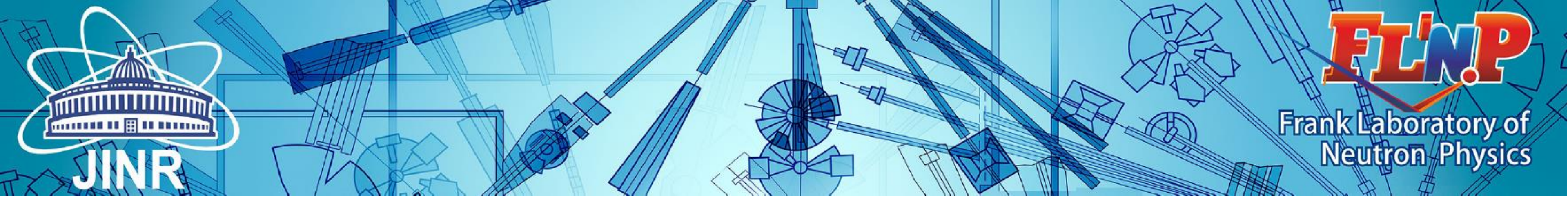
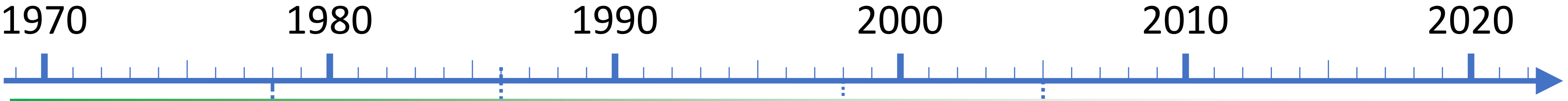


Possible UCN source at DNS-IV

Egor Lychagin



Developing of experimental technic, of UCN sources, UCN detectors and etc.
Search reasons of abnormal large losses of UCN from traps

Discovering of hydrogen contamination of surfaces

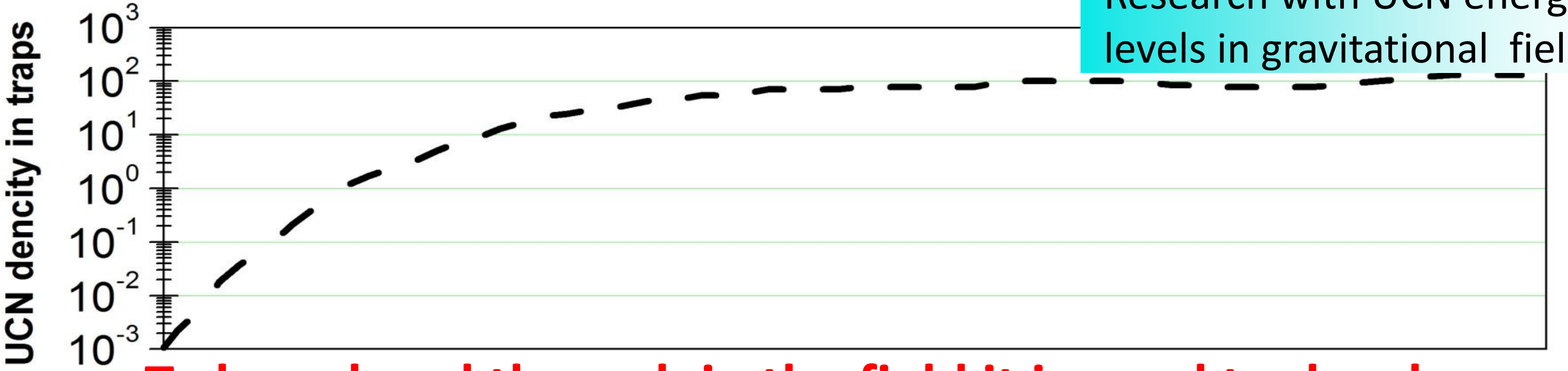
τ_n 903±13 978±0.8

$|d_n| < 3\cdot 10^{-24}$ e·cm (90% C.L.)

$|d_n| < 9.7\cdot 10^{-26}$ e·cm (90% C.L.)

Discovering of UCN “small heating and cooling”

Research with UCN energy levels in gravitational field



To have breakthrough in the field it is need to develop and construct new powerful UCN sources.

Physical problems for UCN

- Neutron life time (electroweak interaction theory)
- Neutron EDM (T-invariance)
- Neutron wave properties (quantum mechanics, theory of relativity)
- Researches with gravitational levels
- Surface investigations
- Methodical developments

World UCN sources are in operation now

Neutron center	Neutron facility	UCN converter
ILL (PF2)	Steady state reactor, 58MW	VCN beam+Turbine
ILL (Sun-2)	Steady state reactor, 58MW	**He-II**
PSI	Spallation	**SD_2**
UNIVERSITY OF MAINZ	TRIGA reactor, 250MW/25kW (pulse/average)	**SD_2**
LANCE	Spallation	**SD_2**
KEK	Spallation	**He-II**
NIST	Steady state reactor, 20MW	**He-II**

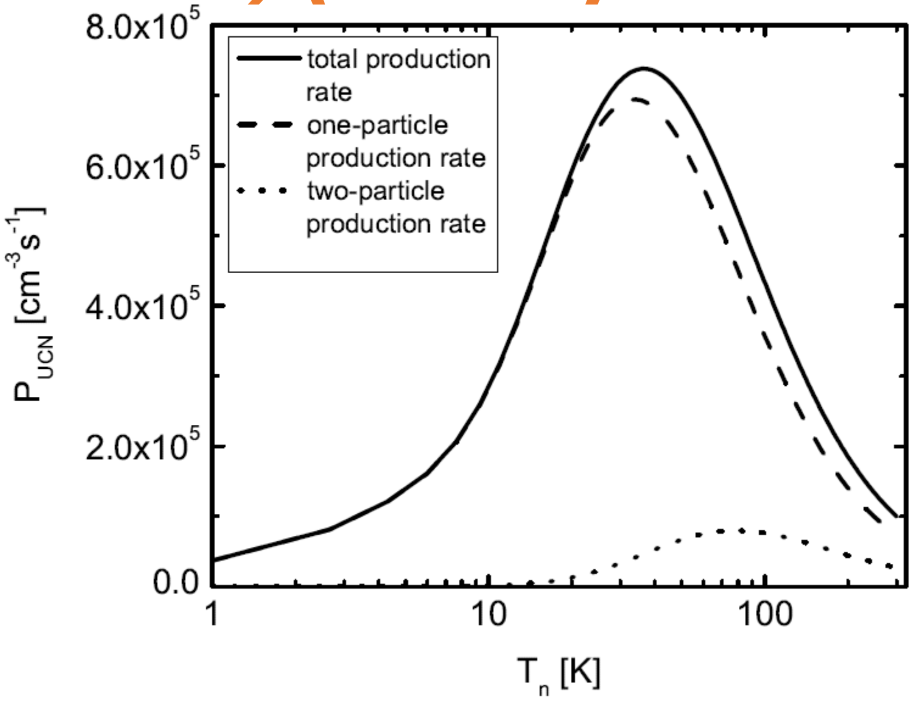
World UCN sources under construction

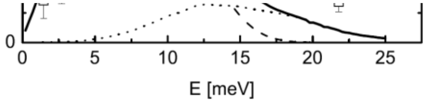
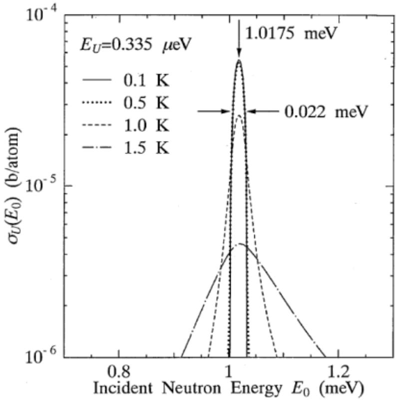
Neutron center	Neutron facility	UCN converter
North Carolina State University	Steady state reactor, 1MW	**SD_2**
TUM	Steady state reactor, 20 MW	**SD_2**
TRIUMF	Spallation	**He-II**

UCN sources projects under consideration

Neutron center	Neutron facility	UCN converter
SNS	Spallation	**He-II**
PNPI	Steady state reactor, 20 MW	**SD_2**
PNPI	Steady state reactor, 100MW	**He-II**
PNPI	Steady state reactor, 100MW	**He-II**

SD, (ortho) vs He-II



	nperature, K	**<0.8**
	ree pass, cm	**⟶ ∞**
	ergy, neV	**105**
	ron spectrum ture T_n, K	**6**
 (0-150neV)	uction cross tion	 (0-335neV)
7×10^5 (0-250neV)	Production rate cm^{-3}s^{-1} for neutron spectrum with T=60K and F=1×10^{14} cm^{-2}s^{-1}	**4.5×10^4** (0-250neV)

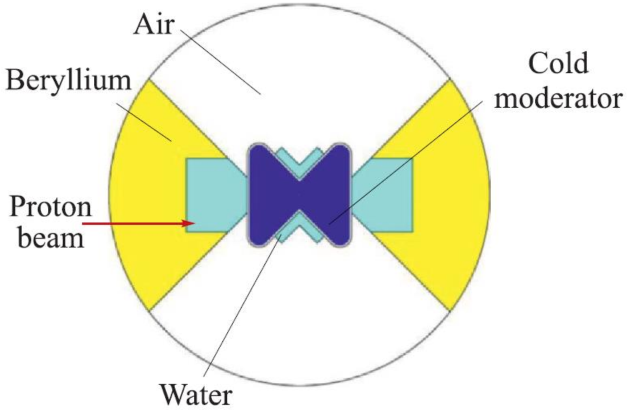
SD_2 (ortho) vs He-II

UCN life time in source is about 20ms. Could have gain from pulse structure of neutron flux at powerful bursts with low repetition rate.

