7th International Workshop
"Ultra Cold & Cold Neutrons. Physics & Sources".
(8-14 of June 2009)

PROJECT OF
SUPERFLUID HELIUM UCN SOURCE AT PNPI

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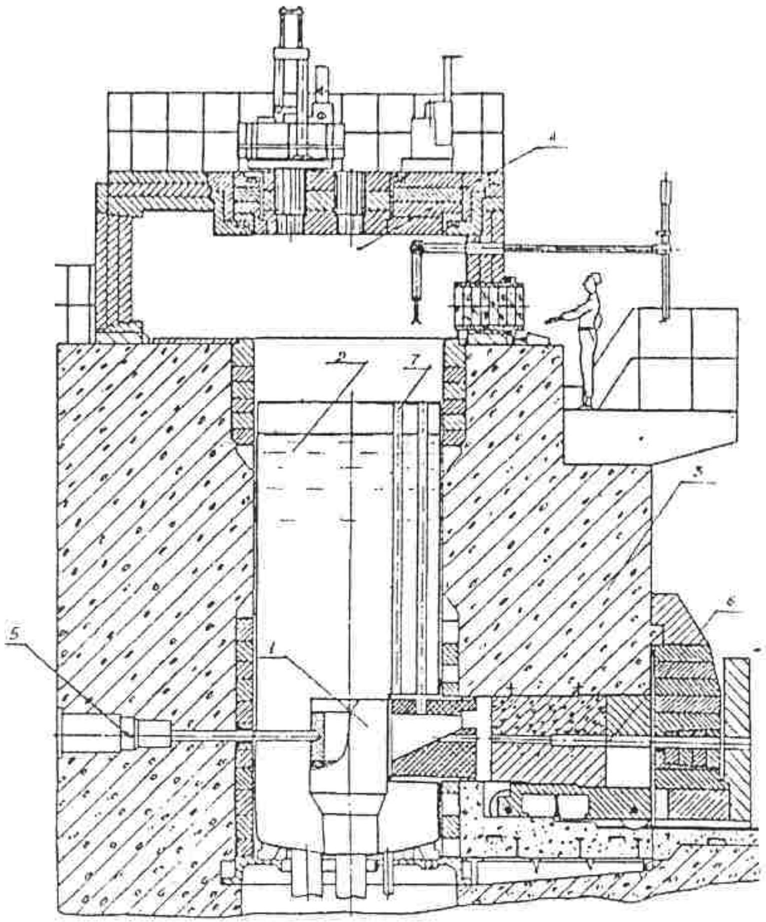
Reactor WWR-M



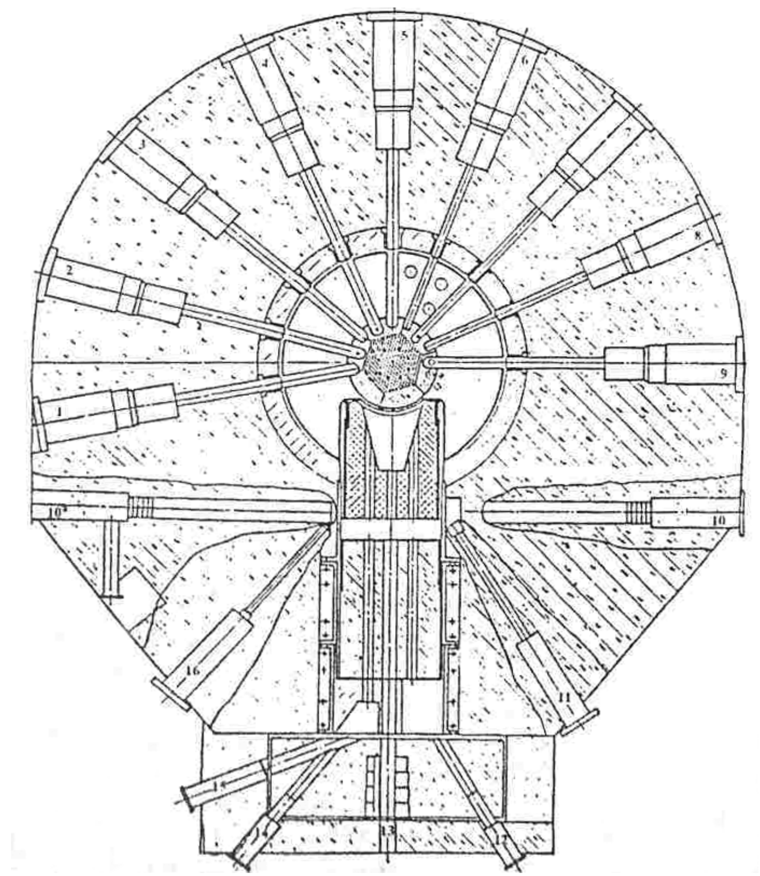
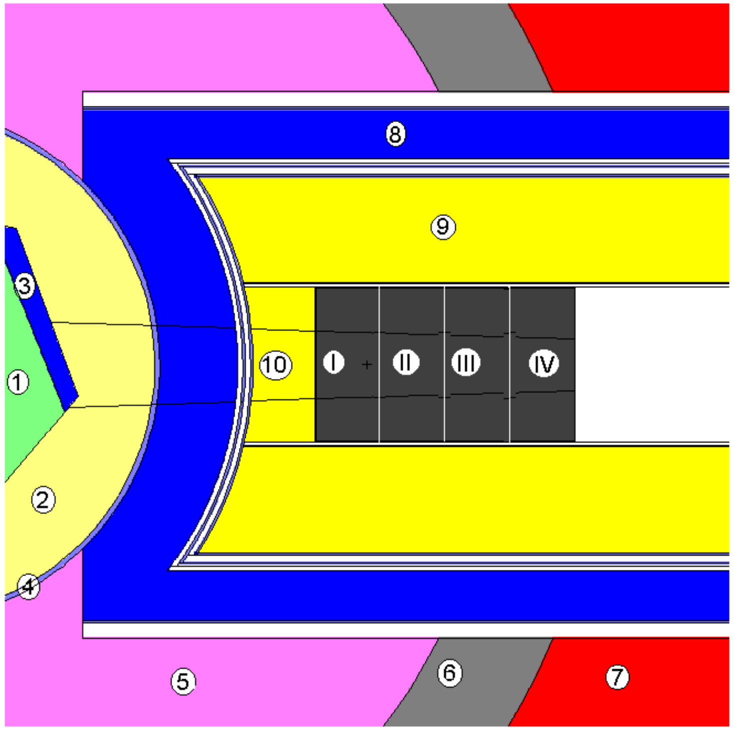


