National Research Centre «Kurchatov Institute»
PETERSBERG NUCLEAR PHYSICS INSTITUTE

ULTRACOLD NEUTRON SOURCE FOR RESEARCH IN FUNDAMENTAL PHYSICS AT THE PIK REACTOR

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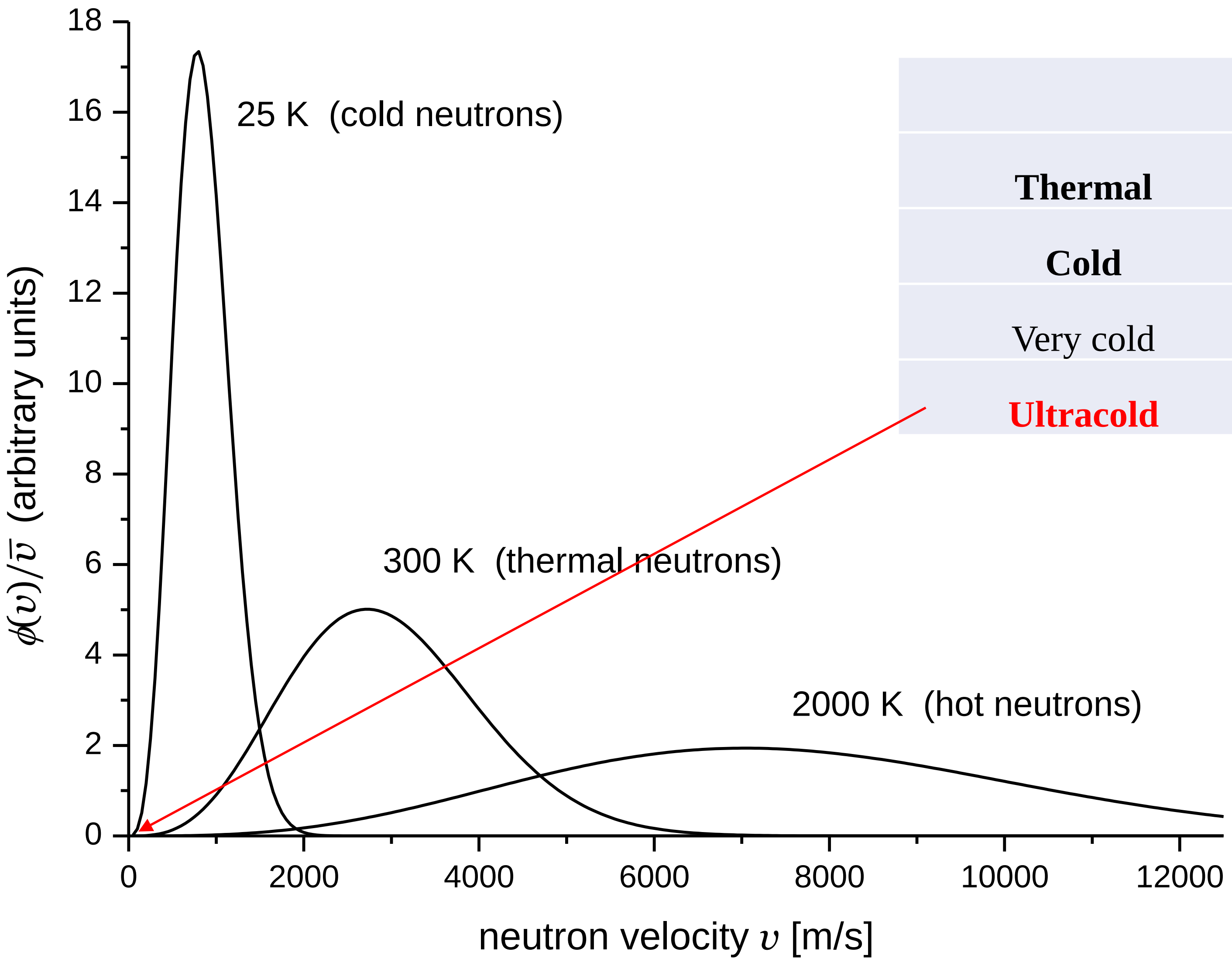
LOMONOSOV CONFERENCE ON ELEMENTARY PARTICLE PHYSICS
August 21-27

ULTRACOLD NEUTRONS

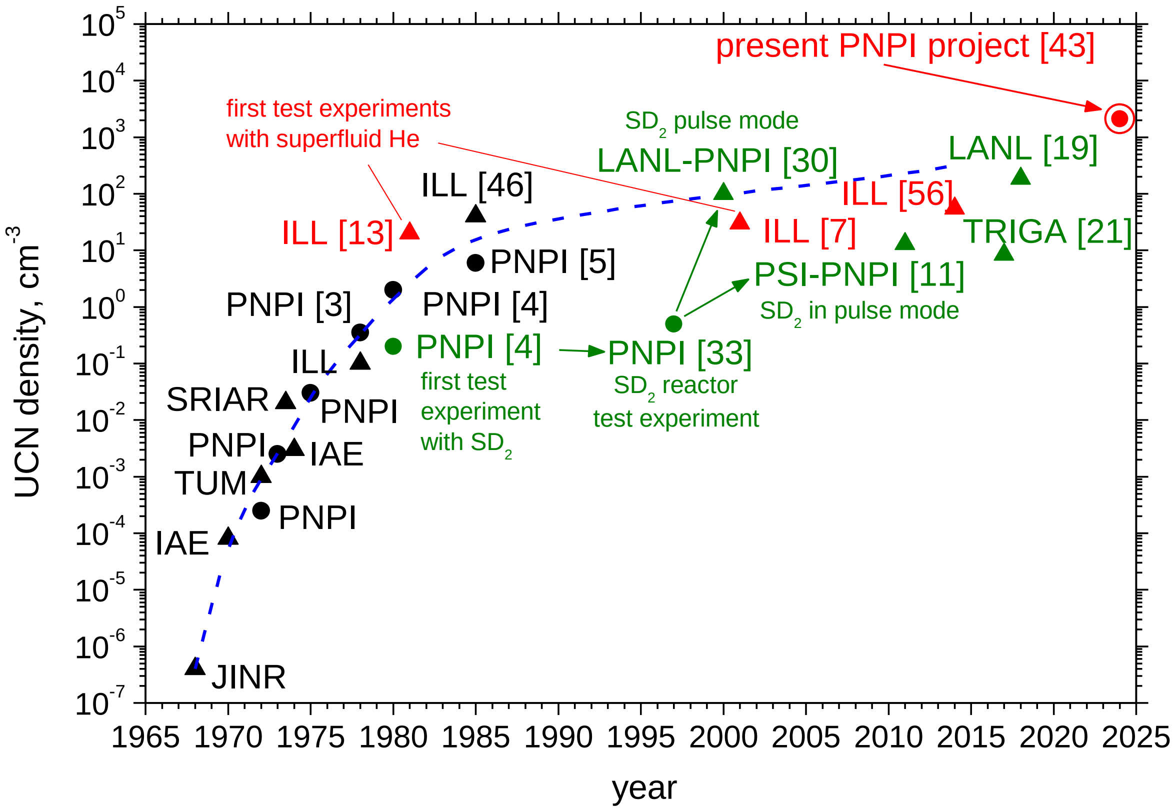


	Energy, eV	Energy, K	Velocity, m/s
Thermal	$5\cdot10^{-3} \div 0{,}5$	$6000 \div 50$	$9{,}8\cdot10^{2} \div 9{,}8\cdot10^{3}$
Cold	$10^{-4} \div 5\cdot10^{-3}$	$50 \div 1$	$1{,}4\cdot10^{2} \div 9{,}8\cdot10^{2}$
Very cold	$10^{-7} \div 10^{-4}$	$1 \div 10^{-3}$	$4{,}4 \div 140$
Ultracold	**$\sim10^{-7}$**	**10^{-3}**	**~4,4**

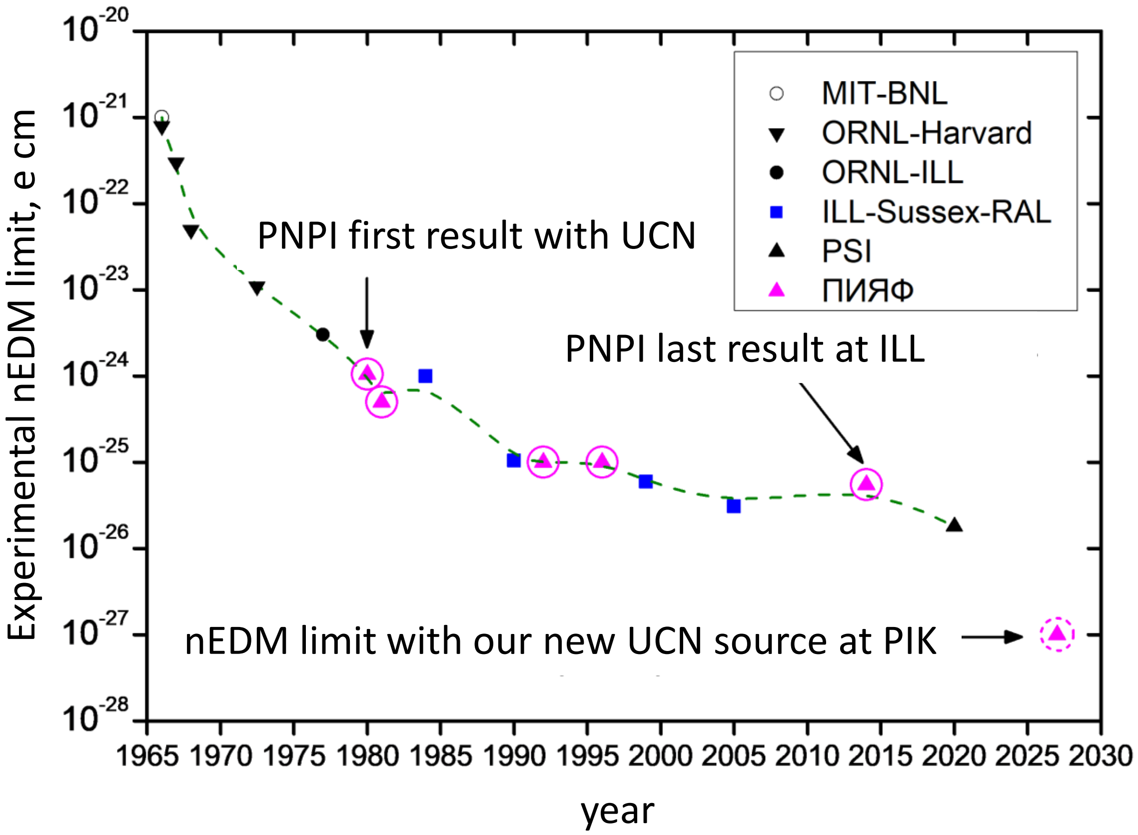
Ultracold neutrons have the property of being reflected from any matter at any angle of incidence, so they can be stored in material traps for tens and hundreds of seconds..