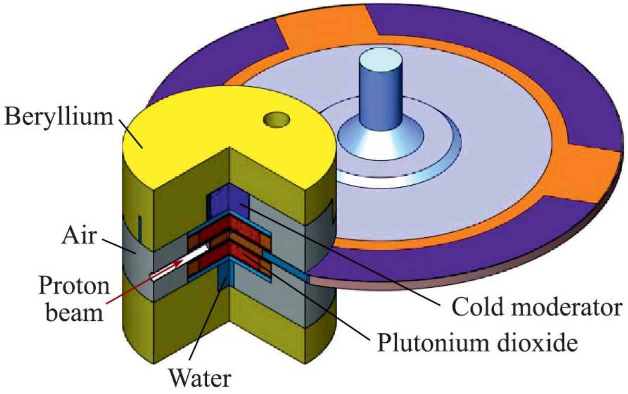
Under 0.8K allow accumulate UCN density. It have no any gain from pulse structure of neutron flux

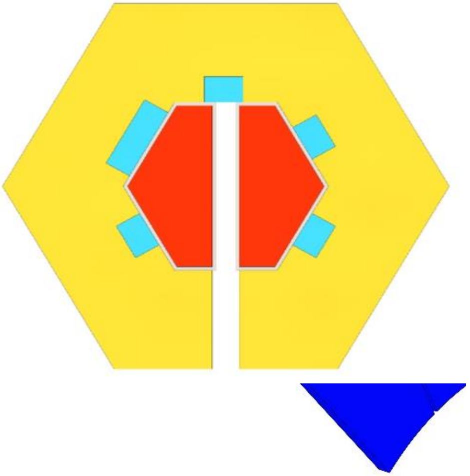
At intense neutron source main limitation in production rate origin from cryogenicc problems.

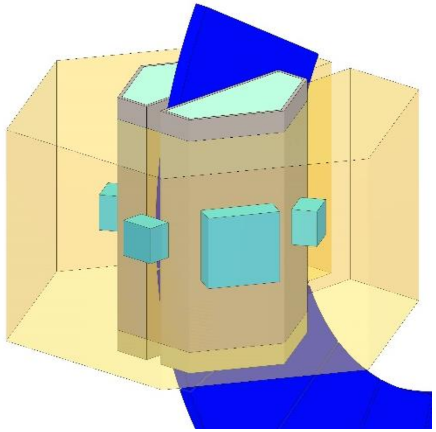
DNS parameters



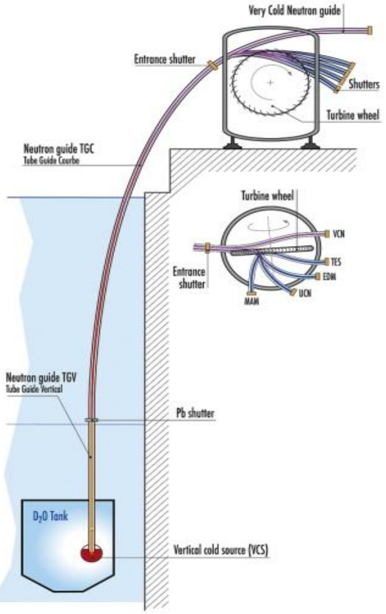
Average neutron flux density of thermal neutrons at the moderator surface, $1/(cm^2 s)$	$\sim 1 \cdot 10^{14}$
Peak neutron flux density of thermal neutrons at the moderator surface, $1/(cm^2 s)$	$\sim 5 \cdot 10^{16}$
Pulse width, ms	0.2
Repetition rate, Hz	10







Sources at ILL

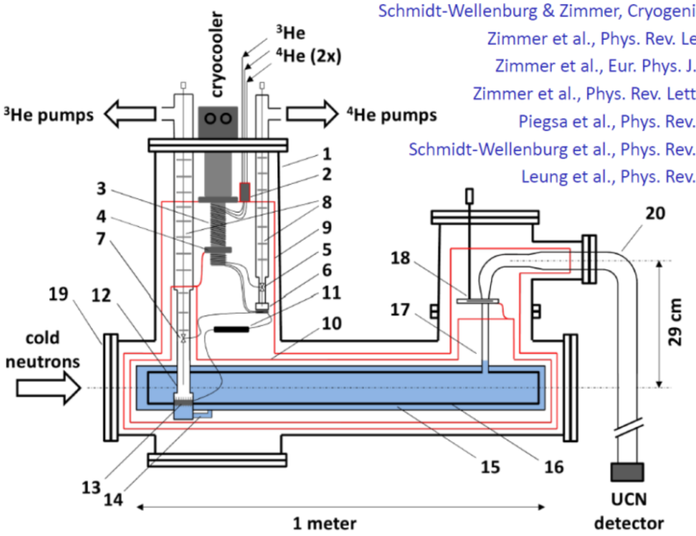


58 MW
Heavy water tank
Liquid D_2 cold source

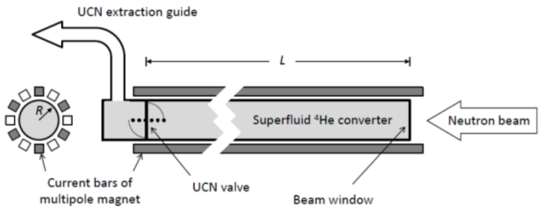
Source prototypes **“SUN-1” & “SUN-2”** (≥2004)

window- and gap-less vertical UCN extraction

Schmidt-Wellenburg & Zimmer, Cryogenics **46** (2006) 799
Zimmer et al., Phys. Rev. Lett **99** (2007) 104801
Zimmer et al., Eur. Phys. J. C **67** (2010) 589
Zimmer et al., Phys. Rev. Lett. **107** (2011) 134801
Piegsa et al., Phys. Rev. C **90** (2014) 015501
Schmidt-Wellenburg et al., Phys. Rev. C **92** (2015) 024004
Leung et al., Phys. Rev. C **93** (2016) 025501



SuperSUN

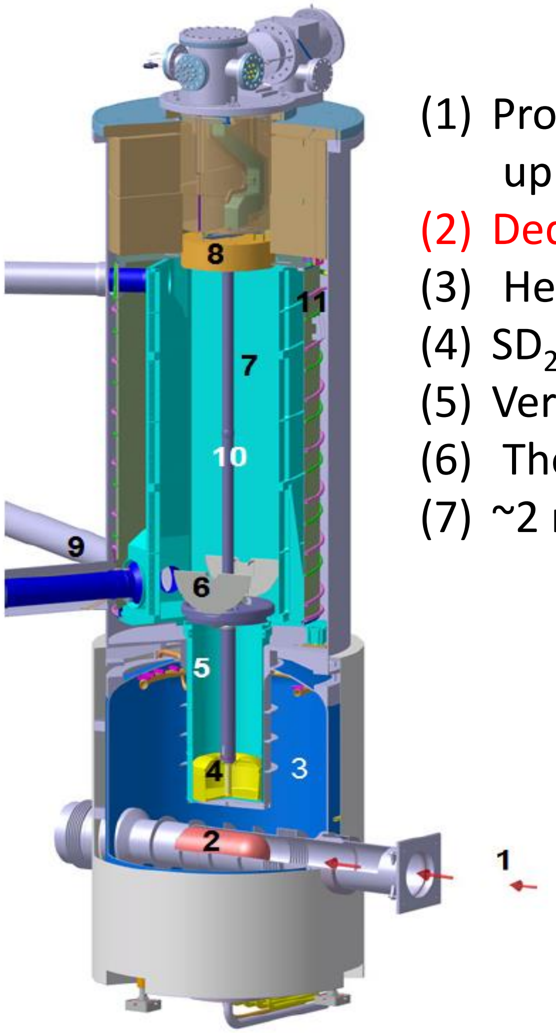


Advantages:

- **in-situ UCN polarizer**
- **long storage lifetime → high saturation UCN density**
- **weak dependence of ρ_{UCN} on wall quality**

Converter volume:	12 litres
UCN production rate:	10^5 s^{-1} ($E < 230$ neV)
UCN saturation number:	4×10^6 (2018, fomblin spectrum)
	2×10^7 (≥2019, polarised, $E < 230$ neV)