Diagram for neutron calculation



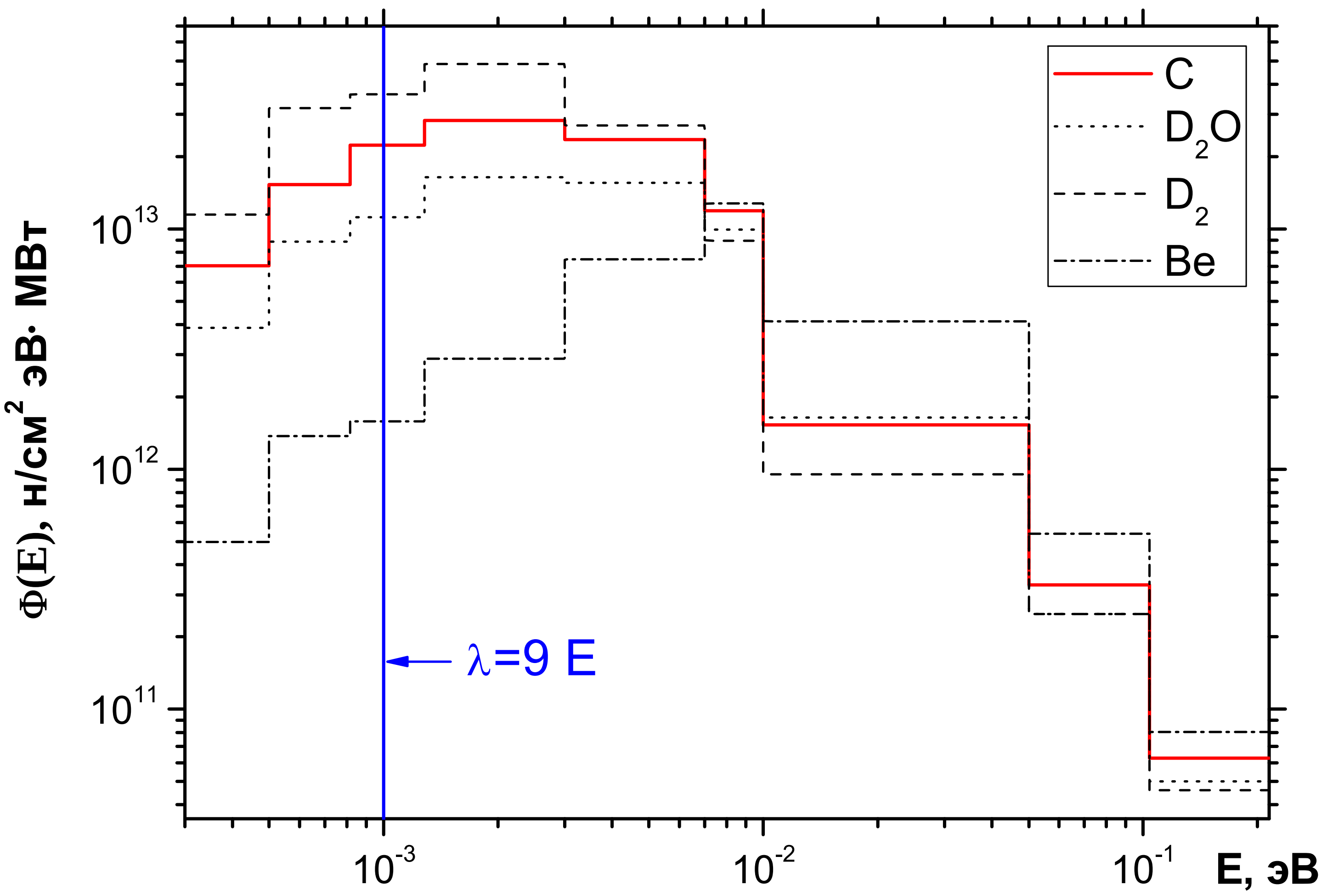
1 – reactor core, 2 – beryllium reflector, 3 – lead shield, 4 – separator, 5 – water, 6 – iron shield, 7 – бетонная shield, 8 – Pb or Bi shield, 9 – graphite moderator, 10 – front part of graphite moderator, I, II, III, IV – cell with superfluid helium

Helium cell shielding

Neutron flux in superfluid helium:
for bismuth shield - $2 \cdot 10^9$ n/cm^2 s MW Å
for lead shield - $1.2 \cdot 10^9$ n/cm^2 s MW Å

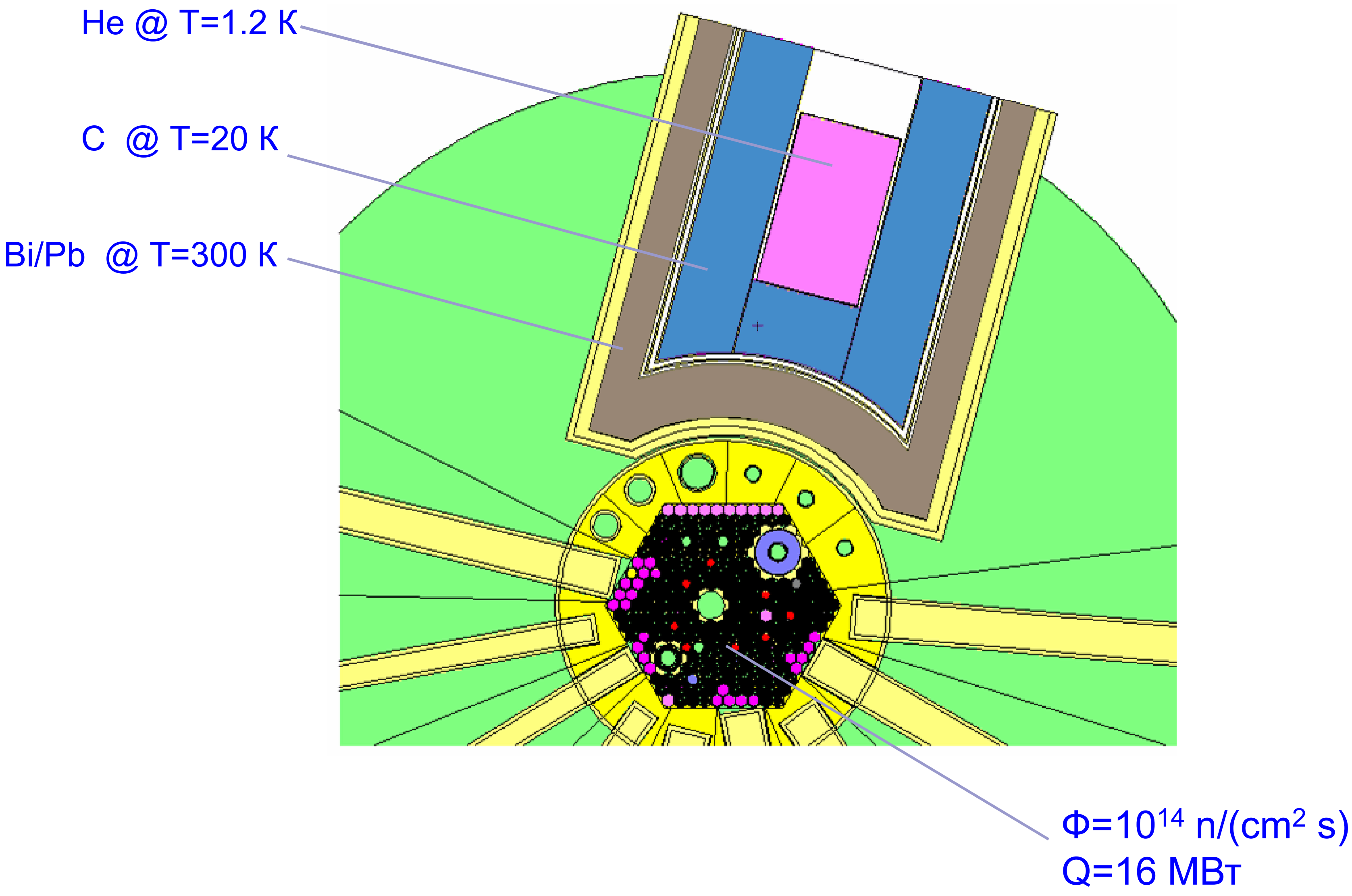
Heat release in the cell (Al+HeII) at Pb shielding is 30% less than at Bi one.