MOTIVATION

- Over the past 20 years, there has been no progress in increasing the density of ultracold neutrons
- Highly efficient cryogenic methods by using **LD2** or **sD2** have been mastered
- For further progress, it is proposed to **use superfluid helium** to obtain UCN
- Progress in the development of UCN sources is holding back progress in researches

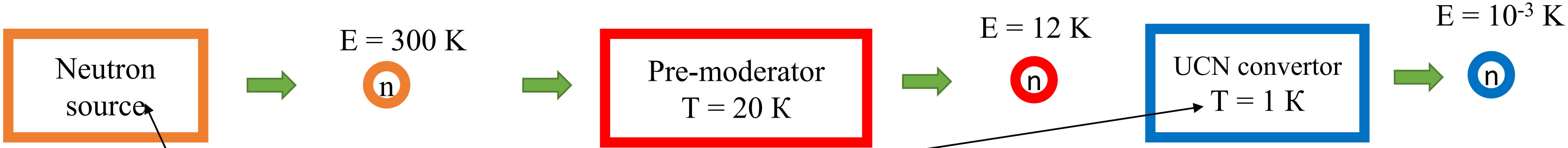


World progress in increasing the UCN density



Progress in lowering the upper limit on the neutron EDM

UCN PRODUCTION



$$\rho_{UCN} = P\tau$$

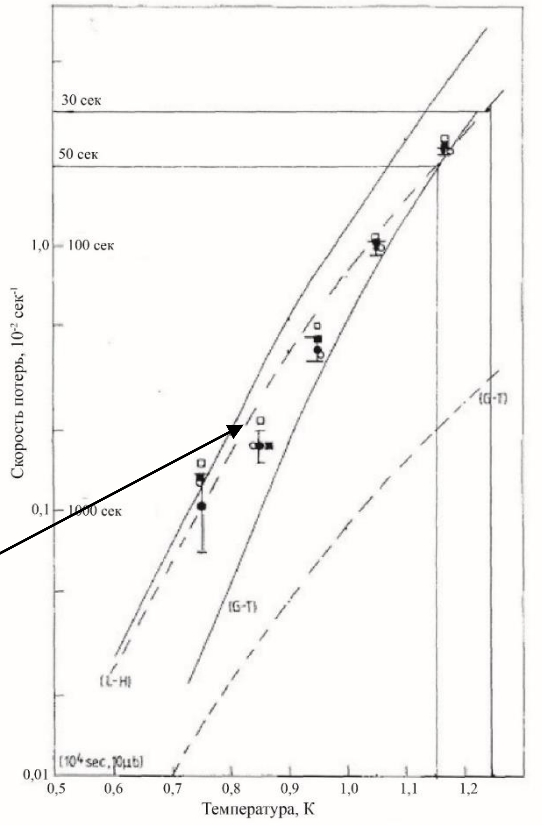
$$\tau^{-1} = \tau^{-1}_{\beta} + \tau^{-1}_{capture} + \tau^{-1}_{wall\ losses} + \tau^{-1}_{upscattering}$$

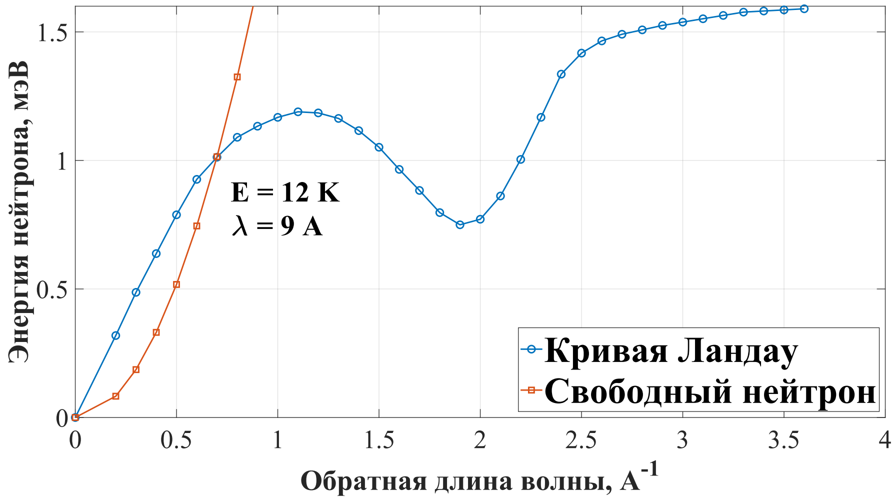
τ_{decay} = const

$\tau_{capture}$ → isopure He4 → $He^3/He^4 = 2\cdot10^{-11}$

$\tau_{wall\ losses}$ → Ni^{58} coating → v_b = 8.1 m/s

$\tau_{upscattering}$ → cryogenics → T_{He4} = 1.0-1.3 K



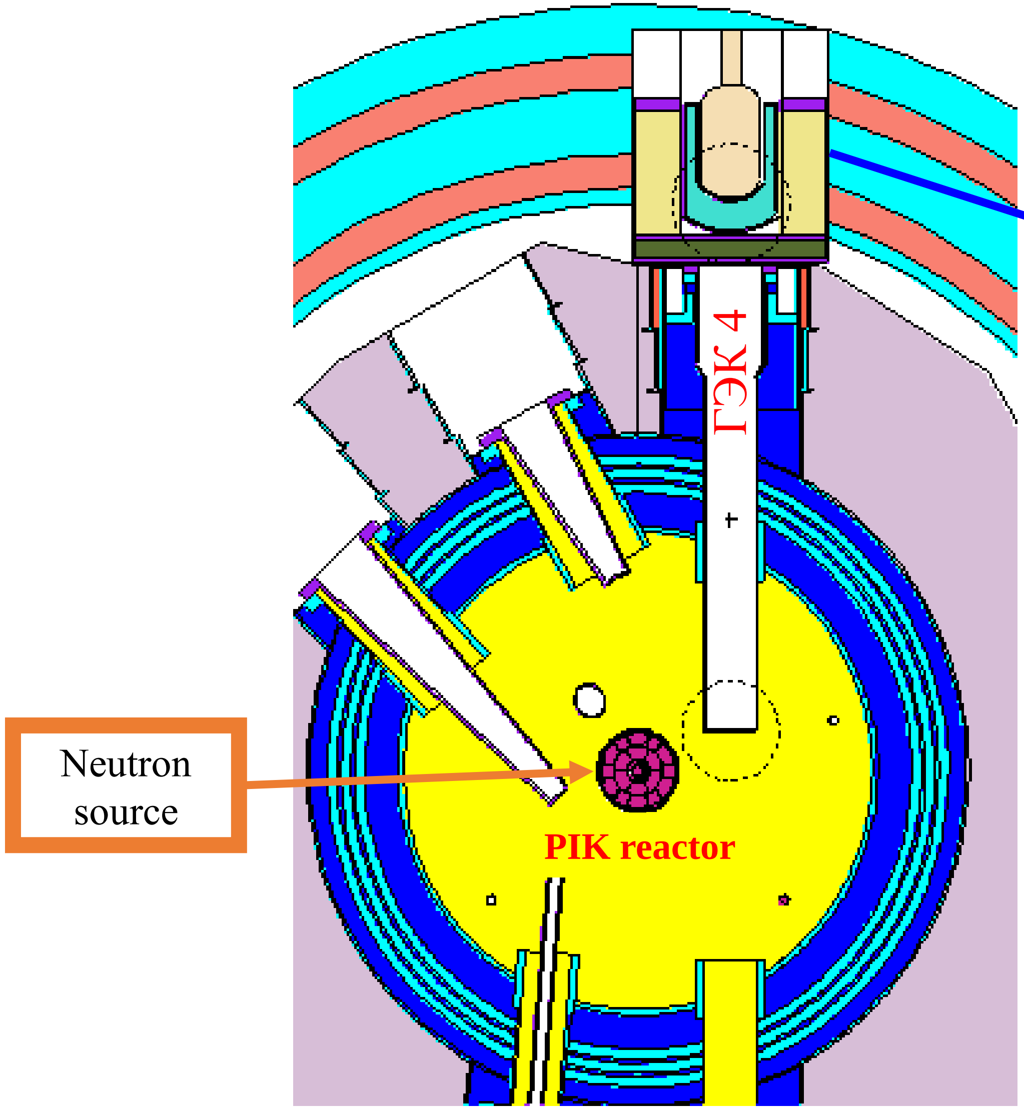


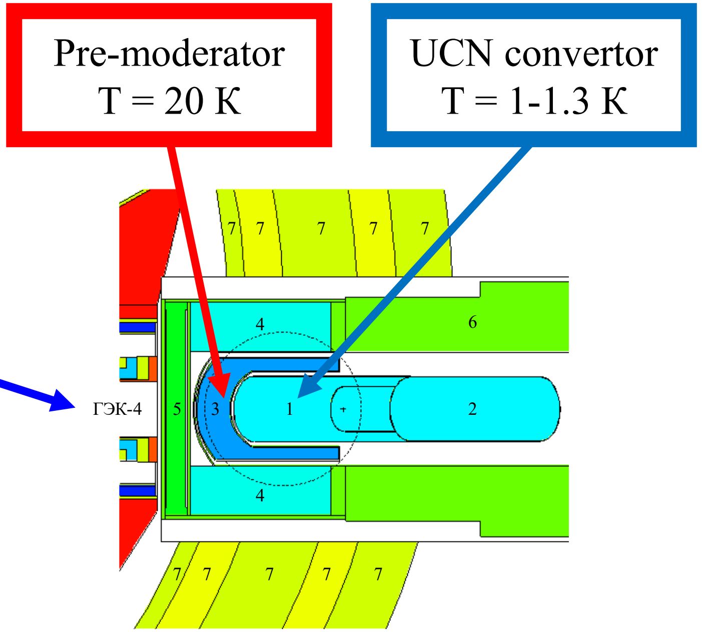
$E_{нач}$=12 K → $E_{УХН}$≈10^{-3} K

λ=9 Å

* ЖЭТФ, 1946, 16, 391; J. Phys. USSR, 1945, 9, 461.

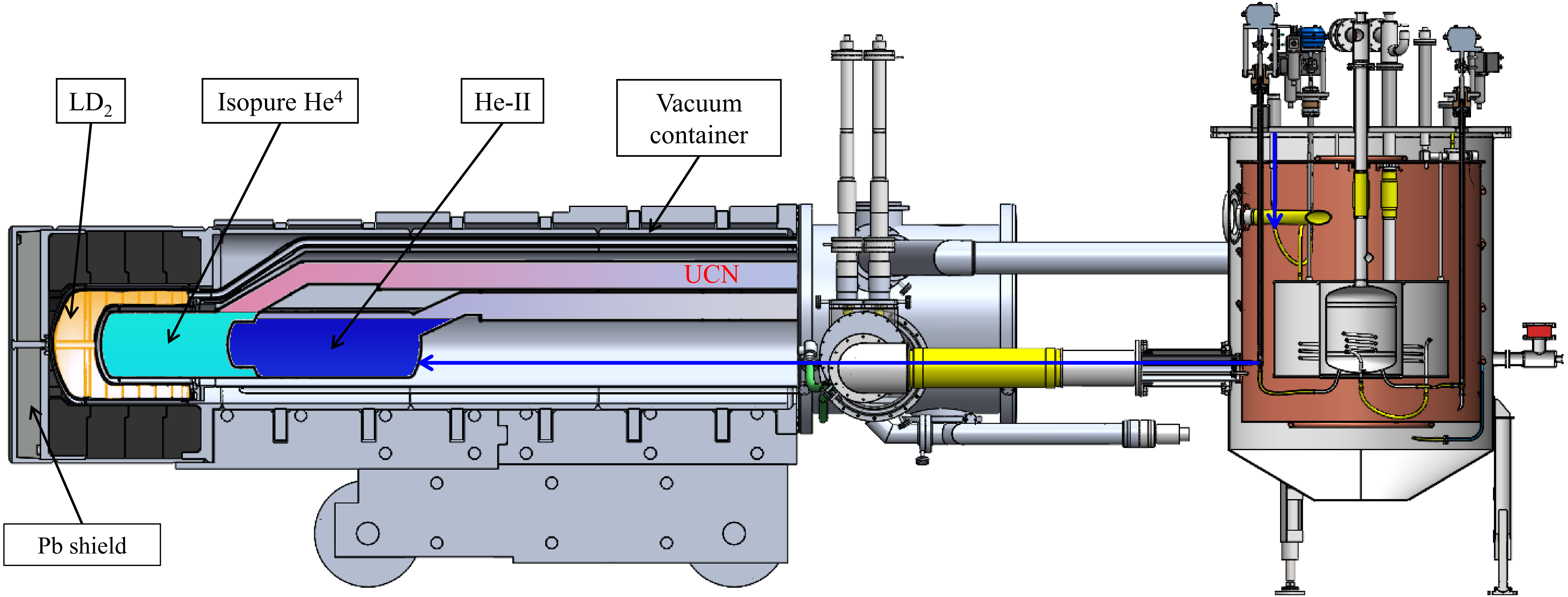
MCNP CALCULATIONS OF THE UCN SOURCE FOR PIK





Parameter	Value
Converter temperature, K	1,0-1,3
Thermal neutron flux in He4, $cm^{-2}s^{-1}$	$6{,}6 \cdot 10^{10}$
9 Å neutron flux in He4, $cm^{-2}s^{-1}$ $Å^{-1}$	$1{,}1 \cdot 10^{9}$
UCN density at EDM spectrometer, cm^{-3} at T_{He4} = 1 K at T_{He4} = 1.3 K	 **200** **150**
He-II heat influx, W	3,85
D2 heat influx, W	10,7
Lead shiel heat influx, W	267

