Troitsk ADS project

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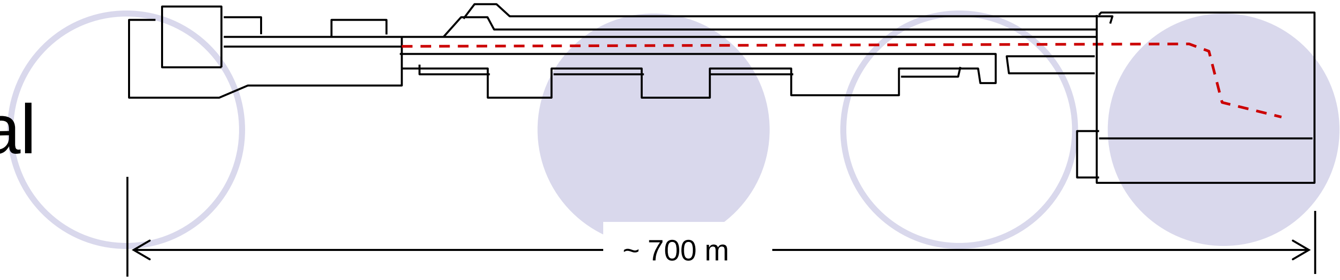
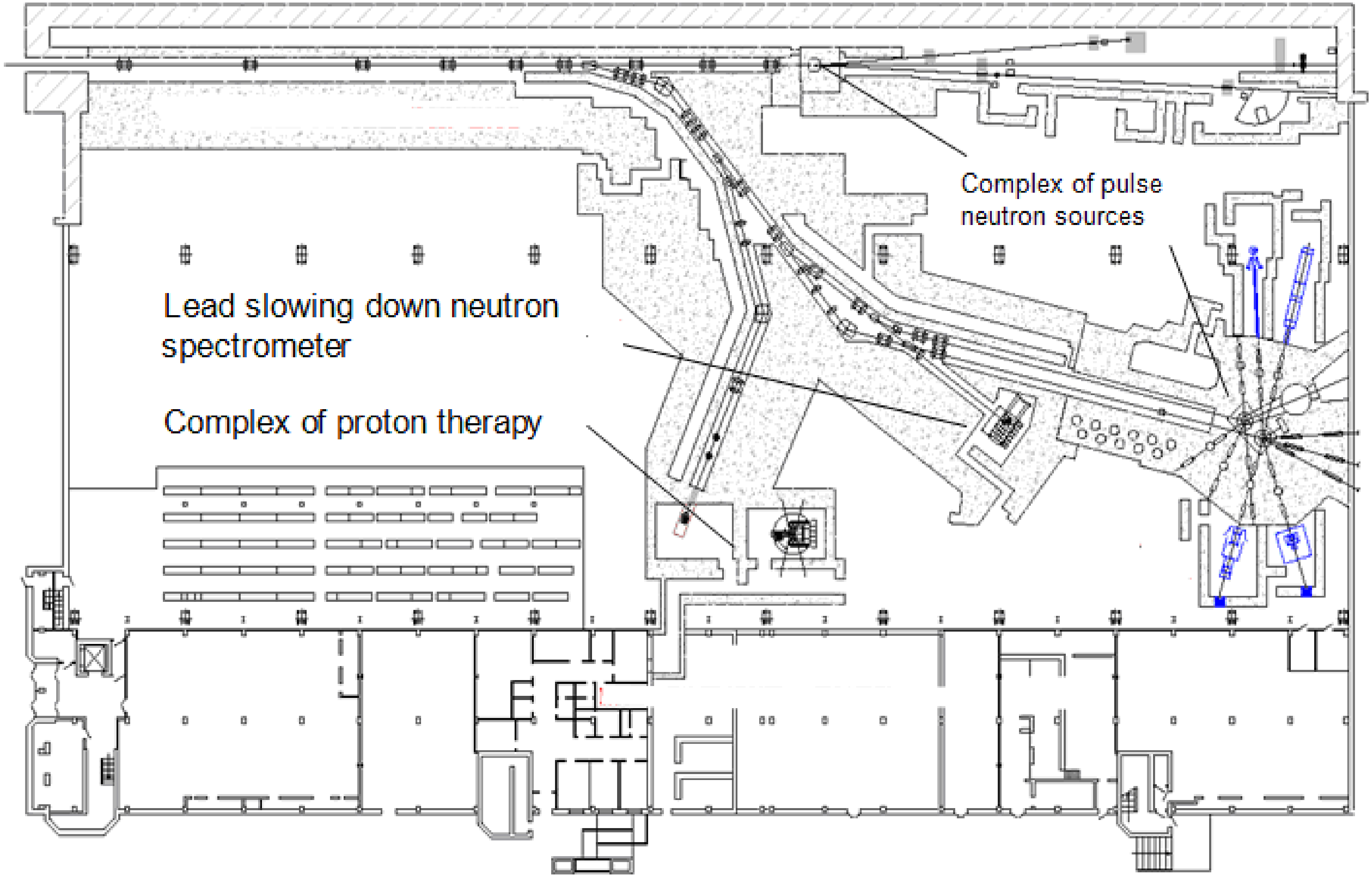
Outline

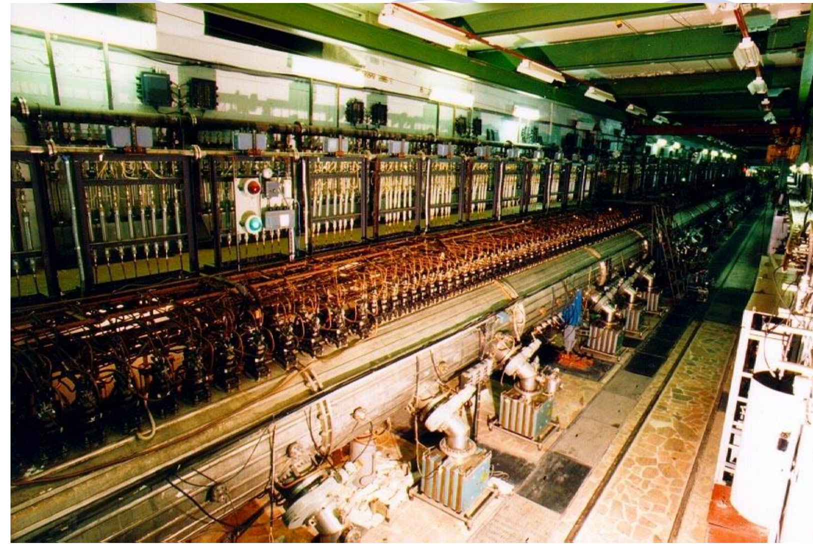
- Linac and experimental complex
- Pulse neutron sources and its infrastructure
- Development and modernization of the neutron sources
- - The ADS proposal
  - Motivation
  - General features
  - Probable difficulties

Linac and Experimental Complex

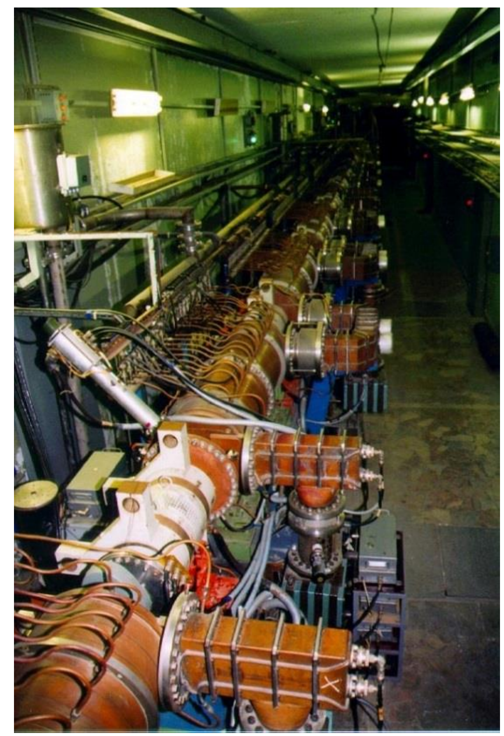




Linac



Initial and main parts of linac



Experimental Complex

Linac parameters

	The design parameters	Running characteristic	Maximum reached value
Accelerated particles	p, H^-	p, H^-	p, H^-
Maximal proton energy, MeV	600	209	502 (1996)
The maximal average current, μA	500	150	180
Pulse current, mA	50	16	22
Pulse repetition rate up to, Hz	100	50 - 100	50
The pulse duration, μs	1-100	0.5-200	0.5-200

The nearest purposes are directed to maintenance and development of the accelerator

- Increase of the pulse repetition rate up to 100 Hz. It will allow to double the beam intensity ~ 300 μA.
- Increase of proton energy up to 500 MeV with obtaining of klystrons.
- Starting of H^- ions source operation for experiments and beam therapy.

Experimental complex

The experimental complex structure:

- ***Complex of neutron sources***;
  - Thermal neutron source with TOF spectrometers.
  - Source of epithermal neutrons (RADEX) with TOF spectrometers
  - 100 t lead slowing down neutron spectrometer. Power will be increase up to 3 kW after creation of new target with air cooling.
  - The free space boxing at the shield designed for the second neutron source.
- *Complex of proton therapy*
- *Channels for transportation of proton beams*
- *Power supplies and support systems*

  (special ventilation, water supply, storage of radioactive isotopes, temporal storages of nuclear waste and irradiated structural elements of experimental complex etc.)