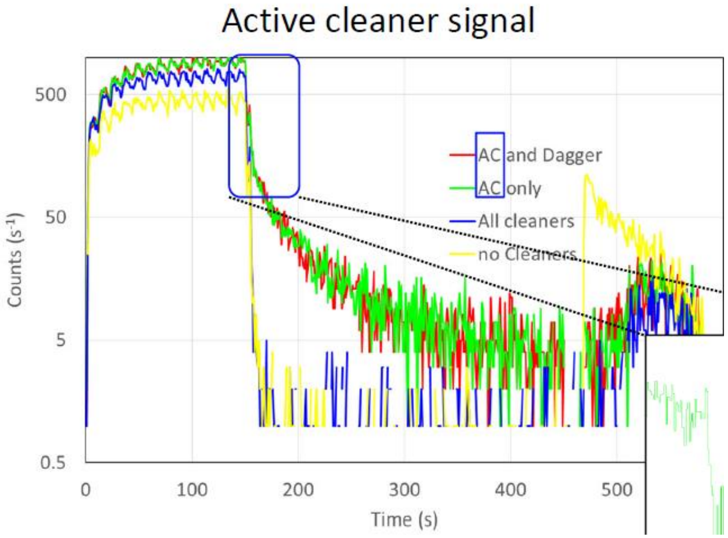
Source at PSI

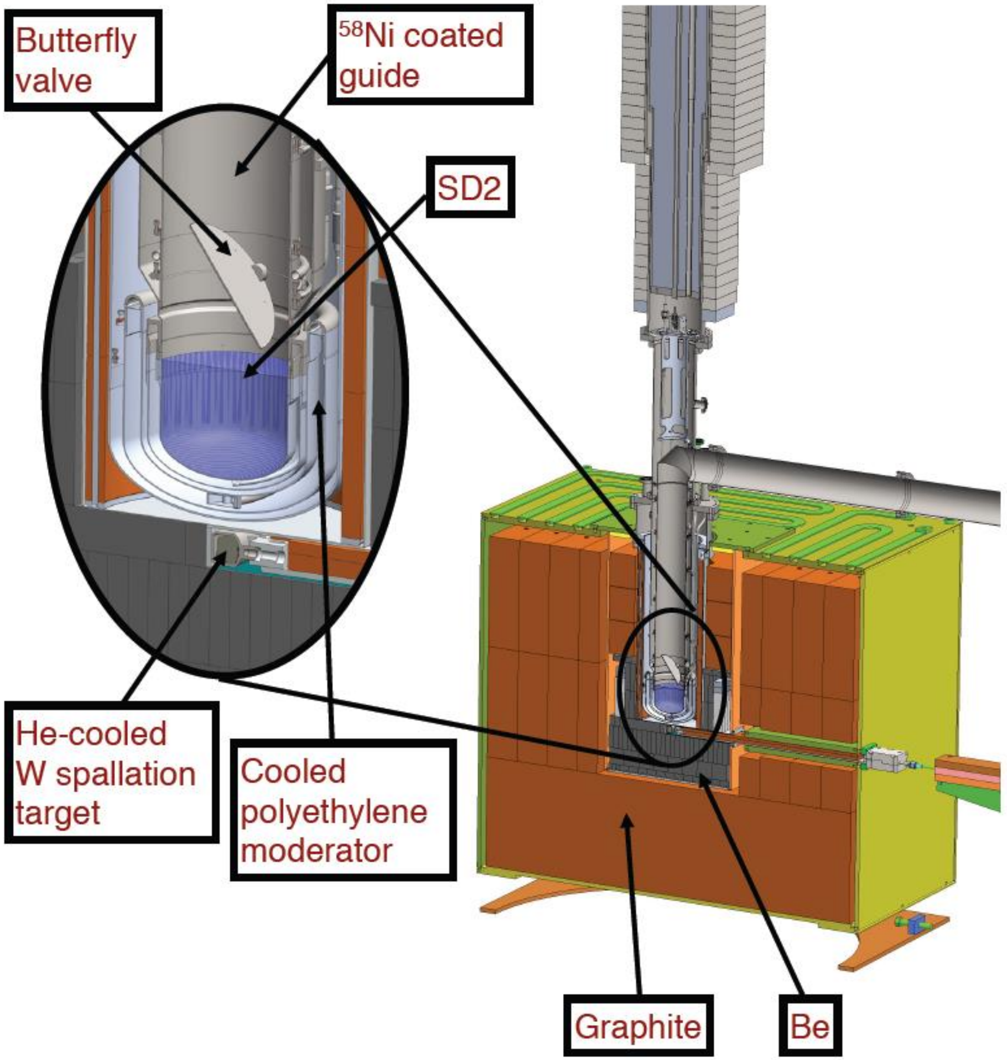


(1) Proton beam 1.5×10^{16} protons/s (2.4mA) @590MeV up to 8 s per 4-13.5 min
(2) Dedicated target
(3) Heavy water (D_2O) 3.5 m^3 moderator at a temperature of ~300 K
(4) SD_2 at 5 K (cold neutron flux of a few times 10^{13} n/cm^2/s inside)
(5) Vertical guide
(6) The big shutter
(7) ~2 m^3 large UCN storage vessel.

Source at LANCE

- Proton beam 45μC during 0.45s (in 10 pulses with 625μs width and 20 Hz repetition) with gap 5 s
- Dedicated target
- SD_2 at 5 K (~1800 cm^3)
- Vertical guide
- The big shutter


