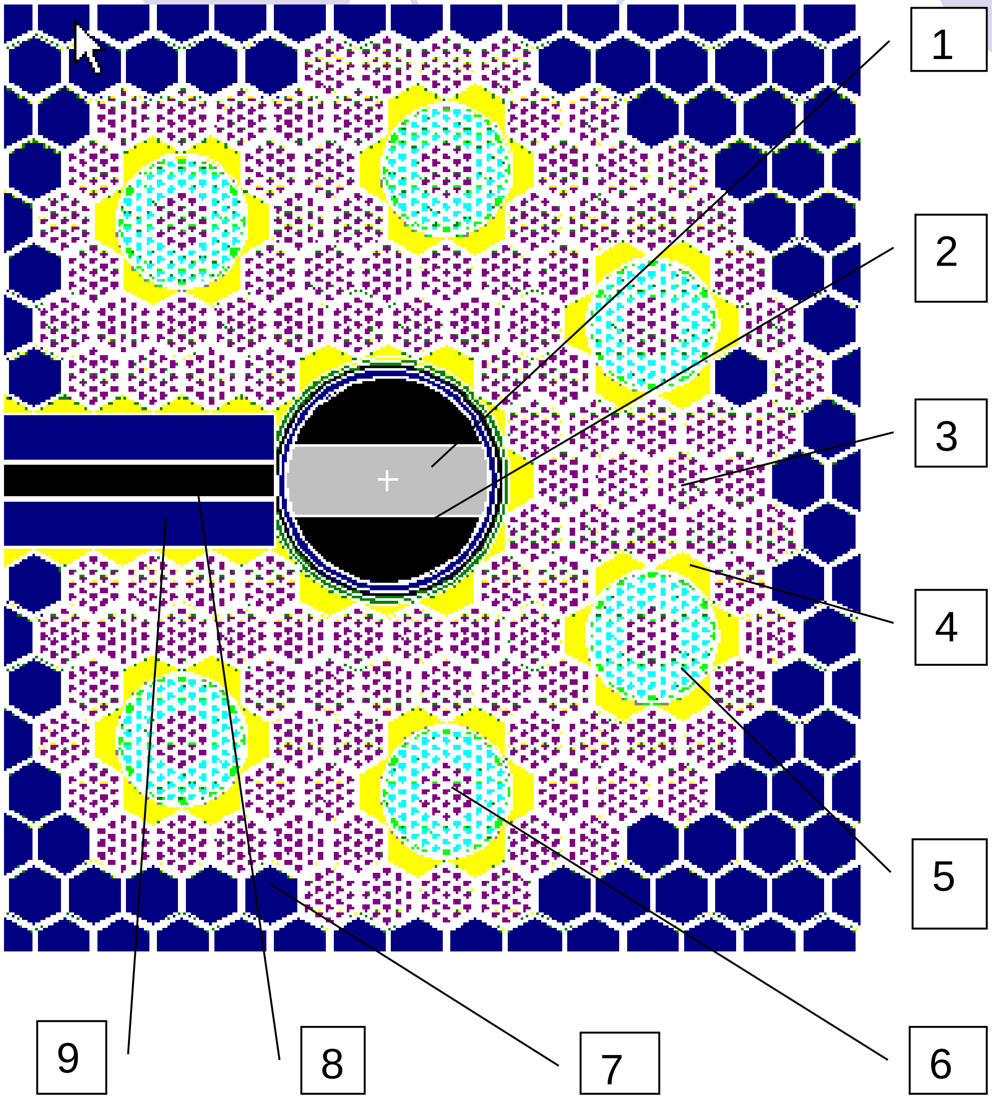
- *The research ADS can work as the pulsed neutron source with coefficient of multiplication up to 20 if to* ***use*** ^{239}***Pu*** *(main fission isotope with low fraction of delay neutrons).*
- ***Blanket with a fast neutron spectrum is required*** *for generation of short neutron pulses.*

Possible design scheme



The shape of beam and ion guide (narrow ellipse)

Basic geometry for studying



1 – Target,
2 – hollow or Al displacer between target and cylindrical body of target module,
3 – Assembly of fuel elements (19),
4 – Water cavity between cylindrical body of PbBi module and the fuel elements assembles,
5 – PbBi module,
6 – 19 central fuel elements with NpO_2 in PbBi module (MA imitation),
7 – Elements of Al reflector.
8 – proton gaide,
9 – displacers and constructional elements between proton guide and blanket.