Cold pre-moderator

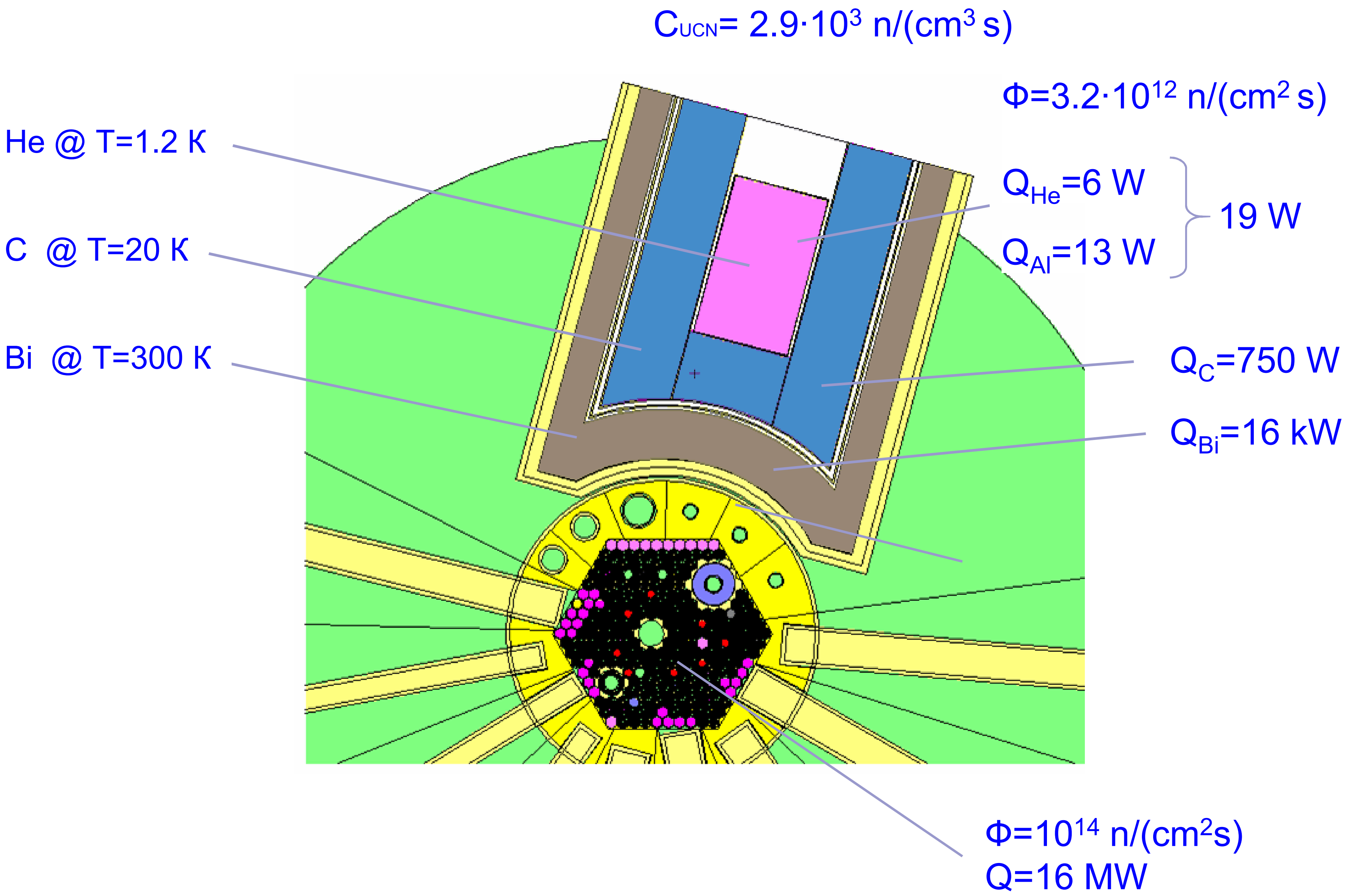


Differential density of neutron flux in the helium cell depending on the pre-moderator material: graphite @ 20K, liquid deuterium @ 20K, heavy ice @ 20K, beryllium @ 20K.

