National Research Centre «Kurchatov Institute»
PETERSBERG NUCLEAR PHYSICS INSTITUTE

UCN source with superfluid helium at WWR-M reactor

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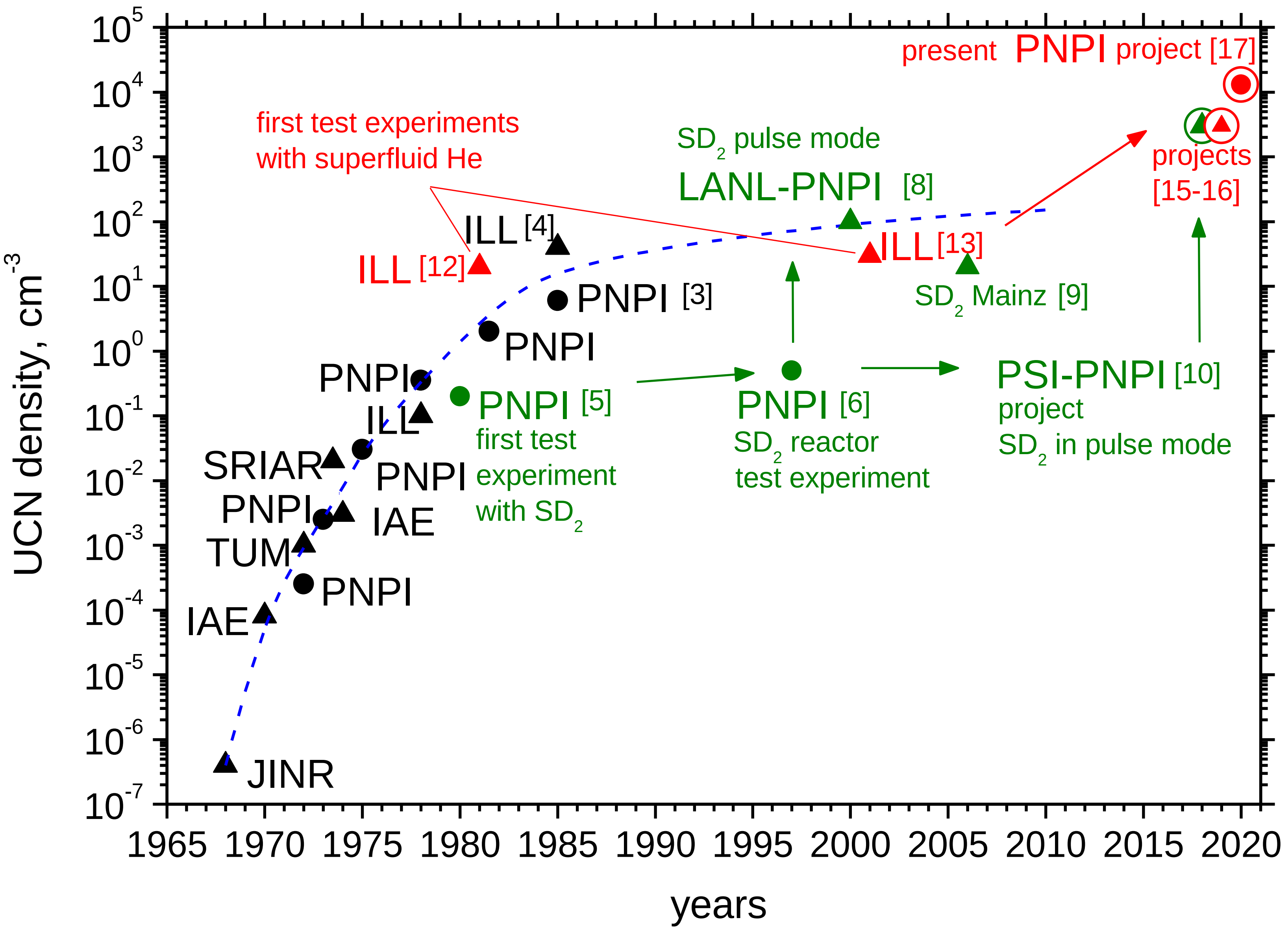
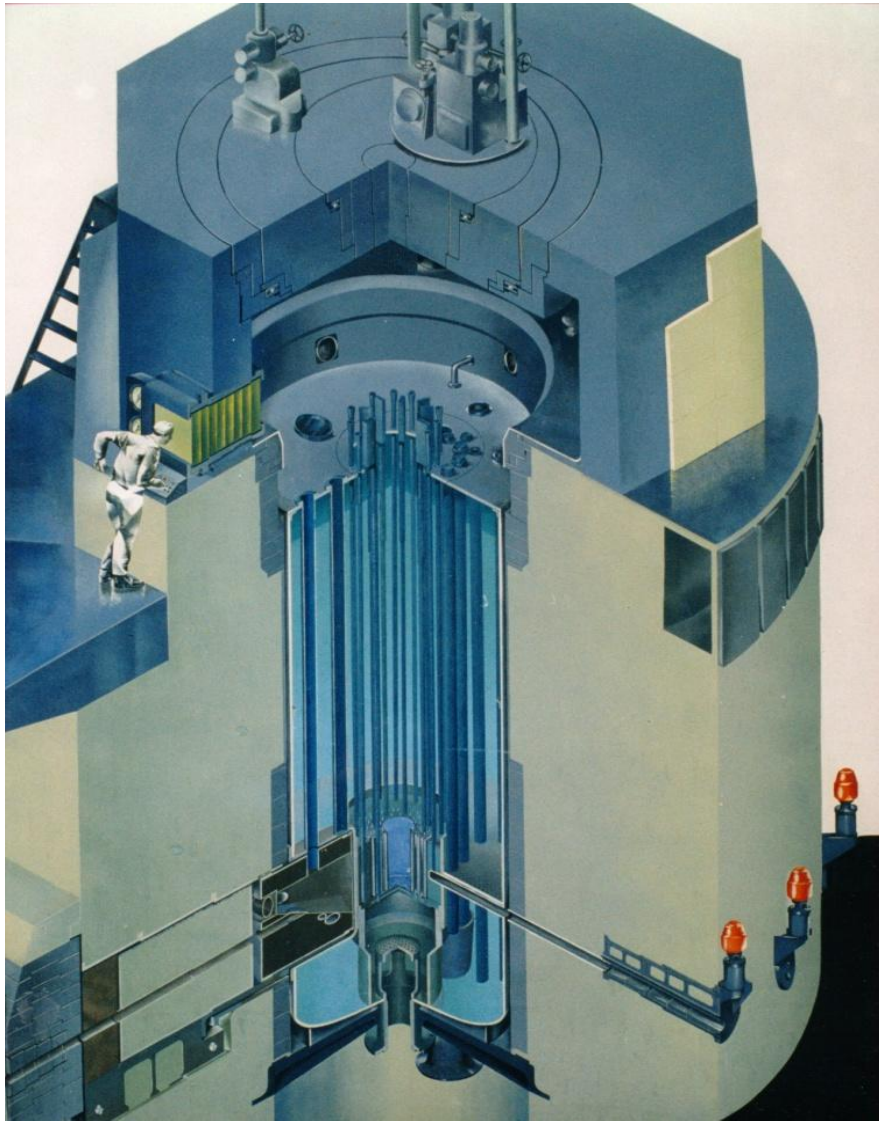
NORDITA workshop on 10-14 December 2018, Stockholm

Progress of UCN sources

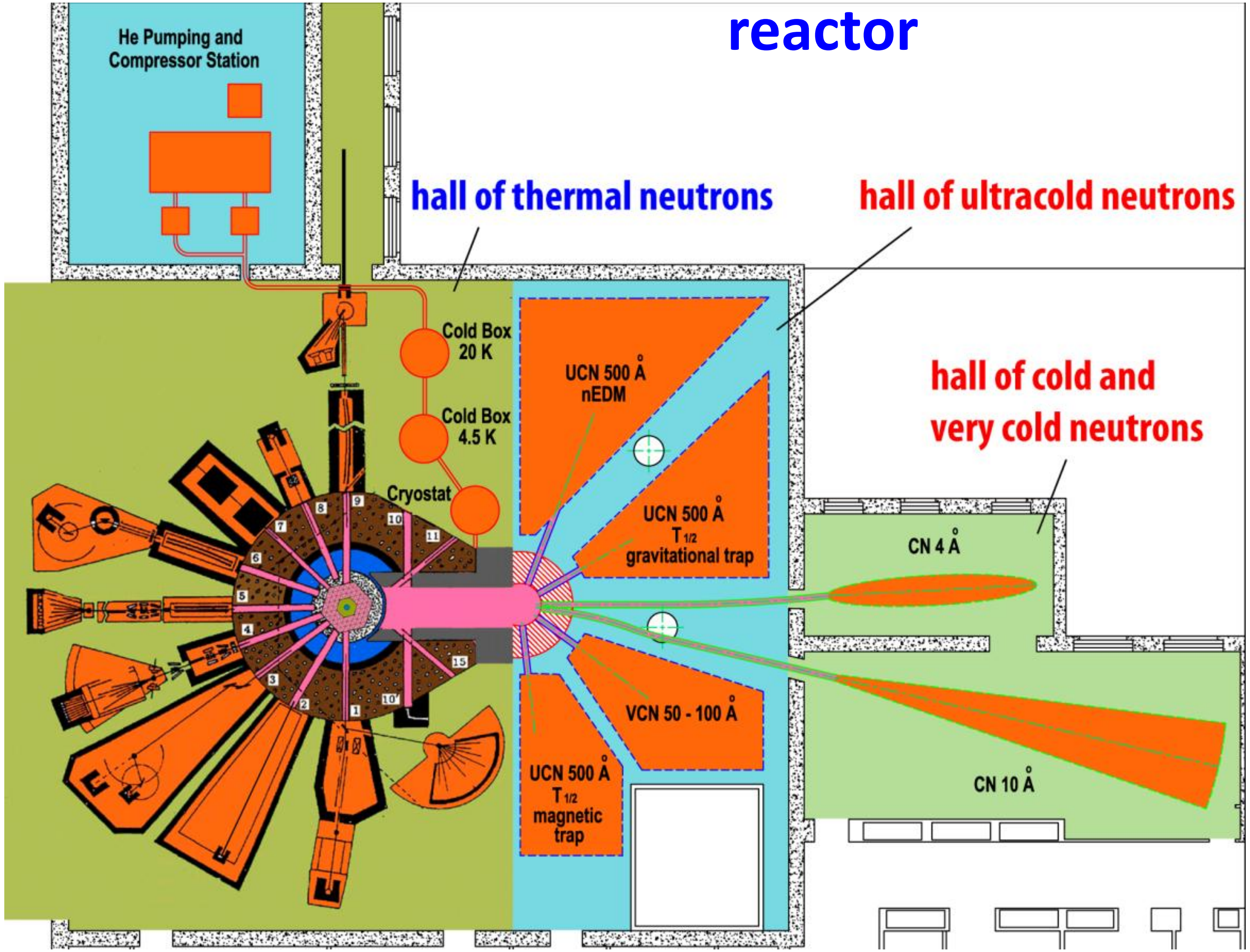


The WWR-M reactor at PNPI is going to be equipped with a high density ultacold neutron source. Method of UCN production is based on their accumulation in the super fluid helium. Our source aims at obtaining a density of UCN up to 10^4 n/cm^3 in the experimental trap, 100 greater then in existing sources presently available in the world.

UCN source at WWR-M reactor



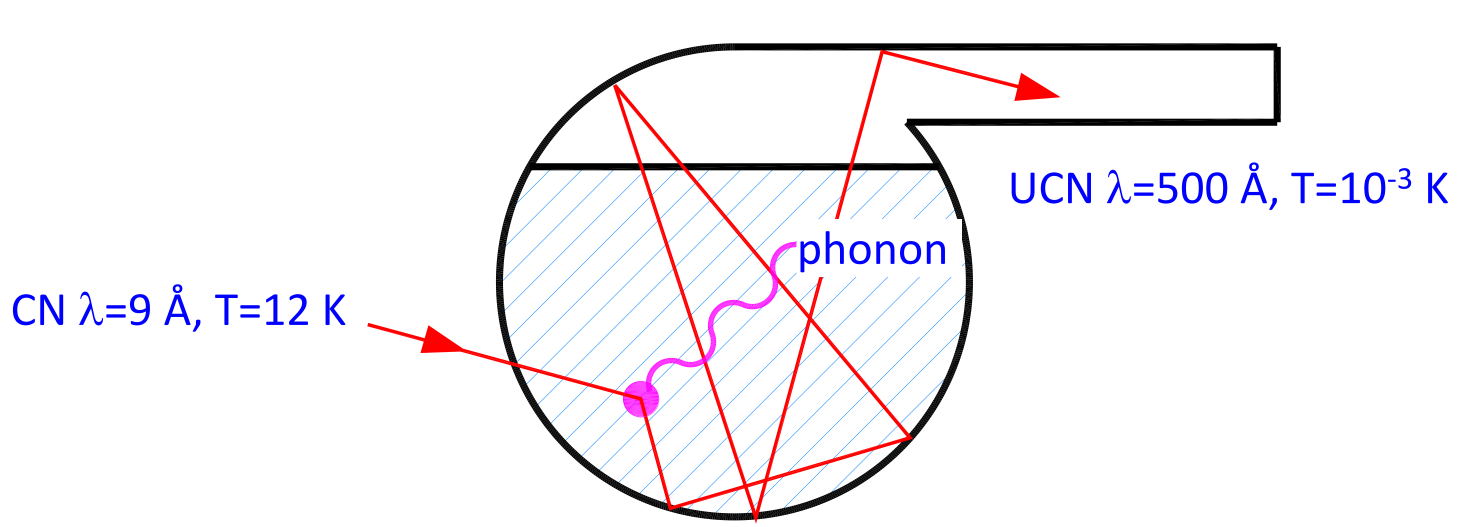
The resource of basic elements of the reactor provides its further operation within 25 years.

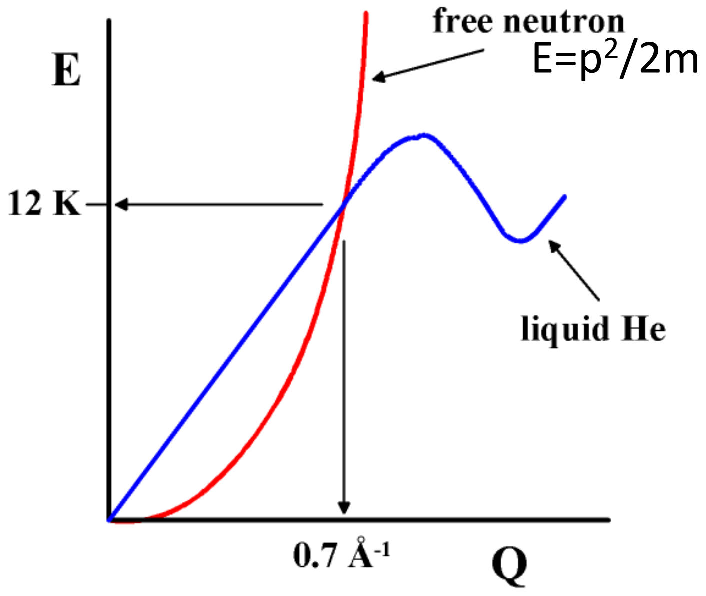


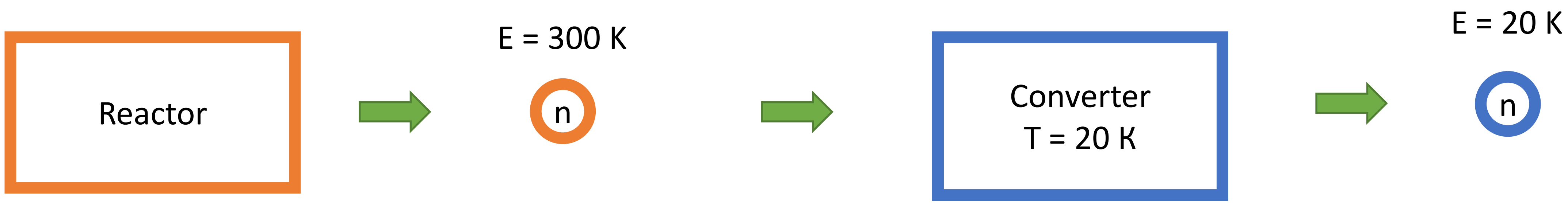
The scheme of experimental installations on the BBP-M reactor after installation in a thermal column of the reactor of UCN source with superfluid helium at a temperature of 1.2 K.