Layout of the experimental complex

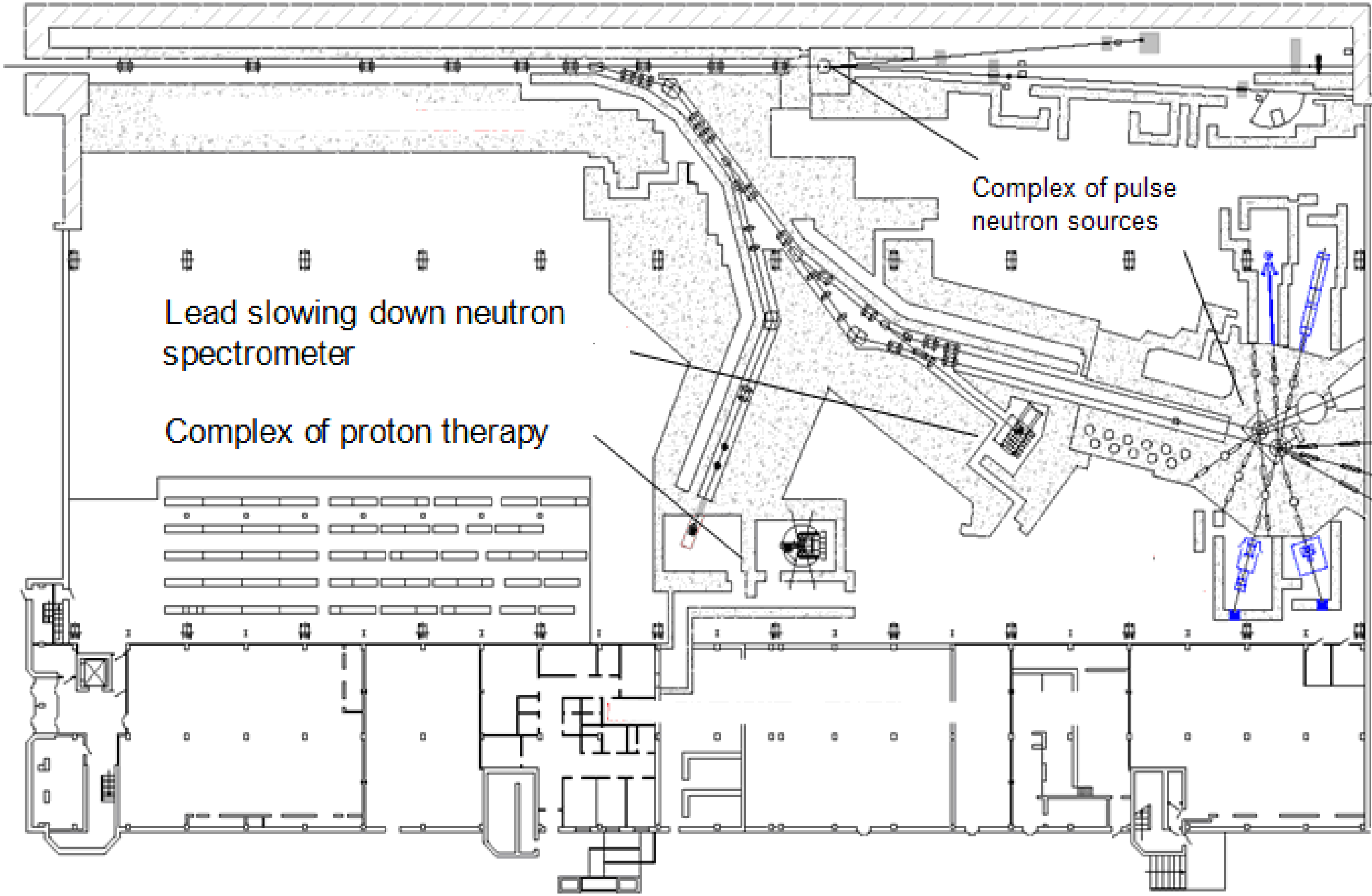
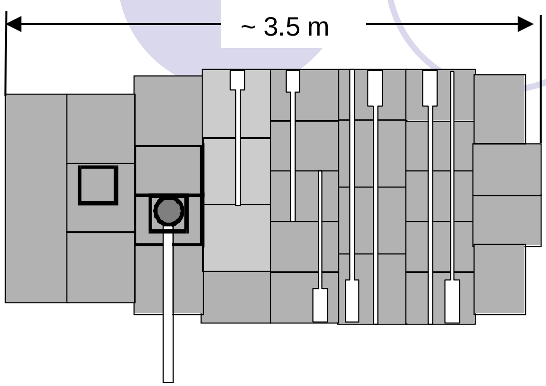
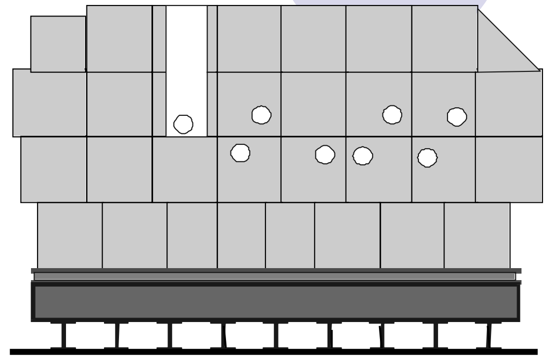
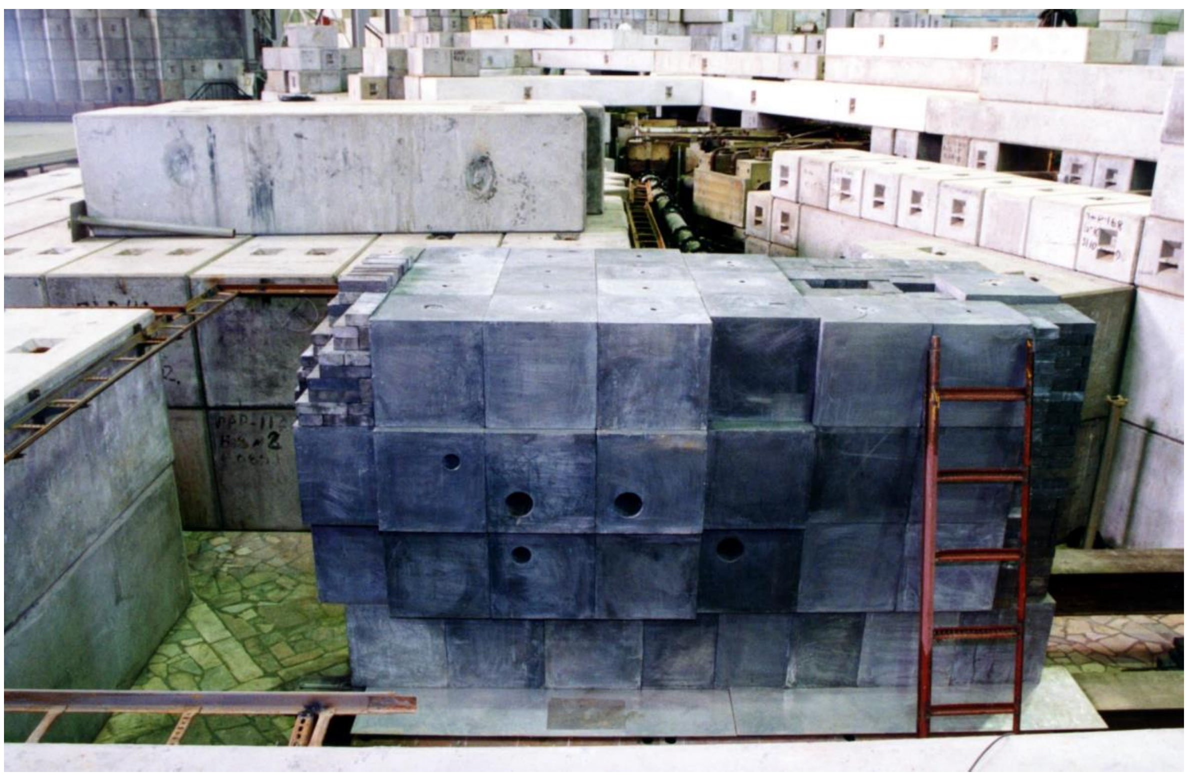


Photo of neutron complex

Lead slowing-down spectrometer: lead (3.0 $\times$ 1.8 $\times$1.5 m^3 ~ 100 t)







Main direction of work :