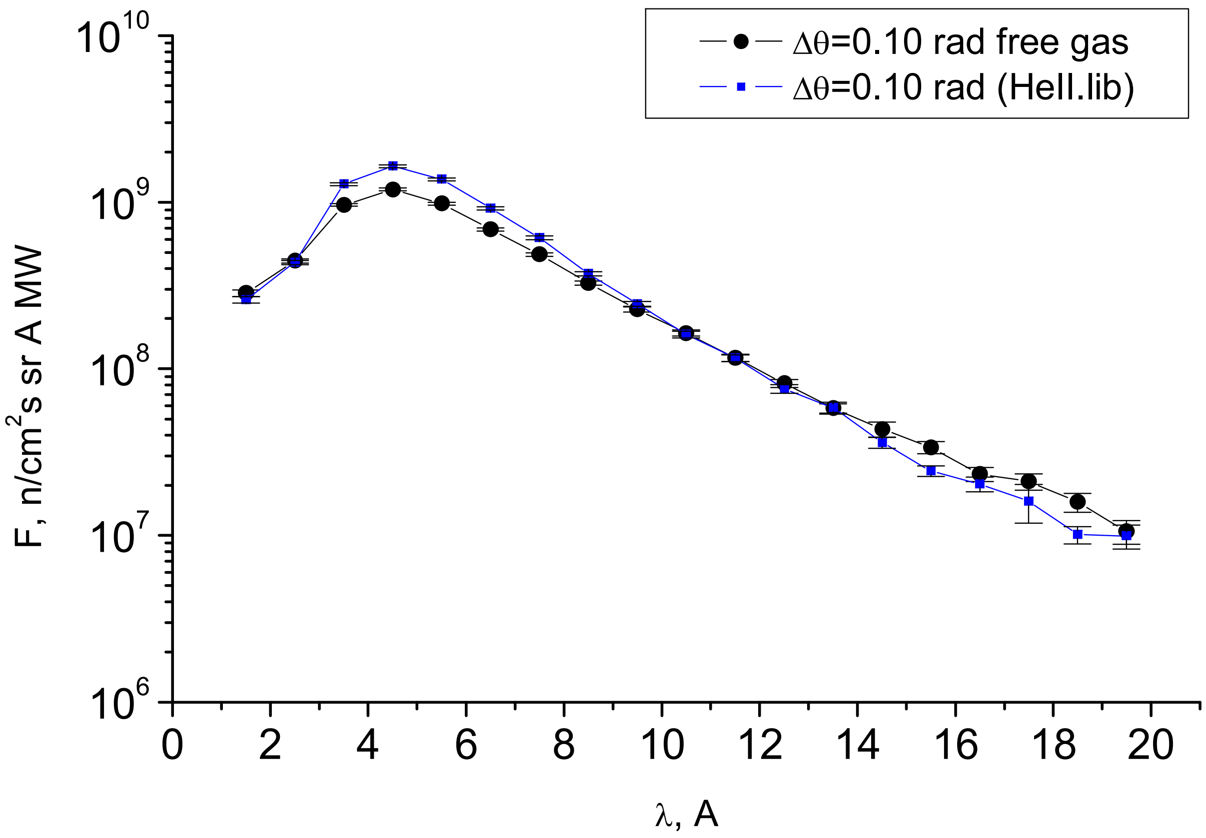
Position on the reactor



Heat release in material

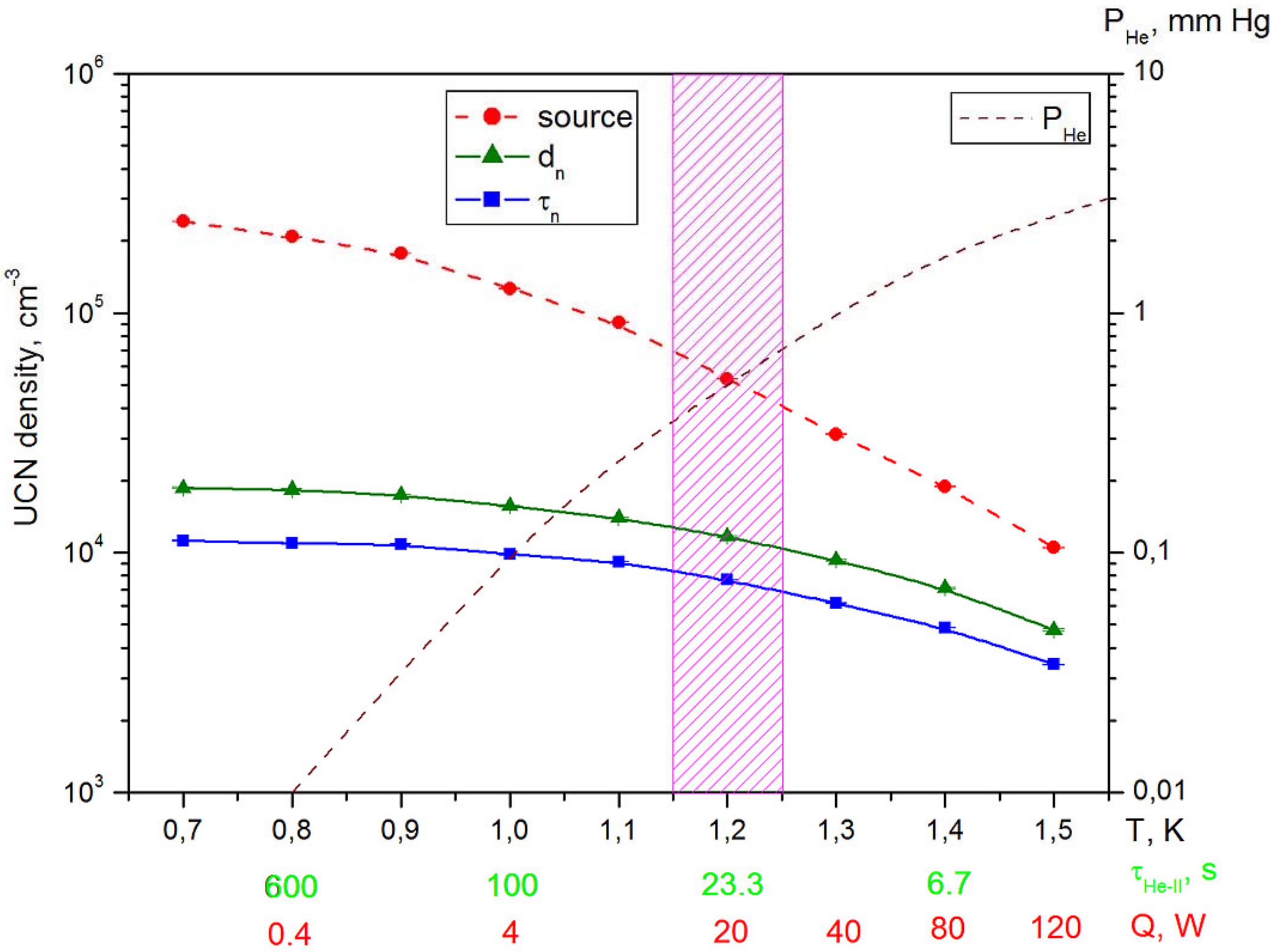


Neutron spectra from helium cell



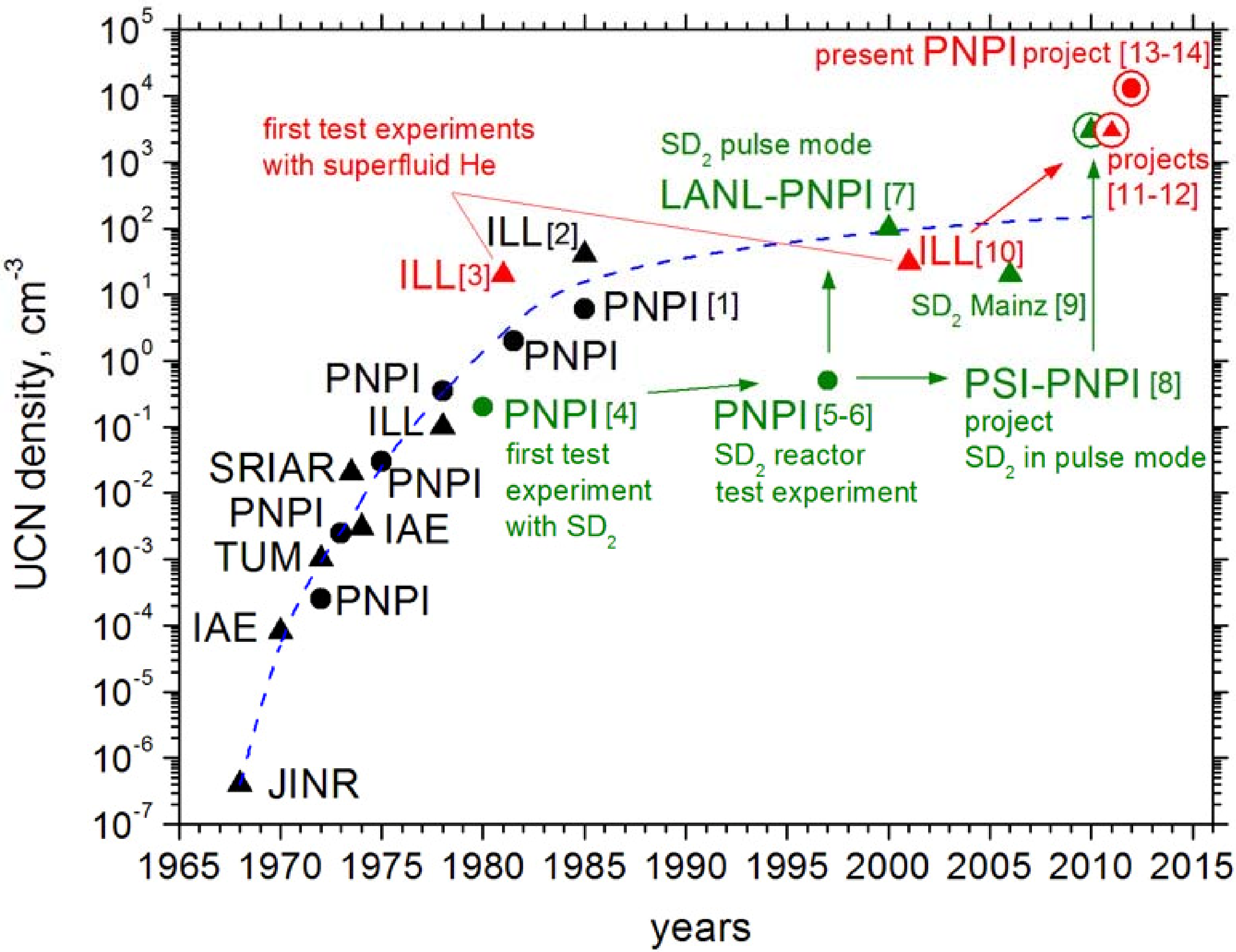
Yield at solid angle ΔΩ=2πΔθ

UCN density



P$_{He}$, mm Hg
10
1
0,1
0,01
10^6
10^5
10^4
10^3
UCN density, cm^{-3}
source
d$_n$
τ$_n$
P$_{He}$
0,7
0,8
0,9
1,0
1,1
1,2
1,3
1,4
1,5
T, K
600
100
23.3
6.7
τ$_{He-II}$, s
0.4
4
20
40
80
120
Q, W

Progress in UCN production



UCN storage time in He II

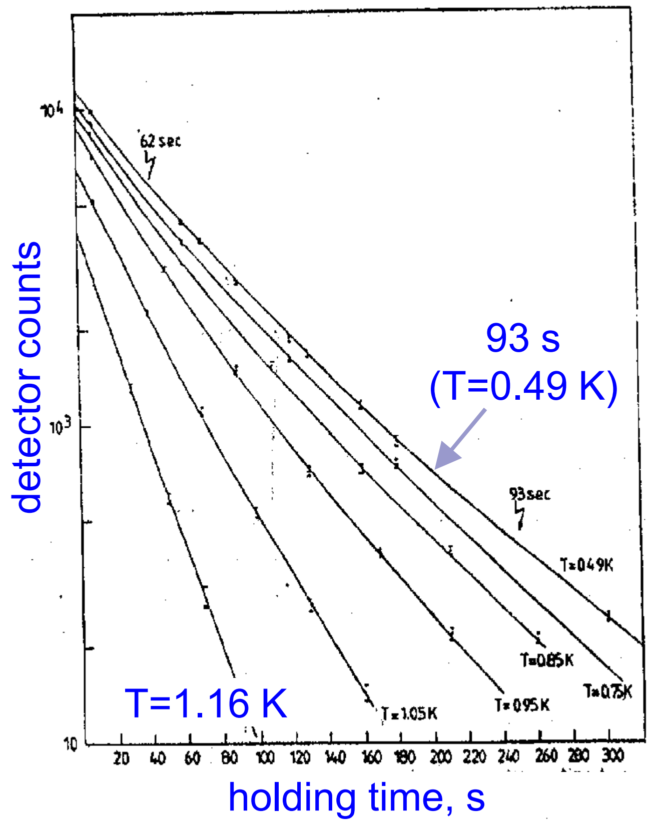


Fig. 2. Storage of UCN in a liquid Helium filled vessel. $N(t_s)$ – number of observed detector counts after a storage time t_s