Reactivity effects

The wall thickness of cassette – 1.0 mm (Hf)

Replacement of one PbBi module by water *- 0.029 k_{eff} (- 2.9%)*

Replacement of one fuel assembly by water *- 0.001 k_{eff} (- 0.1%)*

Replacement of four fuel assembles by water *- 0.010 k_{eff} (-1.0%)*

The wall thickness of cassette – 0.5 mm (Hf)

Replacement of four fuel assembles by water *- 0.004 k_{eff}.*

The wall thickness of cassette – 1.0 mm (SS)

Replacement of four fuel assembles by water **+0.0057 k_{eff},**

The k_{eff} of ADS increase from 0.95 (Hf-wall) to 1.172 (SS-wall)

Assembling and rebuilding of the fast water cooled blanket is impossible under water layer.

Usage of the fuel assembles with 37 fuel elements for decrease of the volume fraction of hafnium in blanket and the additional neutron capture is expedient

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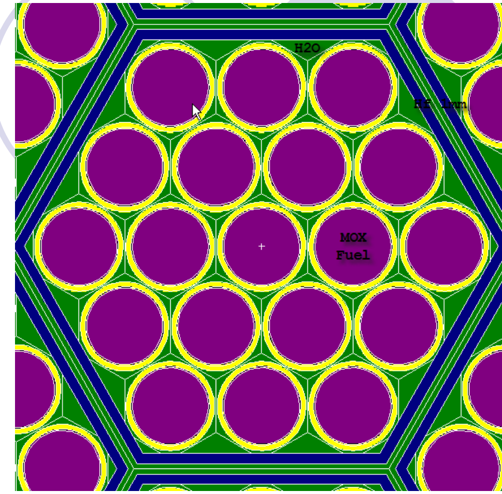
Maximal value of importance is equal $\omega = 1.35$.