Neutron data for minor actinides

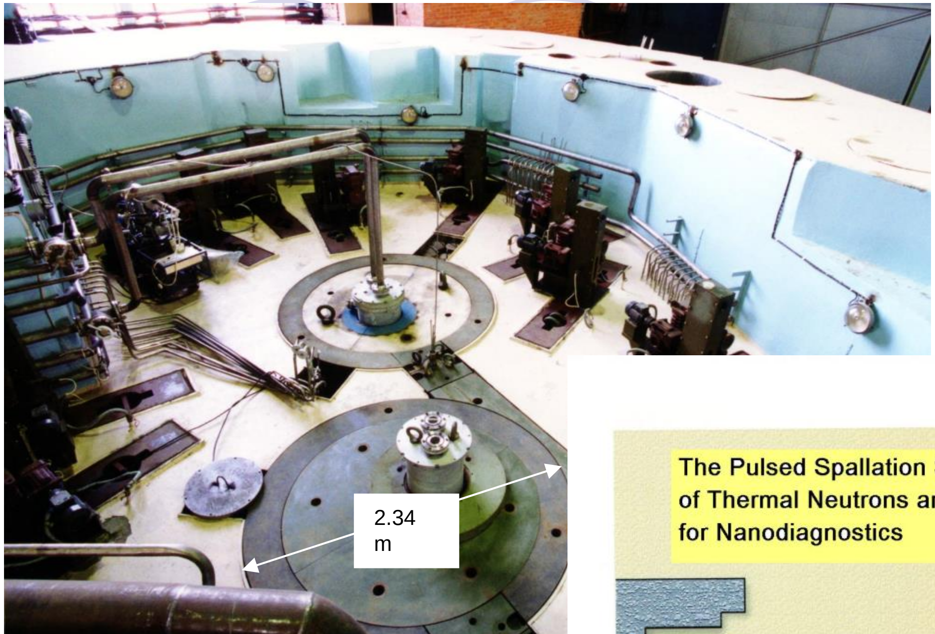
Physics of nuclear fission

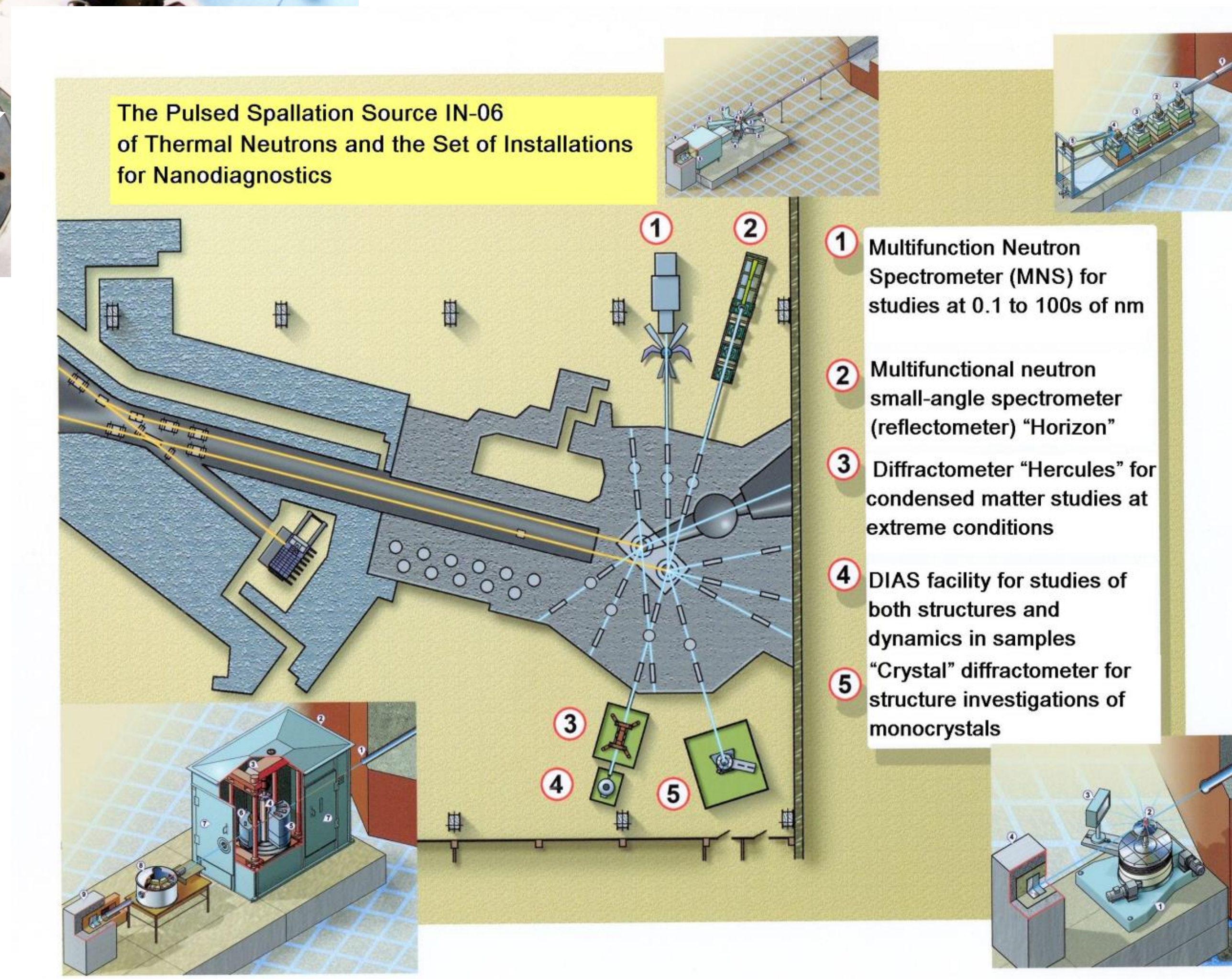
Pulsed source of thermal neutrons

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

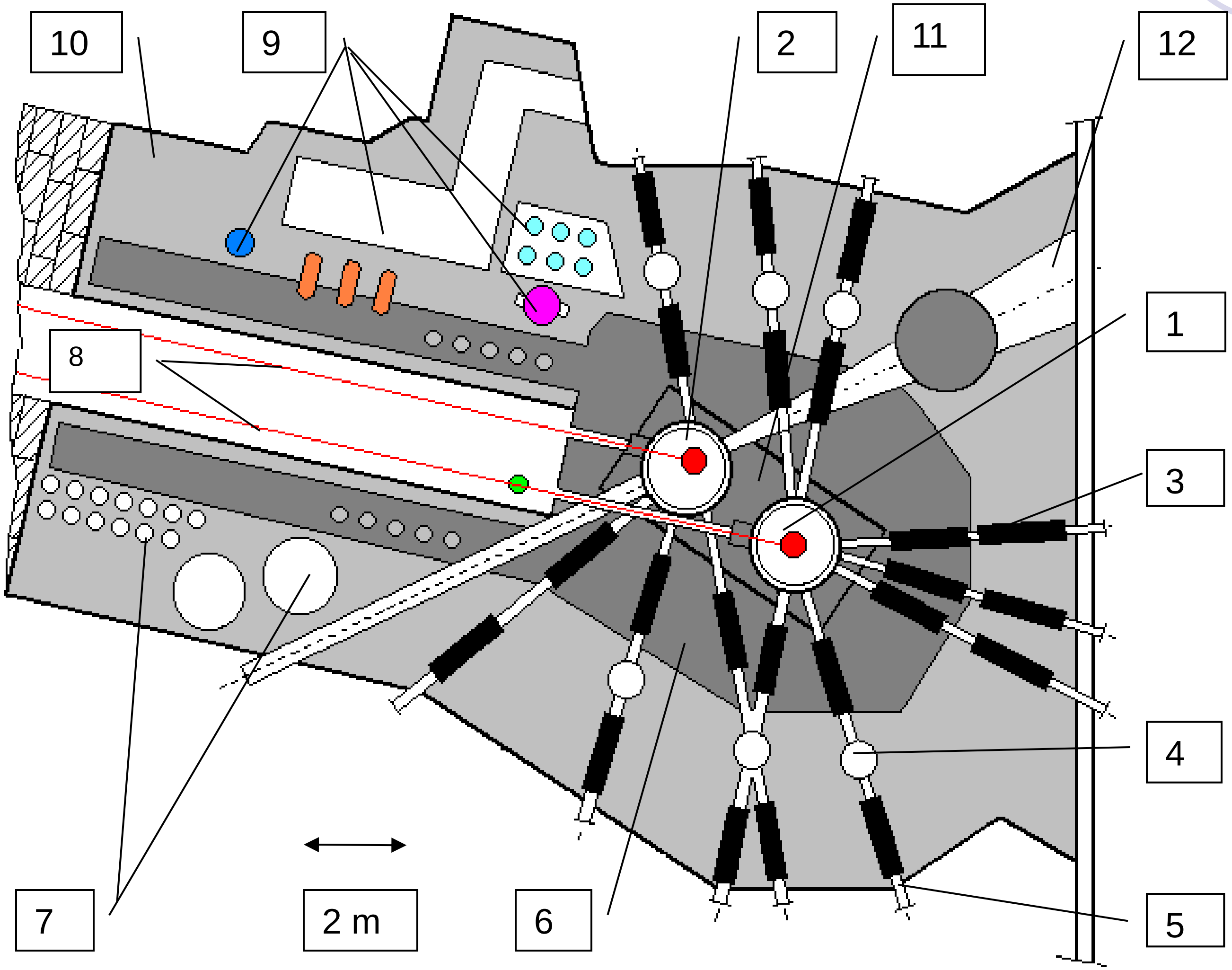
The design of the neutron source is flexible and allows to use modules with different targets and moderators to carry out full replacement of all equipment of the central part for modernization of the source.