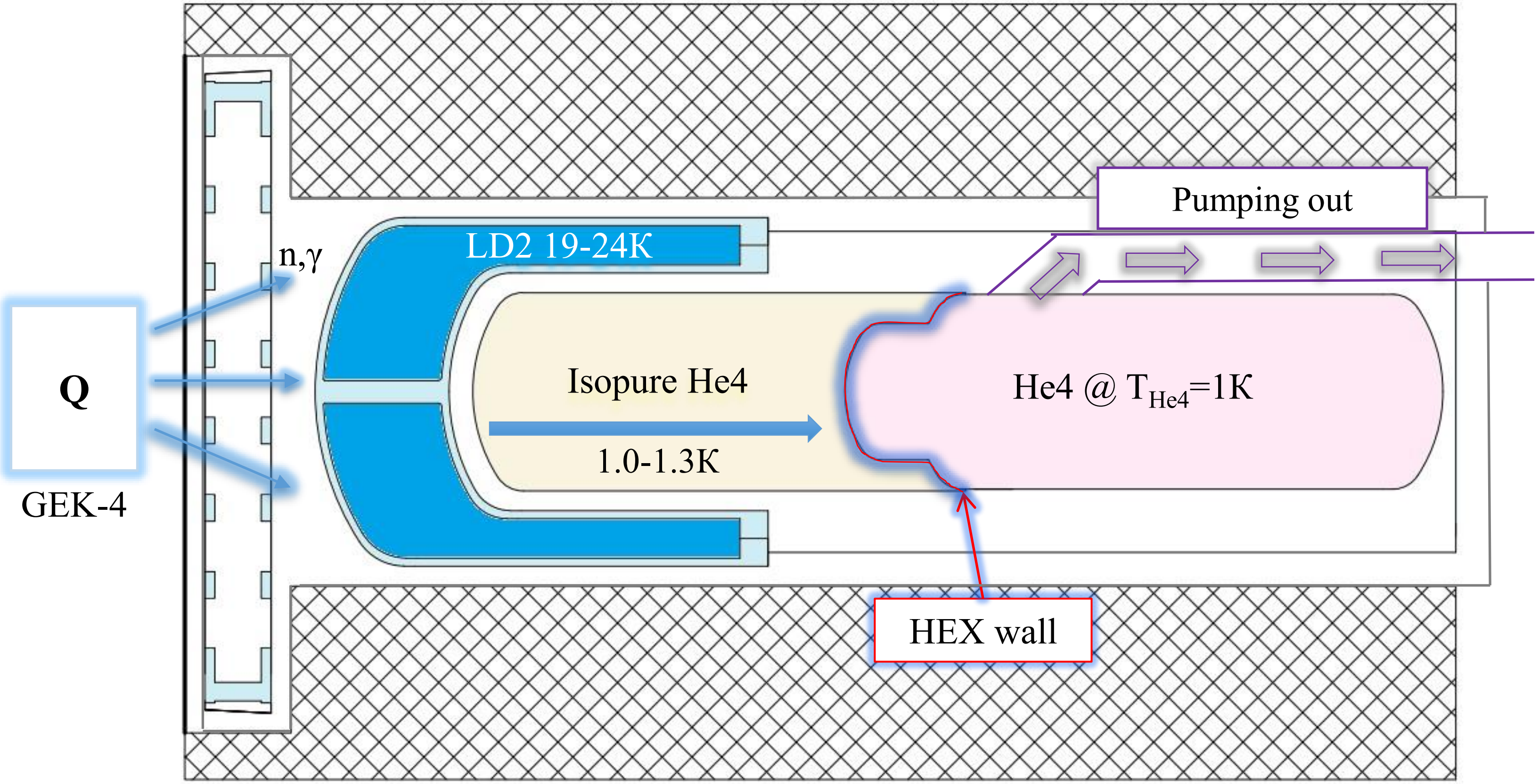
LOW TEMPERATURE PART



- Liquid D_2
  - Volume: 60 l
  - Temperature: 19-24 K
  - Heat inflow: 20 W
- Isopure Helium
  - Volume: 40 l
  - Temperature 1.07-1.33 K
  - Heat inflow: 3.8 W
- Natural He
  - Volume: 50 l
  - Temperature ~1.0 K
  - Heat inflow: 6.2 W

Total He-II Heat inflow: 10 W

HEAT REMOVAL FROM HELIUM CONVERTER

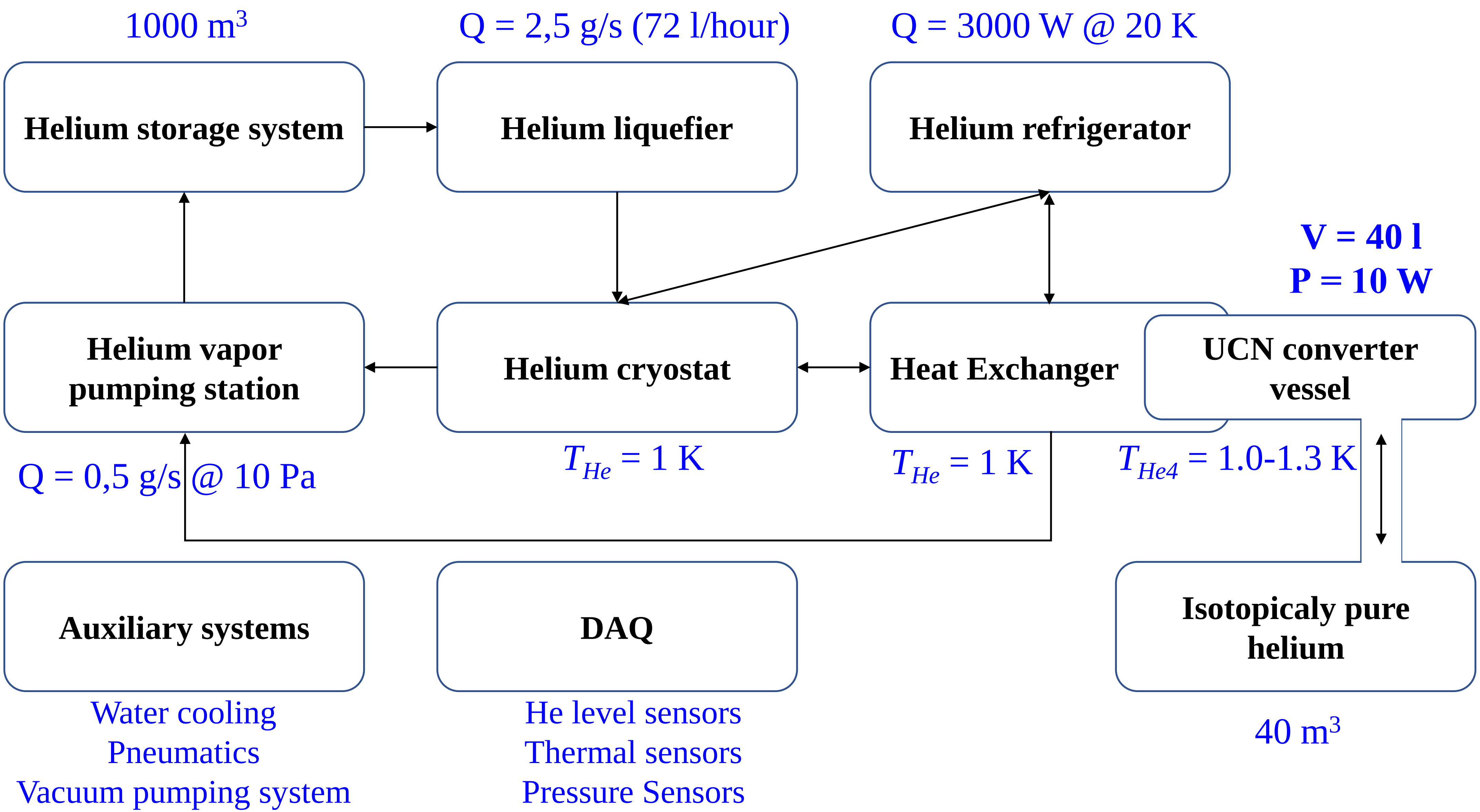


$$T_{UCNS} = T_{He4} + \Delta T_{He4\text{-}steel} + \Delta T_{Ni\text{-}HeII} + \Delta T_{\lambda} + \Delta T_{\kappa}$$

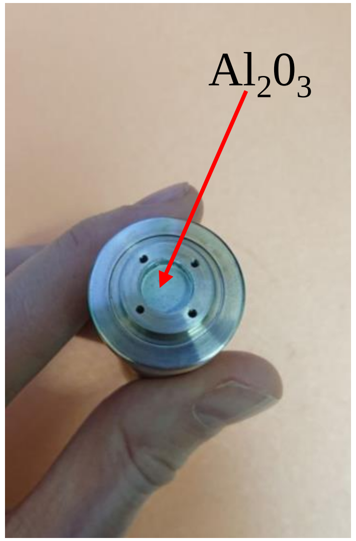
- T_{He4} ← He4 pump perf.
- $\Delta T_{He4\text{-}steel} + \Delta T_{Ni\text{-}HeII}$ ← Kapitza Conductance
- ΔT_{λ} ← Wall heat Conductance
- ΔT_{κ} ← Temperature difference in isotopically pure helium

T_{UCNS} – UCNS convernet temperature, K; T_{He4} – He4 temperature at the HEX, K; $\Delta T_{He4\text{-}Fe}$, $\Delta T_{Ni\text{-}HeII}$ – Kapitza Conductance at He-steel and He-Ni, K; ΔT_{λ} – temperature gradient due to thermal resistance of the HEX wall, K; $\Delta T\kappa$ – temperature gradient due to heat transfer in He-II, K.

UCN SOURCE TECHNOLOGICAL COMPLEX



ISOPURE HELIUM PRODUCTION



$$\tau^{-1} = \tau^{-1}_{\beta} + \tau^{-1}_{\text{upscattering}} + \tau^{-1}_{\text{capture}} + \tau^{-1}_{\text{wall losses}}$$

$$\tau_{\text{capture}} = 28\ s\ @\ \frac{m_{He3}}{m_{He4}} = 1{,}4 \cdot 10^{-6}$$

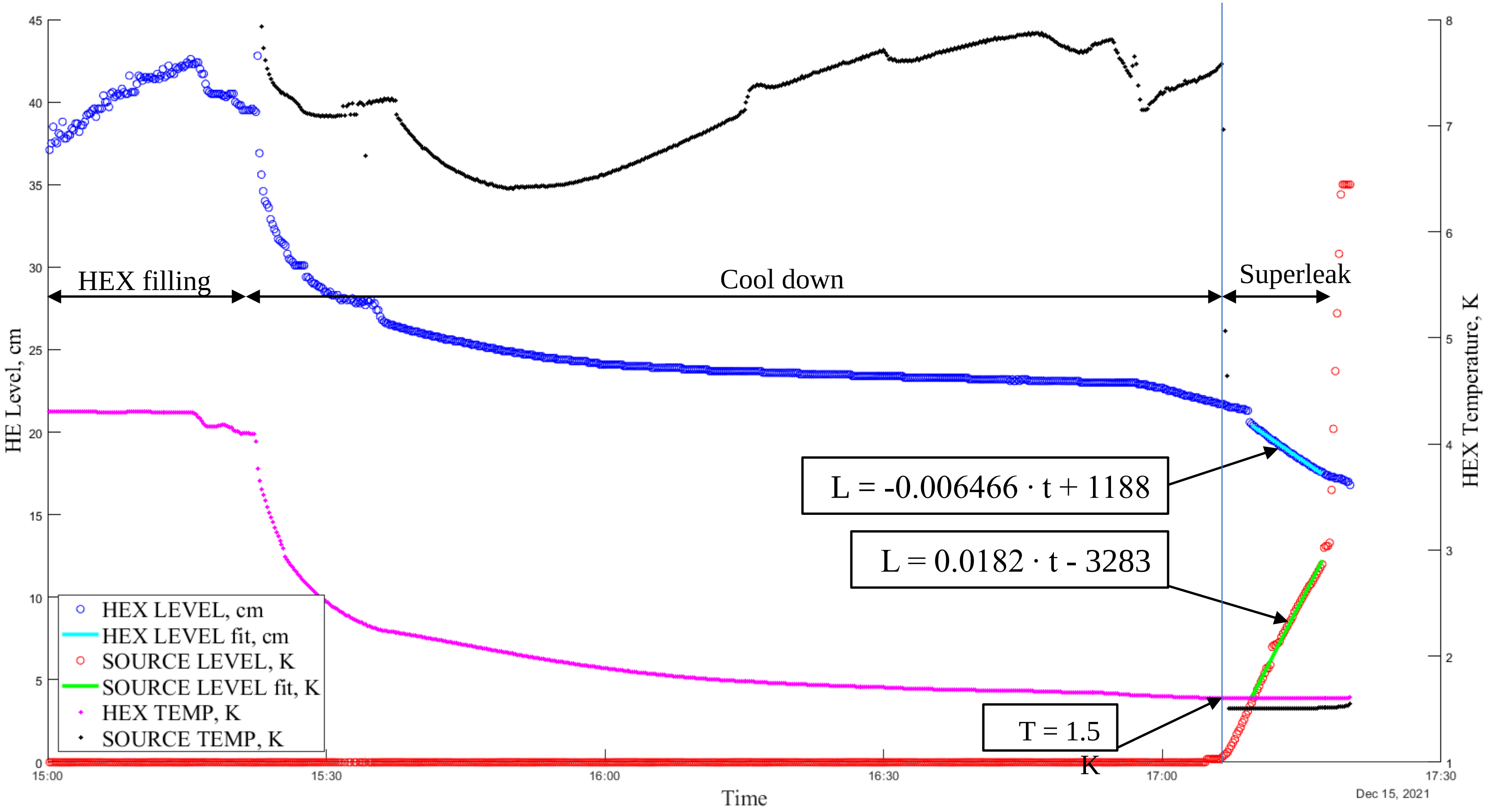
$$\tau_{\text{capture}} = 42{,}3\ s\ @\ \frac{m_{He3}}{m_{He4}} = 10^{-8}$$