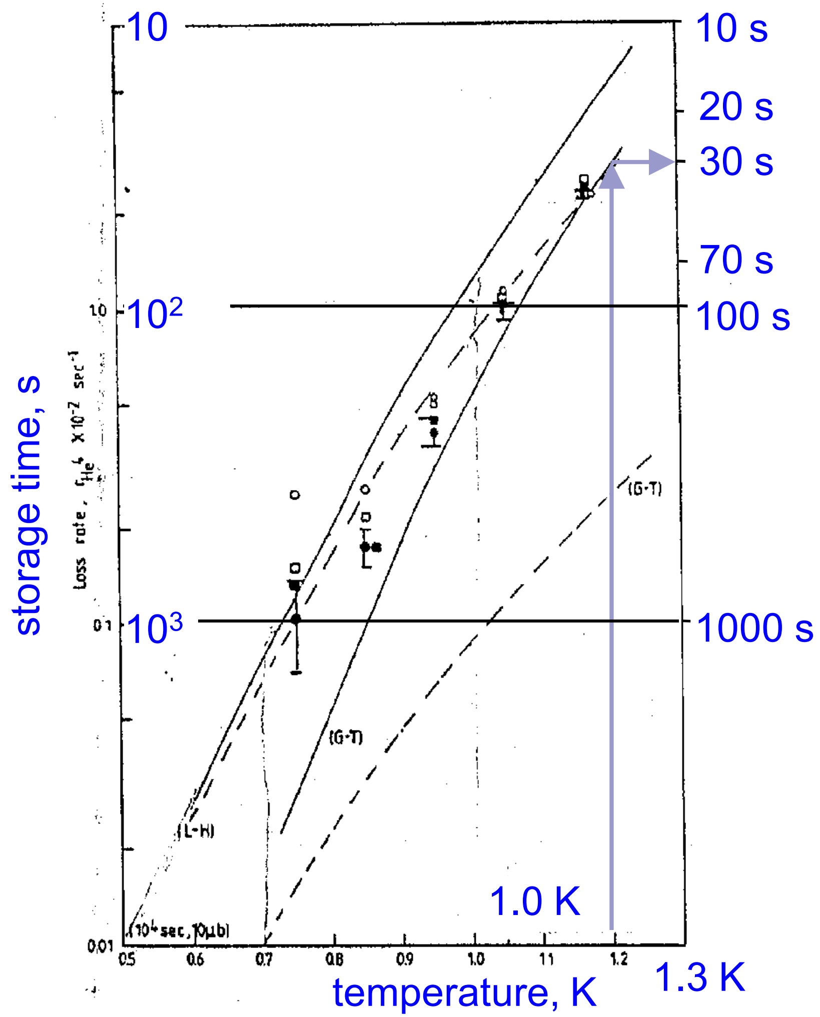


Fig. 3. Loss rate due to the interaction of UCN with superfluid Helium[4] as a function of temperature. The numbers in brackets on the vertical scale give the corresponding storage times and total cross section (for 4.6 m/s UCN), respectively. ● Method A, ■ Method B, ○ Method A (corrected), □ Method B (corrected), see text. Dashed lines show the results for the two phonon scattering process calculated using Landau's Hamiltonian [4] (L-H) and by Griffin and Talbot [6], (G-T). Solid lines show the total loss rate using these two approaches

Z.Phys.B – Condensed Matter 51, 1983.

Experimental data obtained at ILL

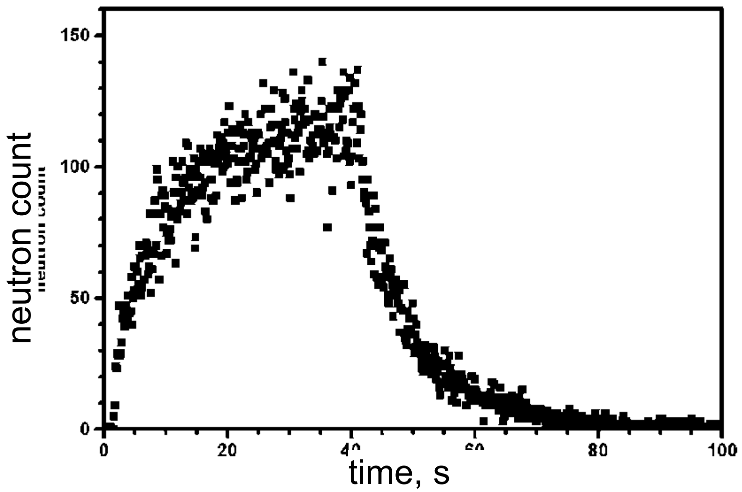


Fig. 5. The UCN detector counts as a function of time, with the velocity selector set to 9 Å.

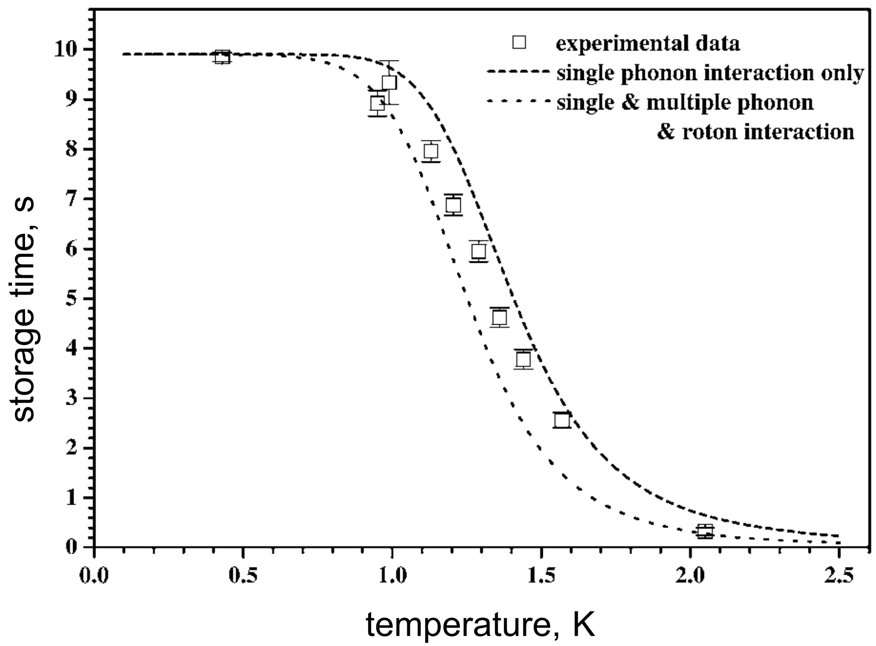


Fig. 4. Experimental measurement of the temperature dependence of UCN storage lifetime, together with the theoretical expectations [6] from two models of phonon and roton interactions.

UCN density $\rho=C\tau$

$\Phi(\lambda=9Å)=2.7\cdot10^7$ n/(cm$^2\cdot$s$\cdot$A)

C – UCN production rate (0.9±0.1) n/(cm^{3}s)

τ- storage time

$\rho\approx10$ cm^{-3}

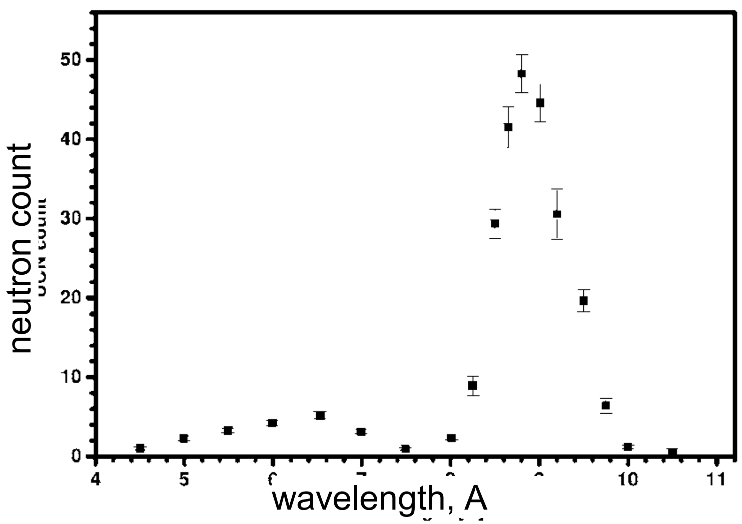


Fig. 6. The UCN count rate recorded at wavelengths between 4 Å and 11 Å.

$\Delta T=0.1K$ changes the storage time of about 15%.