Principle of a source

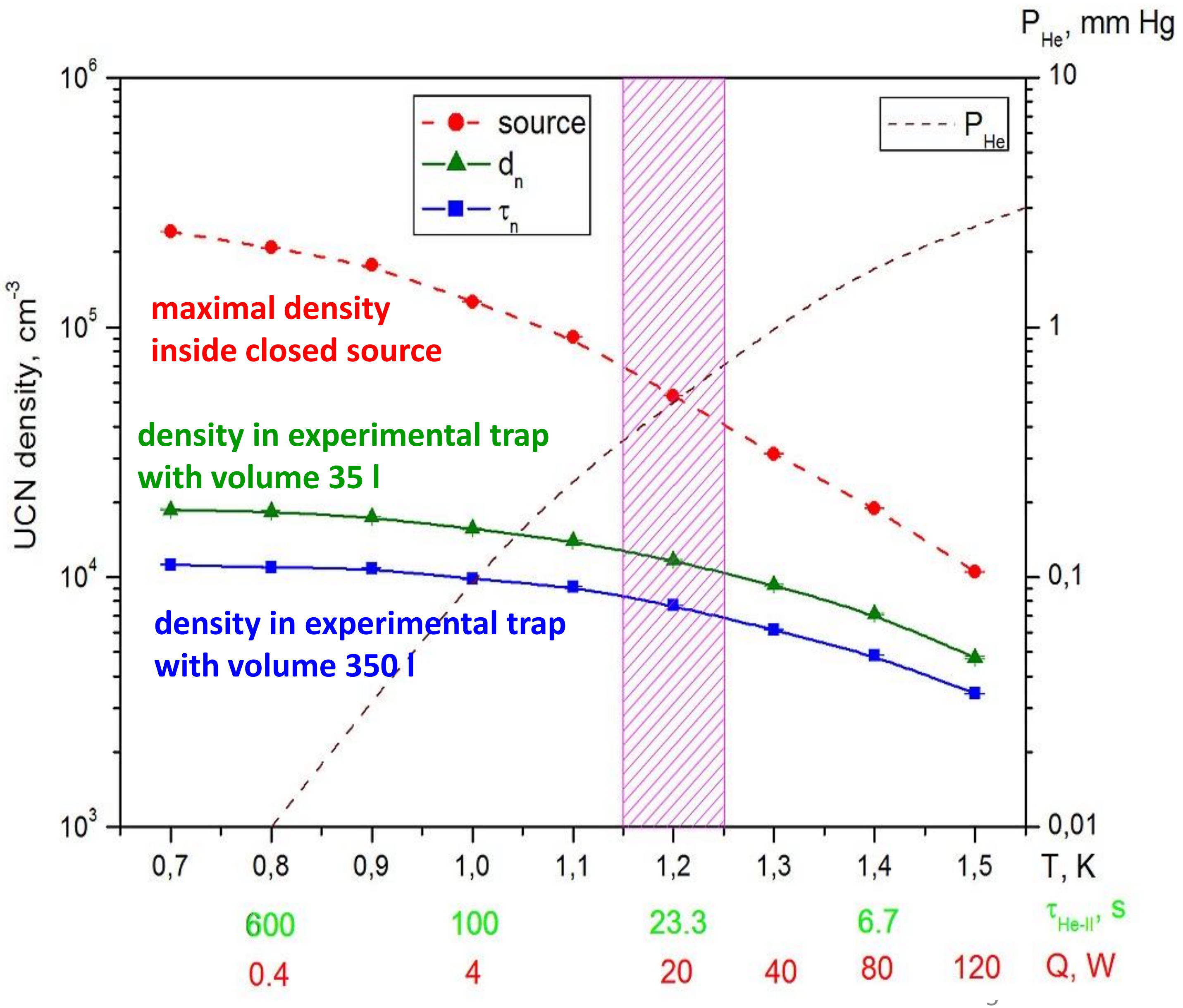
UCNs are generated in helium from cold neutrons of 9Å wavelength (12 K energy).
Cold neutron produces phonon, practically stops and becomes an ultracold one.
UCN can “lives” in superfluid helium for tens or hundreds of seconds until a phonon be captured.
Cold neutrons (9Å) penetrate through the wall of a trap, but ultracold neutrons (500Å) are reflected.







How to obtain the greatest possible density of UCN?



$$\rho = C \cdot \tau$$

C - rate of UCN production

τ - storage time of UCN in a trap

ρ - UCN density in a trap

There are two ways:

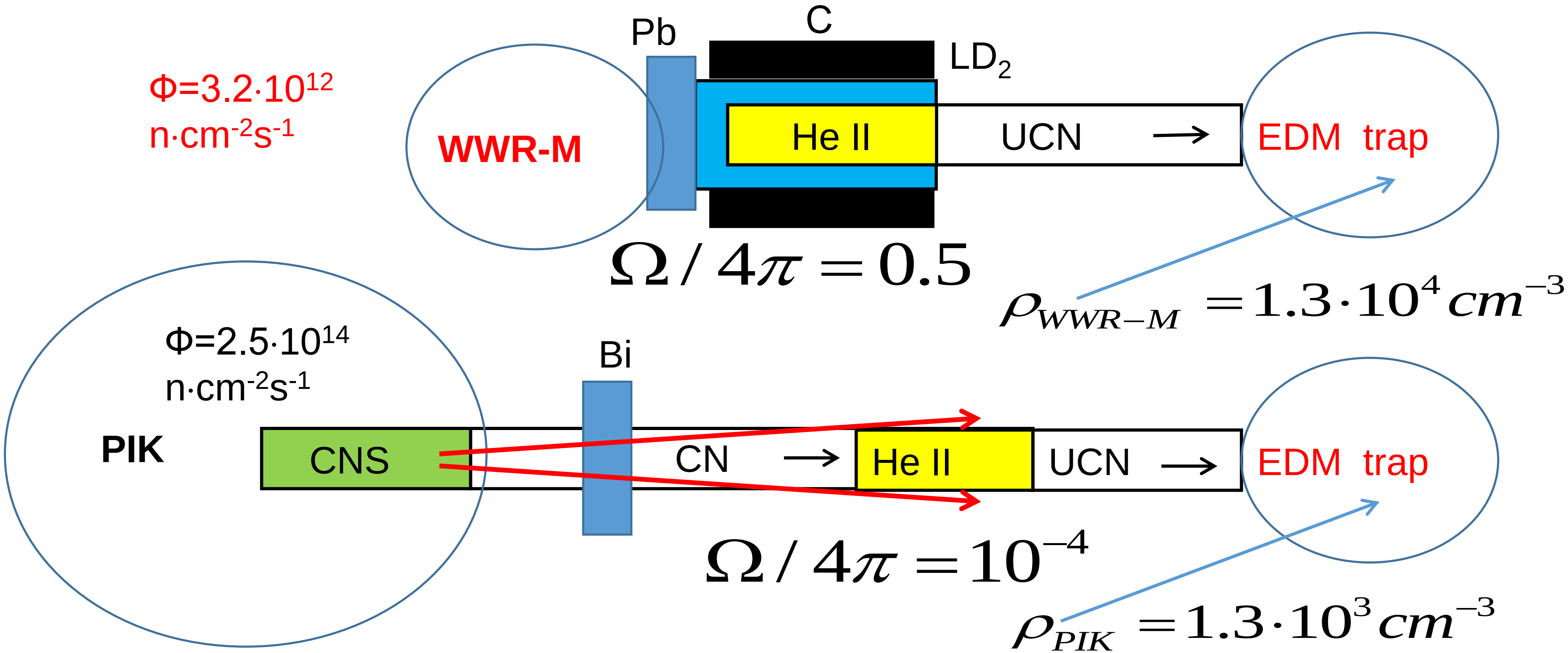
1. To increase the rate of UCN production , i.e. to increase an initial neutron flux, so thermal load by a source. In these conditions it is difficult to receive the low temperature of superfluid helium, so big storage time of UCN.

2. To increase storage time of UCN thanks to lower temperature of superfluid helium and restriction of any leakages of UCN. But then for obtaining low temperature the initial neutron flux has to be limited.

Schemes of UCN sources to compare the projects for WWR-M reactor and PIK reactor

WWR-M
He II inside thermal column
$\Phi=3.2\cdot10^{12}$ n·cm^{-2}s^{-1}
$d\Phi/d\lambda$ (9 A)=
$3.2\cdot10^{10}$ n·cm^{-2}s^{-1}A^{-1}

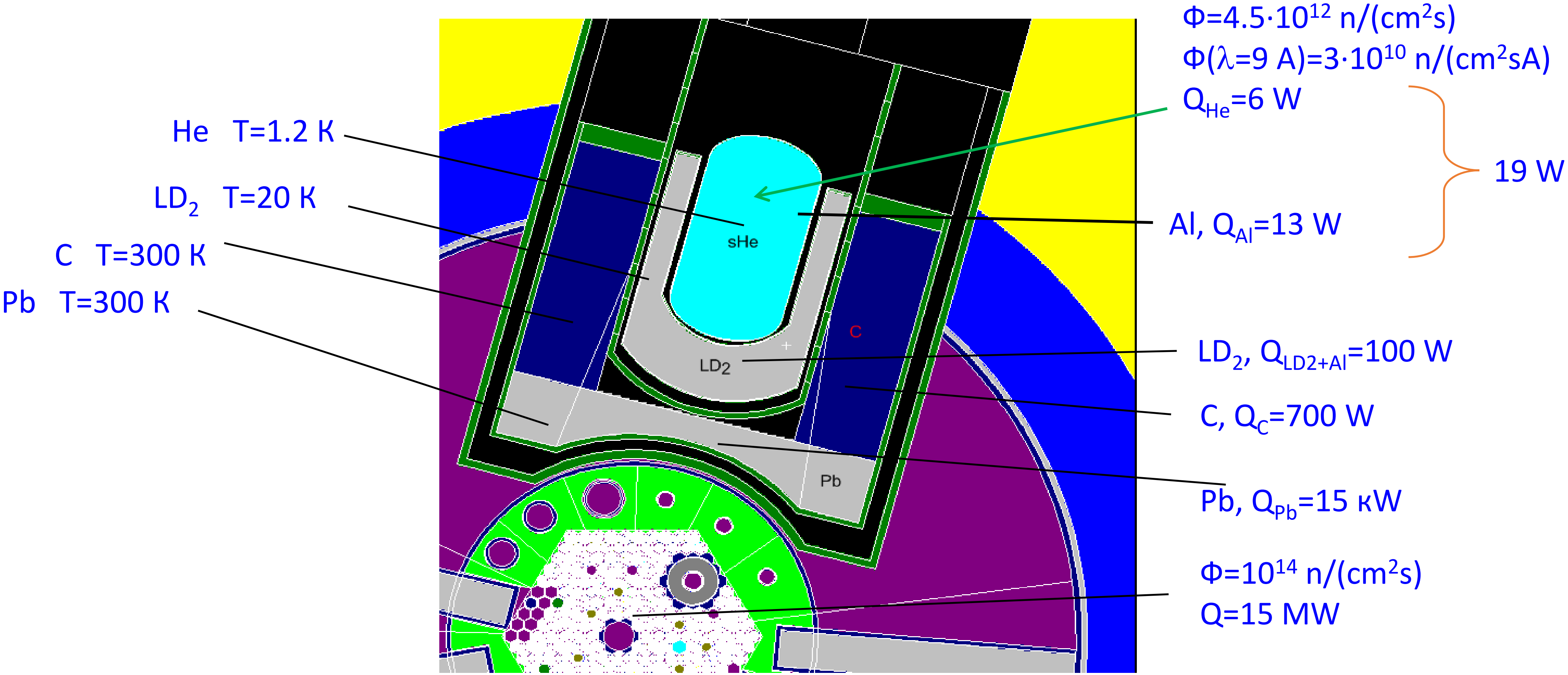
PIK
GEK 4-4′
He II on the beam
$\Phi=2.5\cdot10^{14}$ n·cm^{-2}s^{-1}
$d\Phi/d\lambda$ (9 A)=
10^{9} n·cm^{-2}s^{-1}A^{-1}



$$\Phi_{WWR-M}\cdot\Omega_{WWR-M}/\Phi_{PIK}\cdot\Omega_{PIK}=50$$

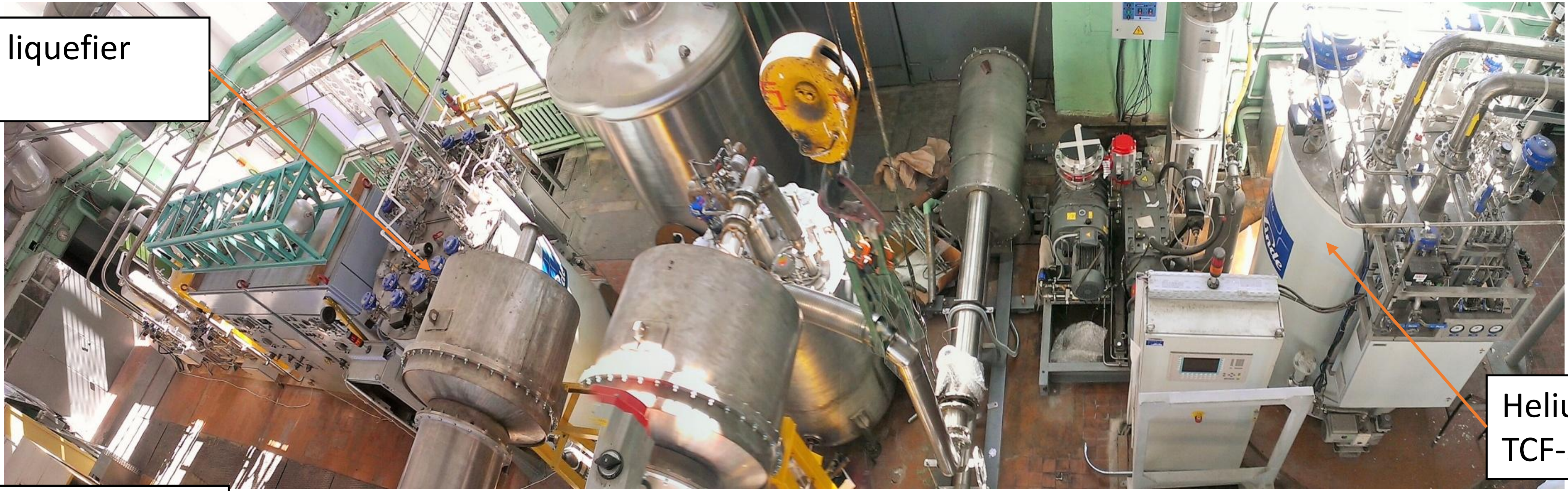
$$\rho_{WWR-M}/\rho_{PIK}=10$$

MCNP neutron flux calculation results and heat generation in thermal column of WWR-M reactor at 15 MW