$$\tau_{\text{capture}} = 3900\ s\ @\ \frac{m_{He3}}{m_{He4}} = 10^{-11}$$

$$\sigma_a(He^3) = 5300\ barn$$

$$\sigma_a(He^4) = 0\ barn$$

ISOPURE HELIUM PRODUCTION

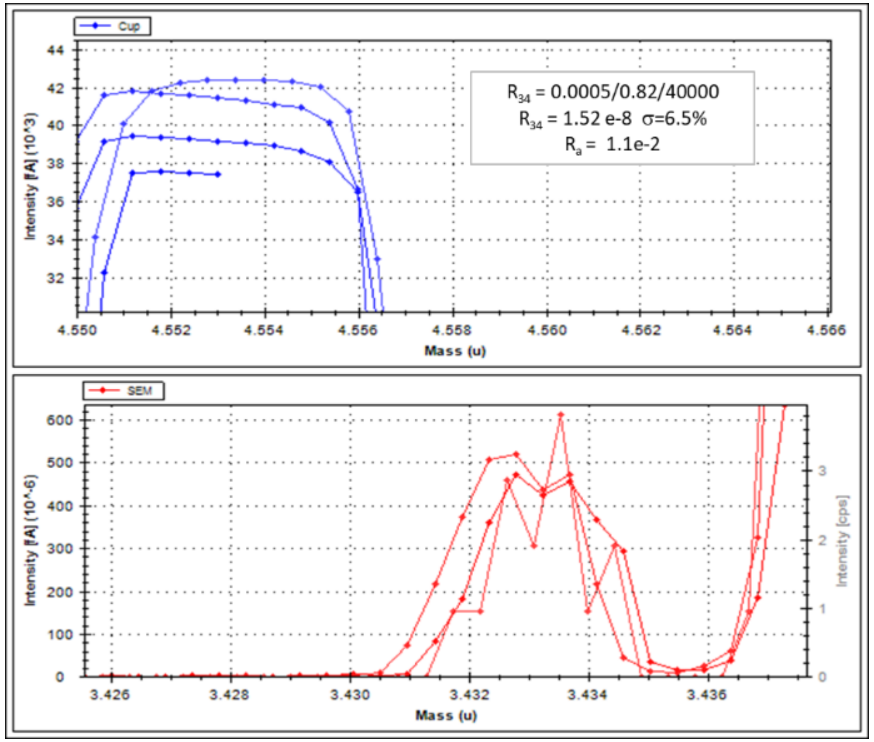


- Helium inflow rate into SOURCE – 0.0182 cm/s – 0.003215 l/s – 0.5037 g/s
- Helium outflow rate from HEX – 0.006466 cm/s – 0.003427 l/s – 0.4725 g/s

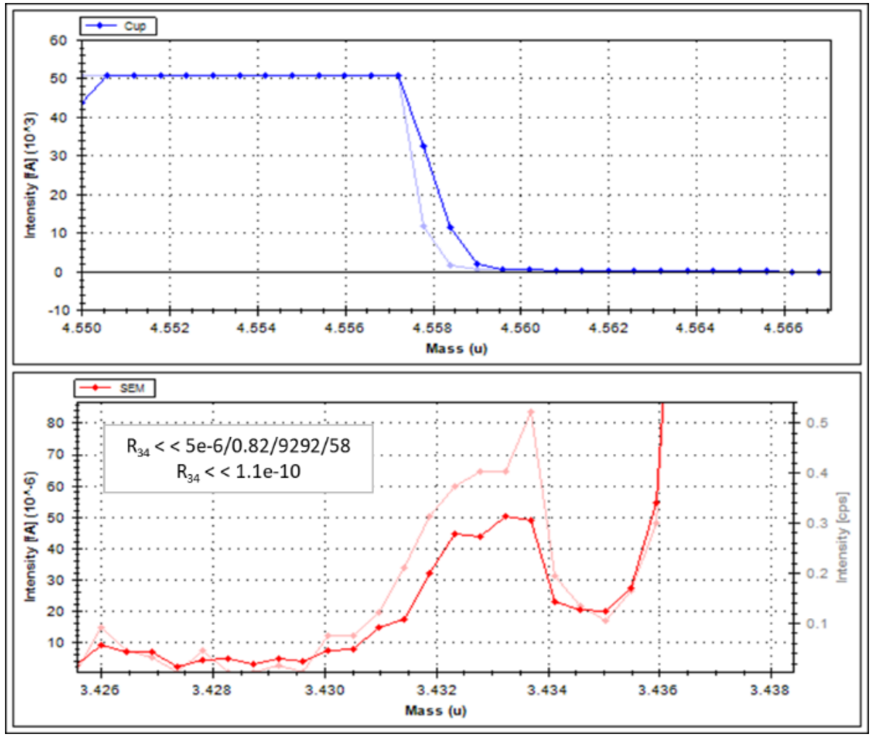
With a filter diameter of 8 mm, the critical flow of superfluid helium through the filter was 1 g/cm²s.

ISOPURE HELIUM ANALYSIS

The analysis of isotopically pure helium was carried out at the V.I. Ilychev Pacific Oceanological Institute using a mass spectrometer HELIX SFT Static Vacuum Mass Spectrometer (Thermo Scientific, USA).



Natural helium

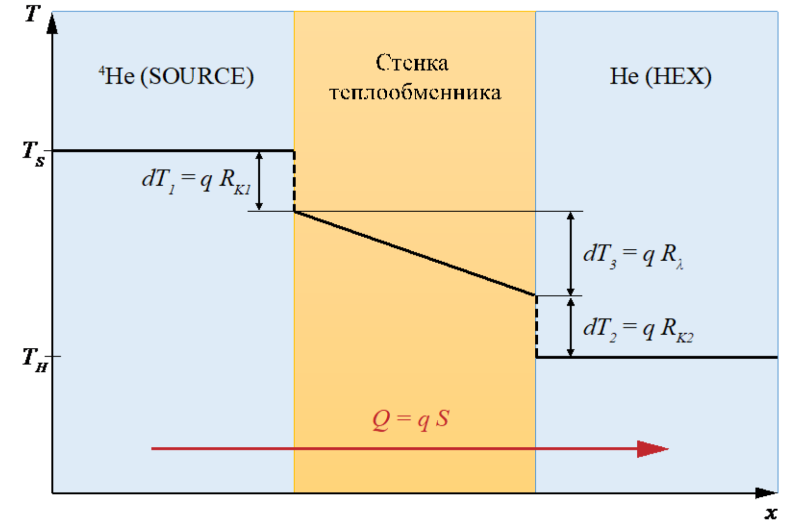


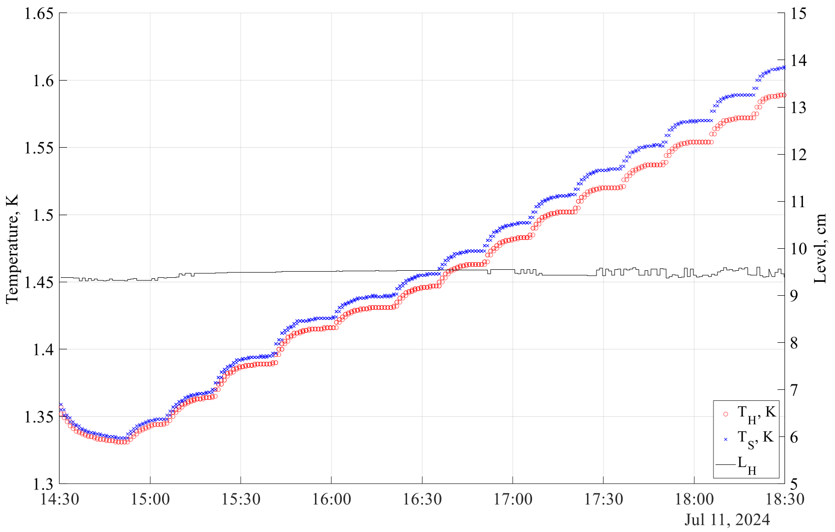
Isotopically pure helium

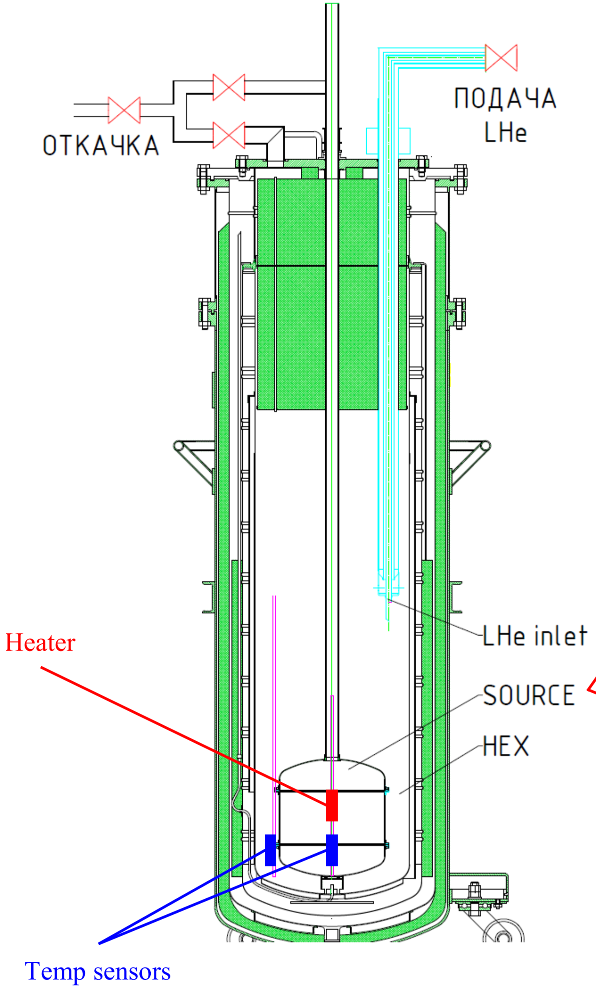
- For natural helium: $R_{34} = 1.52 \cdot 10^{-8}$
- For isotopically pure helium: $R_{34} = 2 \cdot 10^{-11}$, so τ_a = 1718 s, significantly higher than the neutron lifetime