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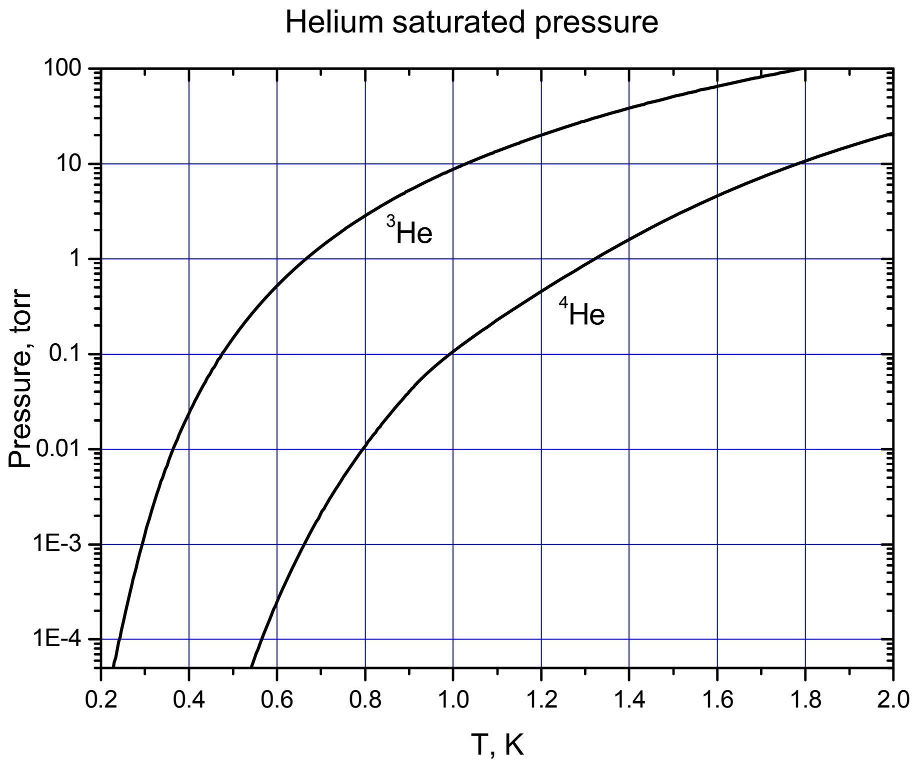
Is it possible to use ^{3}He at 20W heat release to reach a lower temperature ?



Heat removal is produced due to the helium evaporation.

^{3}He evaporation heat @ 0,6K - 10,5 J/g
^{4}He evaporation heat @ 1,2K - 21,5 J/g

Employment of ^{3}He

To remove 20 W it is necessary to withdraw by pumping ~ 2 g/s.

To cool down incoming He from 3.2 K to 0.6 K it is necessary to withdraw by pumping ~ 2.2 g/s.

Vacuum facility capacity: **63.5 m^3/s** (T = 273K, P = 50 Pa)

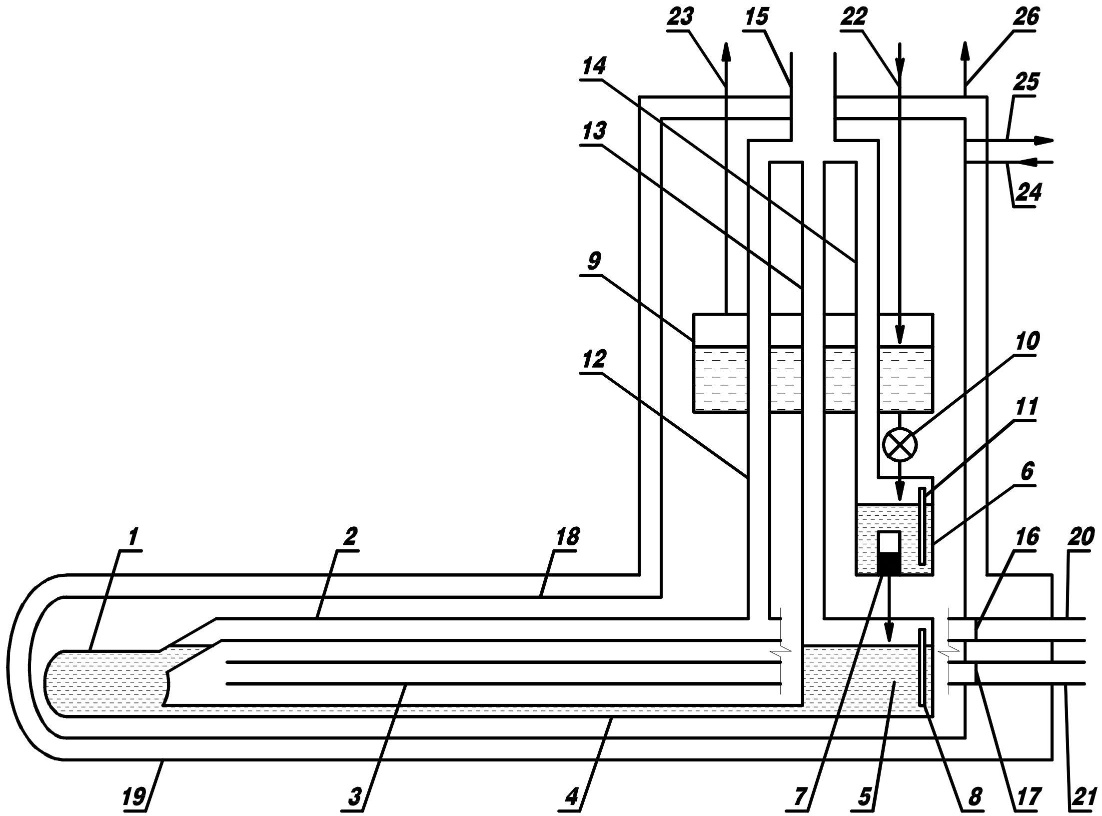
Employment of ^{4}He

To remove 20 W it is necessary to withdraw by pumping ~ 1g/s.

To cool down incoming He from 4.2 K to 1.2 K it is necessary to withdraw by pumping ~ 0.5 g/s.

Vacuum facility capacity: **17 m^3/s** (T = 273K, P = 50 Pa)

Diagram of low temperature part



1 – He II cell; 2 – UCN neutron guide, 3 – CN neutron guide, 4 – He II supply pipe, 5 – lower bath @ 1.2 K, 6 – intermediate bath @ 1.2 K, 7 –^{3}He filter, 8 – level sensor, 9 – upper bath @ 4.2 K, 10 – helium supply valve, 11 – level sensor, 12 – vacuum pipe (gravitation trap for UCN), 13 – vacuum pipe for lower bath, 14 – vacuum pipe for intermediate bath, 15 – main vacuum manifold, 16 – UCN neutron guide membrane, 17 – CN neutron guide membrane, 18 – thermal shield @ 20 K, 19 – vacuum jacket, 20 – UCN outer neutron guide, 21 – CN outer neutron guide, 22 –helium supply at temperature of 4.2 K, 23 – pipe for helium vapour removal, 24 – helium supply for thermal shield 18, 25 – helium removal from thermal shield 18, 26 – pumping of vacuum jacket.

UCN storage time in the neutron guide

Storage time:
$\tau^{-1} = \sigma_t \, n \, \upsilon$,

σ_t – total cross section,
n – amount of atoms in unit volume,
υ - velocity of atoms.
For helium $\sigma_t = \sigma_0$ = 0,8 ±0,2 barn.
Cross section of $8 \cdot 10^{-29}$ m^2 is used for calculation.

Amount of atoms in unit volume can be defined from equation:
P = n k T,
P – gas pressure [Pa],
T – temperature [K],
k – Boltzmann const. : 1,38 10^{-23} [J/K].

Amount of atoms in unit volume: n = 3,3 10^{24}.

Most likely velocity of atoms:
$\upsilon = (2\,k\,T\,/\,m)^{0/5}$,
m – mass of helium atom: 6,7 10^{-27} kg.
υ = 70 m/s at temperature of 1.2 K.

UCN storage time in the neutron guide filled with helium at 55 Pa and temperature of 1.2 K is equal to

$$\boldsymbol{\tau = 54\ s.}$$

Storage time obtained from experimental data [1] for conditions in the neutron guide: **τ = 54 ± 4 s.**

1. Ю.Ю. Косвинцев, Ю.А. Кушнир, В.И. Морозов, Г.И. Терехов. Взаимодействие ультрахолодных нейтронов с газообразной средой. Нейтронная физика. Часть 1, М.,1980, с. 130 – 137.

Diameter of pipe for helium vapour pumping

Molecular flow:

$$Q = m\frac{R}{M}T$$

m – mass flow rate;
R – universal gas constant,
M – molecular mass,
T – gas temperature.

At flow rate of 1 g/s and temperature of 1.2 K **Q = 2.5 Pa m^3/s.**

Allowable pressure drop in the pipe dP= 0.3 Pa.