Active cleaner signal



^{58}Ni coated guide

Butterfly valve

SD2

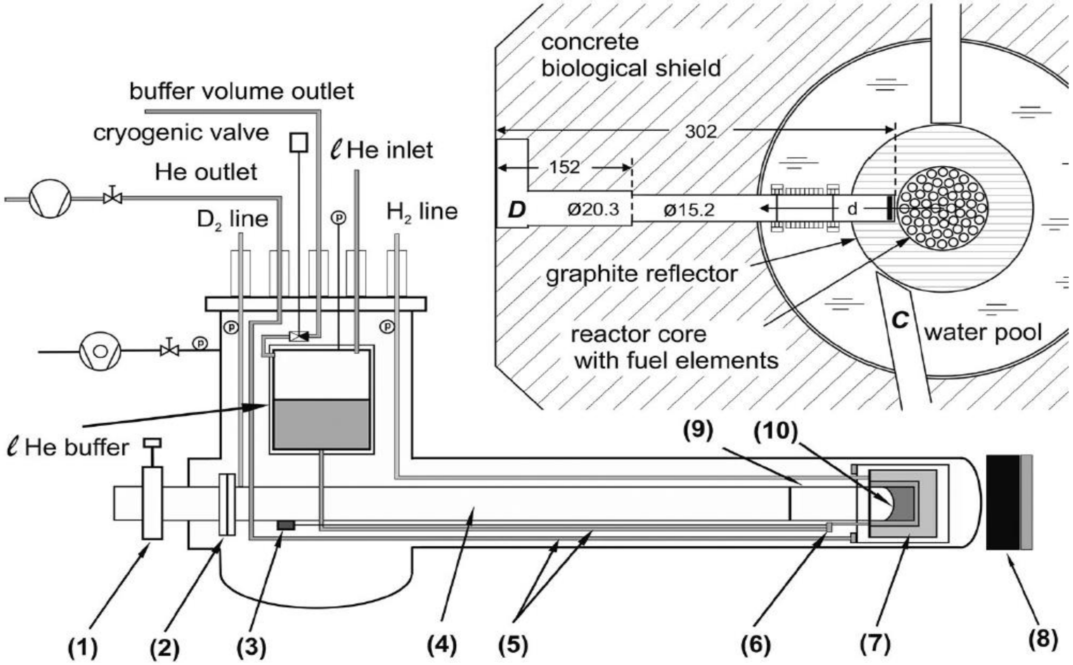
He-cooled W spallation target

Cooled polyethylene moderator

Graphite

Be

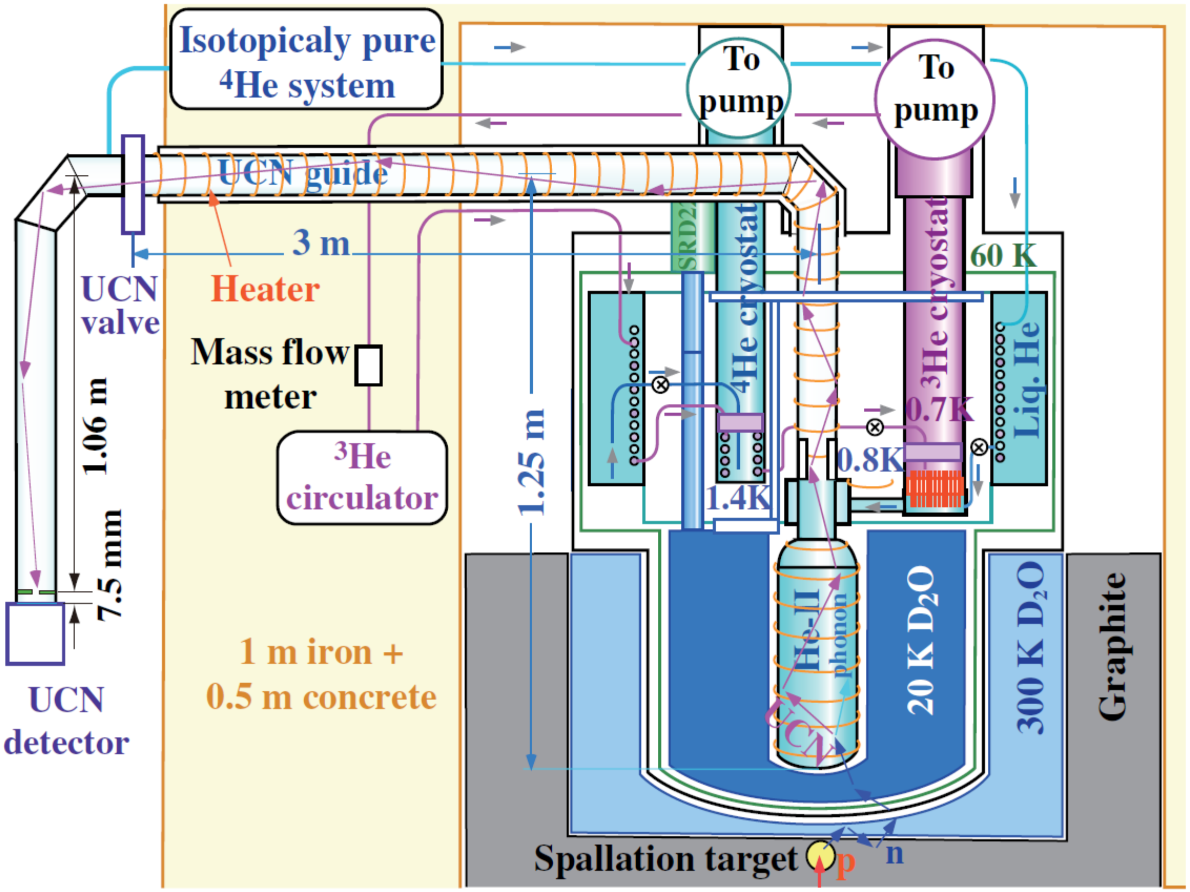
Source at University of Mainz



- TRIGA reactor 250 MWs (in pulse)
- Pulse 30ms per 5 min
- Solid methane/para H_2 pre-moderator
- SD_2 at 6 K (~160 cm^3)

(7) premoderator (H_2,D_2 or CH_4), (8) graphite/bismuth stopper, (10) nose with SD_2 converter. Inset: Scale drawing (measures in cm) of the horizontal section at reactor TRIGA Mainz with focus on the radial beamport D

Source at KEK



- Proton beam 400 MeV, 1 μA during 100 s
- Dedicated target
- Steady state regime

It is stationary neutron source indeed

Development at North Carolina State University

PULSTAR Reactor 1MW

- Heavy water tank (300K)
- Solid methane pre-moderator (40K)
- SD_2 at 5 K

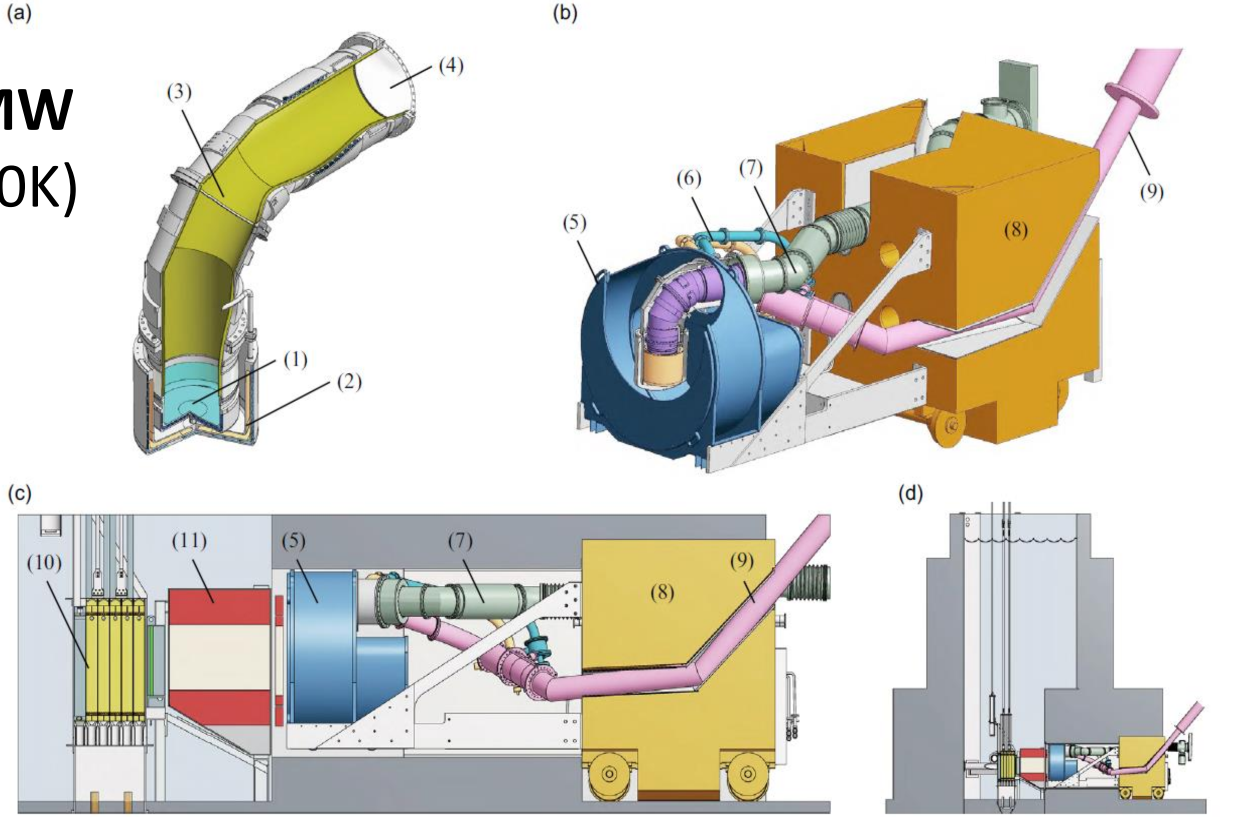
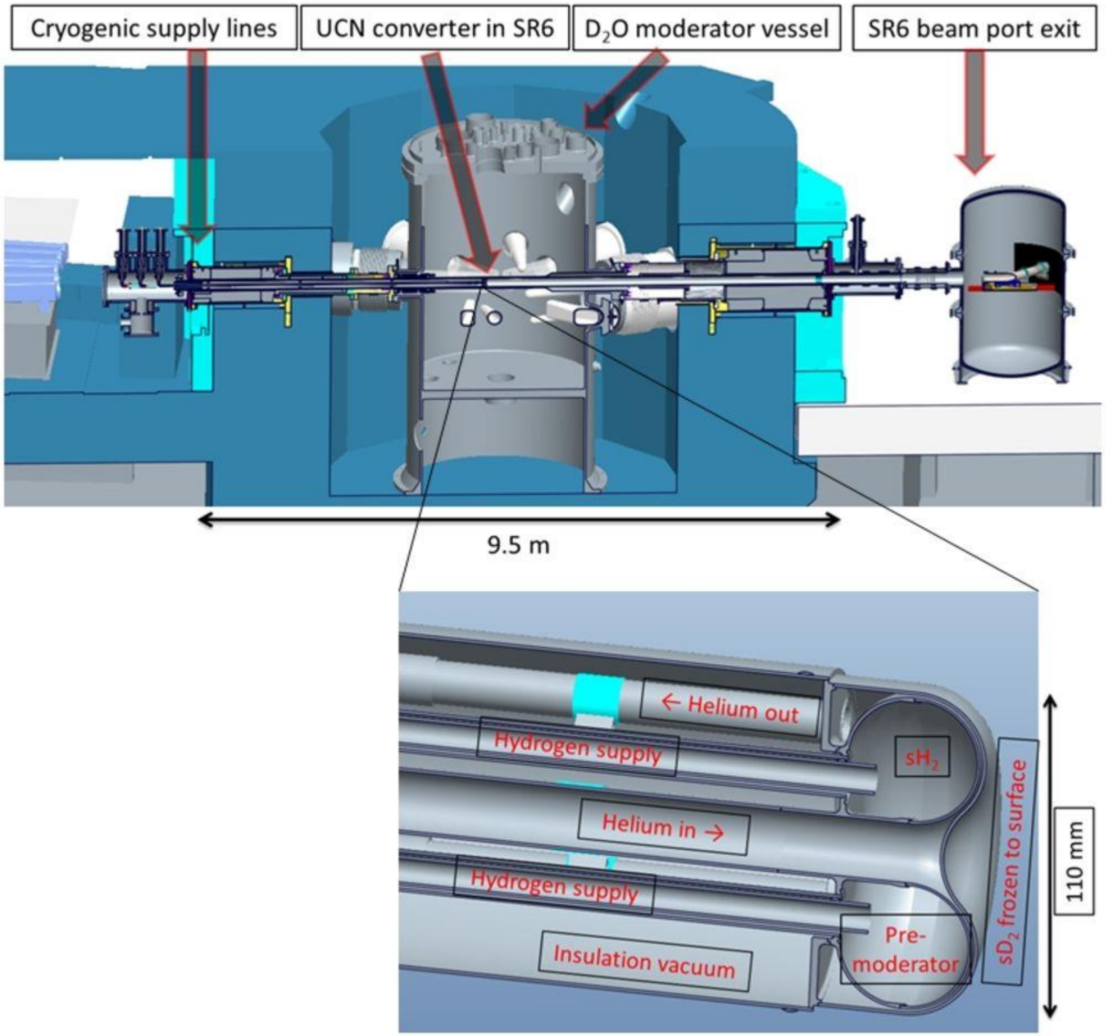


Fig. 1. A cutaway engineering drawing of the UCN source cryostat, as envisioned installed in the reactor thermal column, is shown in (a), including the (1) deuterium container, (2) methane container, (3) UCN guide, and (4) UCN window foil. The UCN source assembly mounted on the shielding door is shown in (b), including the (5) heavy-water tank, (6) deuterium and methane gas inlets, (7) UCN guide, (8) thermal column shield door, and (9) liquid helium transfer line. The heavy-water tank and the cryostat vacuum jacket have been cut away to show the cryostat. A cross-section of the reactor showing the source assembly in the thermal column is shown in (c) and (d), where (10) is the reactor core and (11) is the neutron transport system. In all drawings, neutrons from the reactor core enter from the left and UCN exit to the right of the shielding door.