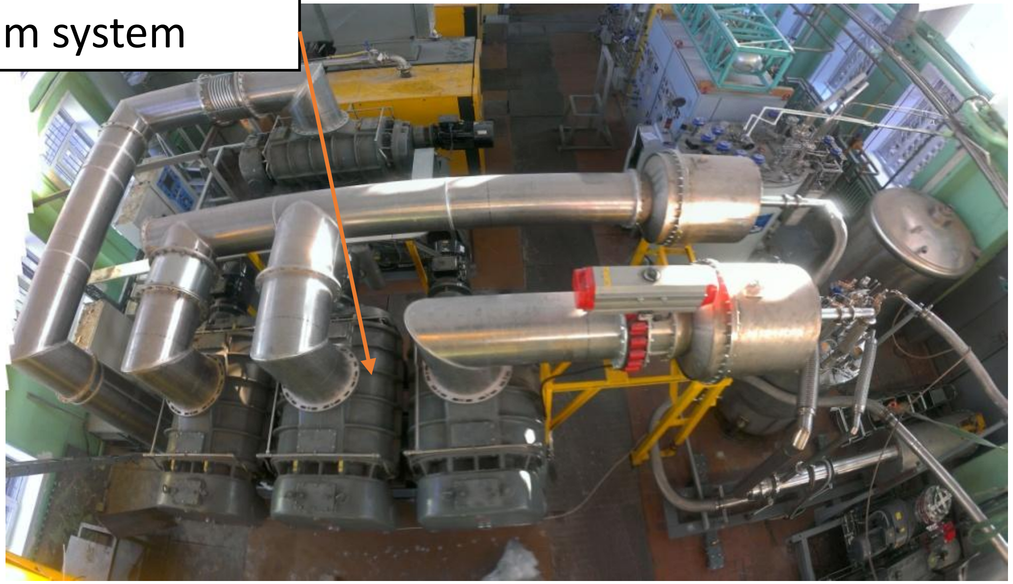
The main question: is it possible to remove 20W power?
UCN source full-scale model

Helium liquefier
L-280



Helium refrigerator
TCF-50

Vacuum system



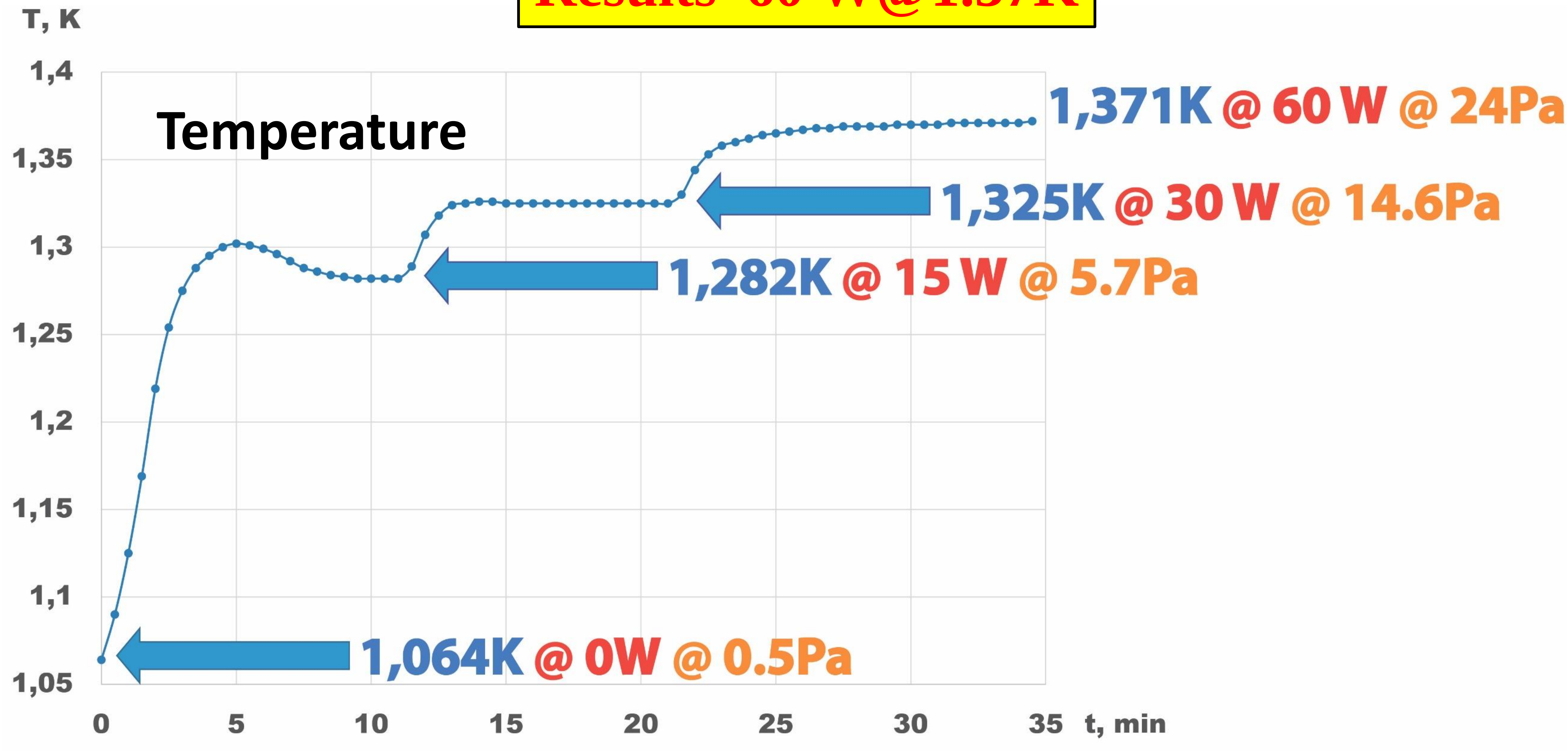
UCNS model

Experiment at full-scale model

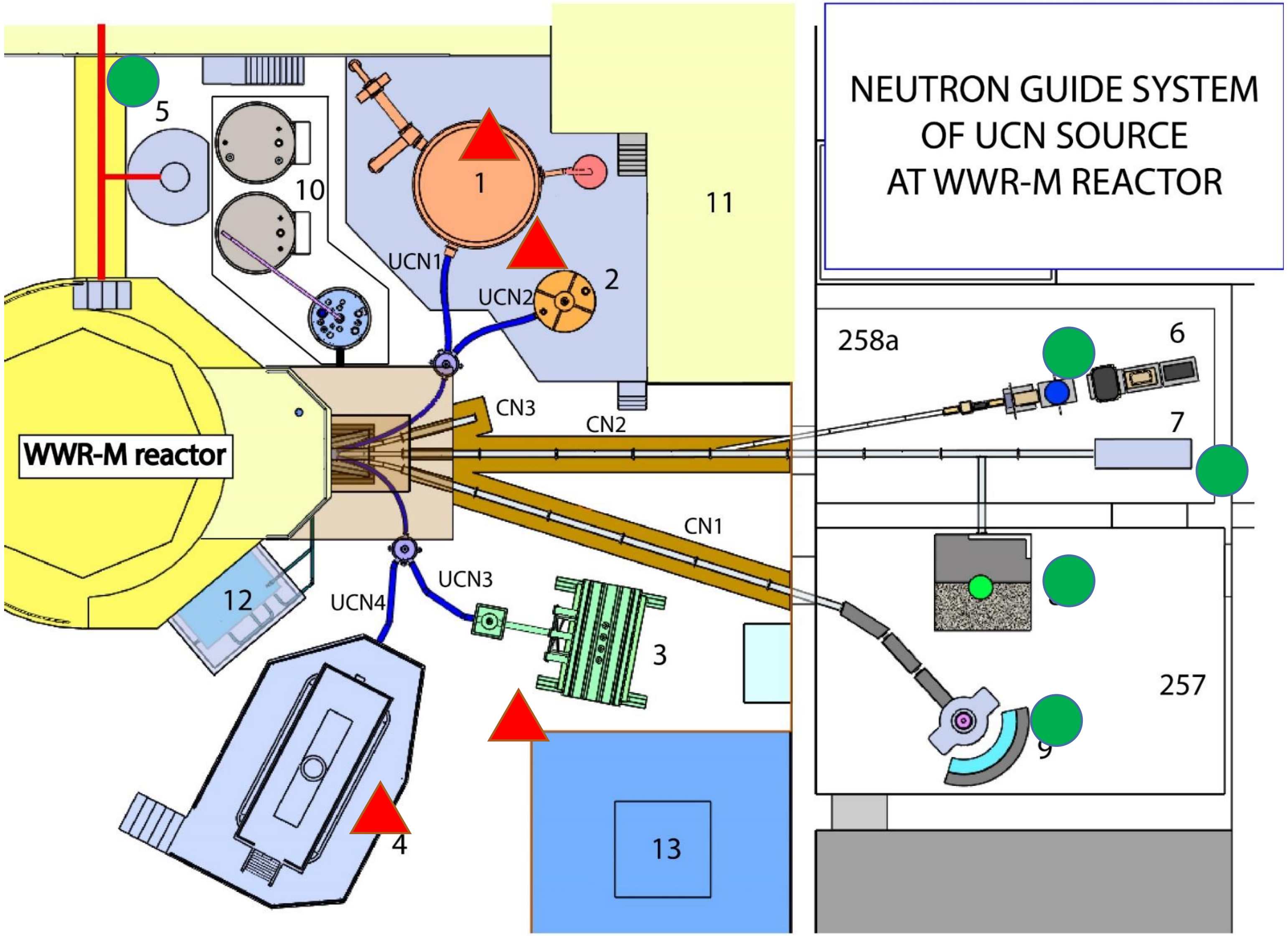
First experiments with heat load simulations on superfluid helium were completed

Experiment at full-scale model

Results 60 W@1.37K



UCN source at WWR-M reactor and scientific program



UCN - Beams of ultracold neutrons

CN - Beams of cold and very cold neutrons

1 - EDM spectrometer
2 - UCN magnetic trap
3 - Experiment n-n '
4 - UCN gravitational Trap
5 - Diffractometer
6 - Reflectometr
7 - Polarimeter
8 - Powder Diffractometer
9 - Spin-echo spectrometer
10- Cryogenic equipment of the UCN source
11- Platform for experimental equipment
12 - Lead shield cooling system
13- Transport entrance