Photo of the central part



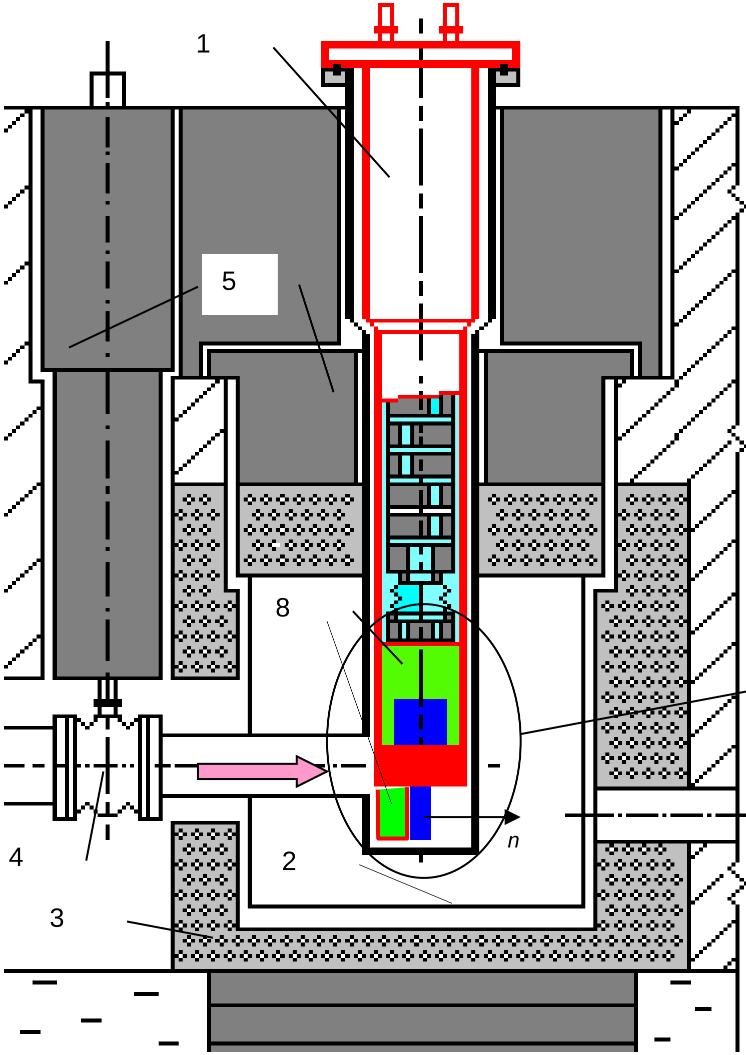


Infrastructure of the neutron sources assembly

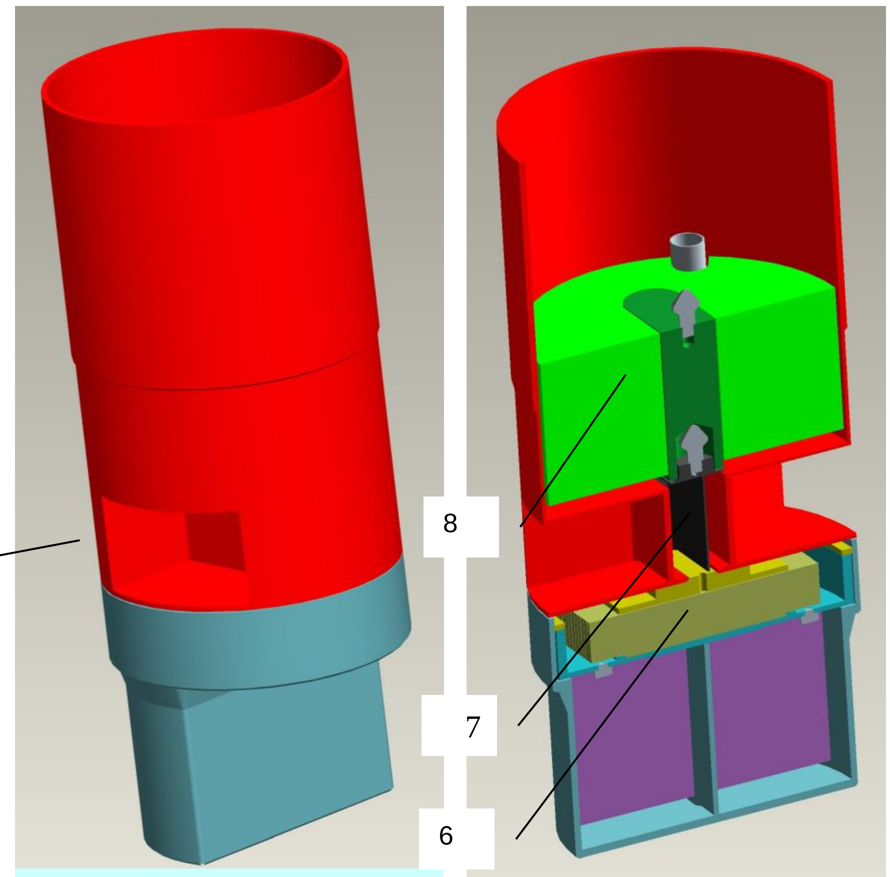


1 – cell of the neutron source,
2 - cell of ADS stand,
3 – neutron gates,
4 – vertical channels,
5 – neutron guides,
6 – iron shield,
7 – storages of modules,
8 – proton guides,
9 – equipment of the first water loop,
10 – heavy concrete shield,
11 – heat shield,
12 – the wide aperture channel.

Scheme of the pulsed neutron source with a new module

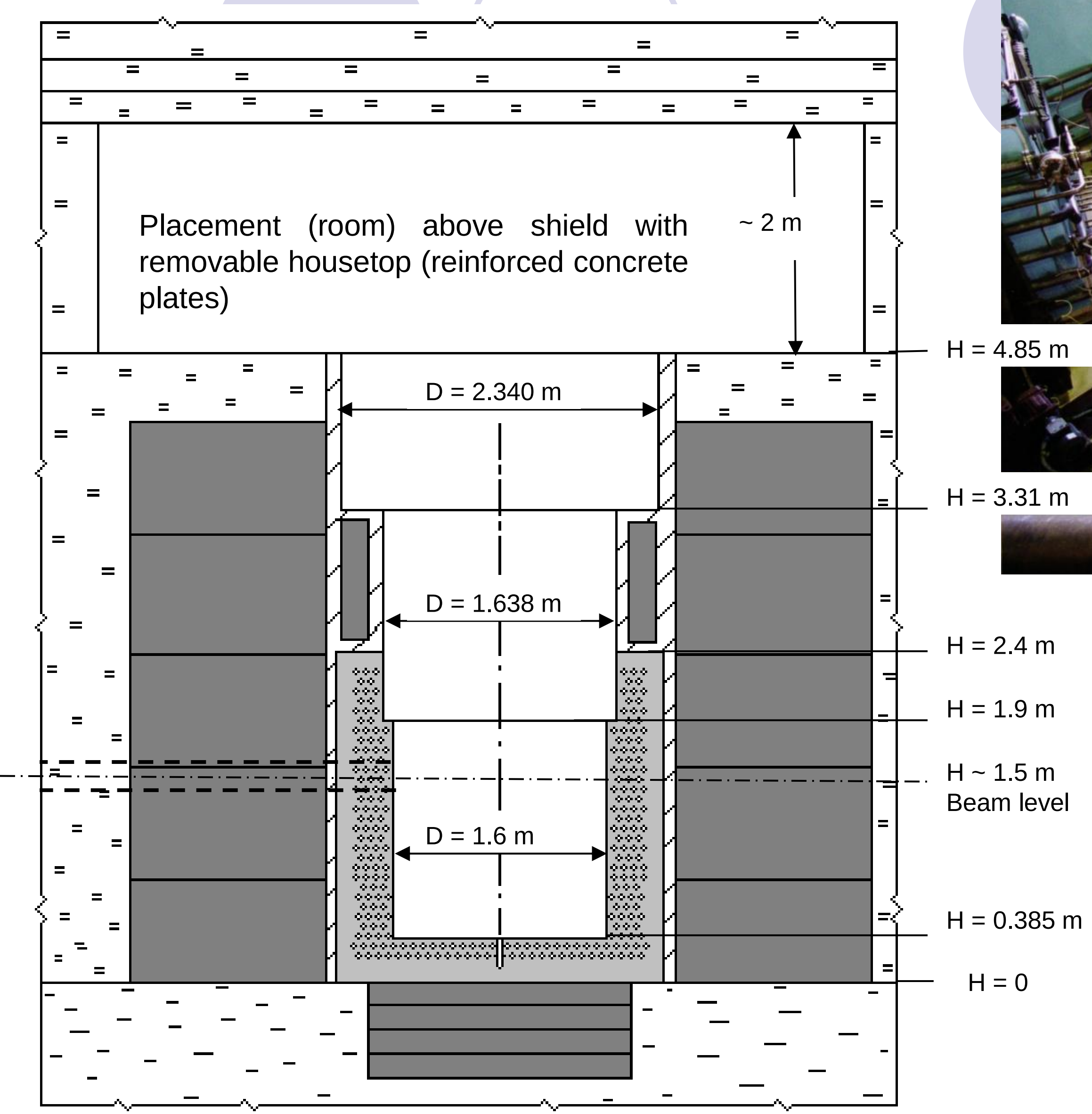


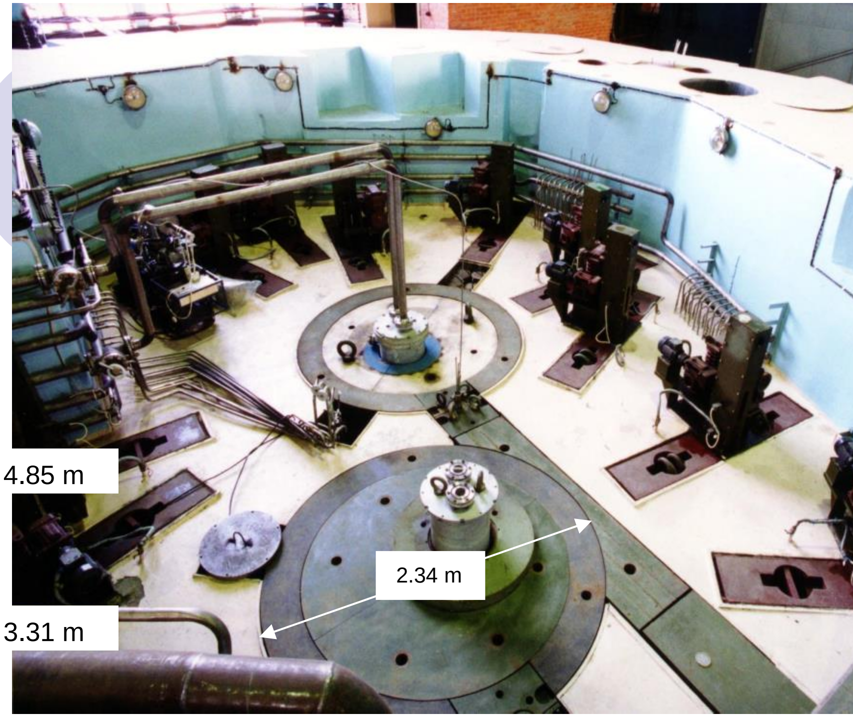
Position of a target module in the neutron source and the arrangement of basic elements



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

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.

Demo ADS - motivations and goals

ADS is considered as one of possible ways for reducing of store of the long living fission products and minor actinides

- **ADS have not fundamental physical problems like the controlled thermonuclear reaction.**
- **Existing questions are related to technology and the economy.**
- **Minor actinides can burn almost completely in some variants of ADS (e.g., the transmutation in a direct proton beam), in contrast to the fast reactors, in which the equilibrium level of minor actinides will be maintained at a high level.**

Deeply subcritical operation mode ADS reduces the risk of a nuclear accident, and allows:

- **To use fission materials with a low proportion of delayed neutrons (^{239}Pu, ^{233}U, minor actinides)**
- **To use fuel based on the threshold fissile isotopes (^{237}Np and minor actinides). This is impossible in the reactor mode because of the positive reactivity effect on loss of coolant and the low β_{eff}** (except for some variants of MSR)

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.