Development at TUM

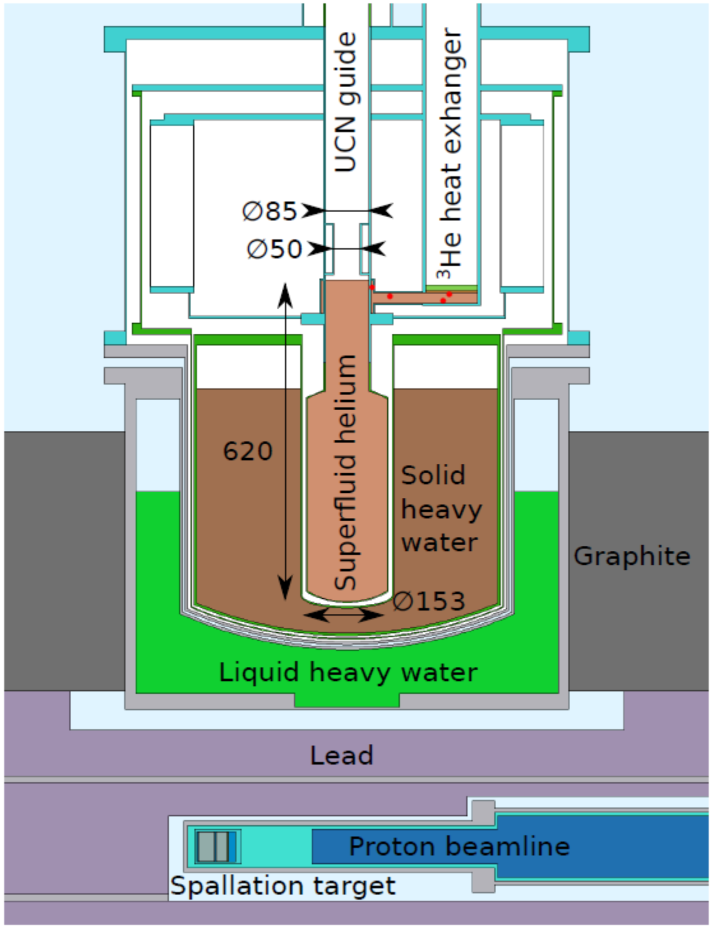
FRM II reactor 20 MW

- SD_2 at 5 K (~? cm^3)
- Pre-moderator volume (sH_2) 250 cm^3
- Converter volume (sD_2) 250 cm^3

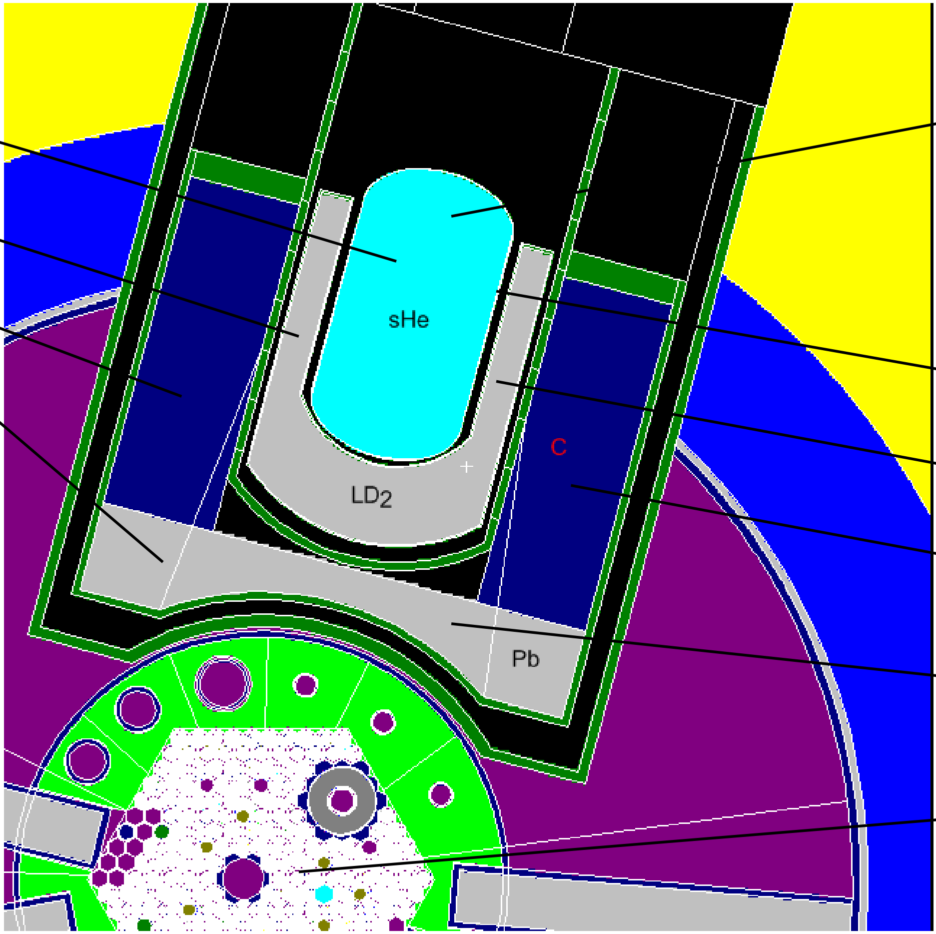


Development at TRIUMF

- Spallation at tungsten by protons 482 MeV, 40 μA
- Pulsed 1ms, 33 Hz (“quasi-stationary”)
- Dedicated target



Project for VVR-M at PNPI



He **T=1.2 К**

LD_2 T=20 К

C T=300 К

Pb T=300 К

$\rho_{UCN}=10^4$ cm^{-3} (τ=10 c)

$\Phi=4.5\cdot10^{12}$ n/(cm^{2}c)

$\Phi(\lambda=9$ A$)=3\cdot10^{10}$ n/(cm^{2}c)

$Q_{He}=6$ W

19 W

Al, $Q_{Al}=13$ W

LD_2, $Q_{LD2+Al}=100$ W

C, $Q_C=700$ W

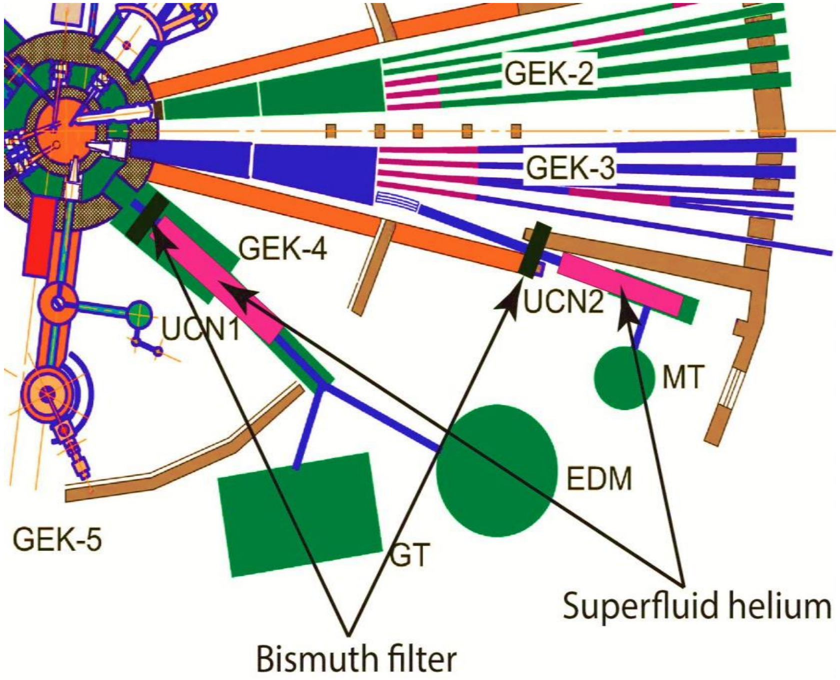
Pb, $Q_{Pb}=15$ kW

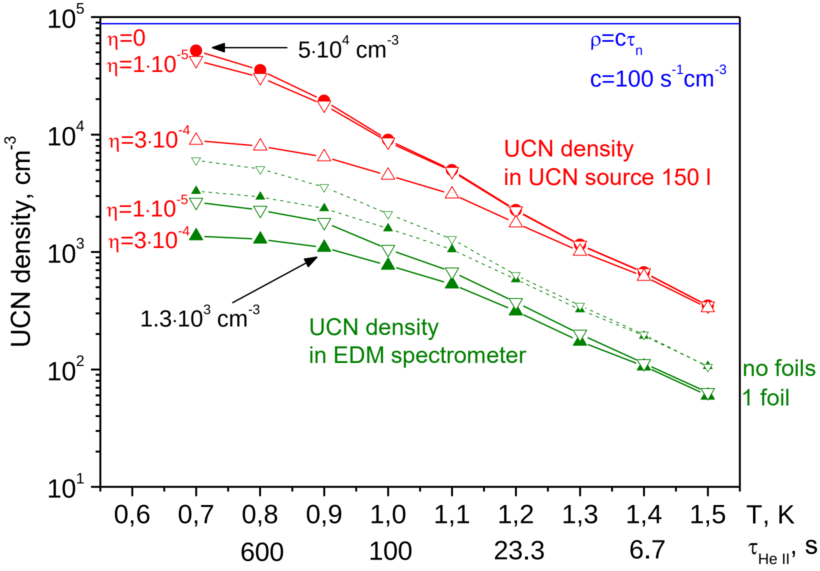
$\Phi=10^{14}$ n/(cm^{2}c)