Cryogenic complex at WWR-M reactor

Hall of the cryogenic equipment

Helium liquefier and refrigerator

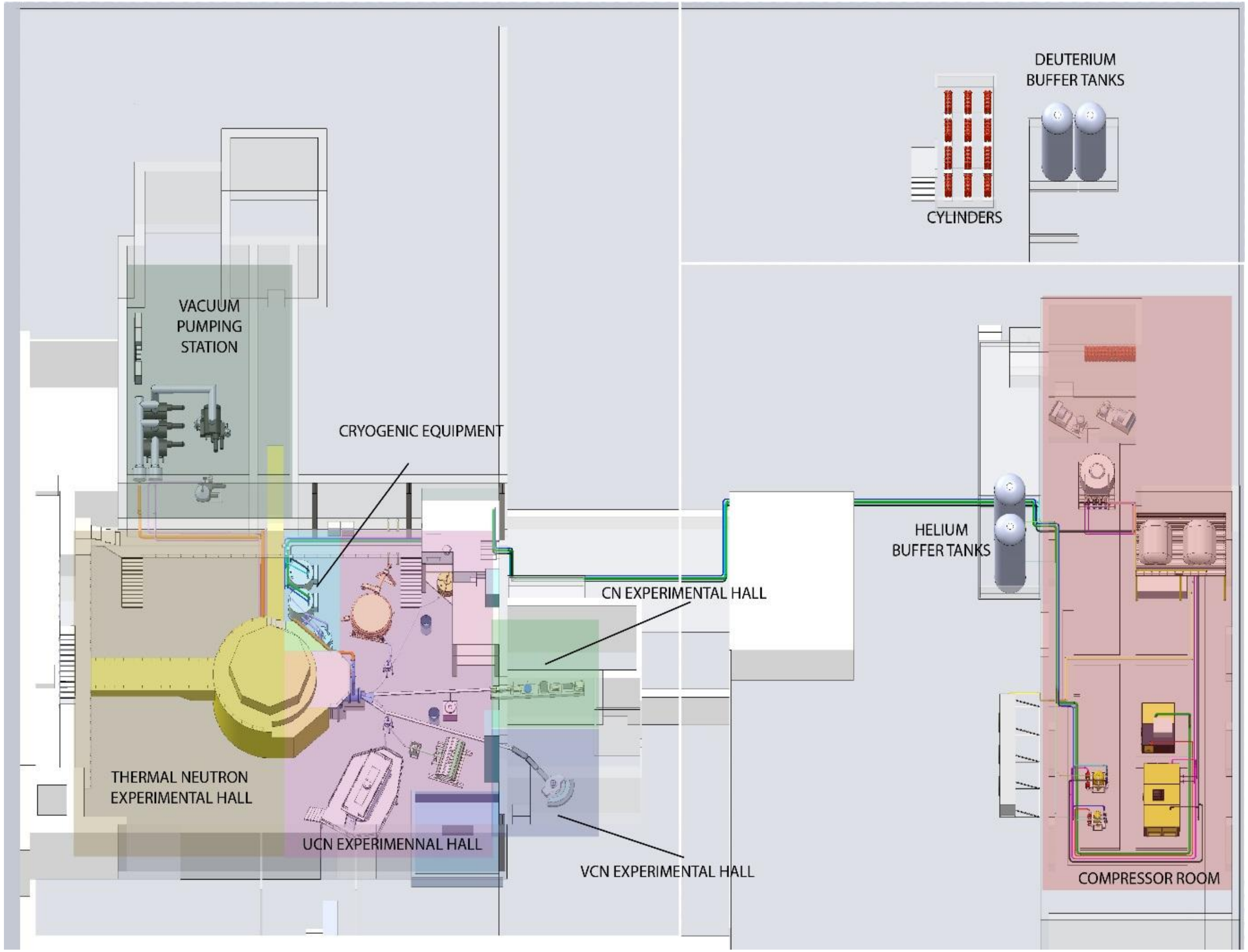
Vacuum equipment

Cryostat

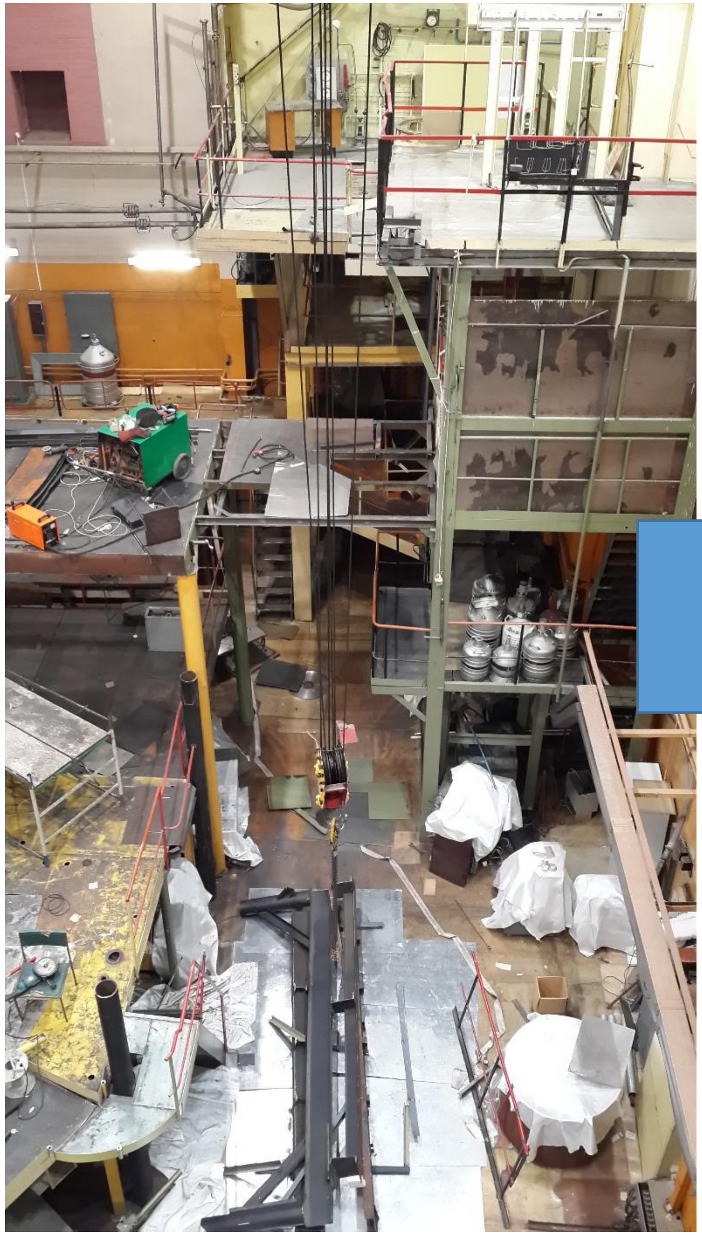
Compressors

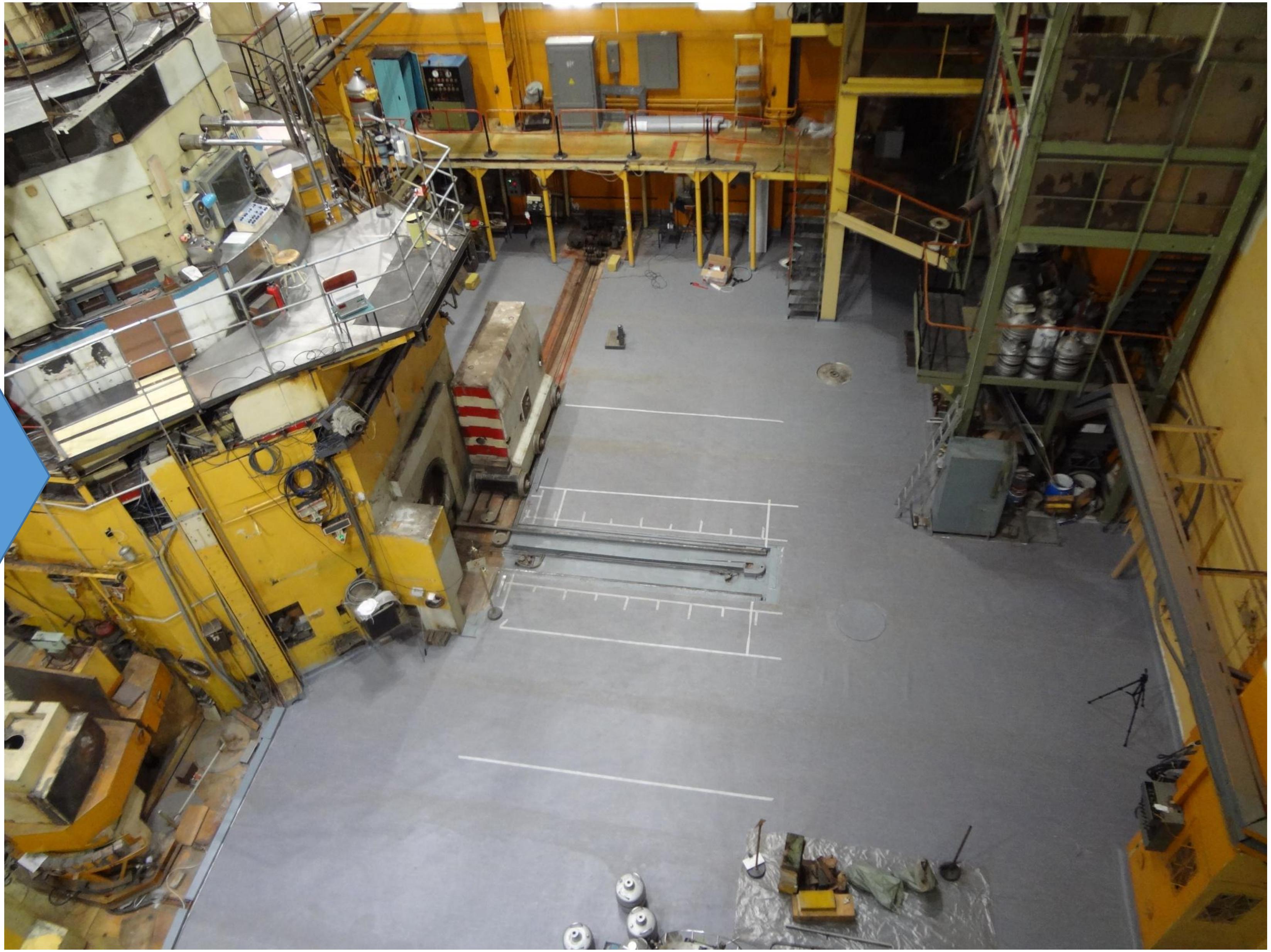
Receivers,
cryogenic building

General scheme of placement of the cryogenic equipment



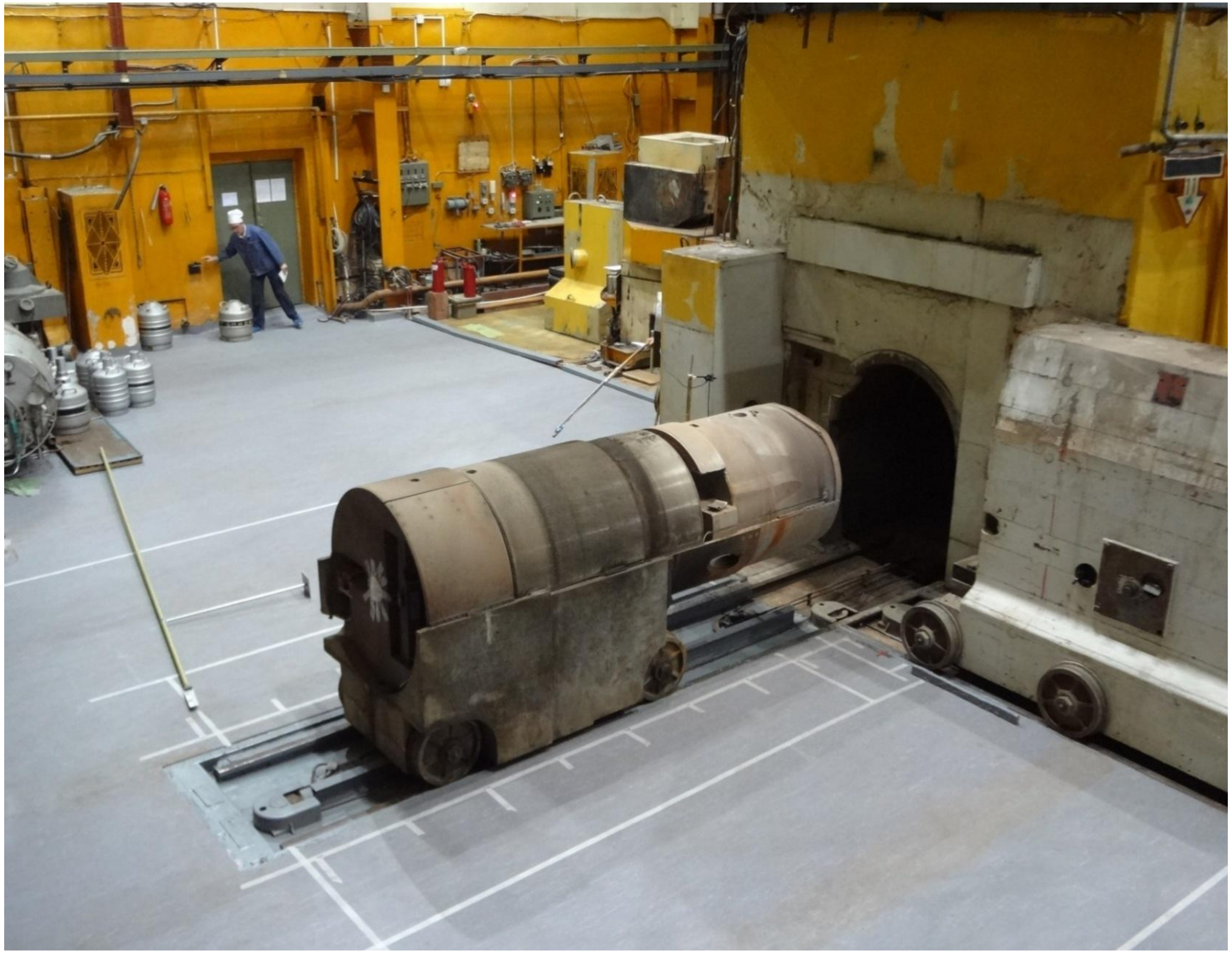
Reconstruction of the main hall of the reactor



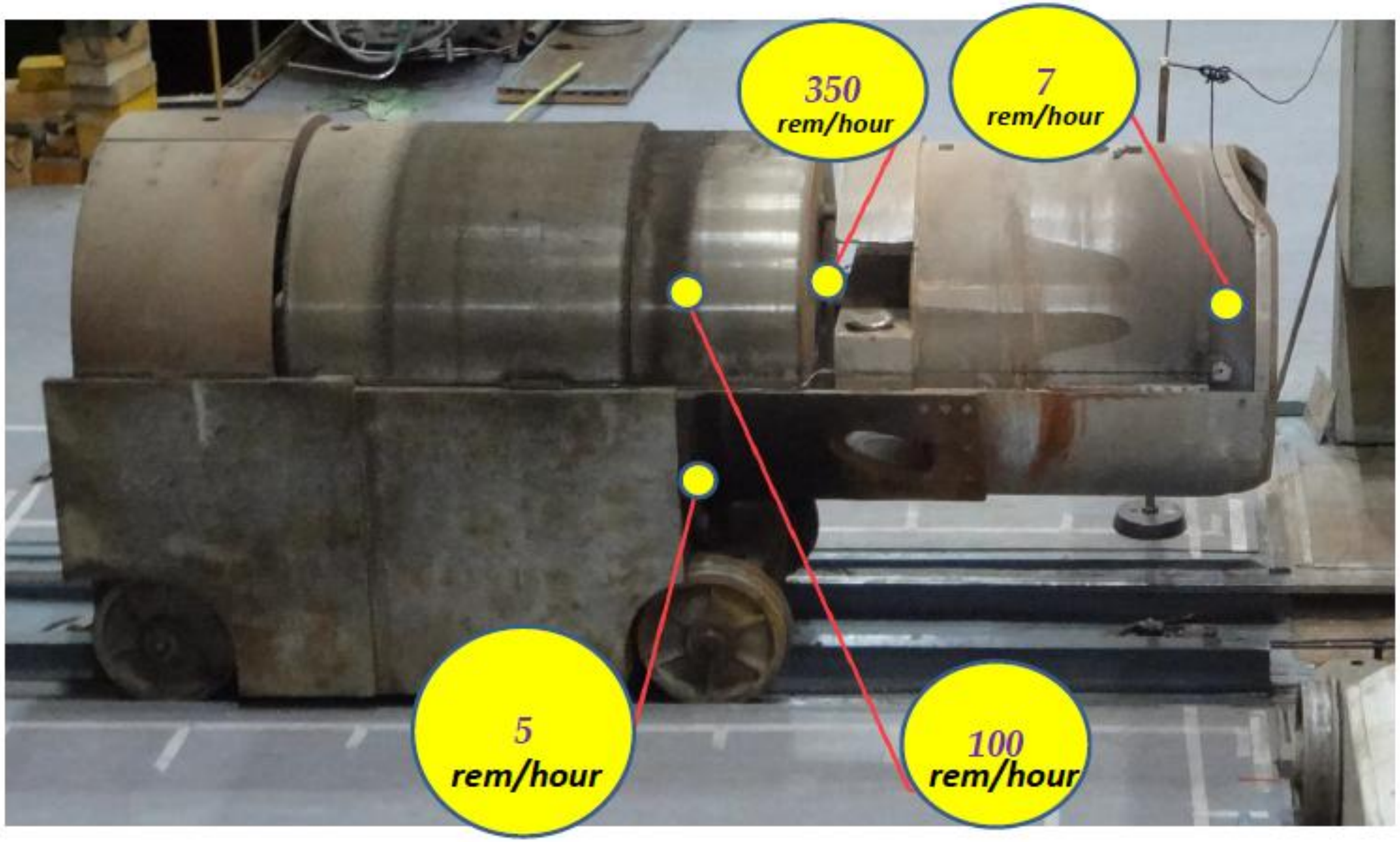


Preparation of the experimental hall of the reactor and thermal column

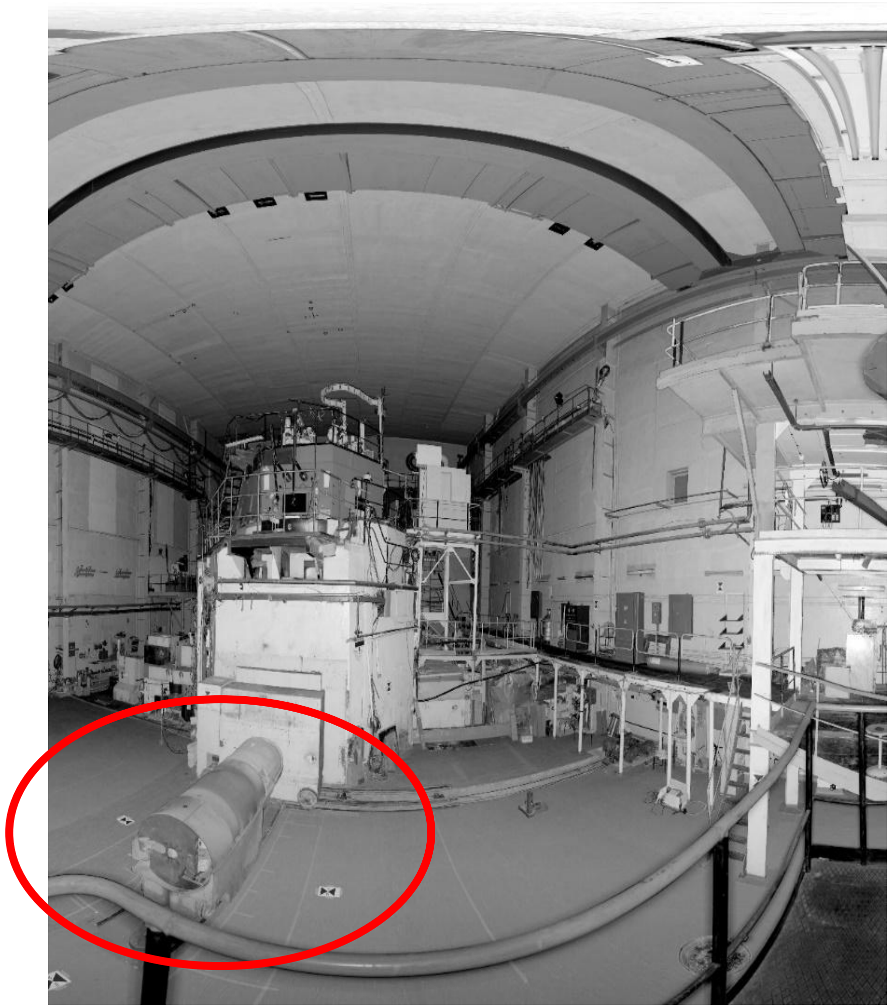
The thermal column was taken for measurement of its radioactivity