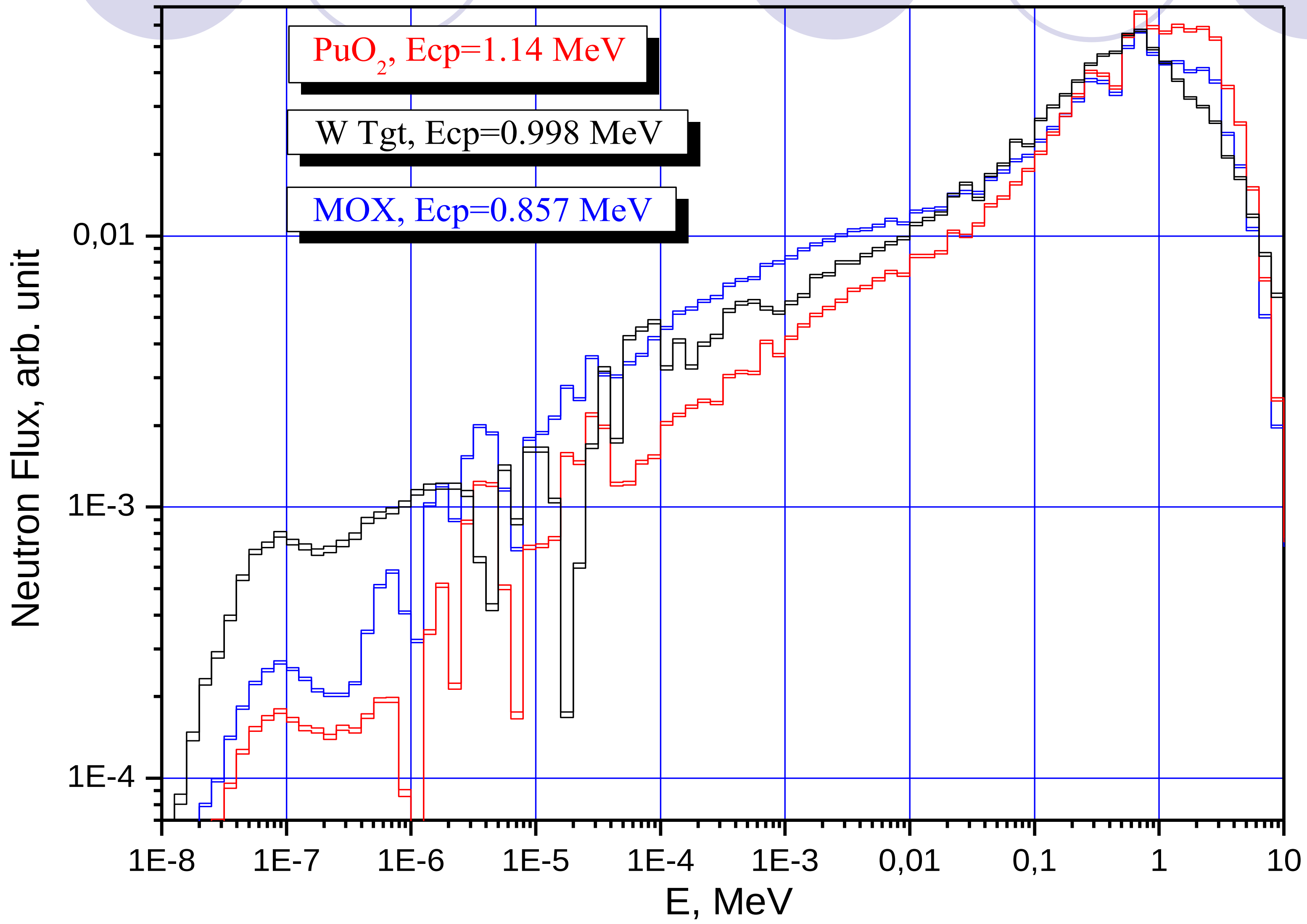


The fuel cassette scheme of the water cooled part of blanket

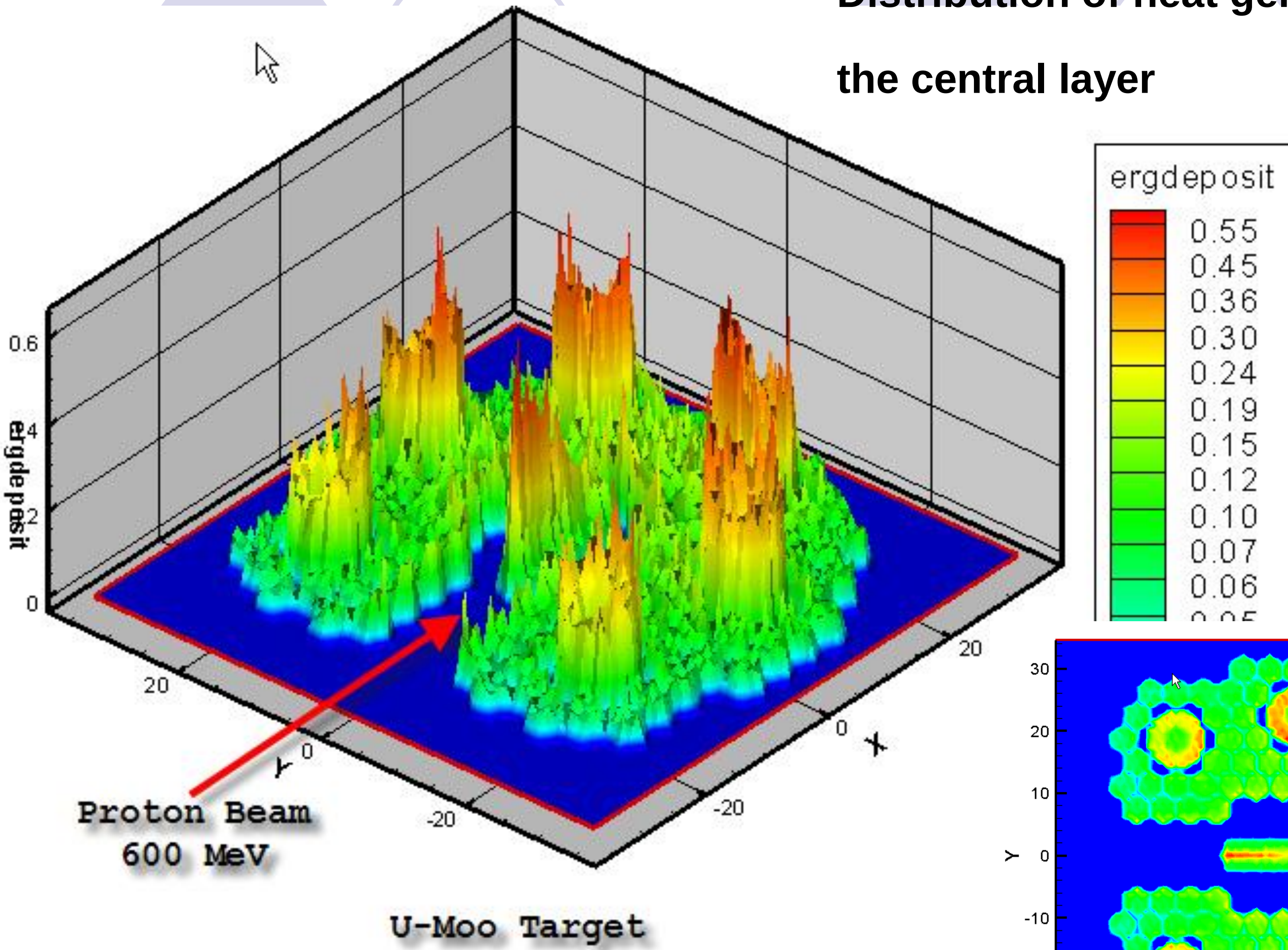
There are three parameters for minimization of the additional neutron capture in hafnium at keeping of the negative effect of reactivity:

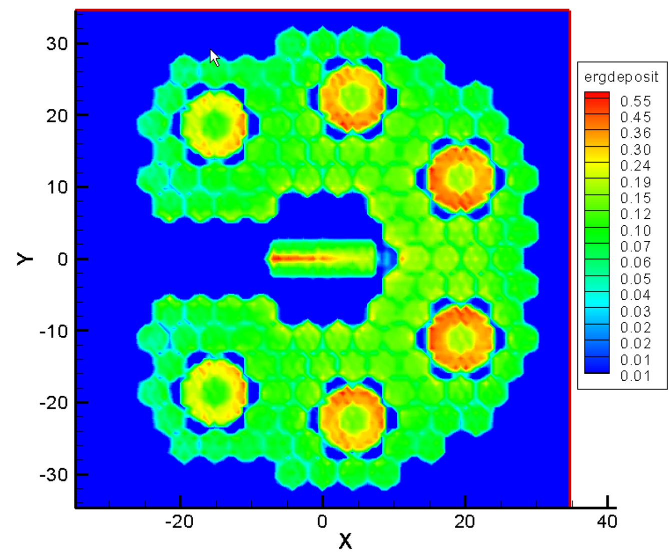
- Percentage hafnium in alloy. For ex. Hf(78%)Nb(2%)Zr(20%),
- The wall thickness of cassette,
- **The number of fuel elements in cassette**

Spectrum of the water cooled part and PbBi



Distribution of heat generation in the central layer





Activity: directions of studies

We carry out the similar study for the molten-salt modules.
Melt of 46.5LiF–11.5NaF–42KF has the high solubility of Th and MA in the interval 550–700°C.