Q=15 MW

Project for PIK at PNPI

The general scheme of a complex of experimental installations for carrying out research of fundamental interactions with UCN at PIK reactor

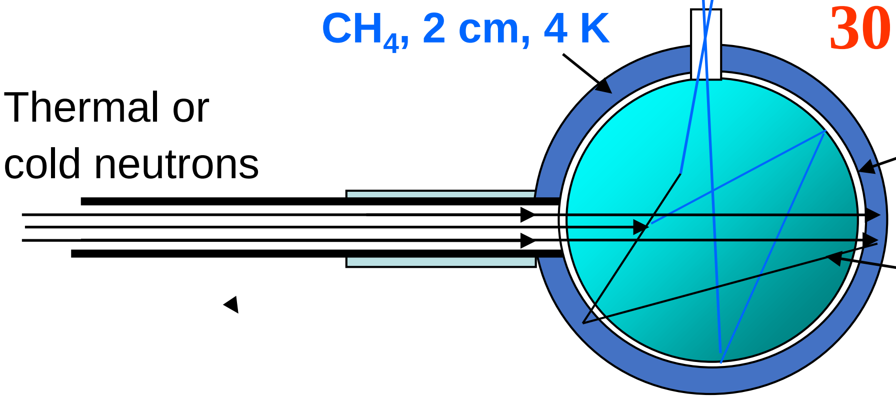




Extracted beam
Need cold source

The thermal load will be much higher at DNS due to hydrogen moderators. The gamma flux should be decreased, or heavy water moderator should be installed (neutron flux will be suppressed)

Project for PIK at PNPI



Reflector-Moderator:
CH_4, 2 cm, 4 K

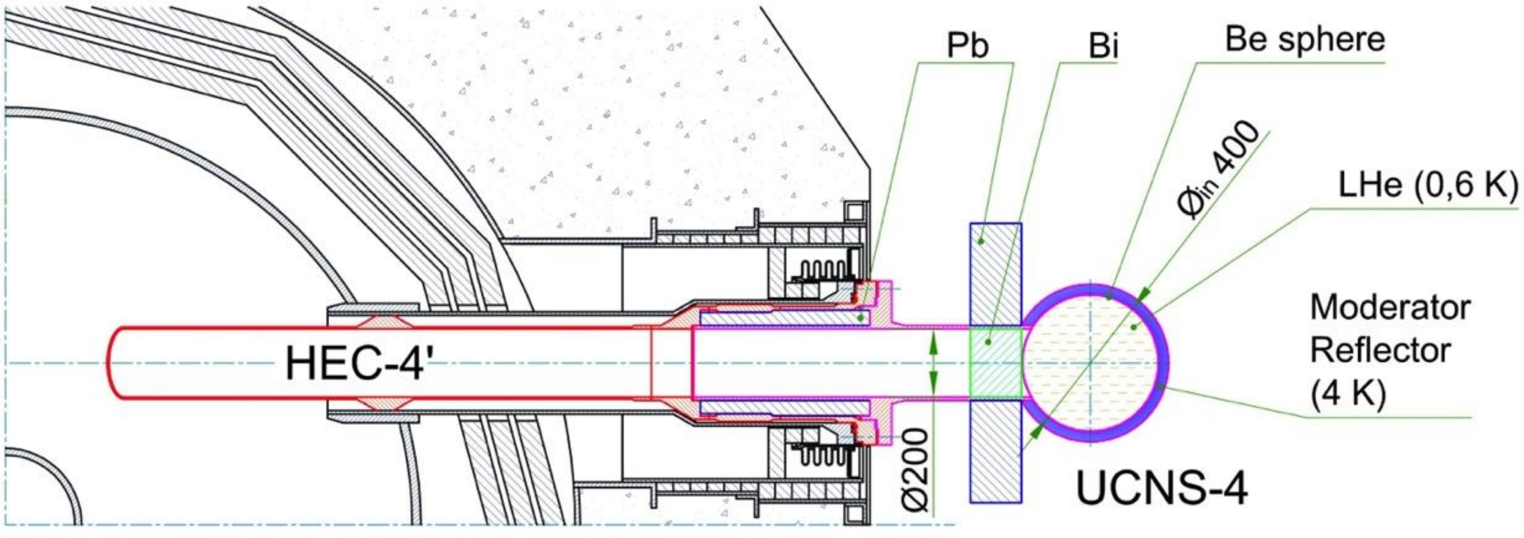
UCN, < 7 m/s, τ = 300s

30 - 60 l

Thermal or cold neutrons

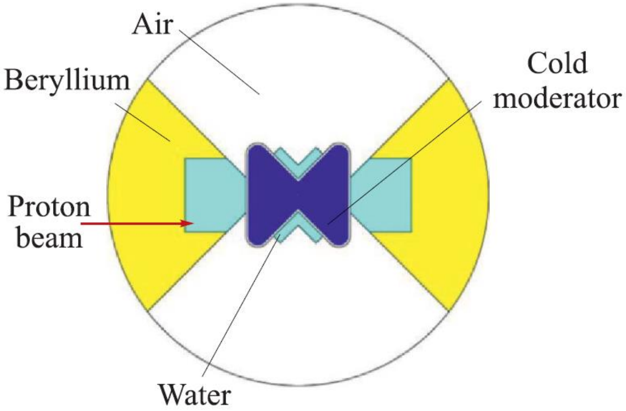
Be (BeO)

^{4}He (0.6 K)

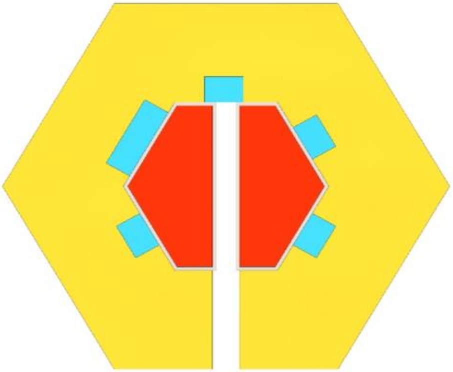


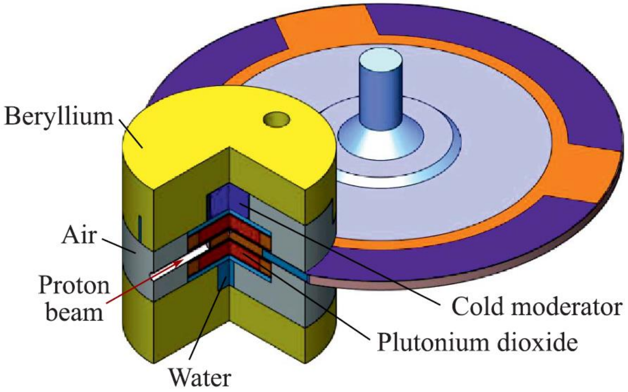
UCN density ~10^5 cm^{-3} UCN flux ~10^7 c^{-1}