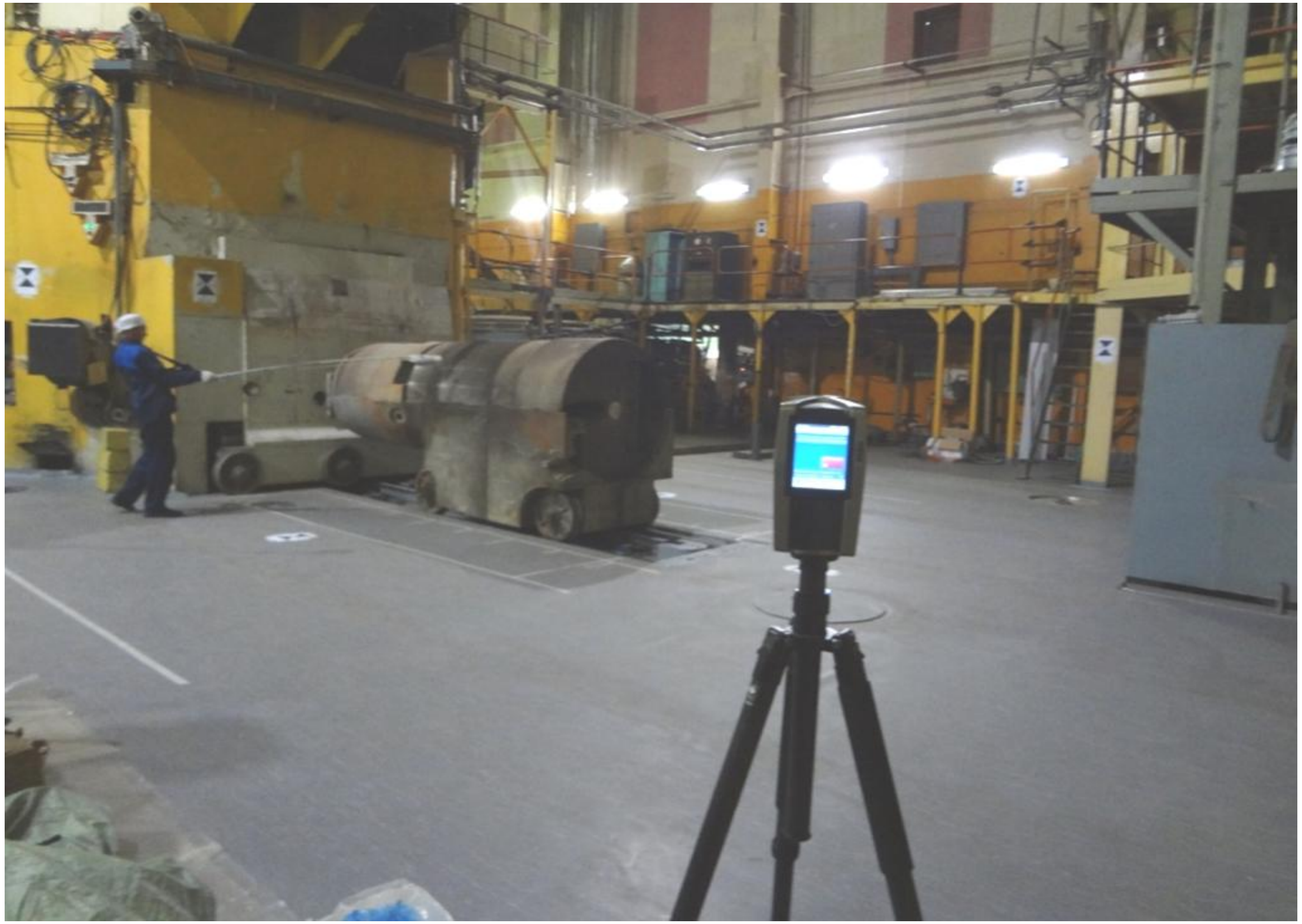


350 X-ray per hour (closely) it is too much



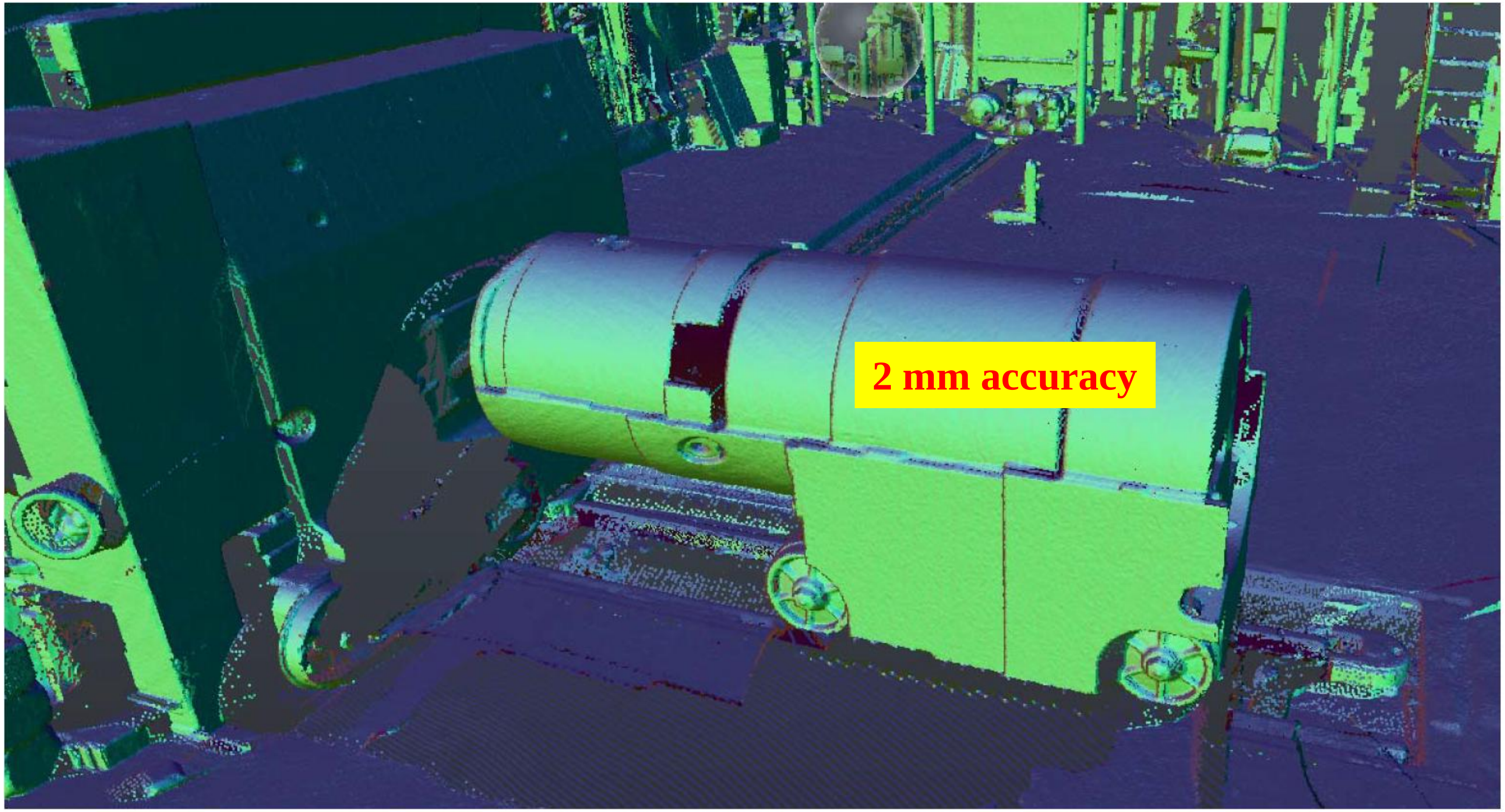
Thermal column measurements





3D scan were done from 7 point
without contacting radioactive thermal column

Thermal column measurements

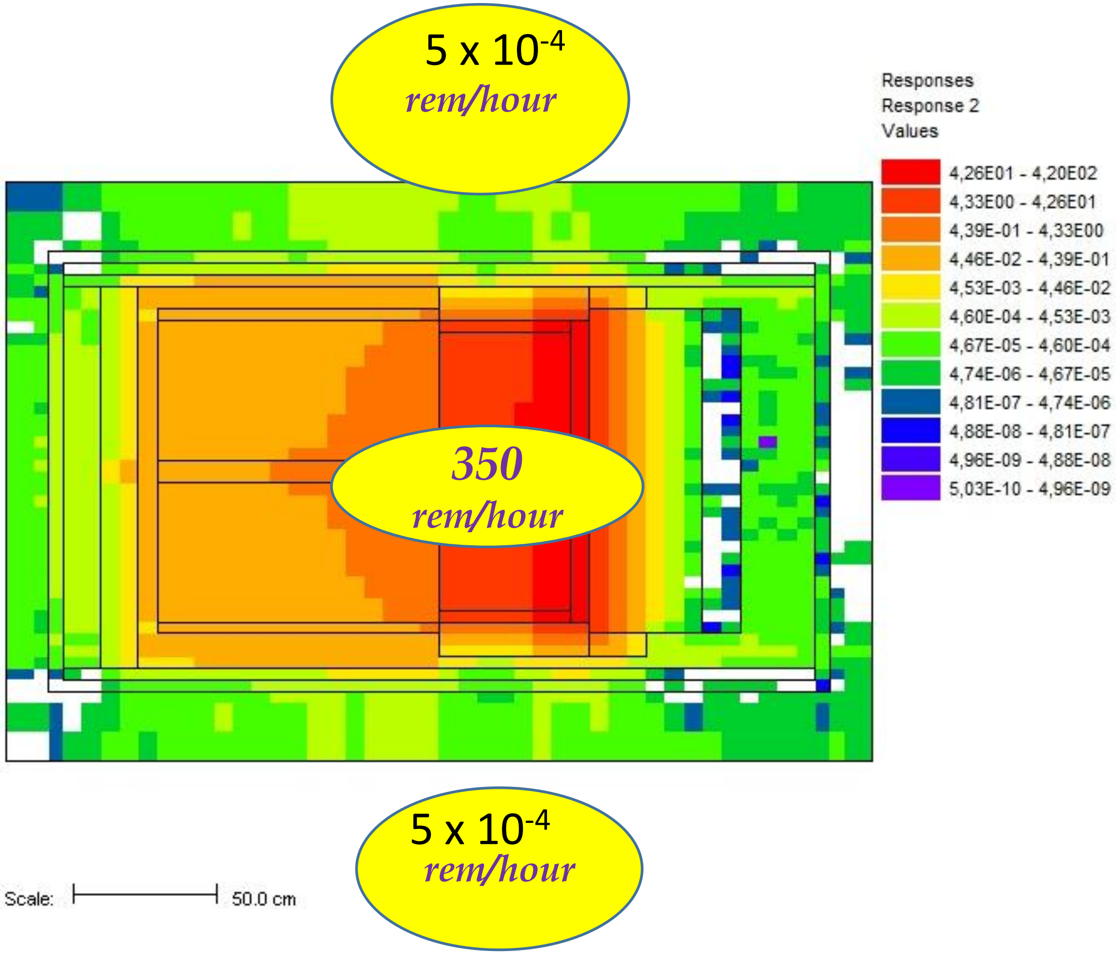


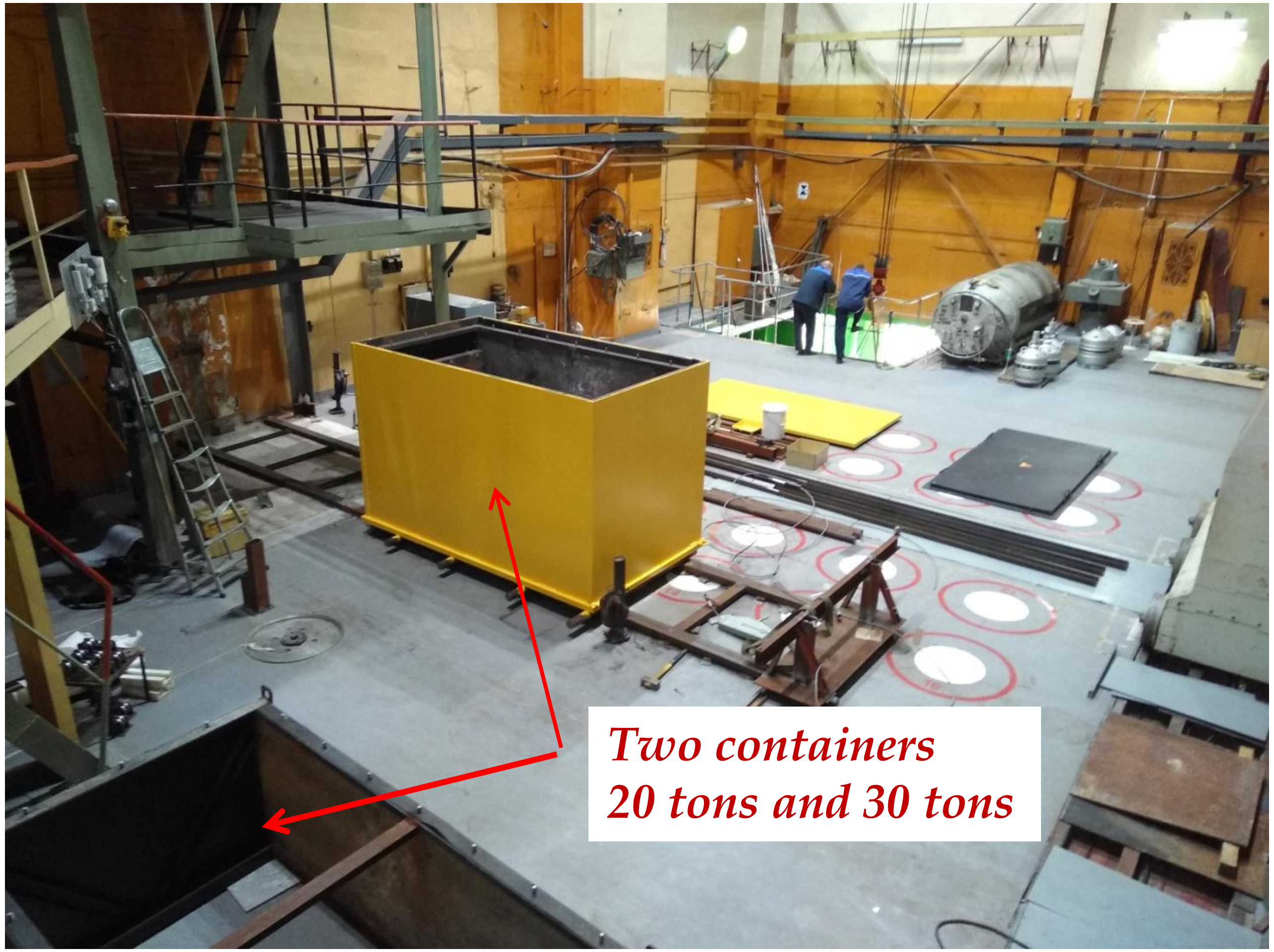
FARO FOCUS
3D scanner

2 mm accuracy

Creation of a supersource of UCN on the WWR-M reactor

Two storages for an old thermal column within the hall of the reactor are established