Pipe conductivity: C = Q/dP

Diameter of pipe:

$$D(dP) := \sqrt[4]{\frac{\frac{Q}{dP}\cdot 128\cdot \mu \cdot L}{\pi \cdot gc \cdot p}}$$

μ - dynamic viscosity,
p – average pressure in the pipe,
L – length of pipe,
gc – the conversion rate coeff.

The necessary diameter of pipe is equal to **5.2 cm**.

UCN neutron guide diameter is **10 cm.**

Surface area which is necessary for evaporation in the cell

At equilibrium conditions at saturated pressure P_n:

$$Q_{ev} = Q_{con} = \frac{N_a P_n}{\sqrt{2\pi MRT}} AkT$$

Withdrawal gas flow: *Q = Qev – Qcon*

$$Q = \frac{N_a}{\sqrt{2\pi MRT}} AkT(P_n - P)$$

Gas flow to be removed:

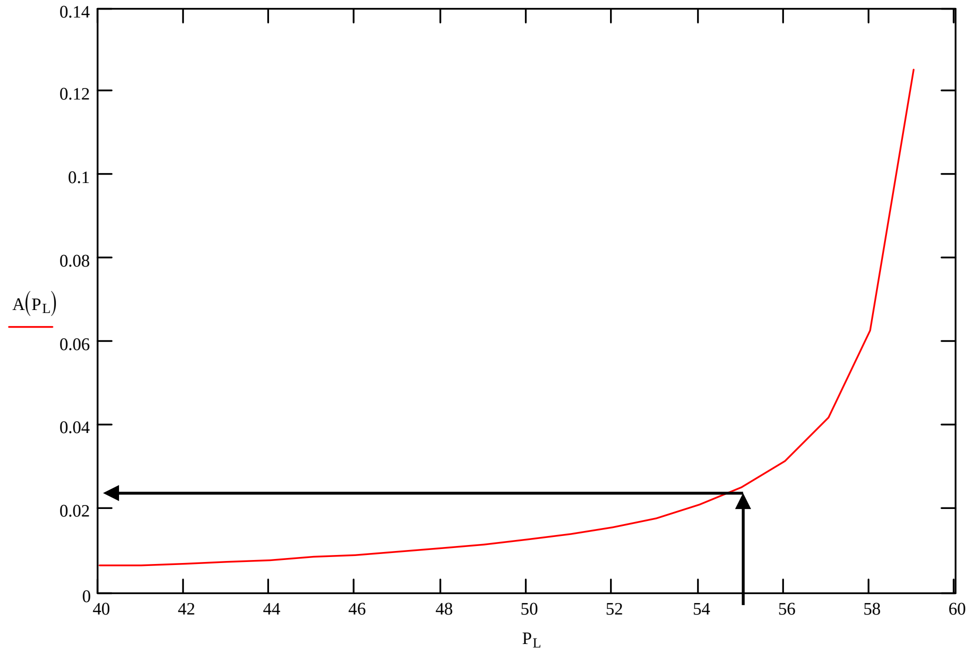
$$Q = m\frac{R}{M}T$$

Necessary surface for evaporation:

$$A = \frac{Q\sqrt{2\pi MRT}}{N_a kT(P_n - P)}$$

A – surface area, m^2
k – Boltzmann const., J/K
T – temperature, K
R – universal gas constant
M – molecular weight, kg/mol
N_a – Avogadro const., 1/mol
P – pressure above the surface, Па
P_n – saturated pressure, Па

It is necessary to have the surface area equal to **0.025 m²** to remove a gas flow of 2.5 Pa m^3/s at pressure above the surface of 5 Pa below the saturated pressure.



Capacity of the thermo-mechanical pump (filter)

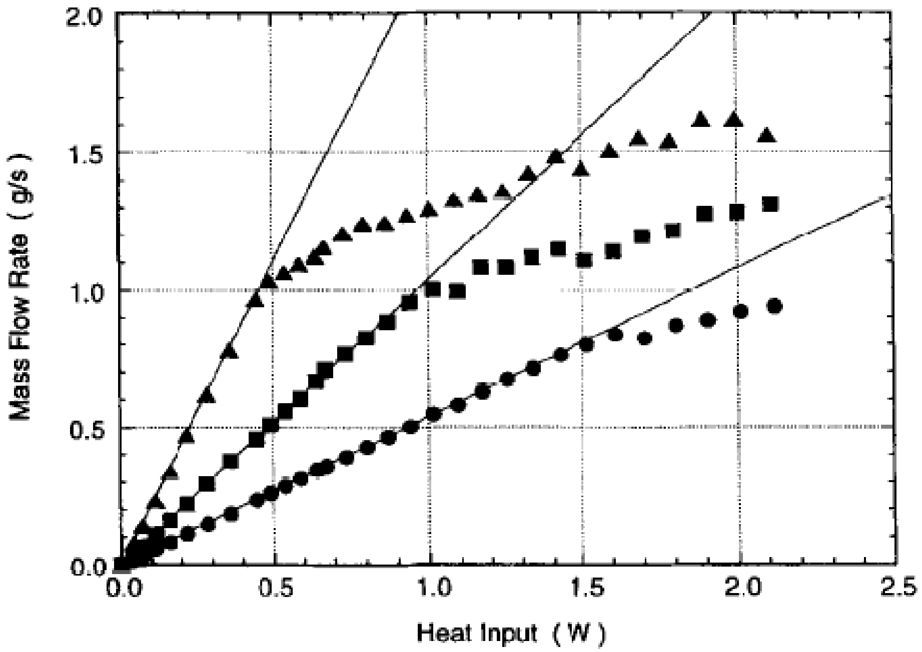


Figure 2 Mass flow rate *versus* heat input at various temperatures (TMP No. 221). ●, $T_B = 2.0$ K; ■, $T_B = 1.8$ K; ▲, $T_B = 1.6$ K; —, theory

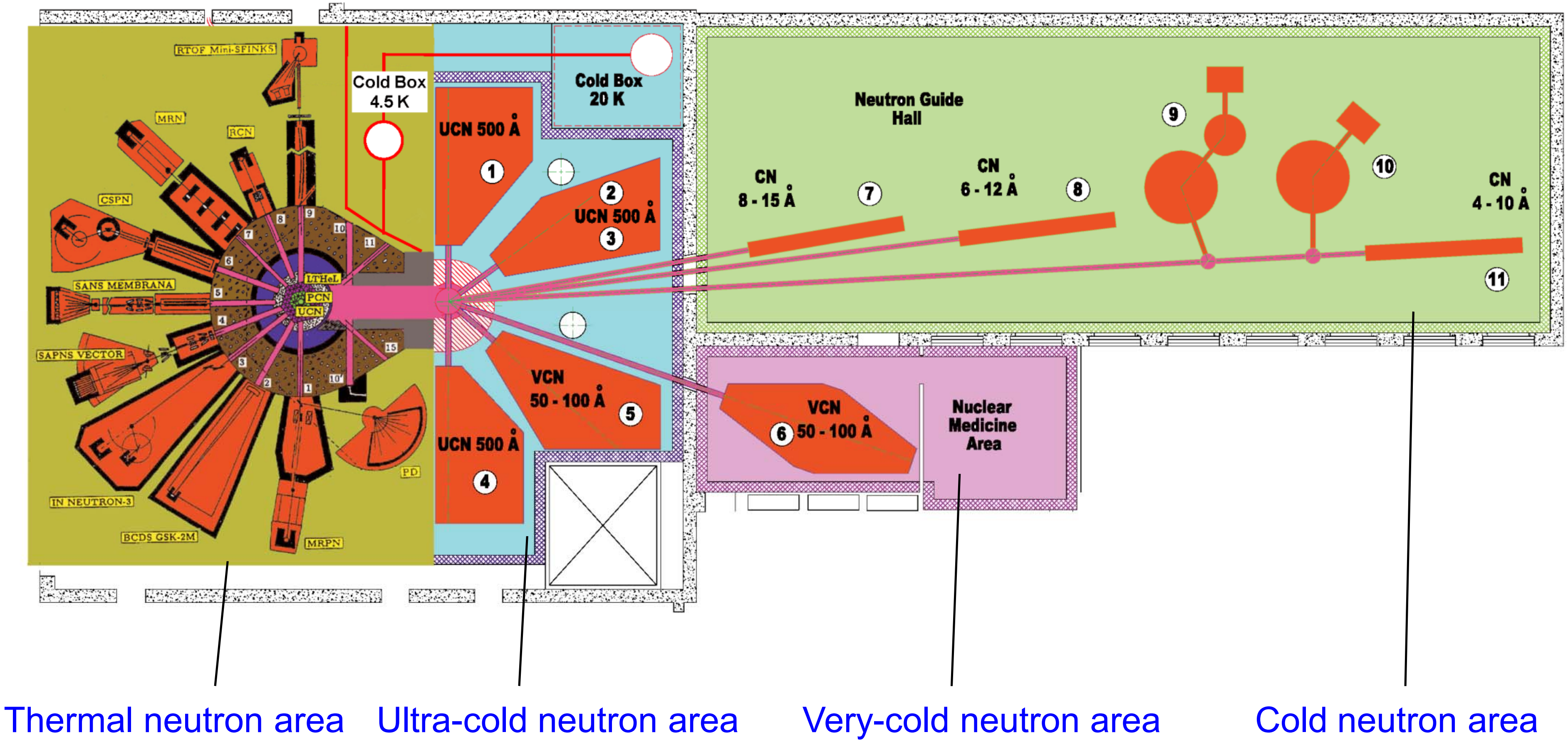
H. Nakai, N. Kimura, M. Murakami *, T. Haruyama and A. Yamamoto. Superfluid helium flow through porous media. Cryogenics, 36, 1996, pp. 667-673.