KAPITZA RESISTANCE MEASUREMENT EXPERIMENT

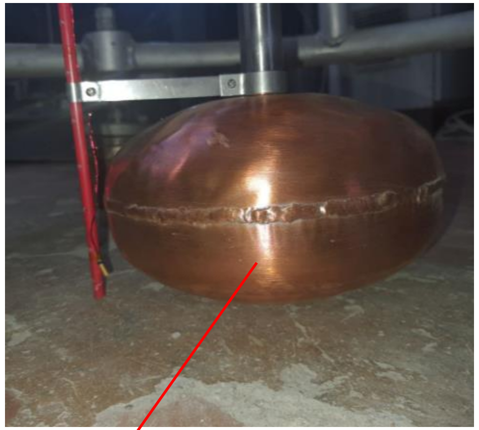
$$T_{UCNS} = T_{He4} + \Delta T_{He4\text{-}steel} + \Delta T_{Ni\text{-}HeII} + \Delta T_{\lambda} + \Delta T_{\kappa}$$



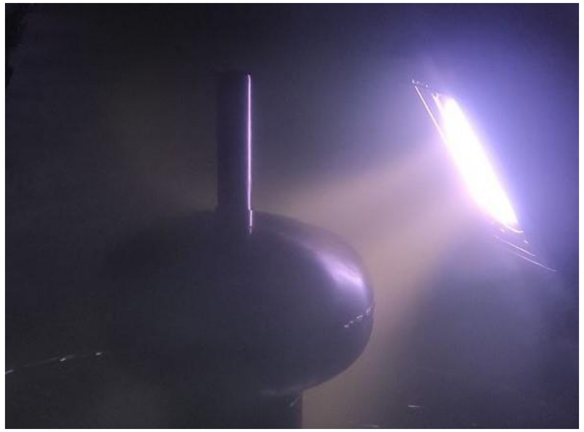




Cu vessel



Cu vessel with nickel



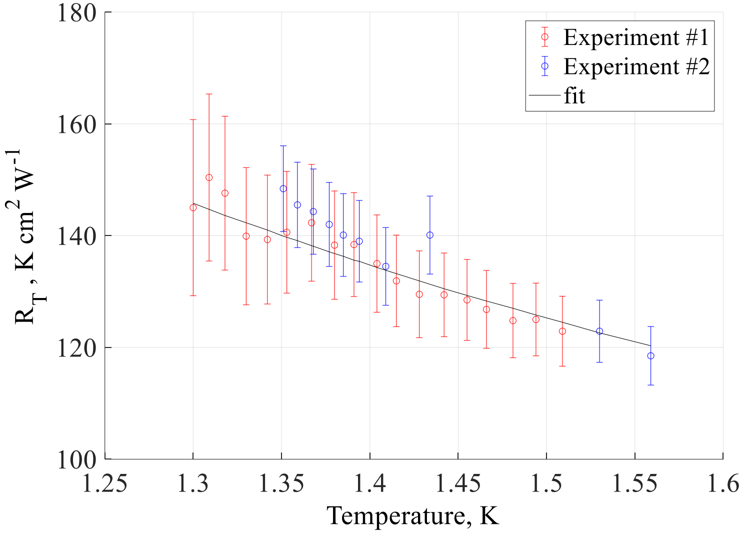
Steel vessel

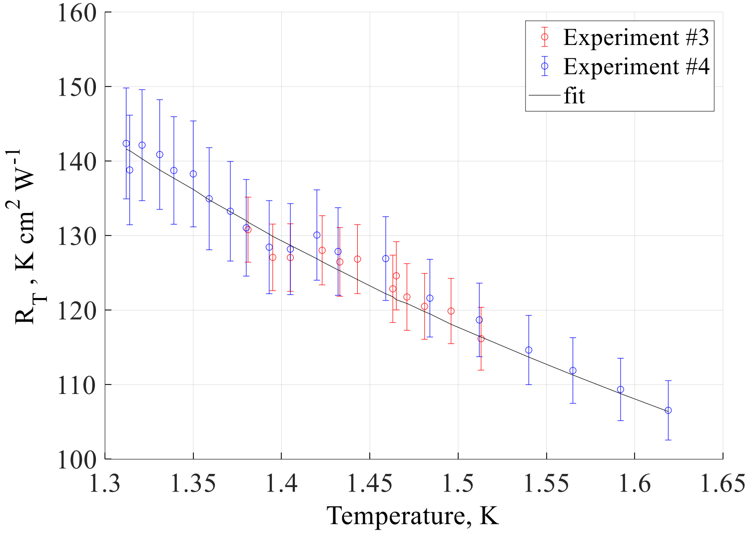
Steel vessel with nickel

KAPITZA RESISTANCE MEASUREMENT RESULTS

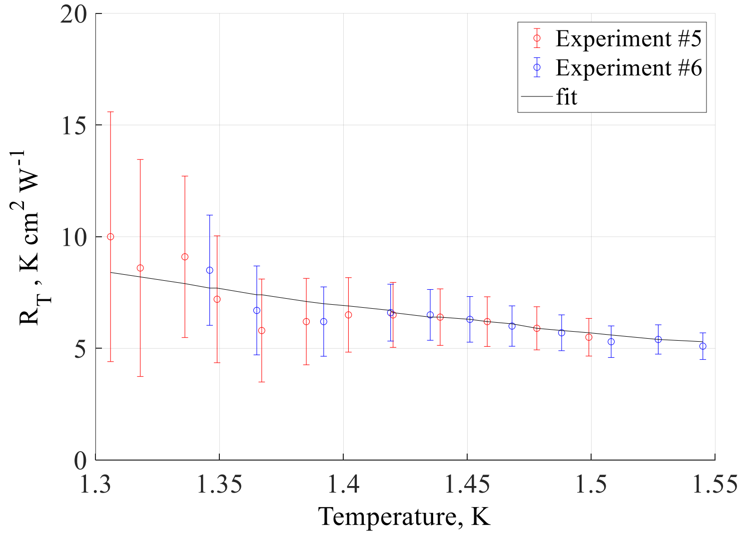
Without Ni coating | **With Ni coating**

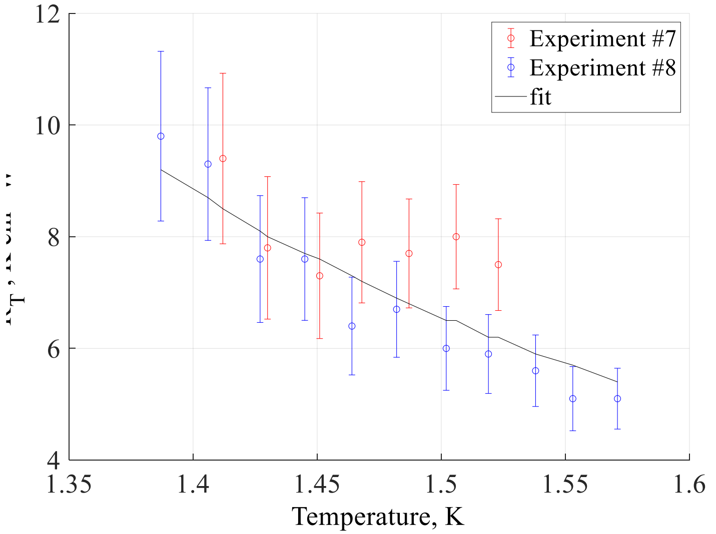
Steel vessel experiment





Cupper vessel experiment





$$h_{k,steel} = \frac{1}{R_{k,steel}} = \frac{2}{\frac{S\Delta T}{Q_p} - \frac{\delta}{\lambda}}$$

$$h_{k,Ni} = \frac{1}{R_{k,steel}} = \frac{1}{\frac{S\Delta T}{Q_p} - \frac{\delta}{\lambda} - \frac{1}{h_{k,steel}}}$$

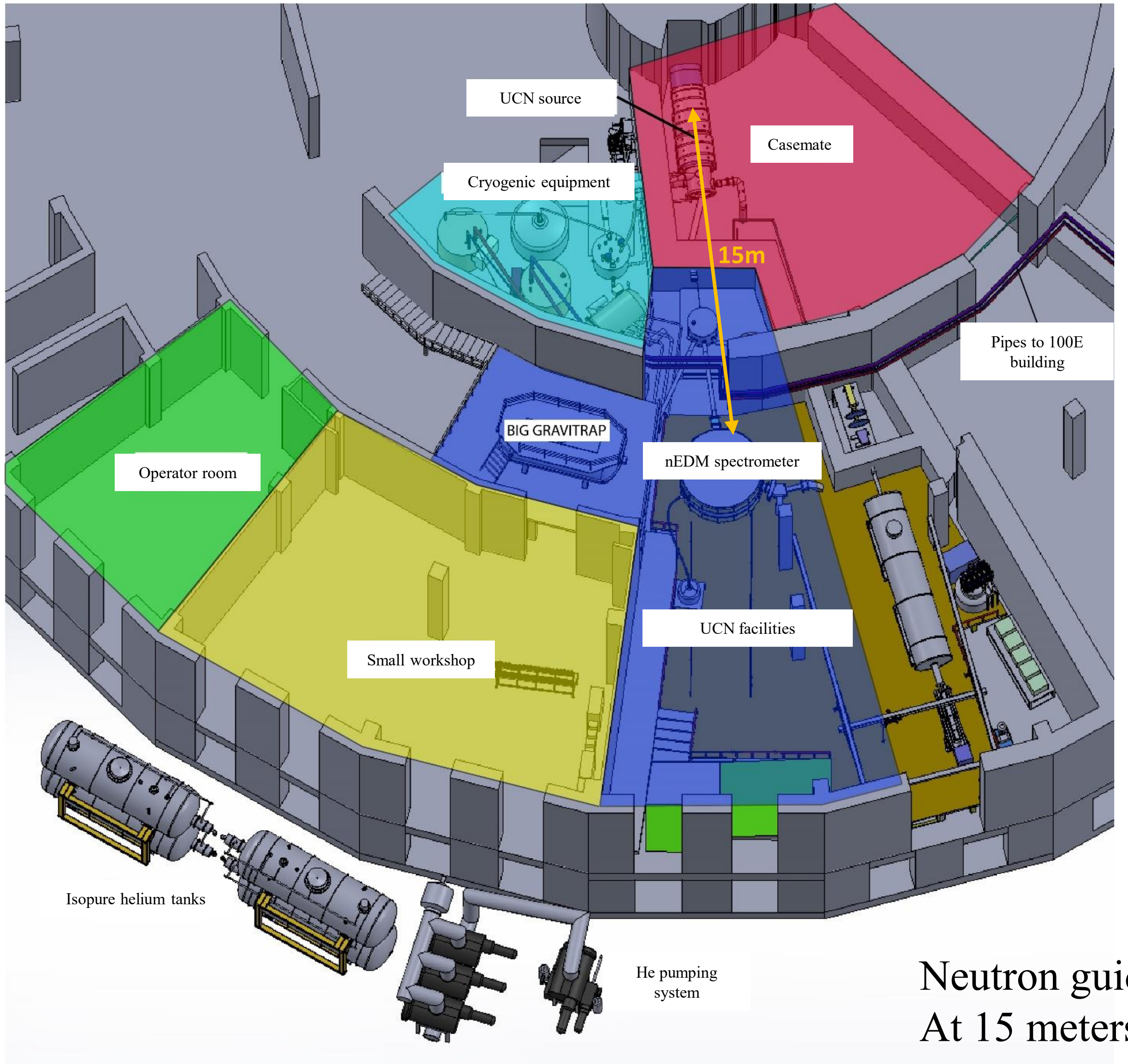
- **$h_{k,steel}$ ~ 220 * $T^{1.2}$ [W/m²K]**
- **$h_{k,Ni}$ ~ 140 * $T^{1.98}$ [W/m²K]**