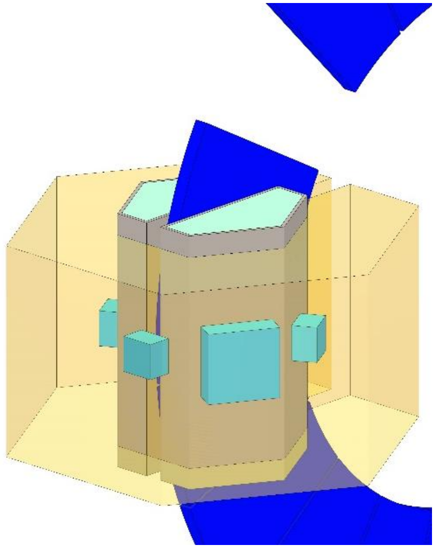
DNS parameters



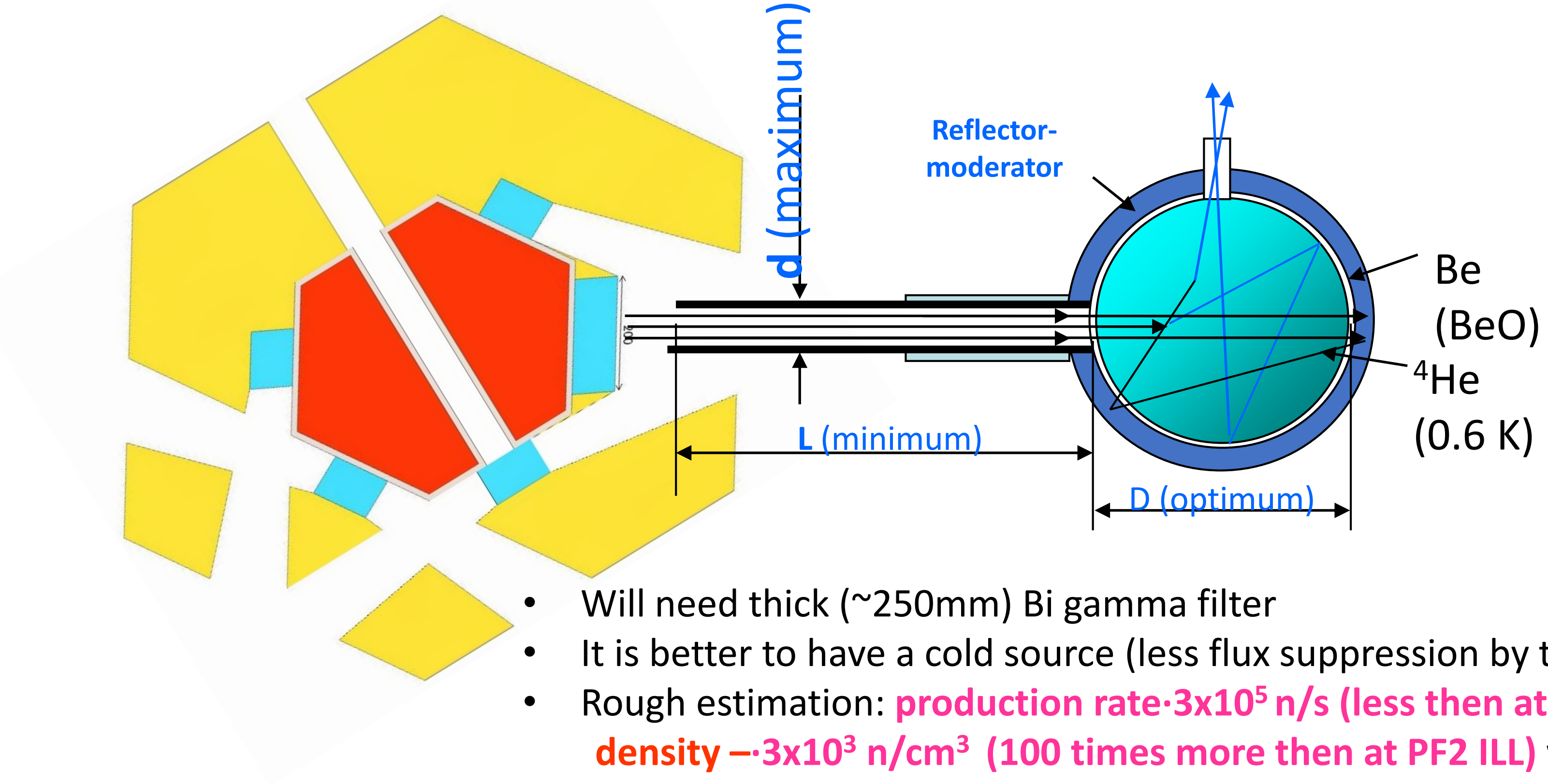
Average neutron flux density of thermal neutrons at the moderator surface, 1/(cm²s)	~$1\cdot10^{14}$
Peak neutron flux density of thermal neutrons at the moderator surface, 1/(cm²s)	~$5\cdot10^{16}$
Pulse width, ms	0.2
Repetition rate, Hz	10

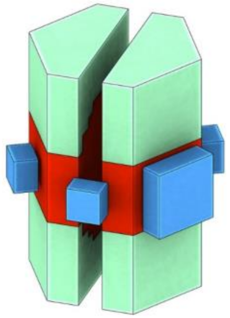






Possibility for DNS



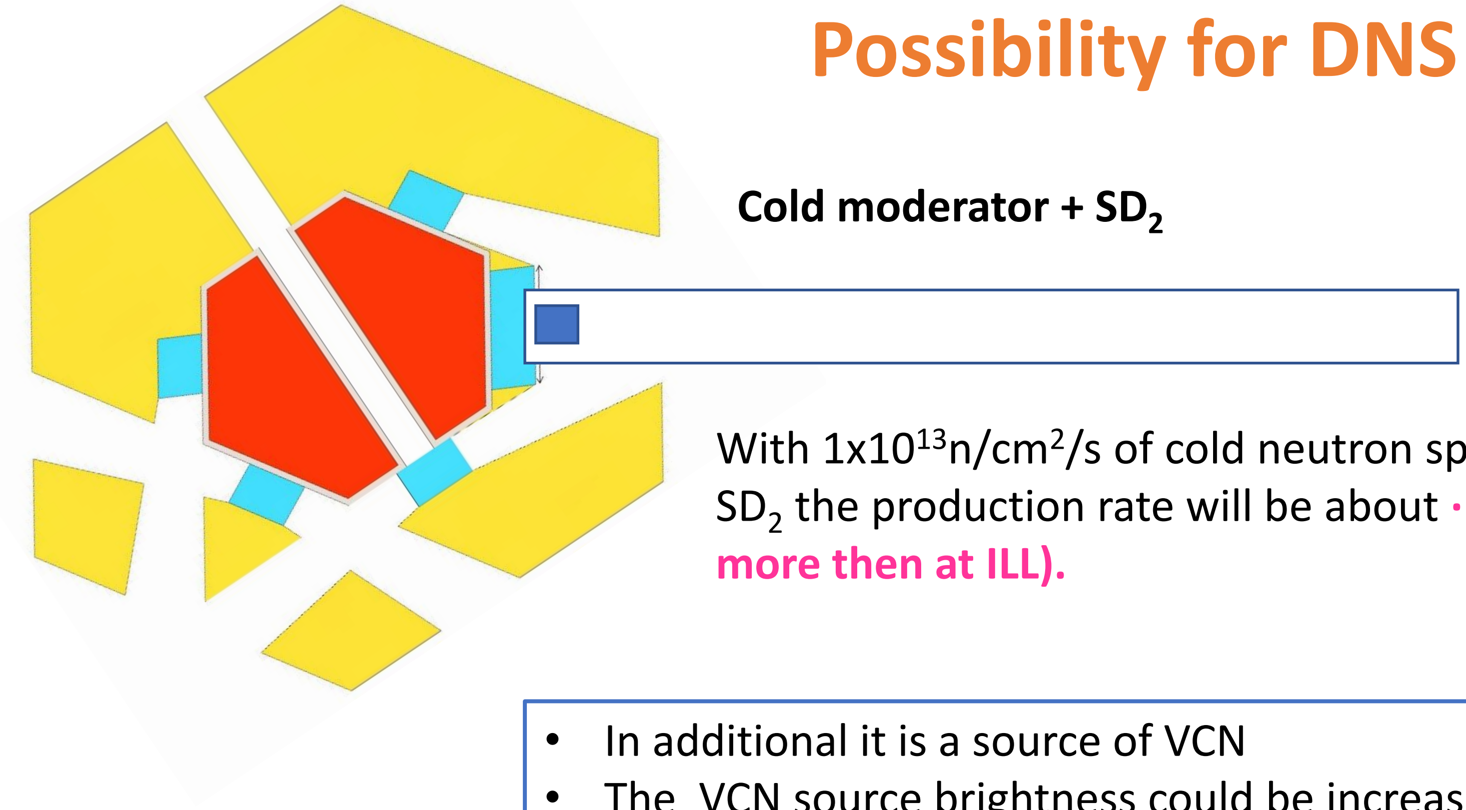


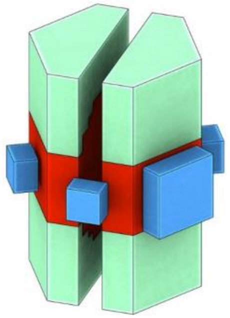
- Will need thick (~250mm) Bi gamma filter
- It is better to have a cold source (less flux suppression by the filter)
- Rough estimation: **production rate·$3x10^5$ n/s (less then at PF2 ILL); density –·$3x10^3$ n/cm^3 (100 times more then at PF2 ILL)** with **$5x10^{13}$n/cm^2/s at the moderator surface (20 times less then at the PIK)**

Calculation of neutron and gamma fluxes needed to define the source parameters

Some questions (trap material, effective extraction) are open.