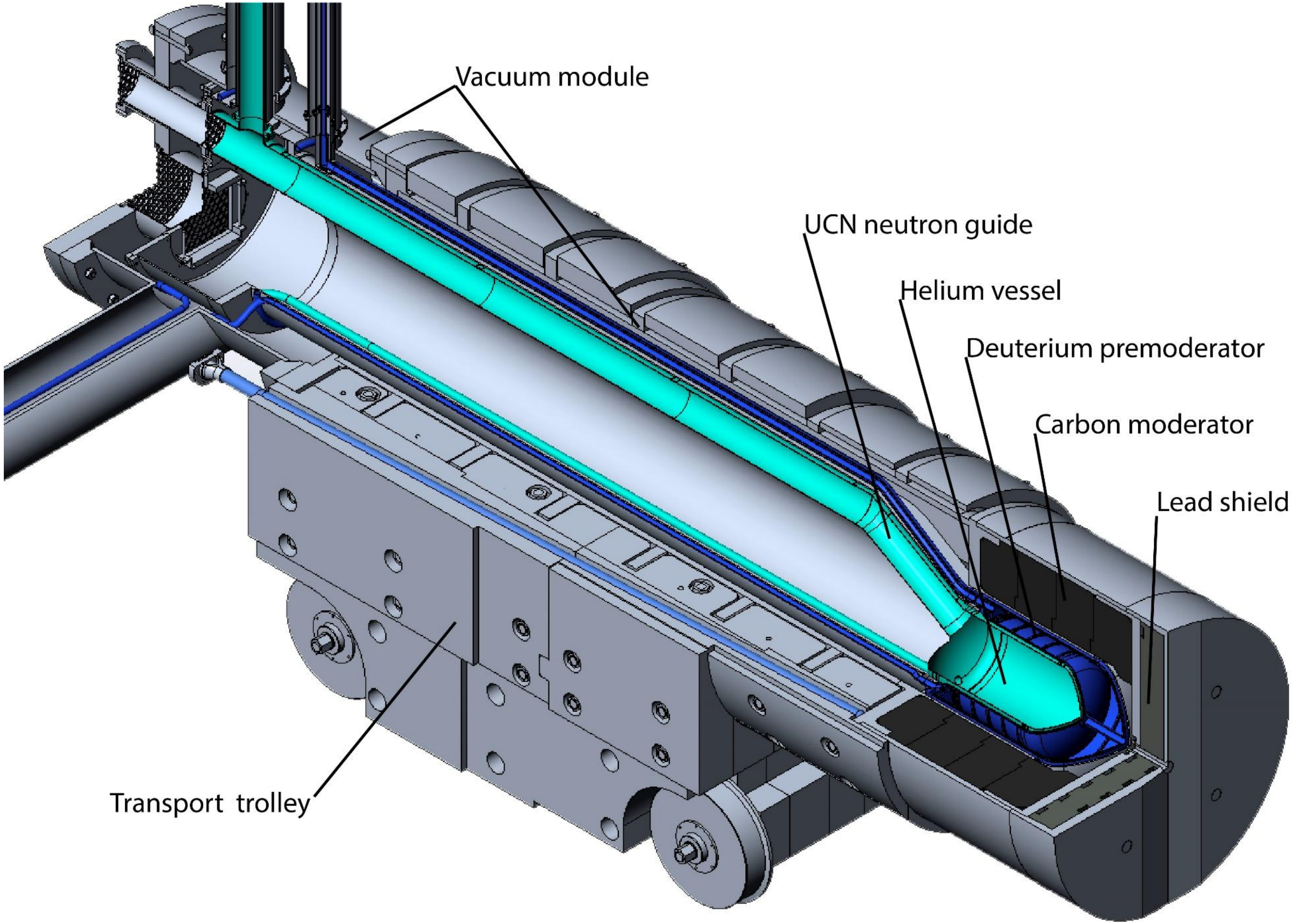




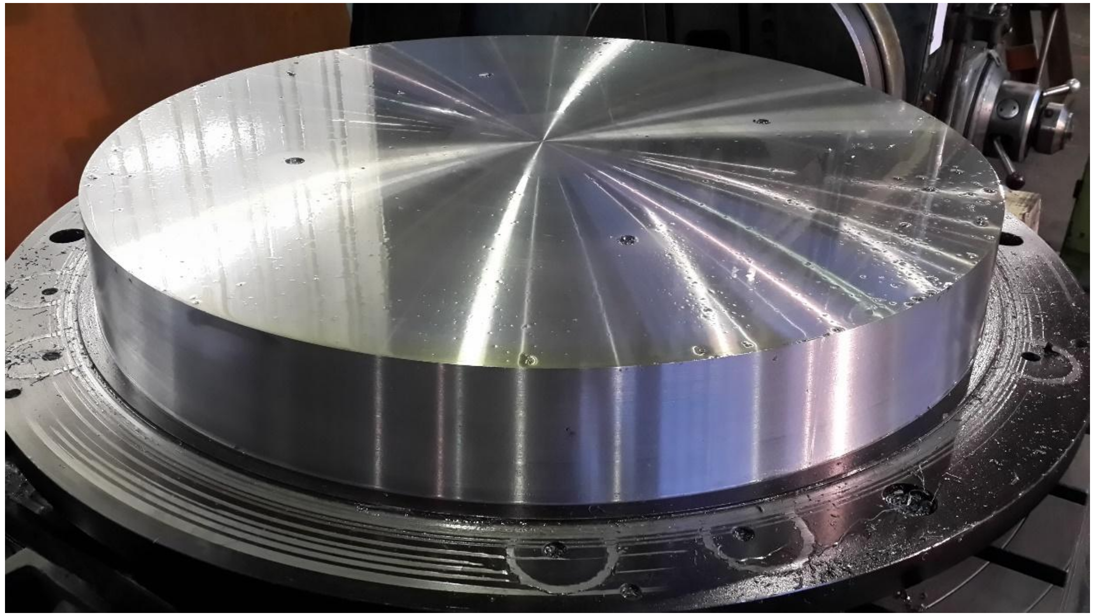
Factor of suppression of radiation one million times