The main physical and technical requirements to demo ADS

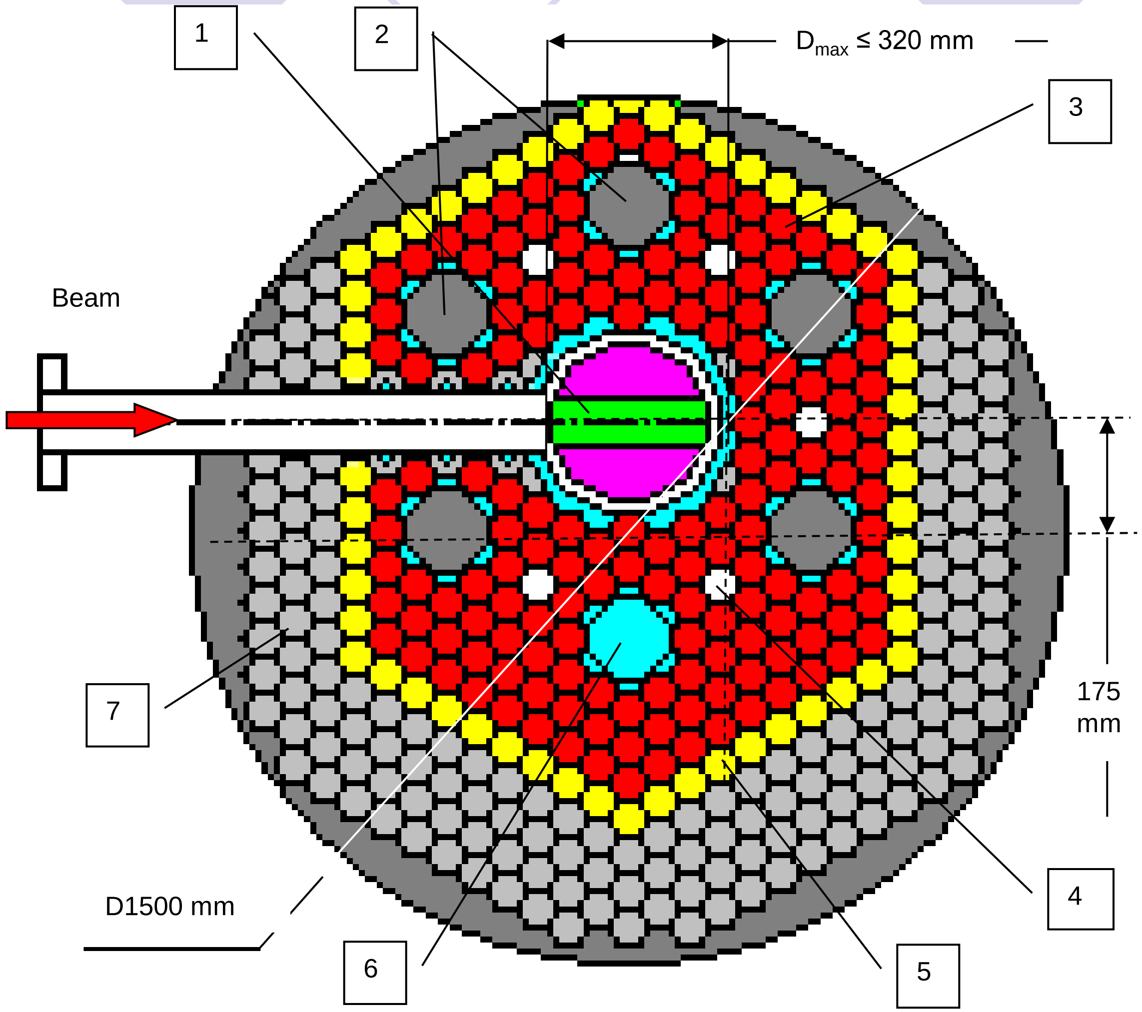
The research ADS should provide:

- The study of different fuel compositions with different contents of minor actinides.
- Fast access to the experimental channels of the blanket, the safe extraction of the irradiated heat-generating-assemblies.
- Fast enough and convenient blanket reprocessing, target change and assembling of the other ADS configurations.
- 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).

Expected average power of research ADS depend upon proton current – I_P, multiplication coefficient - K_m, proton energy – E_P and type of target.

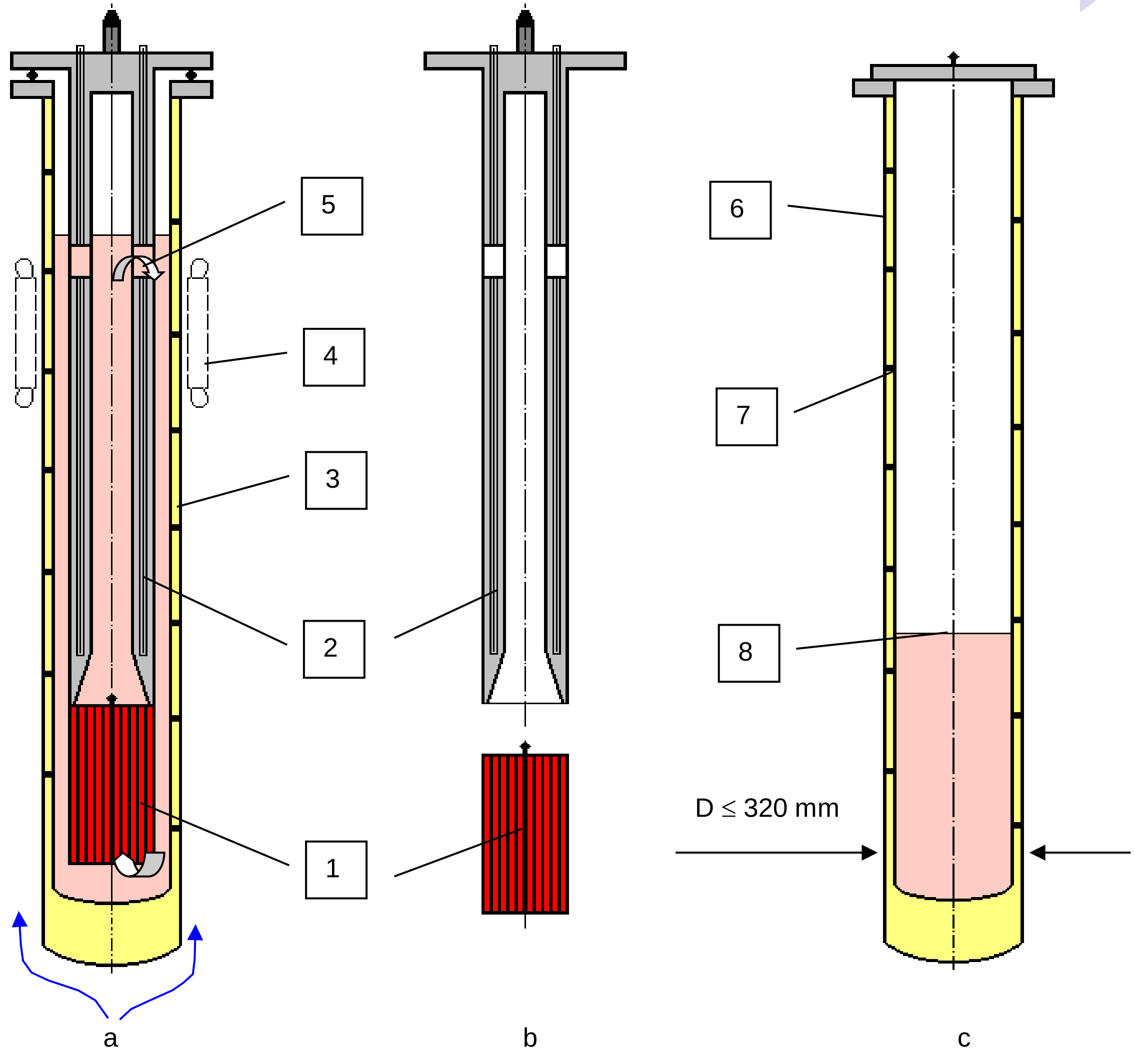
Average Proton Current (μA)	Multiplication K_m (k_{eff})	Average power of blanket – P (MW) for proton energy 300, 500 and 600 MeV					
		W (plates) or PbBi target			Natural uranium target (cylindrical fuel elements)		
		300	500	600	300	500	600
100	10 (0.90) 20 (0.95)		**0.83** **1.04**	**1.04** **2.08**		**1.14** **2.29**	**1.46** **2.91**
150	10 (0.90) 20 (0.95)		**1.25** **2.50**	**1.56** **3.12**		**1.72** **3.44**	**2.18** **4.36**
200	10 (0.90) 20 (0.95)	**0.73** **1.47**	**1.66** **3.32**	**2.08** **4.16**	**1.03** **2.05**	**2.29** **4.48**	**2.91** **5.82**
250	10 (0.90) 20 (0.95)	**0.92** **1.83**	**2.08** **4.16**	**2.60** **5.20**	**1.28** **2.57**	**2.86** **5.72**	**3.64** **7.28**
300	10 (0.90) 20 (0.95)	**0.98** **2.22**	**2.50** **5.00**	**3.12** **6.24**	**1.54** **3.08**	**3.43** **6.86**	**4.37** **8.74**
Neutron yield – Y (n/p)		**3.5**	**8.0**	**10**	**4.9**	**11**	**14**
Importance of the primarily neutrons - $\omega \approx 1.3$							

Conceptual scheme of research ADS



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.

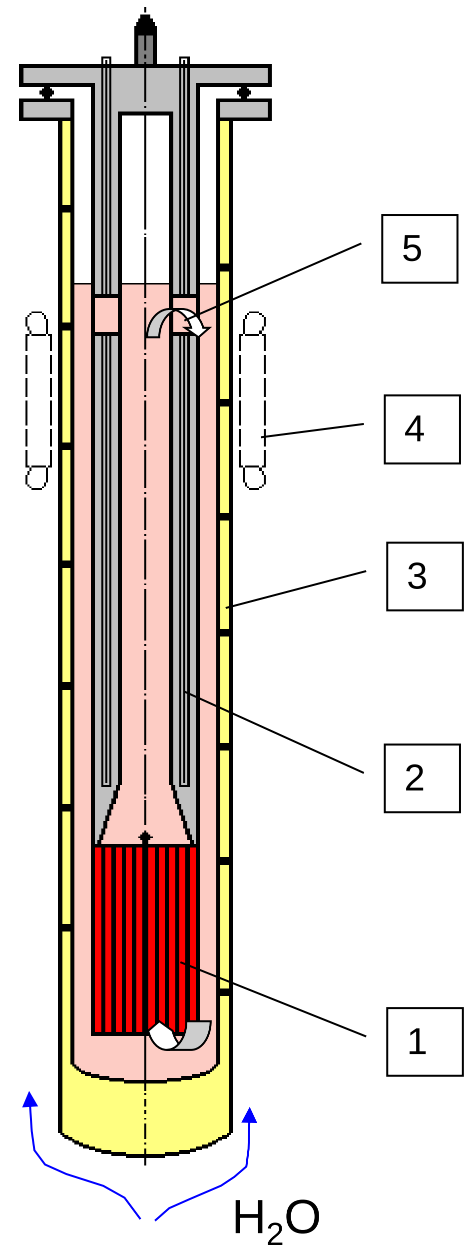
The inset should have double wall to maintain temperature regime and to be safety.