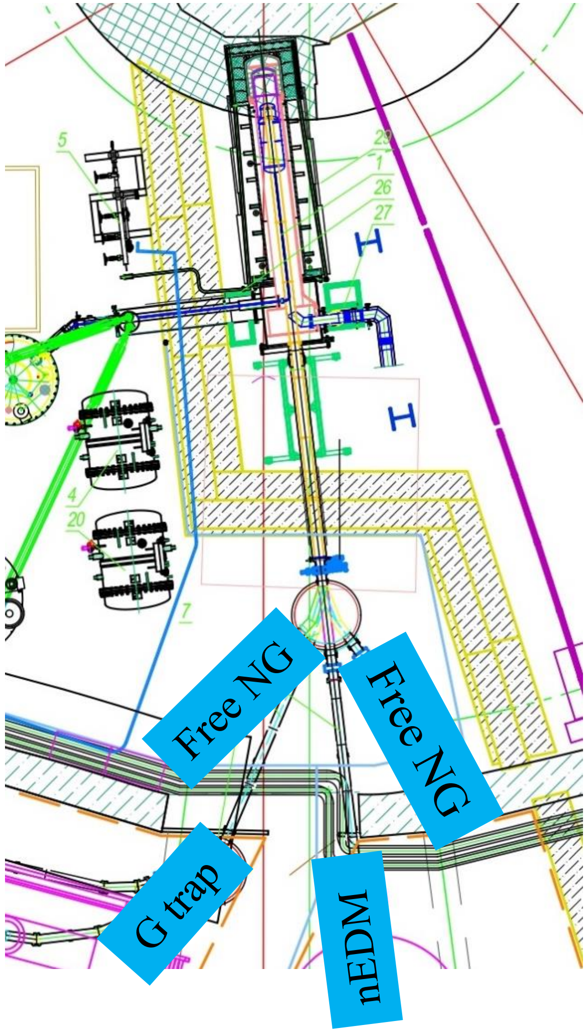
- **$h_{k,Cu}$ ~ 1140 * $T^{2,8}$ [W/m²K]**
- **$h_{k,Ni}$ ~ 300 * $T^{1.98}$ [W/m²K]**

T_{He4}= 1 K, Q = 3.8 W

$\Delta T_{Ni\text{-}He4}$ = 90 mK	$\Delta T_{Cu\text{-}He4}$ = 17 mK
$\Delta T_{steel\text{-}He4}$ = 175 mK	$\Delta T_{Cu\text{-}He4}$ = 0,4 mK
ΔT_{λ} = 66 mK	ΔT_{λ} = 57 mK
$T_{He\text{-}II}$ = 1.33 K	**$T_{He\text{-}II}$ = 1.07 K**

UCN SOURCE LAYOUT





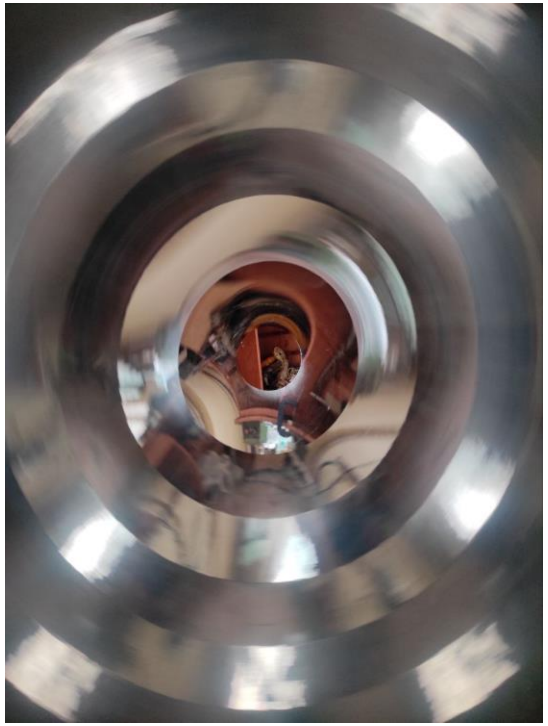
Neutron guides have an UCN transmission value of 0.95-0.98 m^{-1}

At 15 meters only 45-75 % of UCN can reach the experimenters

NEUTRON GUIDES MANUFACTURING

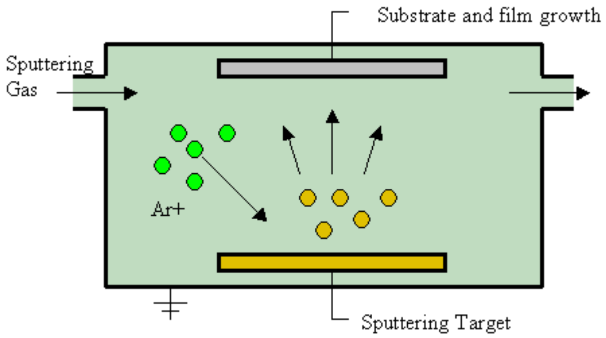
Pipe final polishing machine

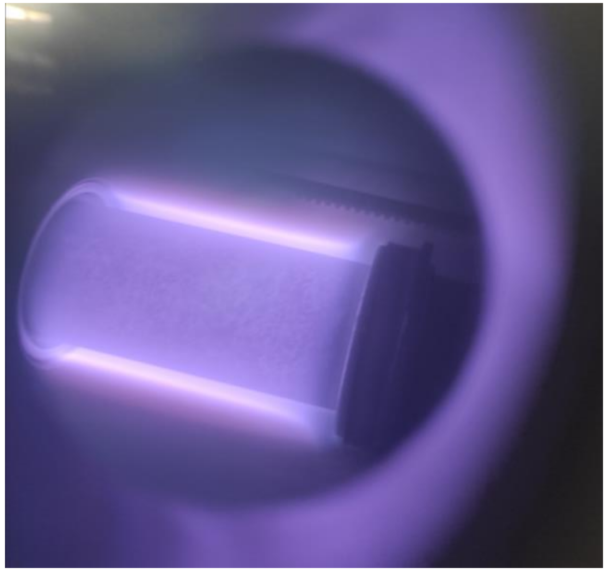
1. Pipe purchasing
2. Obtaining the required (round) geometry
3. Grinding to Ra = 1.6
4. Polishing to Ra = 0.1
5. Final polishing to Ra = 0.025