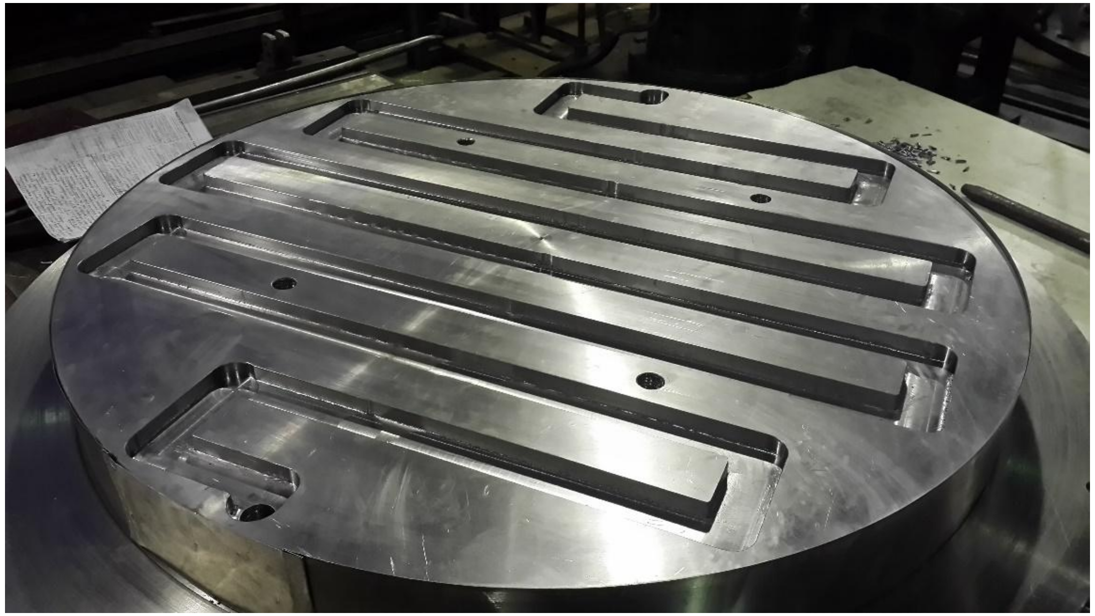
Production of UCN source

UCN source design



Lead shield

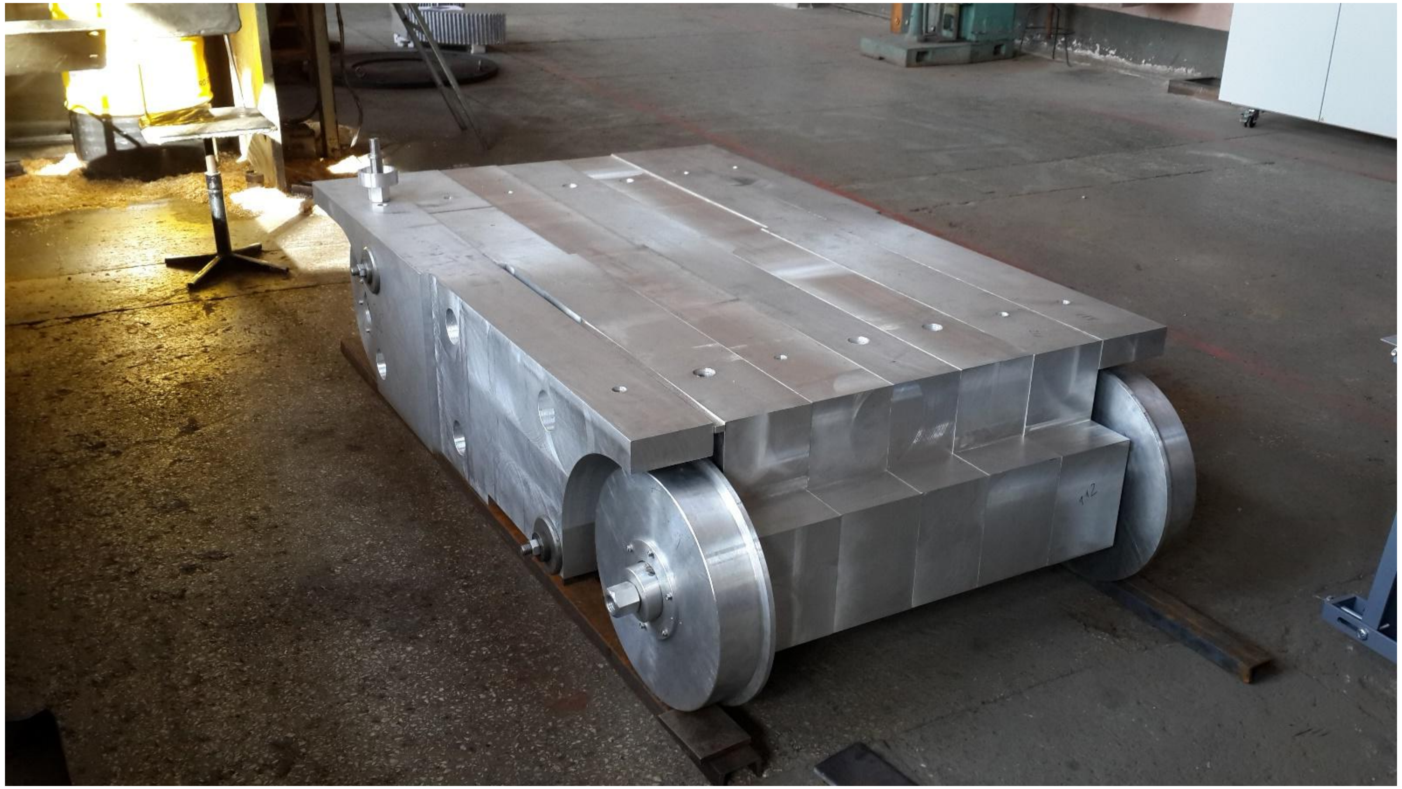




Lead shield	
Pb	95
Sn	5

Carbon premoderator

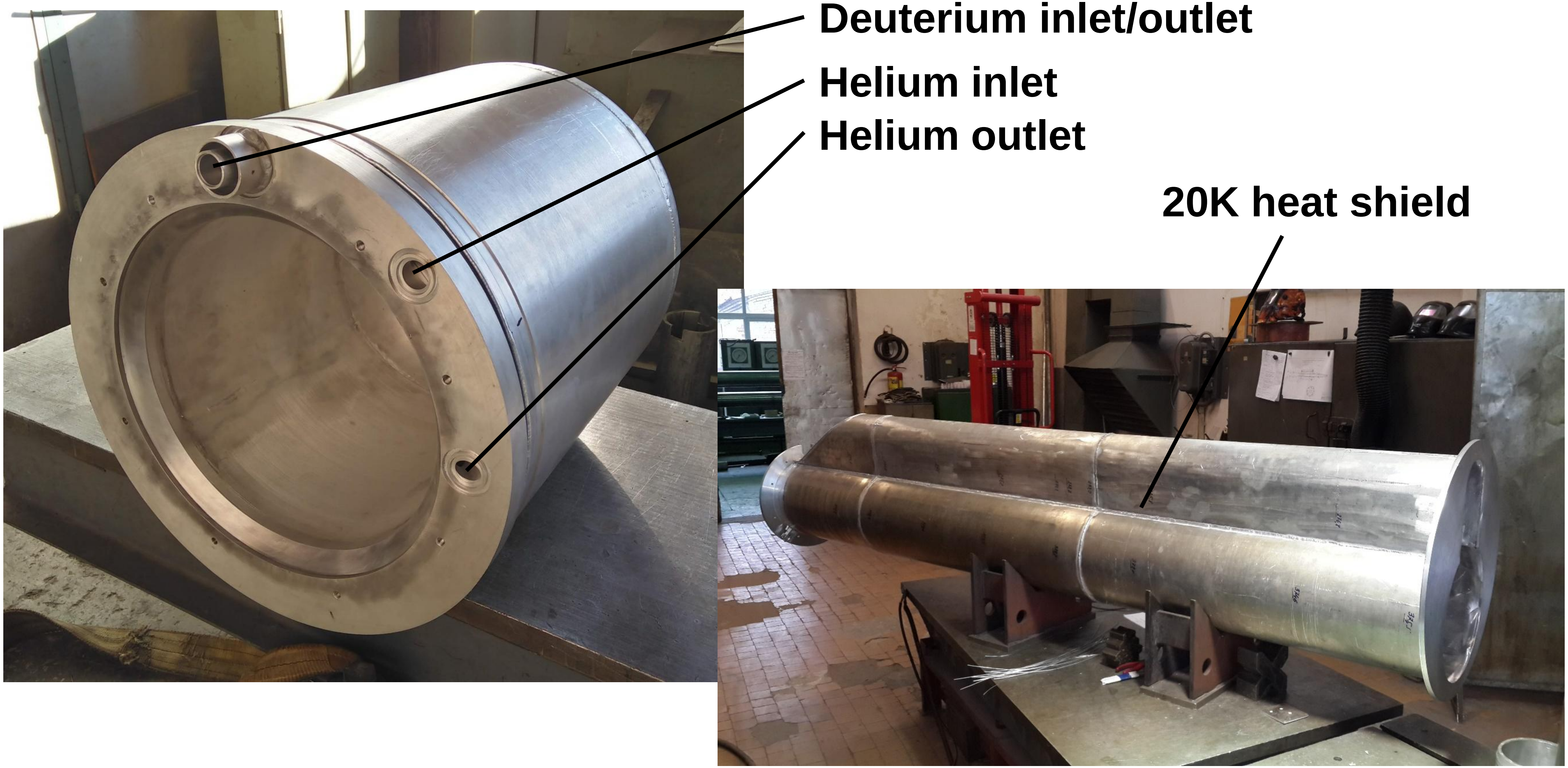
Transport trolley

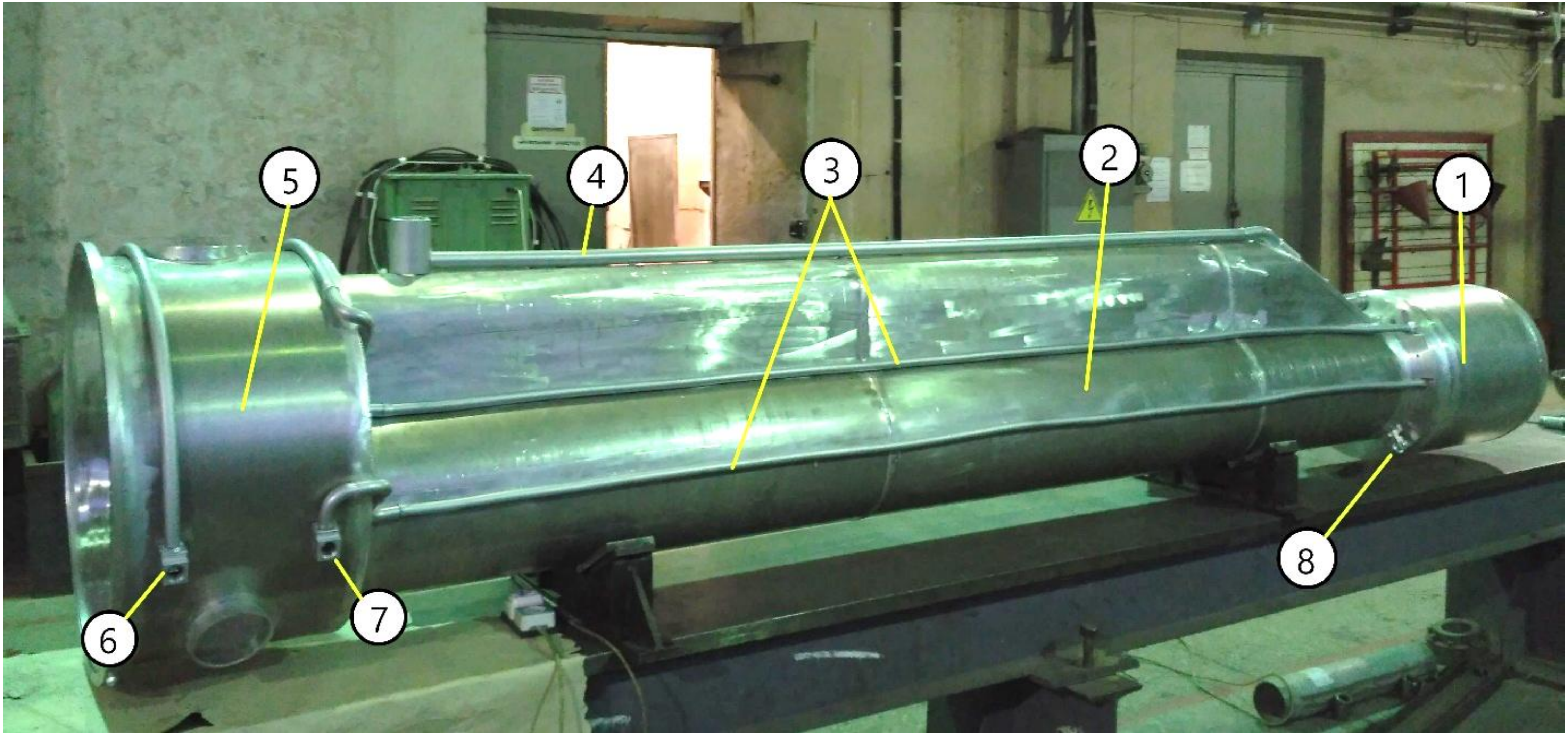
The heaviest part of the source. About 7 tons of aluminum alloy.

Assembling of the vacuum module

D2 module

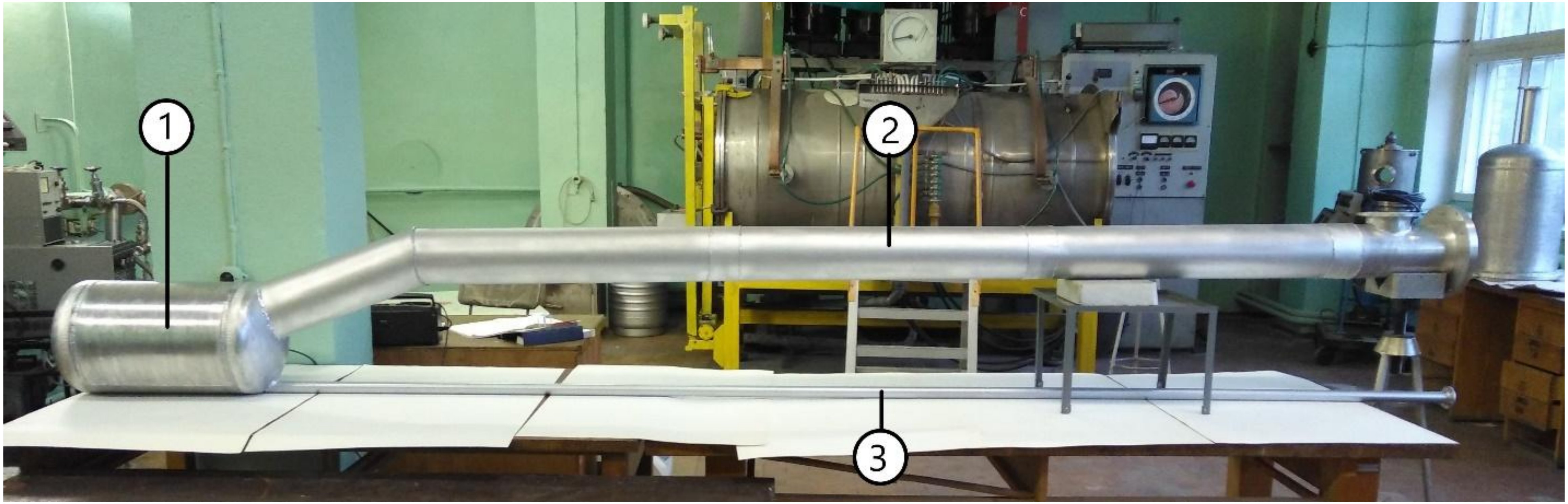

Deuterium inlet/outlet
Helium inlet
Helium outlet
20K heat shield

Assembling of D2 module



1- D2 vessel; 2- 20K heat shield; 3- Helium supply pipes; 4- D2 supply pipe; 5- 20K heat shield extension; 6,7- helium supply flanges; 8- roller seat

Assembling of 1K He module



1- 35 liters He vessel; 2- UCN neutron guide; 3- Superfluid helium supply pipe

Checking source geometry after welding

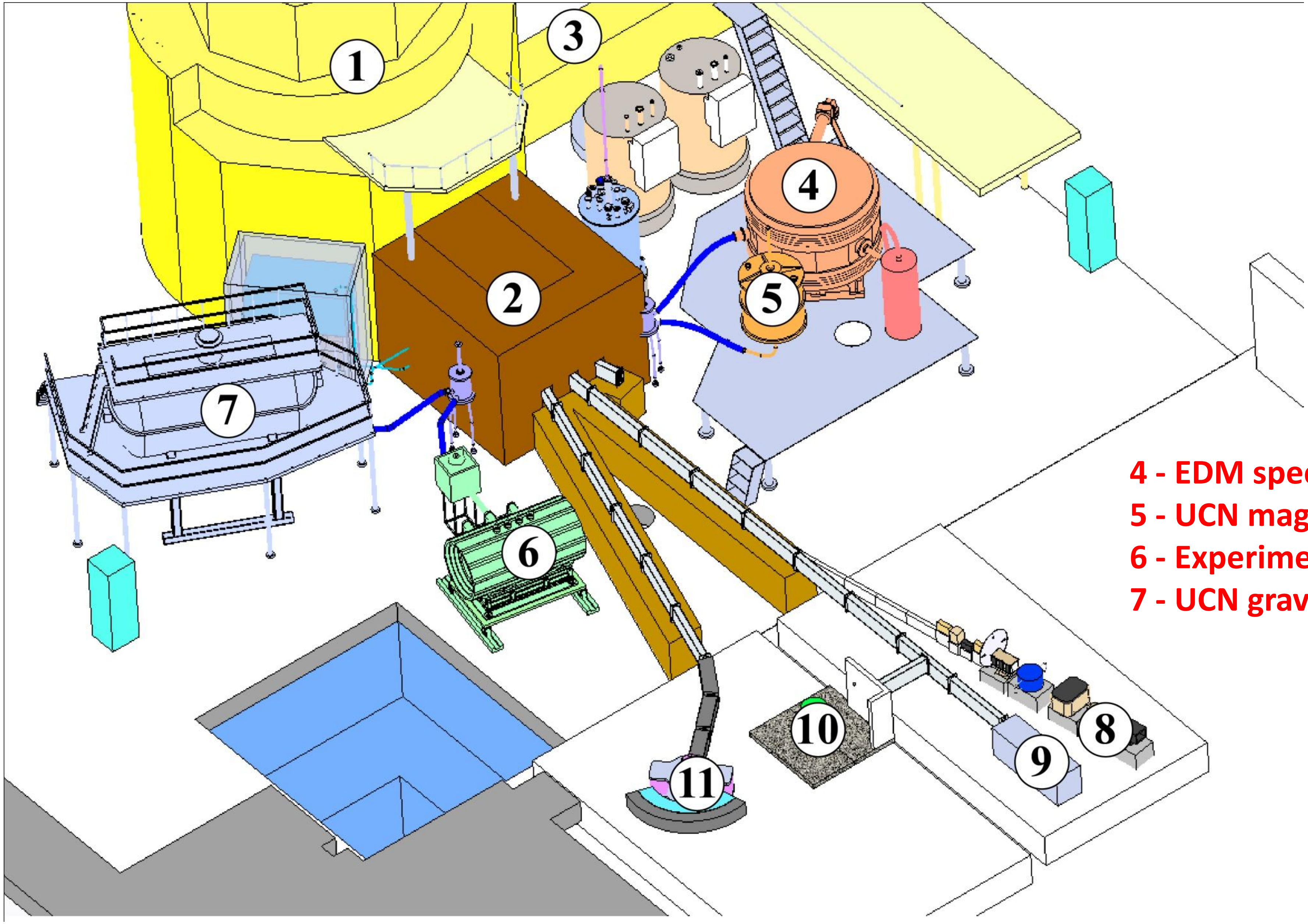
Assembling/testing of the source

Experimental program with UCN at reactor WWR-M

1 - EDM spectrometer
2 - UCN magnetic trap
3 - Experiment n-n '
4 - UCN gravitational Trap

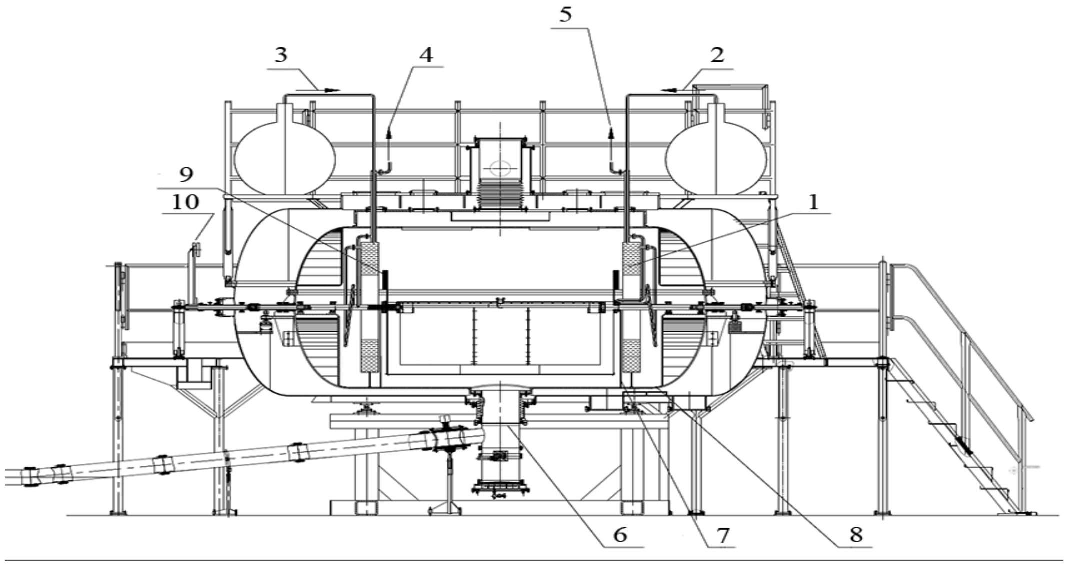
neutron-antineutron setup?