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.

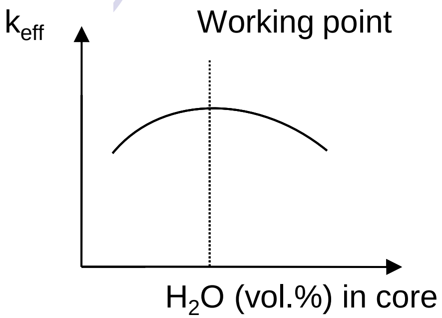
Some physical features of the ADS stand and the fast water cooled blanket

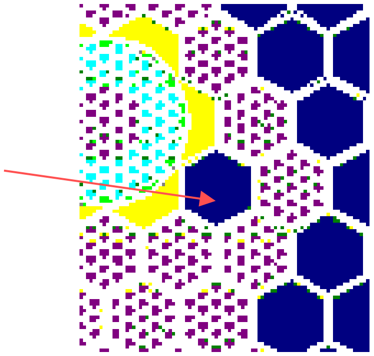
- High sensitive to density of water. Decrease density of water including boiling and full loss makes assembly deep subcritical.
- Water cavity (it appears after replaced a fuel cassette or PbBi capsule - refuelling) is the source of thermal neutrons. It is big positive effect of reactivity can makes 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 heat-generating-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.