General technical specification of low temperature part

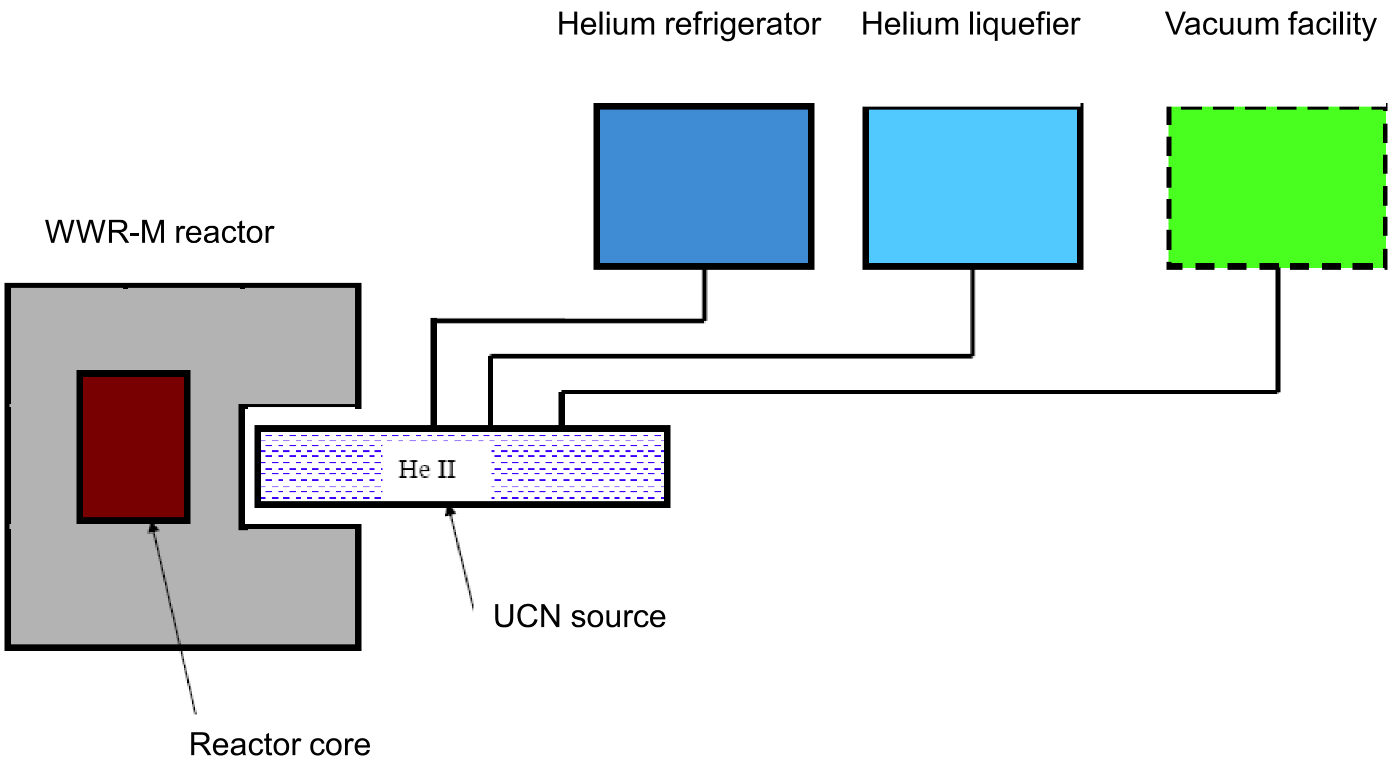
UCN neutron guide	
Pressure in the neutron guide	55 Pa
Temperature of helium vapour	1.2 K
UCN storage time in the guide	54 s
Neutron guide diameter	10 cm
UCN loss in the gas	~ 2%
Intermediate bath at 1.2 К	
Surface are	0.0125 m^2
Diameter of vacuum pipe	~ 7 cm
Volume of He II	~ 2,5 l
Lower bath at 1.2 К	
Diameter of vacuum pipe	~ 5 cm
Volume of He II	~ 2,5 l
He II cell	
Dimensions: length diameter	50 cm 30 cm
Surface area	0.025 m^2
He II temperature	1.15 К
Diameter of He II supply pipe	~ 1 cm
Flow rate of He II	1 g/s
Volume of He II	35 liters

Total amount of He II @ 1.2K is about 40 liters

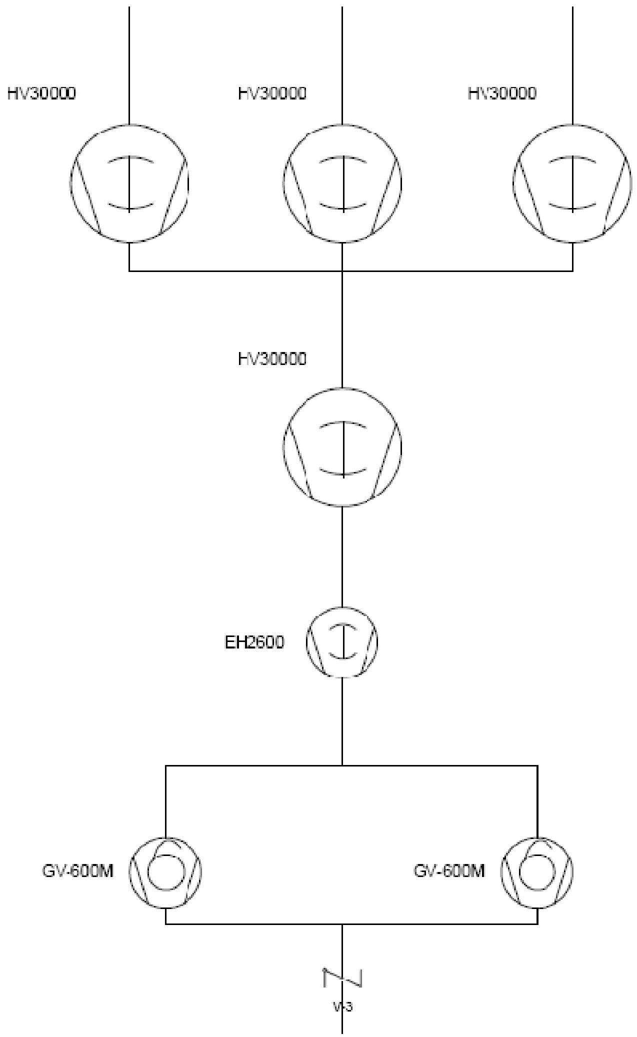
WWR-M reactor neutron beam area



Technological general diagram



Vacuum facility general diagram



Vacuum facility capacity is 17 m^3/s @T = 273 K and P = 50 Pa.

Vacuum pipeline between UCN source and vacuum facility has diameter 50 cm and length about 20 meters.
It transfers 1.5 g/s gaseous helium at 50 Pa.

Helium liquefier

Helium tank

Helium refrigerator

Gas management systems

General view

General view