Possibility for DNS





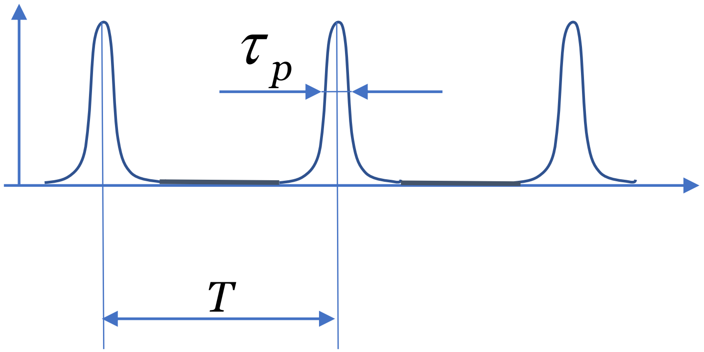
Cold moderator + SD_2

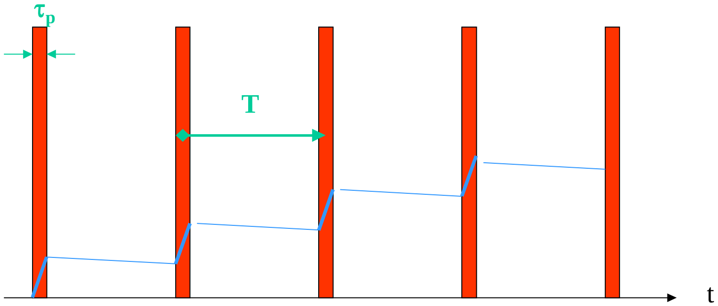
With 1×10^{13} n/cm^2/s of cold neutron spectra in 500 cm^3 of SD_2 the production rate will be about **·1×10^8 n/s (100 times more then at ILL).**

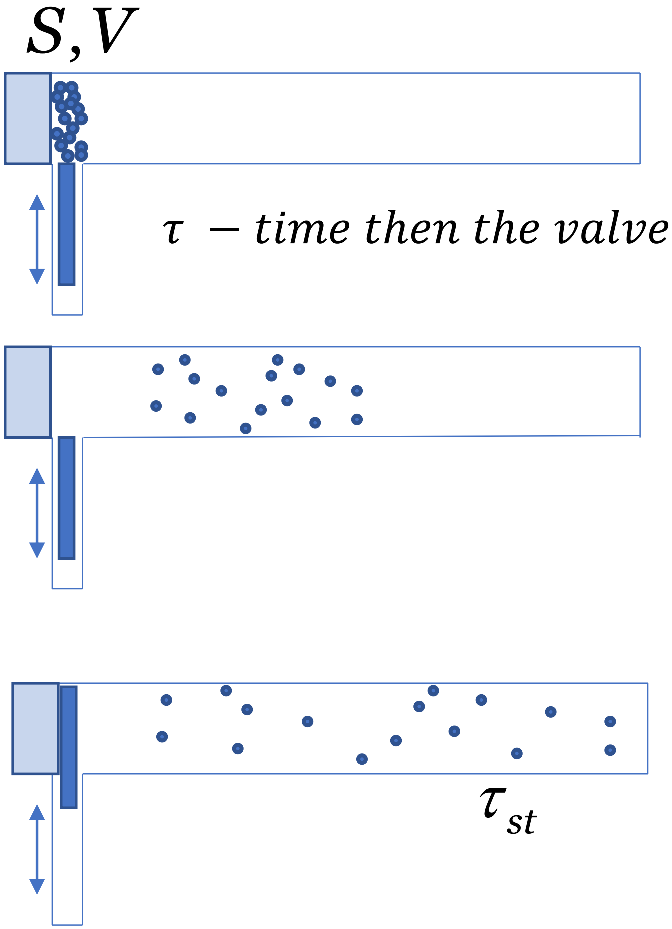
- In additional it is a source of VCN
- The VCN source brightness could be increased by VCN reflector but TOF will be lost (due to the VCN pulse widening)

Calculation of neutron flux and heat relies needed to define the source parameters

Pulse density accumulation?







τ − time then the valve is open

Pulse density accumulation?

At equilibrium case:

$$\frac{\rho_{imp} v}{4} S\tau_p = \frac{\rho v}{4} S\tau + \rho V(1 - e^{-\frac{T}{\tau_{st}}})$$

$$\rho = \frac{\rho_{imp}}{\frac{\tau}{\tau_p} + \frac{4V}{Sv}\frac{T}{\tau_{st}\tau_p}}$$

$$\frac{4V}{Sv} = \tau_{emp}$$

$$\boxed{\rho = \frac{\rho_{imp}}{\frac{\tau}{\tau_p} + \frac{\tau_{emp} T}{\tau_{st}\tau_p}}}$$

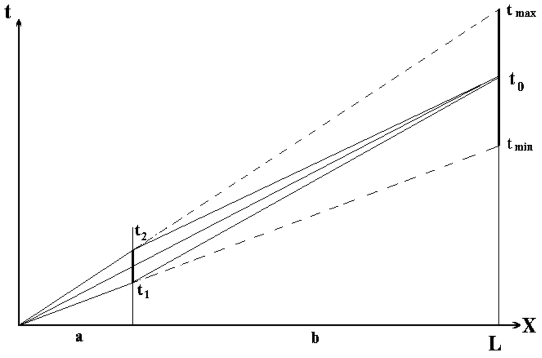
$$\rho = \begin{cases} \rho_{imp} & \text{if} \quad \frac{\tau_{st}}{\tau_{emp}} \square \frac{T}{\tau_p} \\ \rho_{imp}\frac{\tau_p}{T} & \text{if} \quad \frac{\tau_{st}}{\tau_{emp}} \sim 1 \end{cases}$$

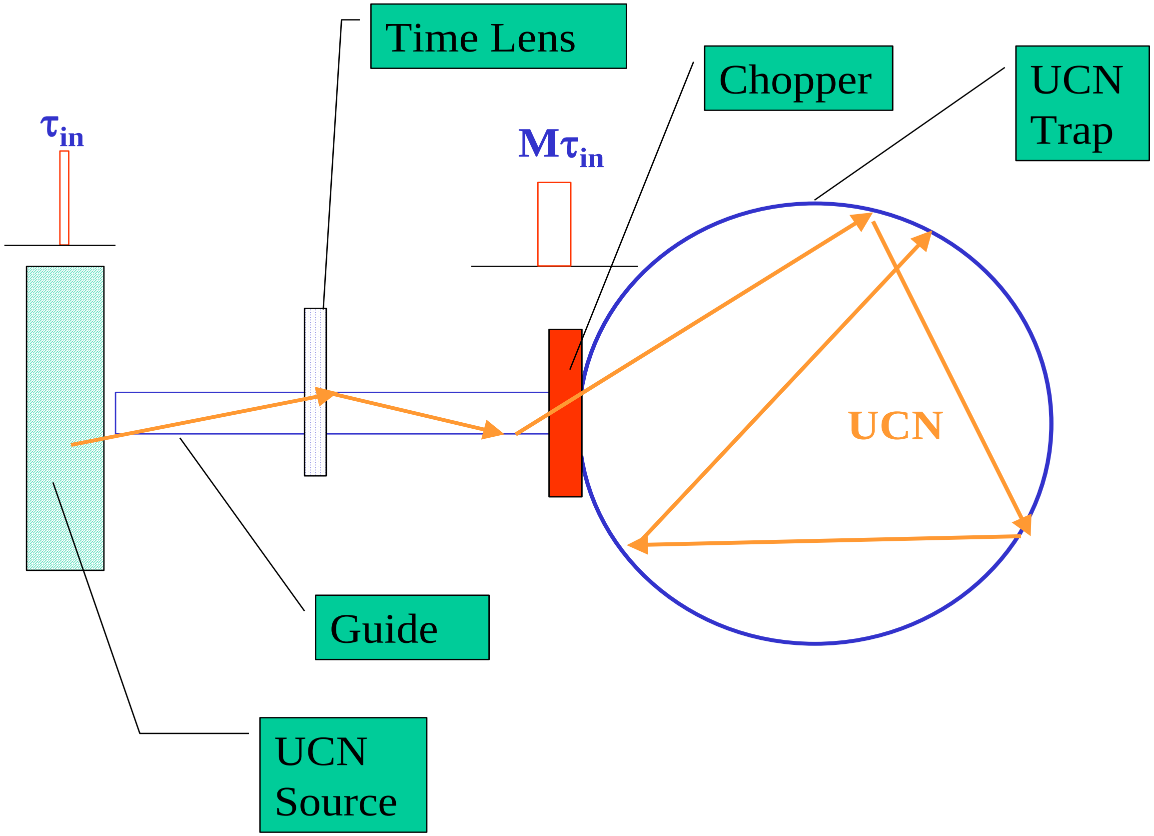
Gain factor for DNS is 500
But technical realization is
questionable.

(For ESS gain factor is 30)

Pulse density accumulation?

A.I.Frank and R.Gähler. Phys. of Atomic Nuclei, 63, (2000) 545





Conclusions:

1. Solid deuterium source looks reasonable for DNS.
2. The extensive calculations (fluxes, heat release ets.) are needed to define the source parameters.
3. Need relatively wide neutron channel without the shatter or with special shatter at any case.
4. It is good to have relatively thin biological shielding (vertical extraction of UCN possible).
5. Accumulation of pulsed density looks attractive but difficult from technical point. The time focusing of UCN "cloud" in mirror neutron guide need search and investigation of «time lens».
6. We should start at IBR-2.

Thank you for attention