Initial / final state of the neutron guide surface

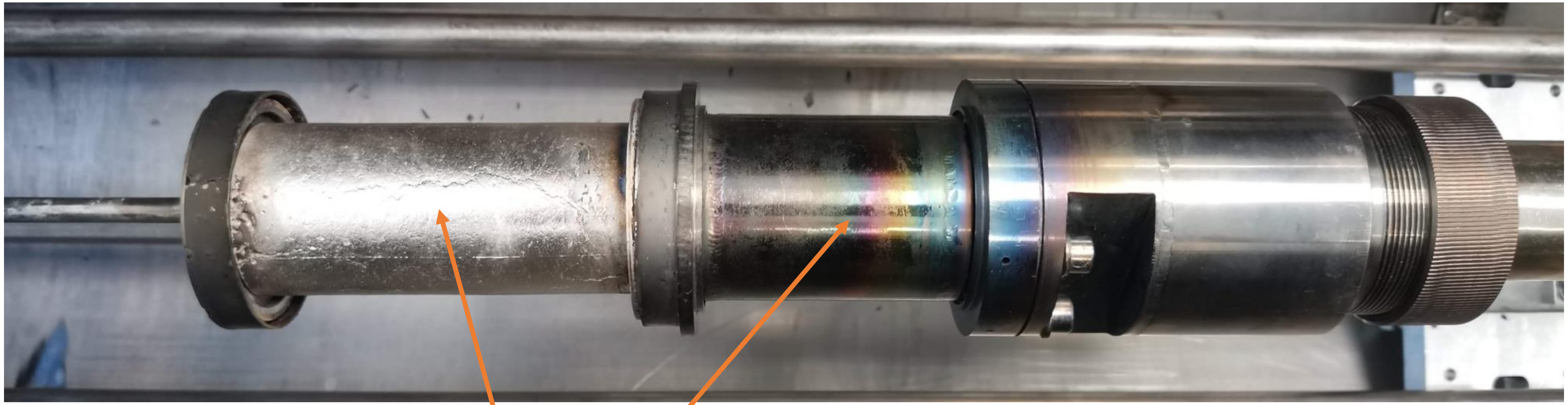
NEUTRON GUIDES COATING



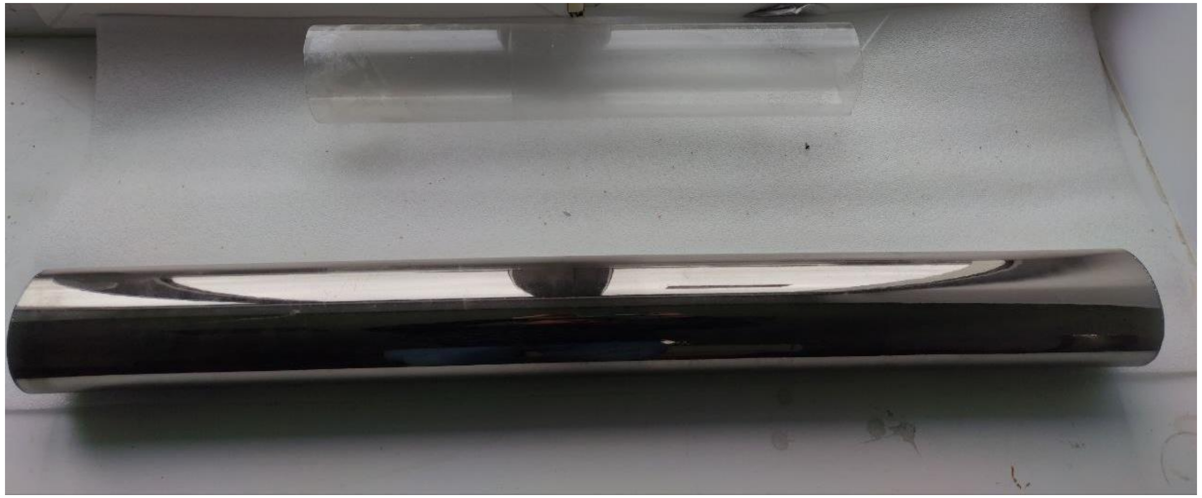


UCN neutron guide coating by ^{58}Ni by using sputter deposition

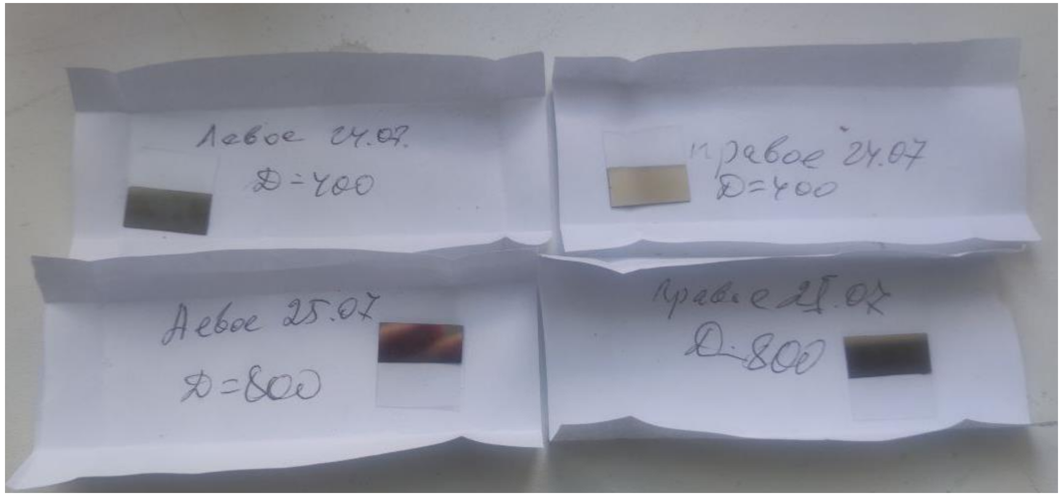
NEUTRON GUIDES MANUFACTURING



Nickel magnetron and ion source for surface pre-cleaning

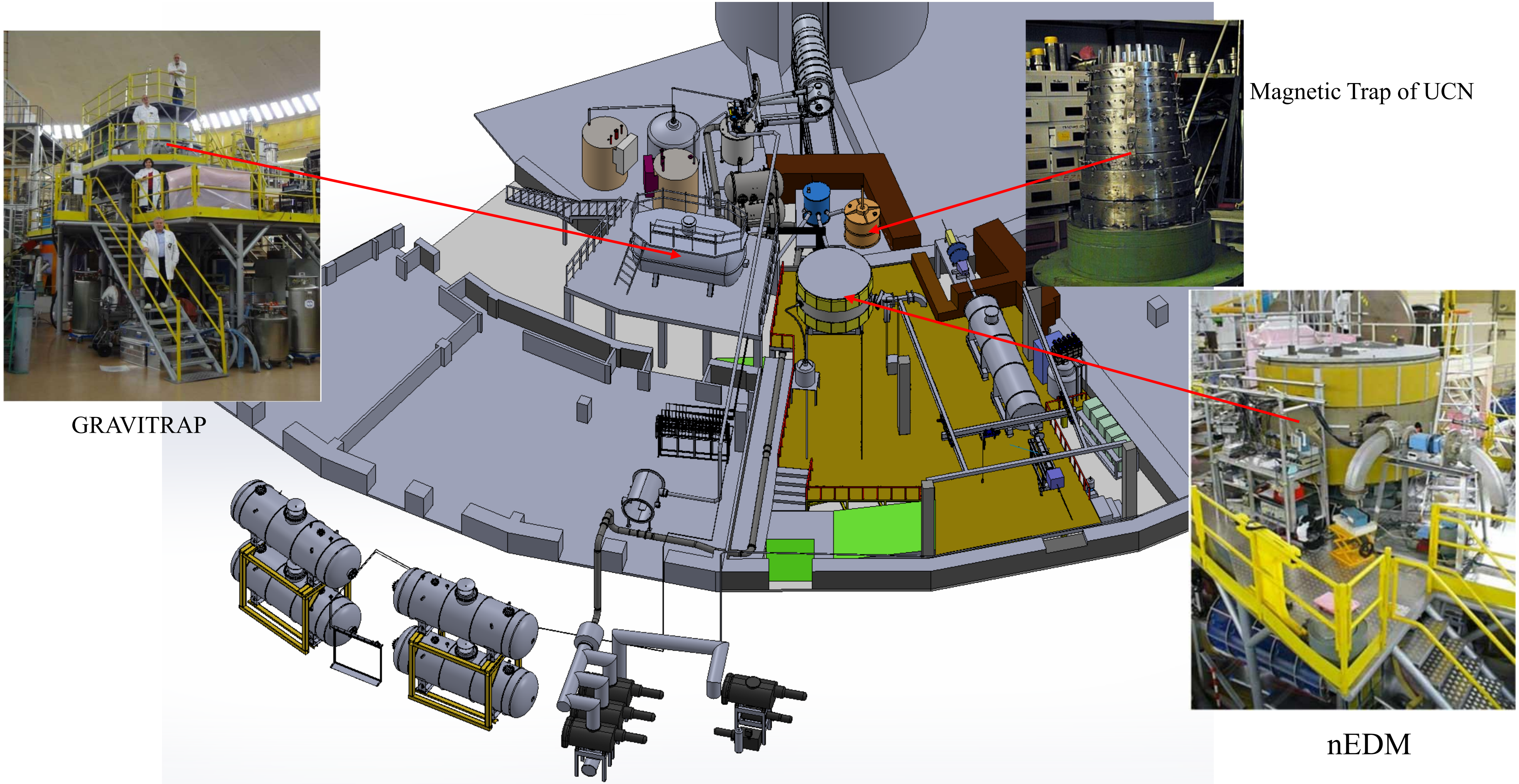


^{58}Ni coated glass pipe compared to a uncoated pipe

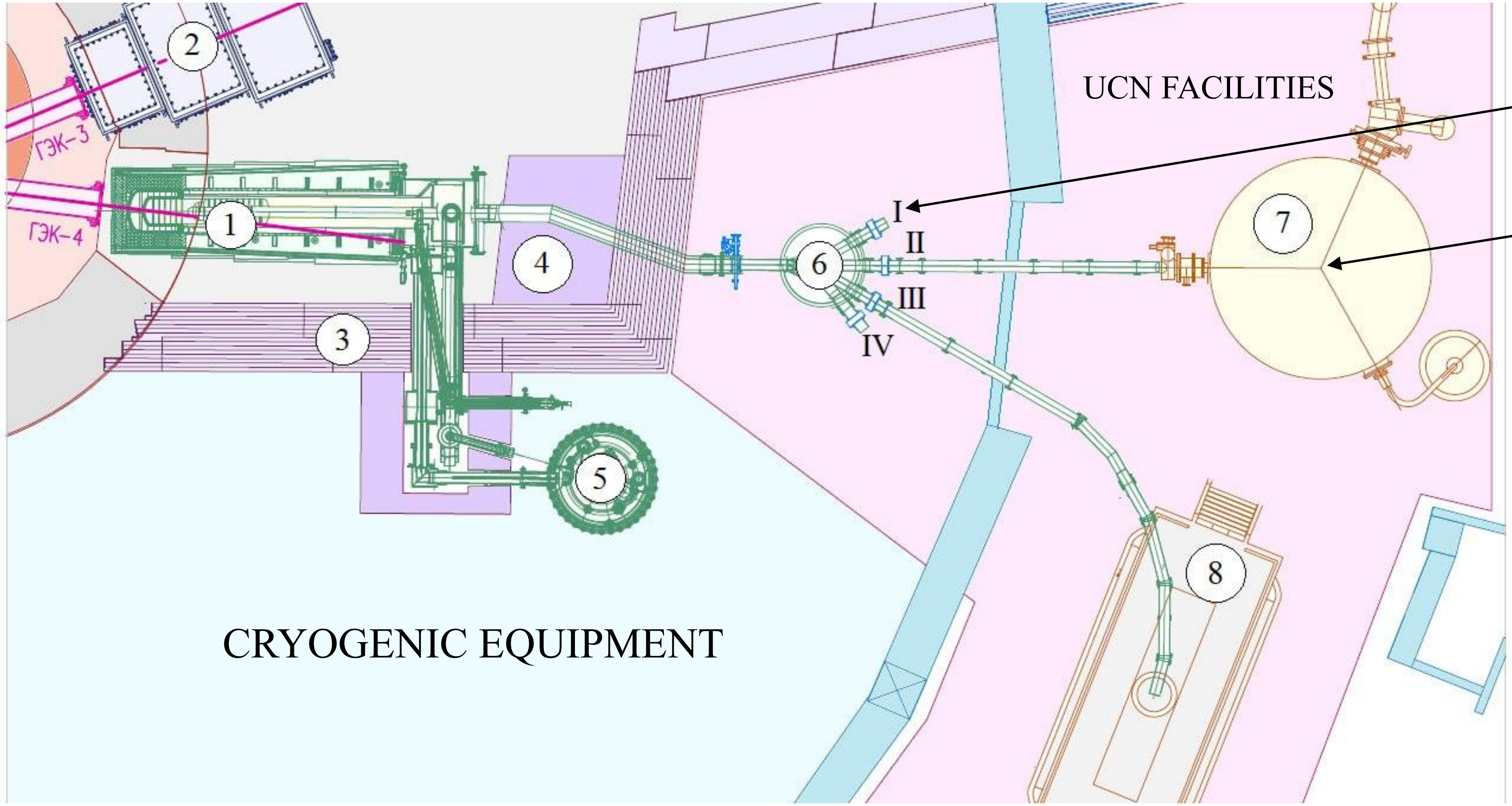


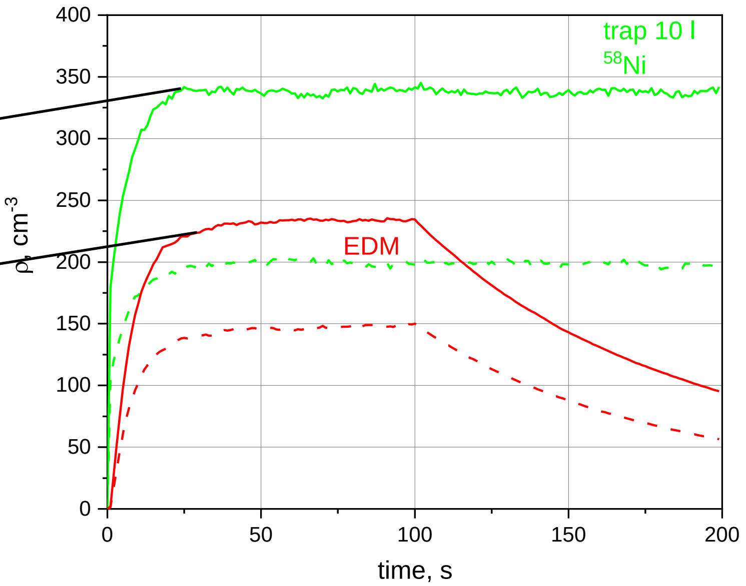
Thickness of coated ^{58}Ni is 3000 Å

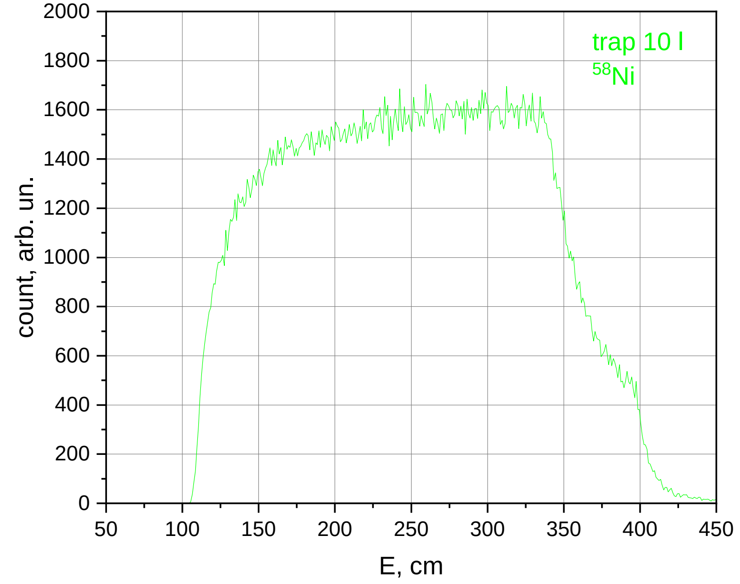
SCIENTIFIC RESEARCH PROGRAM WITH UCN AT THE PIK REACTOR



CALCULATION OF DENSITY AND SPECTRUM AT UCN FACILITIES







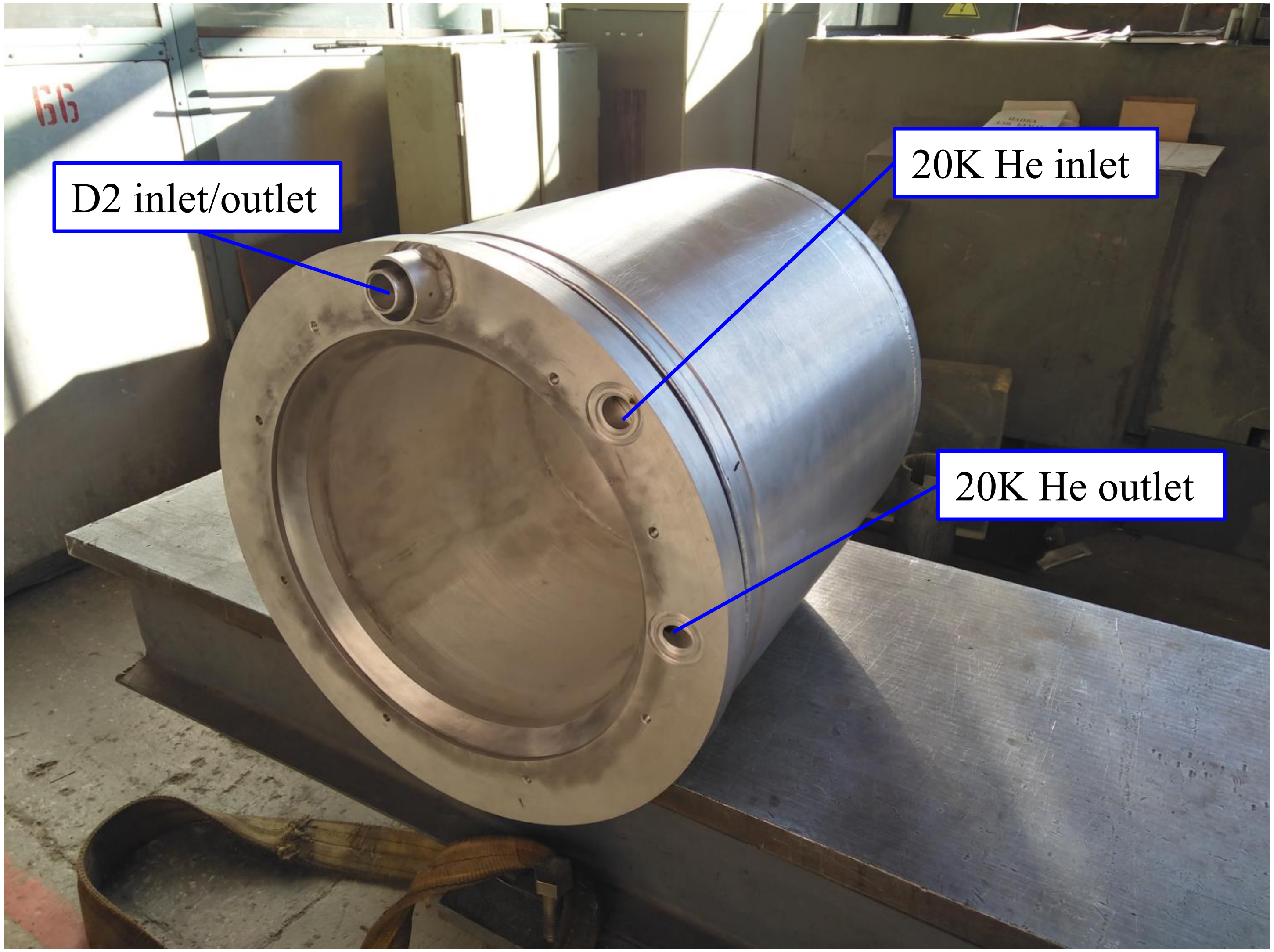
HEX	T_{HE4}	ρ @ He4	ρ @ beamport	ρ @ nEDM
Steel	1.33	950	235	150
Cooper	1.07	3400	340	200