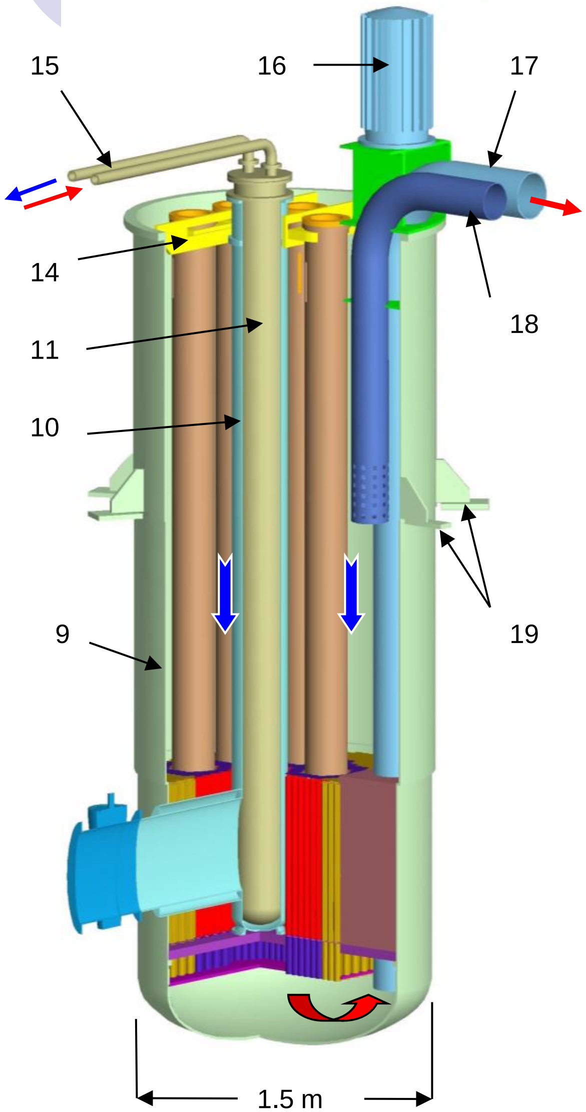


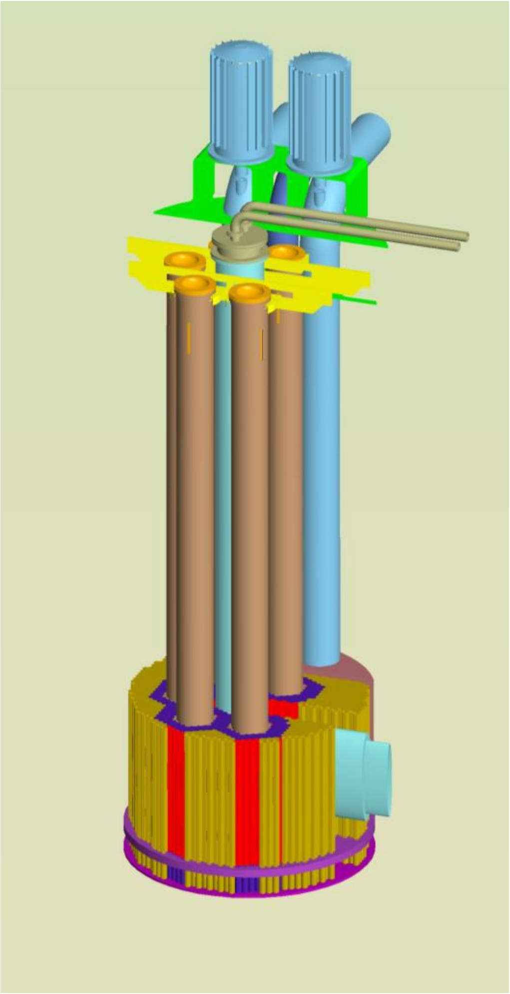


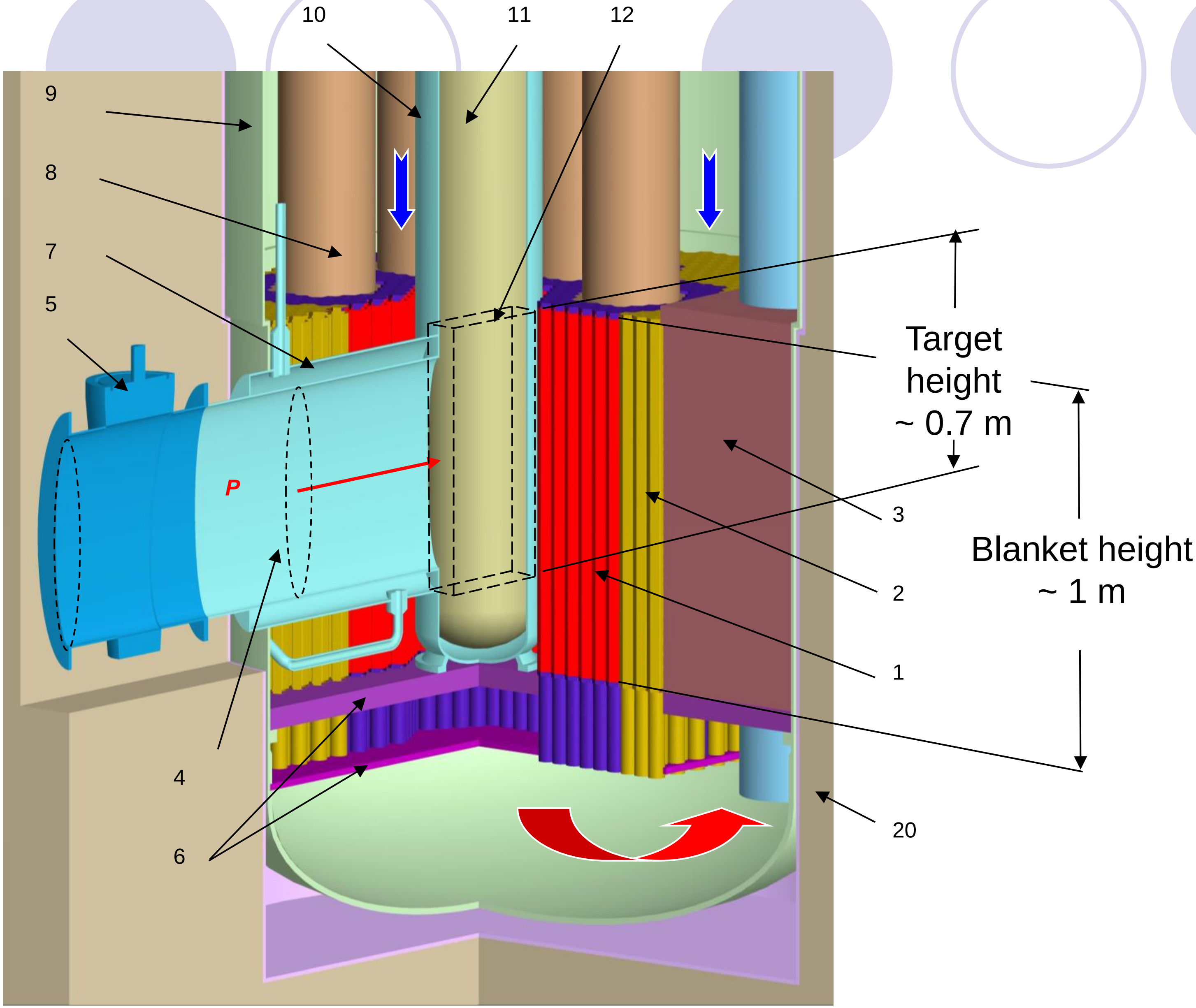
Research ADS and Pulsed Neutron Source

- *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.*

One of the possible ADS schemes

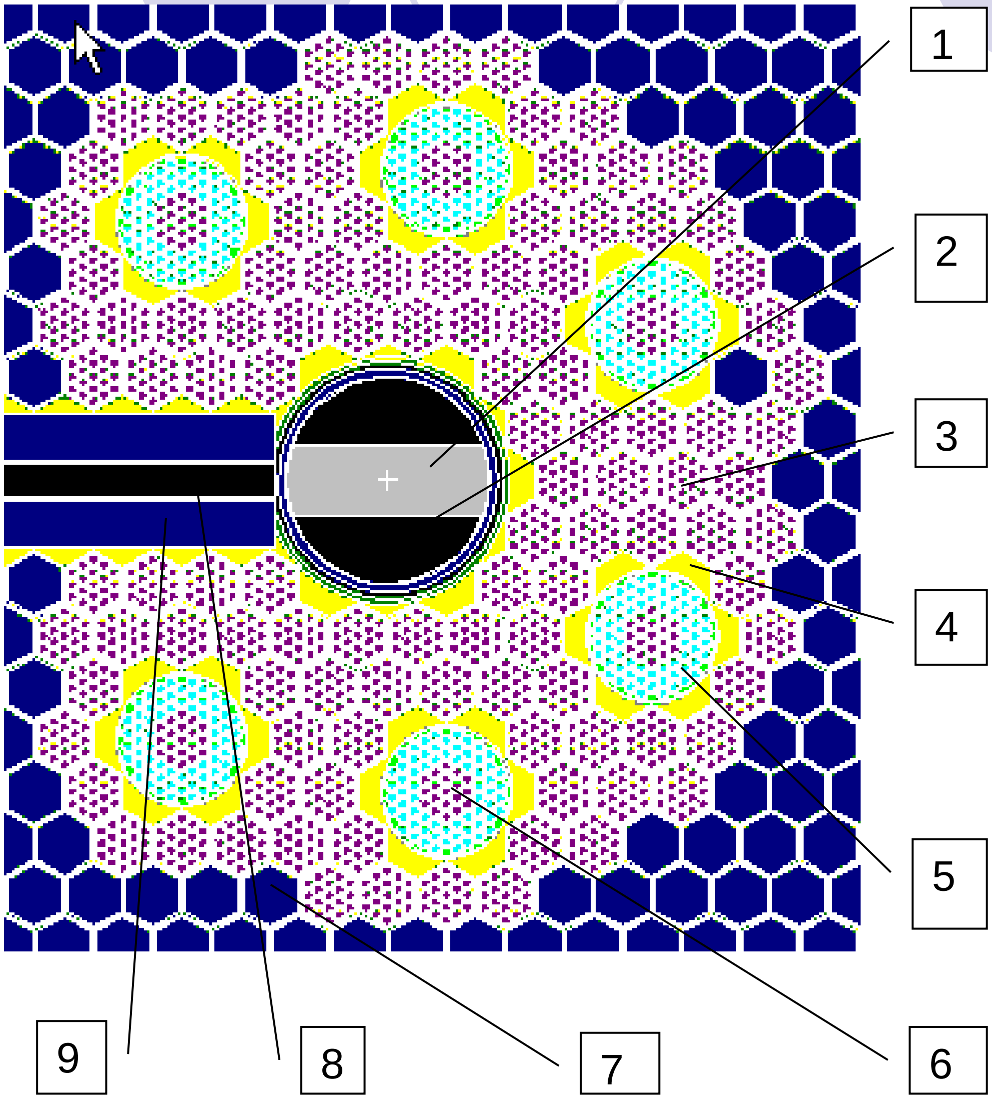






10
11
12
9
8
7
5
P
4
6
Target height
~ 0.7 m
3
Blanket height
~ 1 m
2
1
20

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.

Varied parameters in calculations:

- The number of fuel assemblies in water-cooled parts of the blanket, which were replaced by Al inserts.
- The number of PbBi modules from six to three.
- The distance between the PbBi modules and the target.
- Percentage of PuO_2 in fuel elements in both parts of the blanket.
- The thickness of the Hf shell in the fuel assembly.
- The environment of the proton guide.
- The core height
- and others

Data from one of the ADS options. Parameter of blanket.

Fuel element dimensions (reactor - IBR-2M)

Outer diameter of fuel pills - 0.71 cm

Outer diameter of fuel element - 0.864 cm,

Inner diameter of fuel covering - 0.77 cm,

The gap between a fuel elements - 0.03 cm

Outside size of the fuel element assembly - 4.2 cm

The covering of cassettes – Hf -alloy, thickness - 1 mm

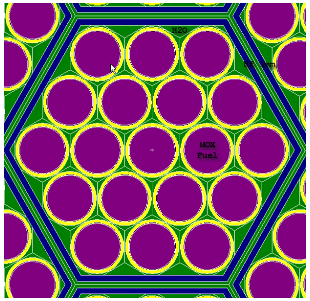
The number of fuel elements in the cassette - 19

Step of fuel elements - 1.03-1.04

Fuel is the mix of natural UO_2 (80%) with PuO_2 (20%).

The enriching of ^{239}Pu - 95%.

The number of assembles with MOX- fuel - 112



The number of PbBi modules 6

The module each replace the seven fuel assembles in water cooled part of blanket.

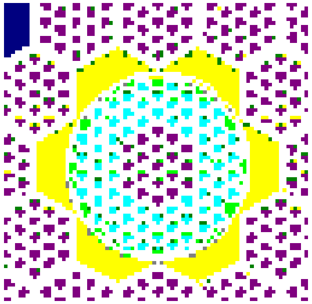
The total number of fuel elements in PbBi module - 95

Among them 19 central fuel elements with NpO_2 (for simulating minor actinides)

Others contain PuO_2.

The geometrical dimensions of the fuel elements are the same.

The height of blanket - 90 cm.



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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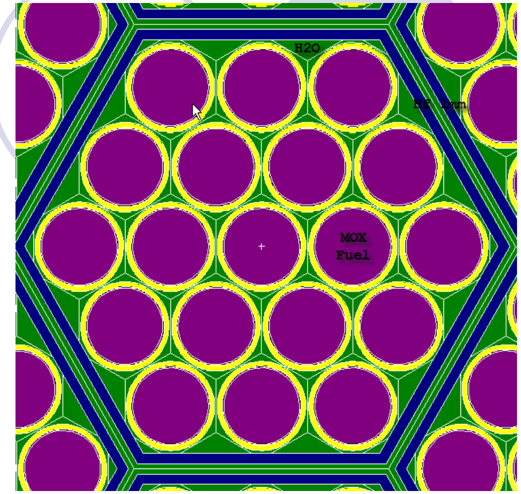
Maximal value of importance is equal ω = 1.35.