Experimental program with UCN at reactor WWR-M

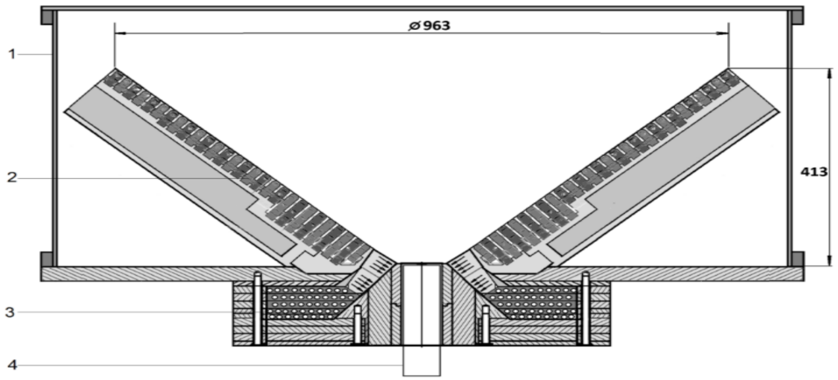


4 - EDM spectrometer
5 - UCN magnetic trap
6 - Experiment n-n '
7 - UCN gravitational Trap

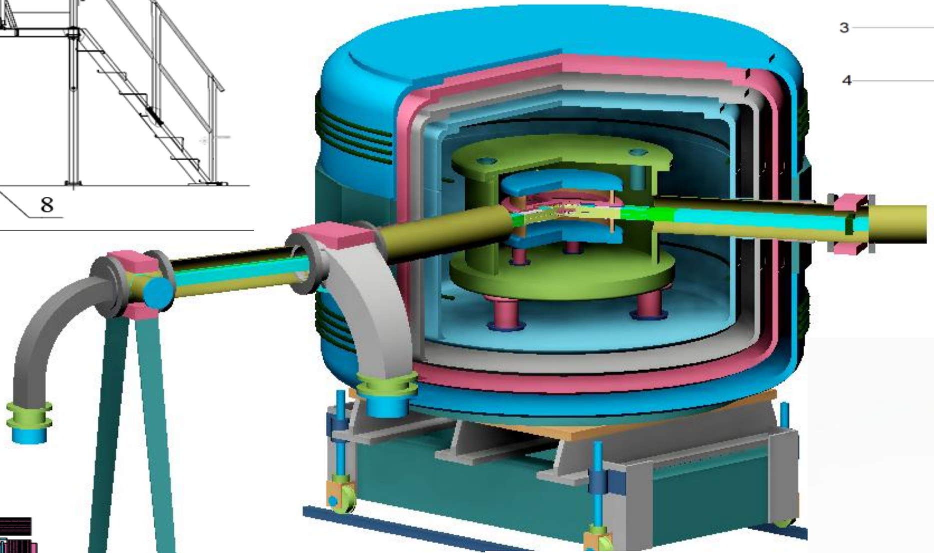
Experimental program with UCN at reactor WWR-M



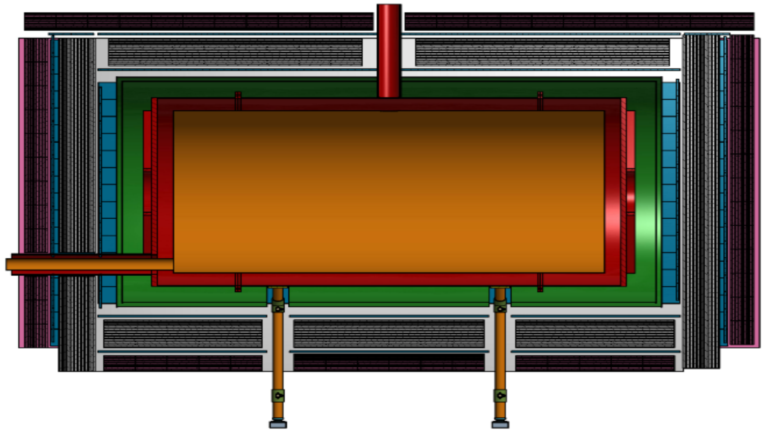
τ_n , Gravitrap



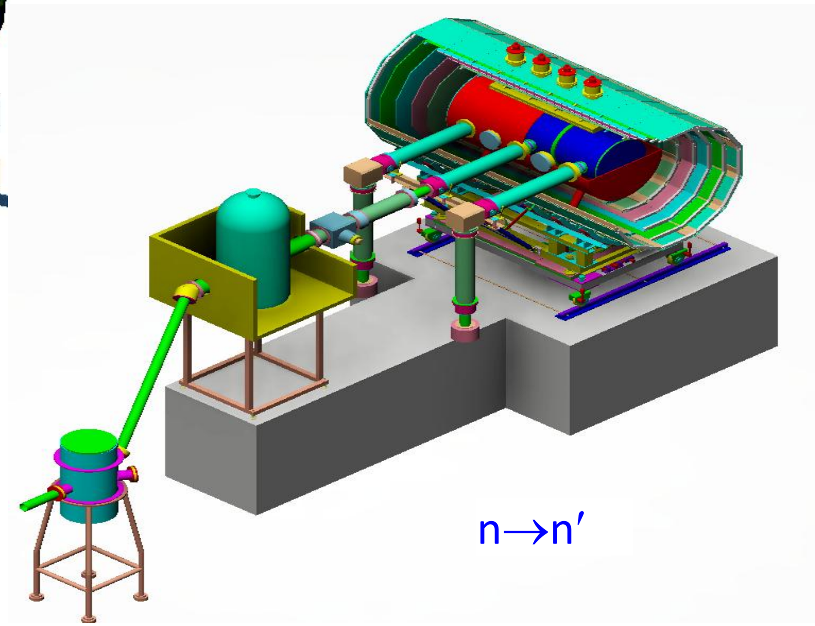
τ_n , magnetic trap



nEDM

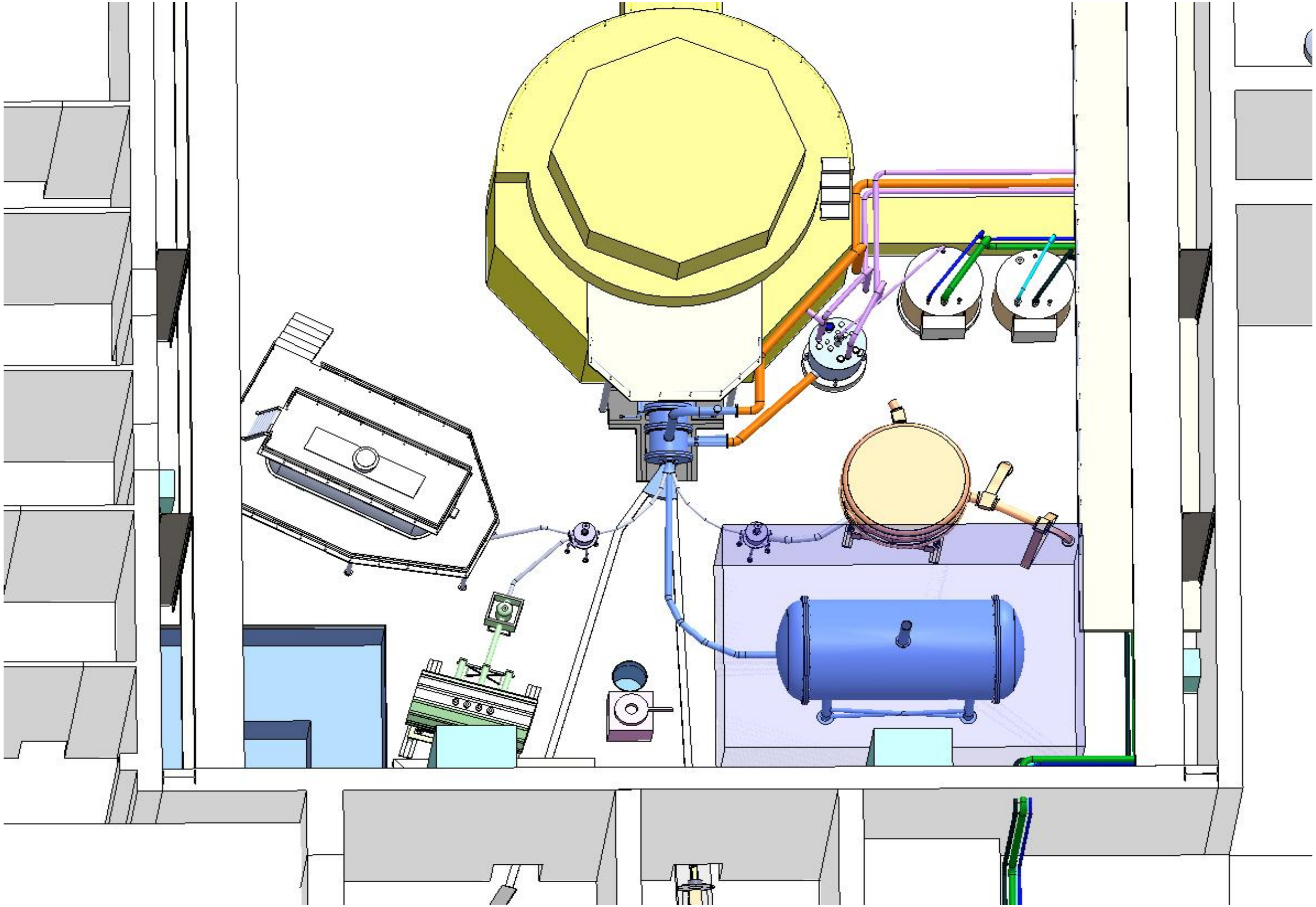


$n \to \tilde{n}$

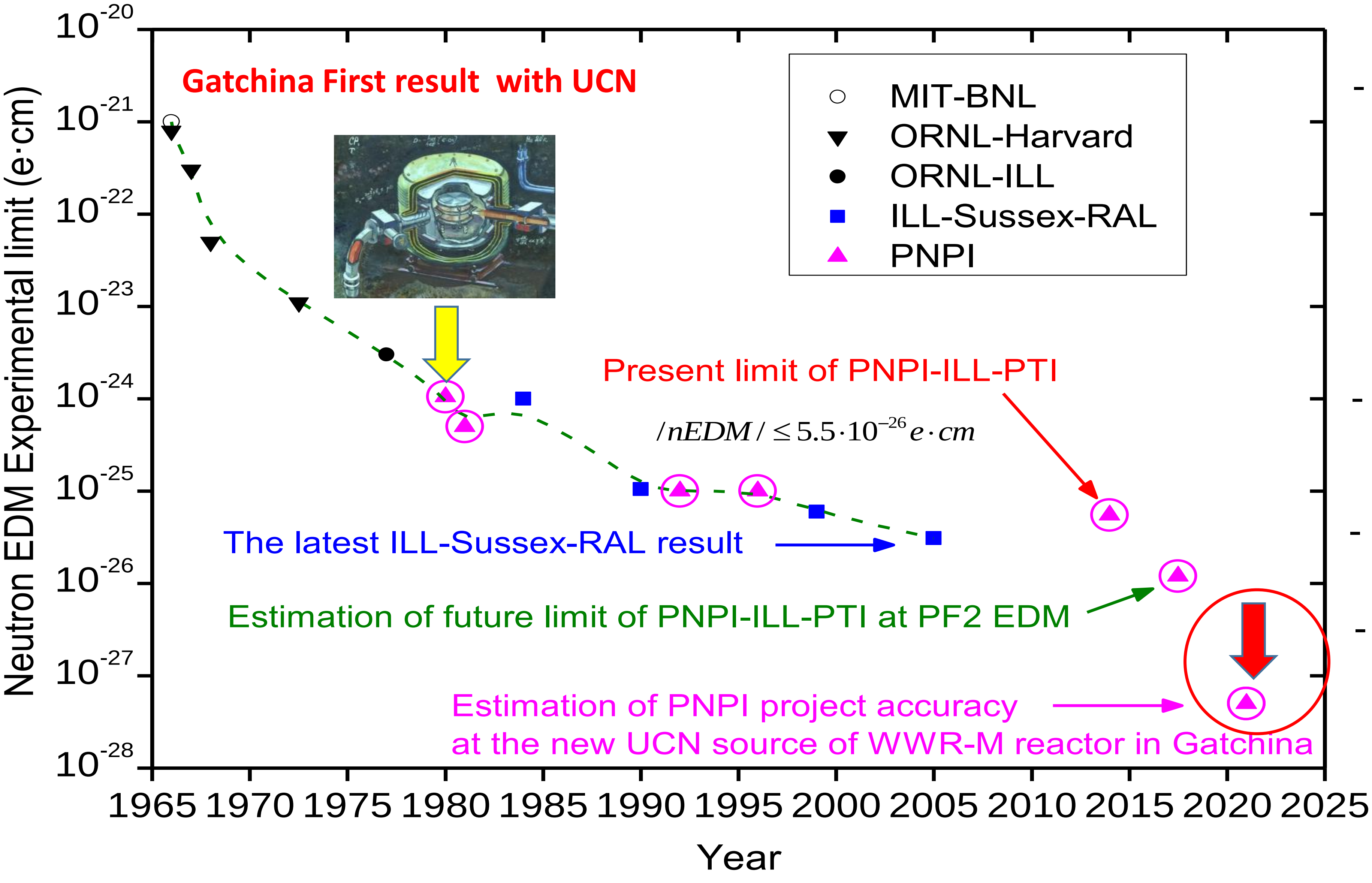


$n \to n'$

UCN facilities at reactor WWR-M+ neutron-antineutron setup?



History of nEDM measurements in Gatchina and Grenoble. Result and prospects of PNPI-ILL-PTI collaboration

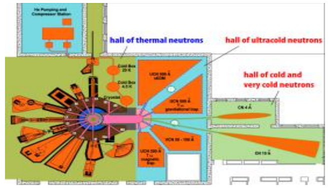


Theoretical Prediction:

- Electromagnetic
- Weinberg Multi-Higgs
- Minimal SUSY

Cosmology

- Left-Right Symm.



UCN source at WWR-M reactor

Comparative table of neutron sources

	WWR-M	PIK		ILL	
	Value	Value	Factor WWR-M/PIK	Value	Factor WWR-M/ILL
Thermal neutrons, $n \cdot cm^{-2}s^{-1}$	$3.2 \cdot 10^{12}$	$2.5 \cdot 10^{14}$	0.01	$2.5 \cdot 10^{14}$	0.01
UCN production rate, n/s	**$1 \cdot 10^{8}$**	**Not planed**		**1.2×10^{6}**	**100**
UCN density at nEDM spectrometer $\rho_{ЭДМ}$, cm^{-3}	**$1.3 \cdot 10^{4}$**	**Not planed**		**10**	**1000**
Cold Neutrons (2-20 Å), $n/(cm^{2}s)^{-1}$	$8.6 \cdot 10^{7}$	$5.44 \cdot 10^{9}$	0.01	$5.5 \cdot 10^{9}$	0.01
Very Cold Neutrons(50-100 Å), $n/(cm^{2}s)^{-1}$	$4.6 \cdot 10^{5}$	**Not planed**		$4 \cdot 10^{6}$	0.1

THANKS FOR ATTENTION and BEST REGARDS FROM RUSSIA