The investigation of the ADS with ring blanket and lead diffusor

Analyzing of possibility to use ^{237}Np
Reasons:

- To exclude usage of ^{239}Pu and high enriched uranium.
- ^{237}Np in target or blanket has low effective fraction of delayed neutrons – $\beta_{eff} << \beta$ that obeys to use the ADS facility as the neutron source. It provides with a low background between pulses.

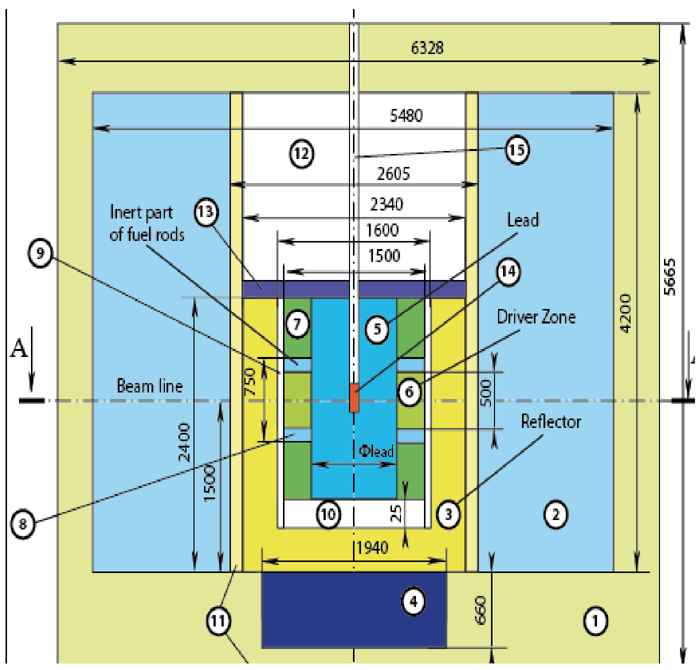
Transmutation of minor actinides (MA) just under the proton beam.

Estimation of the basic parameters of the ADS with ring blanket and lead diffusor

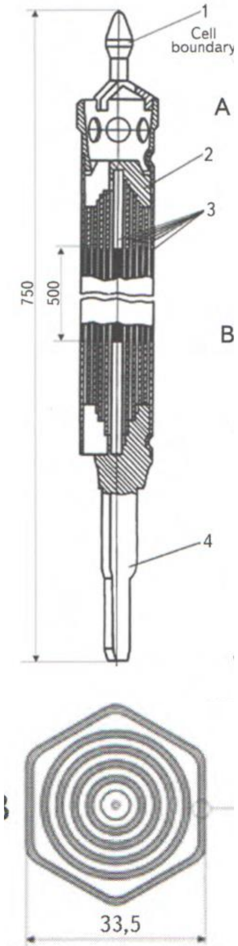
$k_{eff} = 0.98$
$E_{proton} = 300$ MeV
$I_P \sim 100$ μA (30 KW)