UCN SOURCE MANUFACTURING

Neutron thermalization facility «UCN source»

- About 2000 drawings
- 15 tons of aluminum
- 3 tons of steel
- 3300 meters of pipelines
- 460 equipment units (e.g. valves)
- About 40 suppliers
- 1000 m3 of helium
- 100 m3 of deuterium

LD2 VESSEL

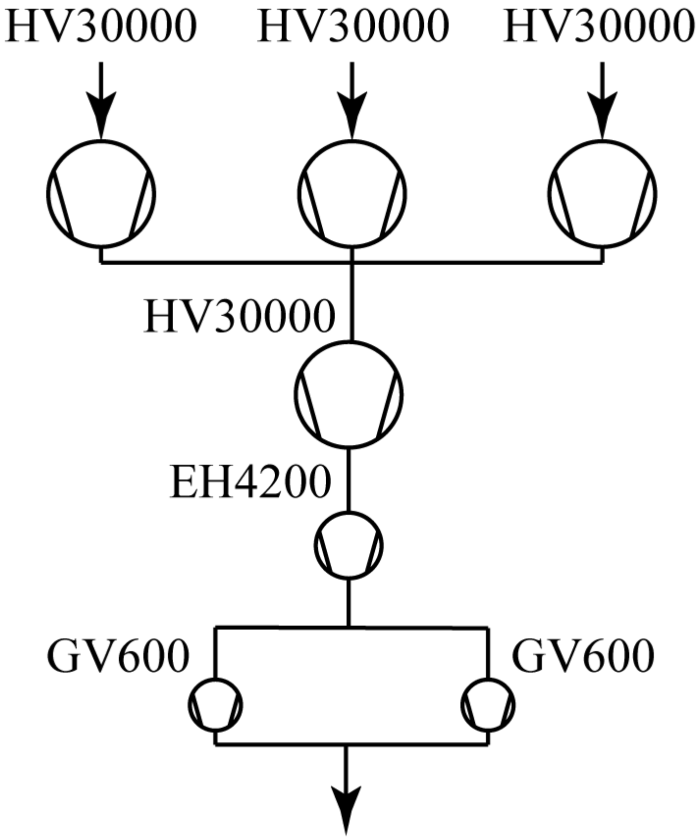


CONVERTER VESSEL

Ni^{58} coating

Assembling

HE VACUUM PUMPING SYSTEM



HE/D2 STORAGE SYSTEM

Refrigerator buffer tank

Liquifier buffer tank

D2 buffer tank

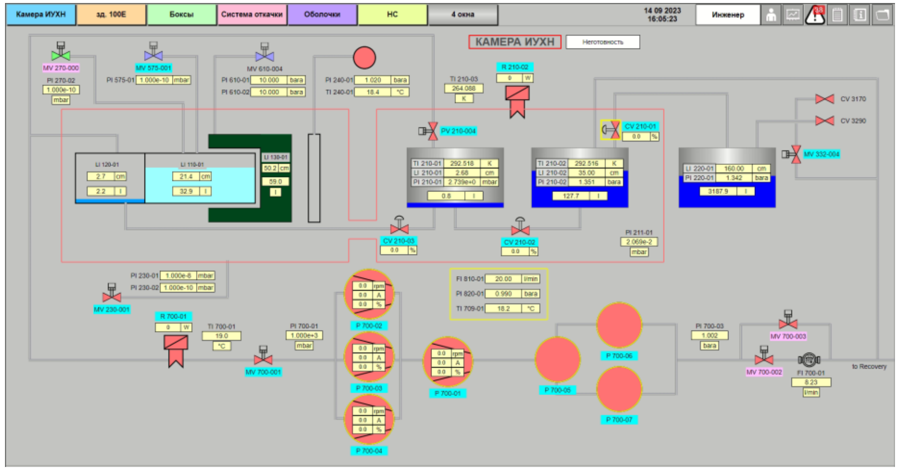
He cylinders

ISOPURE HELIUM VESSELS INSTALLATION

CRYOSTAT MANUFACTURING

UCNS CONTROL SYSTEM

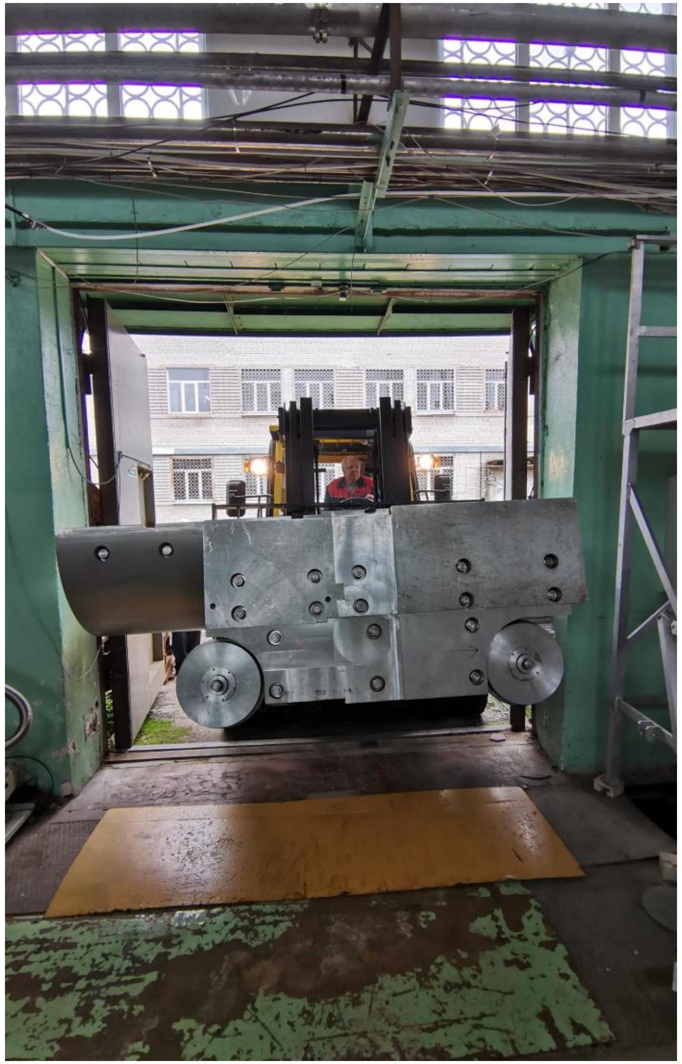
- SIEMENS based S-1500 PLC
- 200 income signals
- 120 outcome signals
- 5,5 km of wire
- 2 operator positions
  - UCNS operator
  - Neutron guide system operator
- 20 pages of built-in algorithms



Main screen with cryostat parameters

CPU cabinet

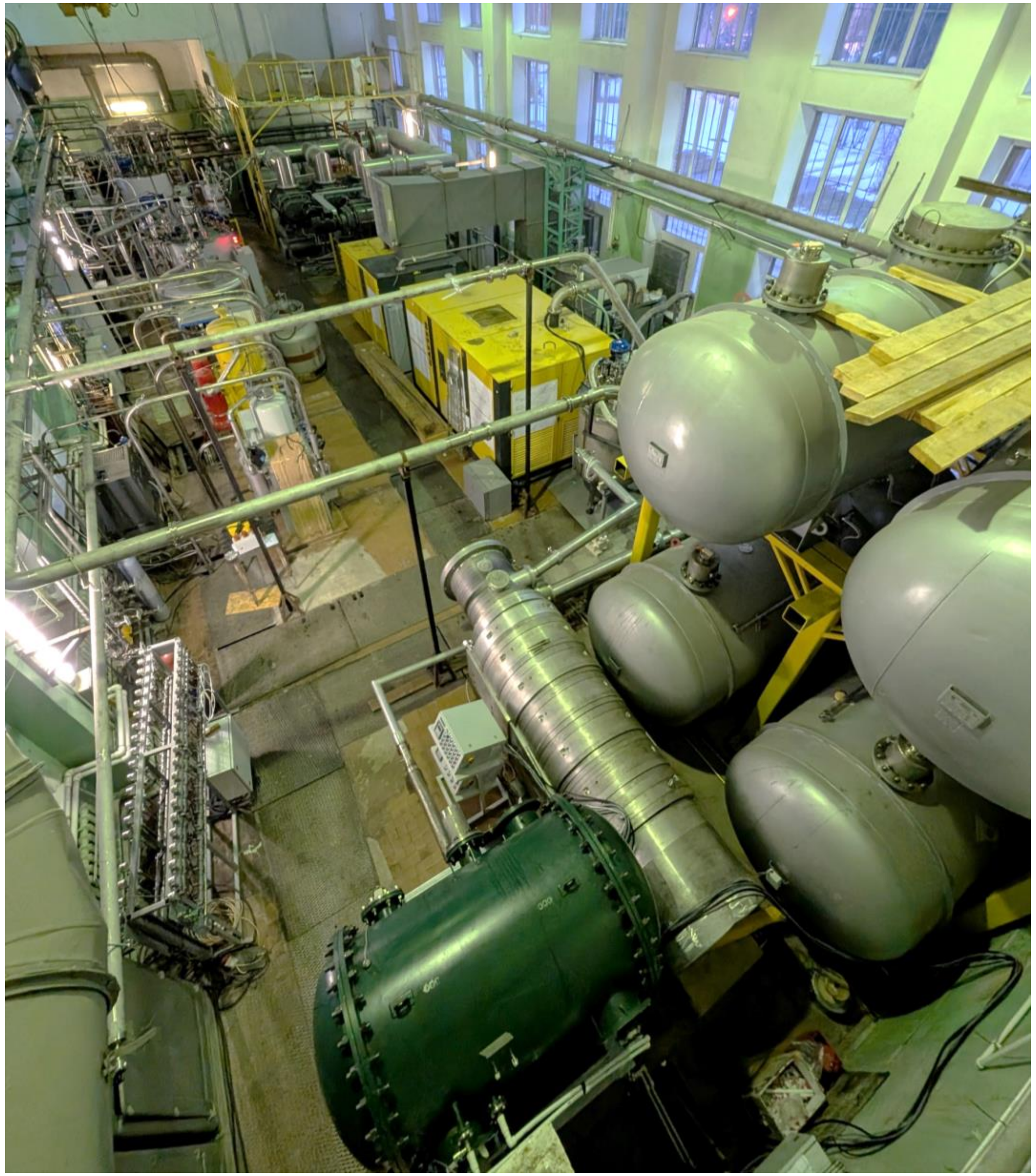
UCN SOURCE INSTALLATION



ASSEMBLY OF THE UCNS LOW TEMPERATURE PART

INSTALLATION OF VACUUM AND DEUTERIUM BOXES

COMLEX IS ALMOST READY FOR THE FINAL TEST



THANK YOU FOR YOUR ATTENTION