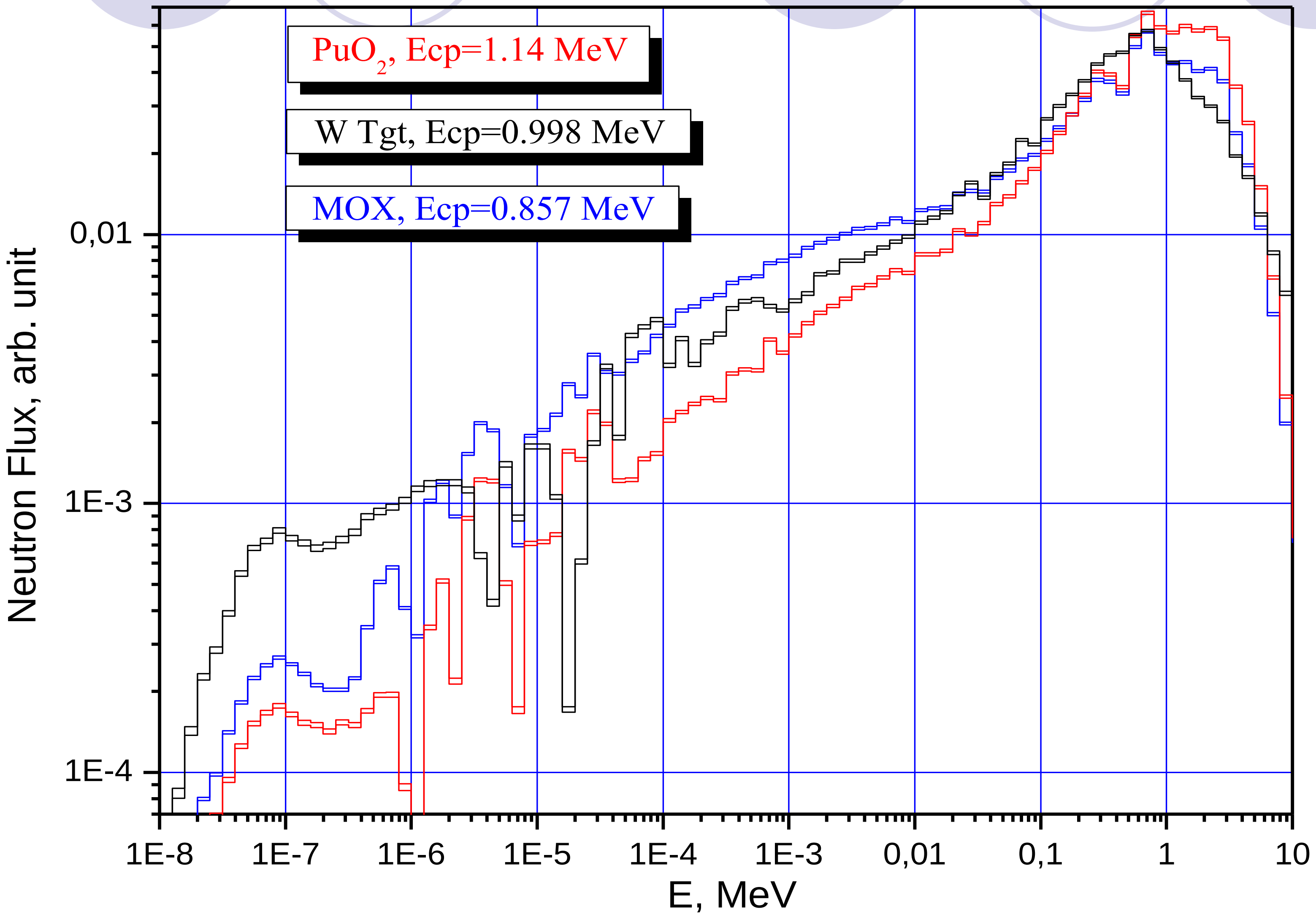


The fuel cassette scheme of the water cooled part of blanket

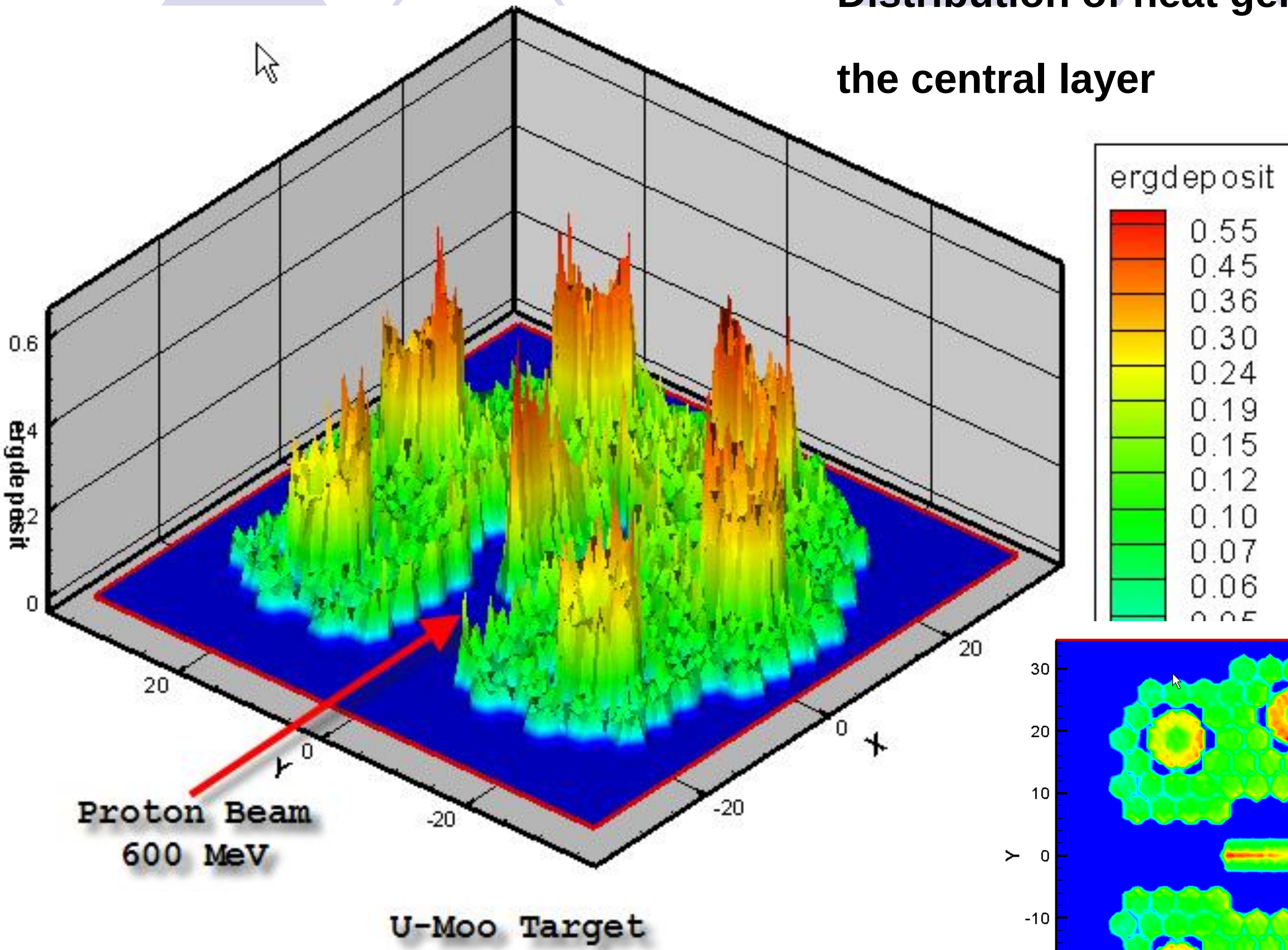
There are three parameters for minimization of the additional neutron capture in hafnium at keeping of the negative effect of reactivity:

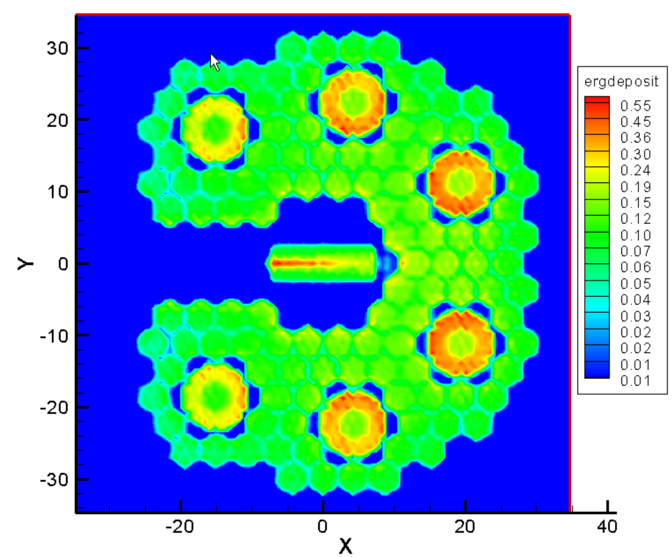
- Percentage hafnium in alloy. For ex. Hf(78%)Nb(2%)Zr(20%),
- The wall thickness of cassette,
- **The number of fuel elements in cassette**

Spectrum of the water cooled part and PbBi



Distribution of heat generation in the central layer



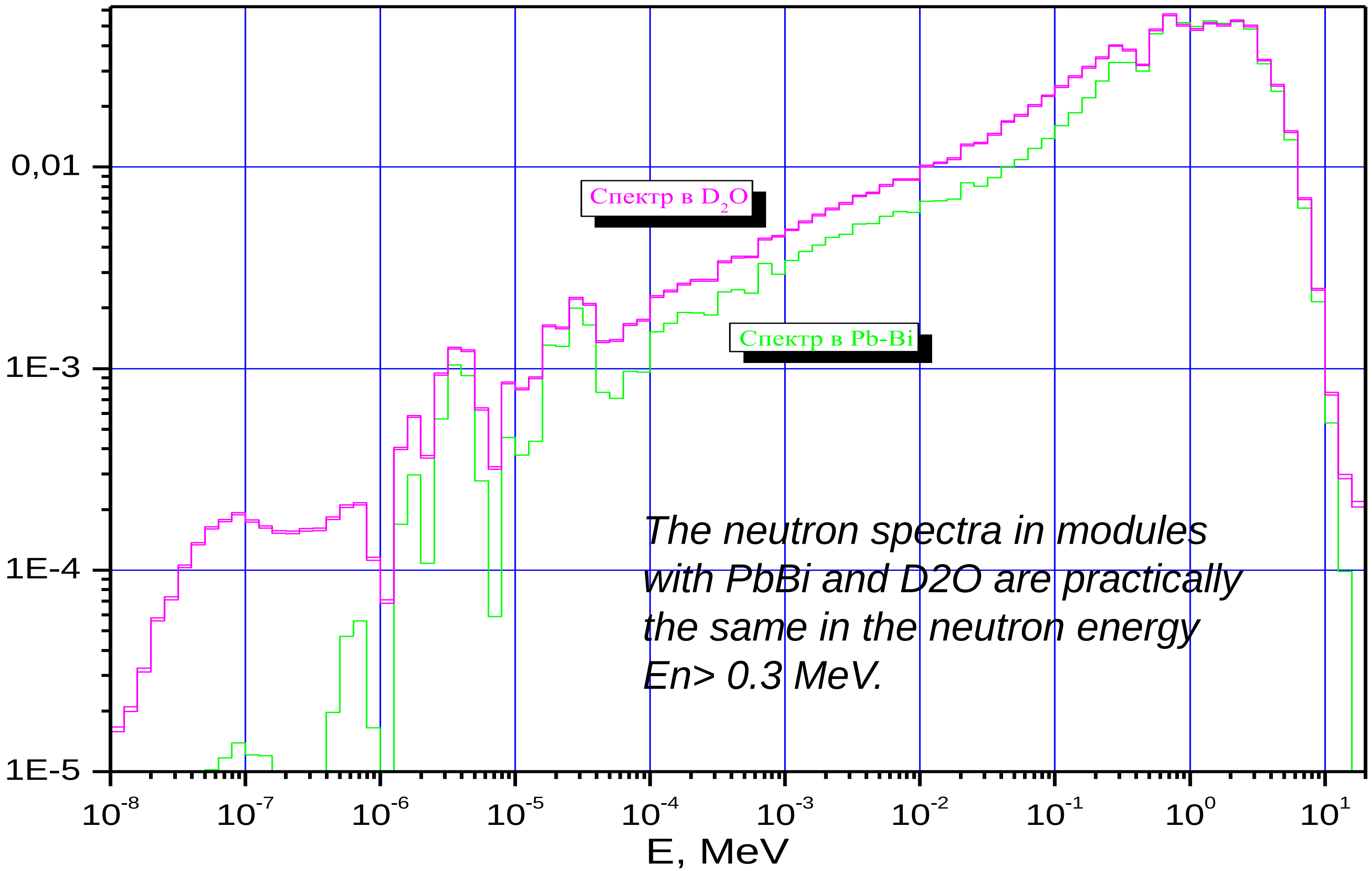


Comparison of ADS with PbBi и D_2O modules

Parameter	**PbBi**	**D_2O**
k_{ef}	*0.9542*	*0.9502*
Average energy (MeV):	0.835	0.801
Number of fissions in modules by neutrons:		
E = 0 – 0.645 eV	10.50 %	10.58 %
E = 0.645 eV – 100 keV	42.36 %	44.67%
E > 100 KeV	47.15 %	44.75%
Heat generation in:		
MOX (water cooled part)	**58.2%,**	**57.69%,**
PuO_2 (modules)	**41.8%**	**42.3%**

Number of fissions in the modules and parts of the water-cooled blanket is substantially the same. ***Manufacture and operation of the D_2O module are simpler.***

Comparison of ADS with PbBi и D_2O modules (spectrum)



The neutron spectra in modules with PbBi and D2O are practically the same in the neutron energy En> 0.3 MeV.

Activity: directions of studies

1. We analyze 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 – $\beta_{ef.}$, that obeys to use the ADS facility as the neutron source. It provides with a low background between pulses.

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

   Reasons:

- High solubility of MA in FLINAK (melt of LiF-NaF-KF). It is allow to use FLINAK as target of proton beam.
- Operation with very low coefficients of multiplicity that reduces the equilibrium level of MA in the target and allows to burn out MA almost to zero.

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. Among them the possibility for a system with intrinsic (natural) safety exists.

Further development of the project depends on the following events and restrictions:

- a result of the RAS status change,
- a situation with future development of new areas (and Troitsk) that are included in the territory of Moscow

Main directions of work (archives)

In these conditions the accelerator mainly operates for

- the isotopes production (~75%) ,
- the lead slowing down neutron spectrometer (~5%) ,
- the medical complex (~5%)
- the source of thermal and epithermal neutrons (~10%) .