Total power – 1.17 MW

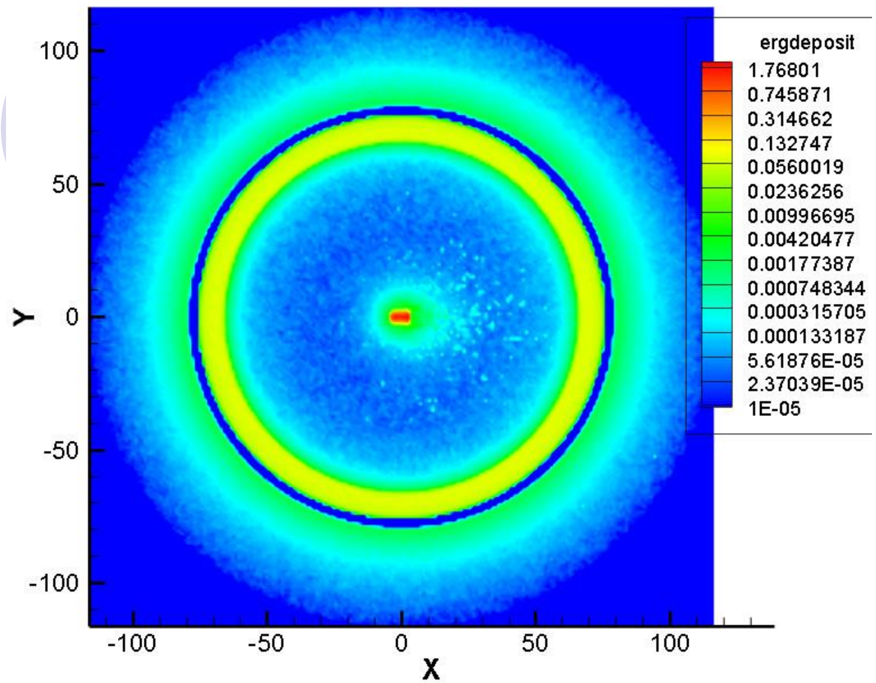
Core - 1080 KW
W target - 25 KW
Reflector - 41 KW (38 KW – γ-rays)
Lead - 24 KW (22.7 KW – γ-rays)

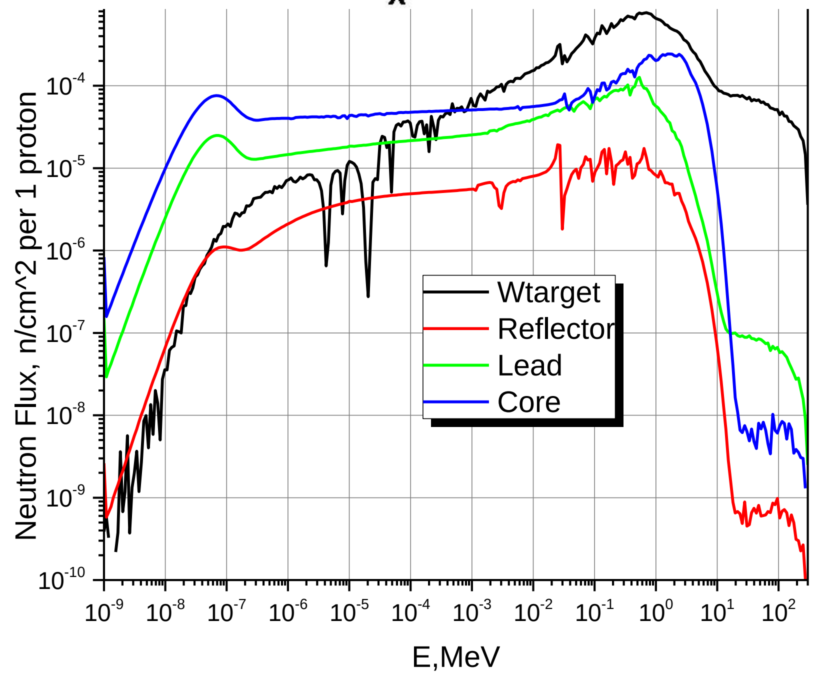


VVR-M5
(90% ^{235}U)



VVR-M5 FA based on U-Al fuel





The percentages of fissions caused by neutrons in the **thermal**, **intermediate**, and **fast** in ranges are:

(<0.625 ev): 85.65%

(0.625 ev - 100 kev): 13.31%

(>100 kev): 1.04%

The thickness of the annular fuel layer ~ 8.7cм (too small !!!)

The standard fuel assemblies VVR-M2 (19.8% ^{235}U) or VVR-C (36% ^{235}U) follows use instead VVR-M5 (90% ^{235}U).

Conclusion

- Existing infrastructure of the Neutron Complex gives a possibility to creation and operation of a ADS research facility

- Modeling shows that practically all starting ideas may be realized.

- There is the possibility of creating a multi-purpose ADS stand with internal (natural) safety

- Further development of the project depends on the licensing and a formal permission to operate with such a nuclear facility.