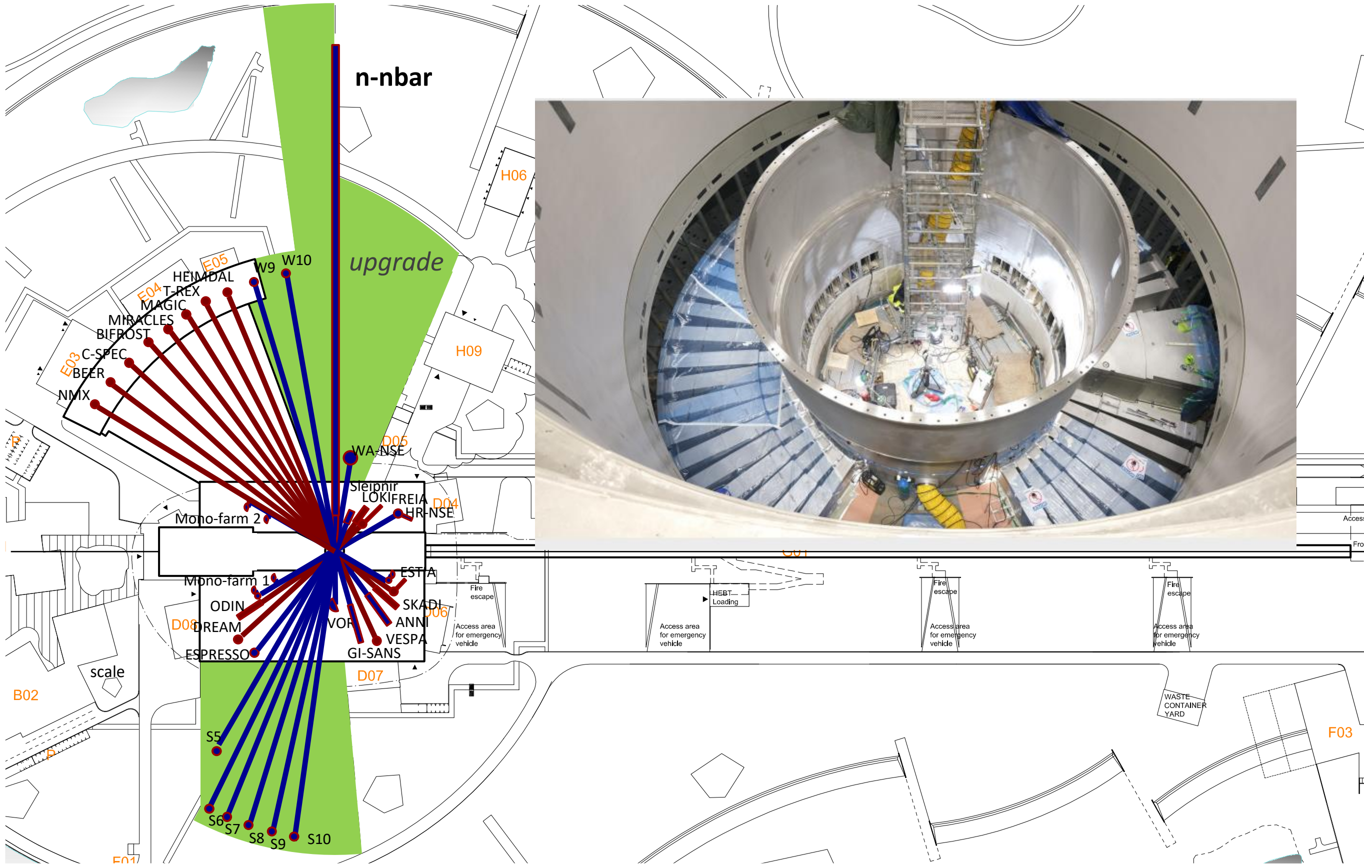
DTU

LENS meeting

Development of in-pile VCN and UCN source for ESS

Upgradeability of ESS

- Primary upgrade path: more instruments
- 42 beamports with ~ 6° separation
- Upgrade areas ~ 35 instruments possible
- **Lower moderator**
  - **All beamports can view both moderators**



The green part show the upgrade area

HighNESS goal

HighNESS aims at complementing the upper source in two different aspects

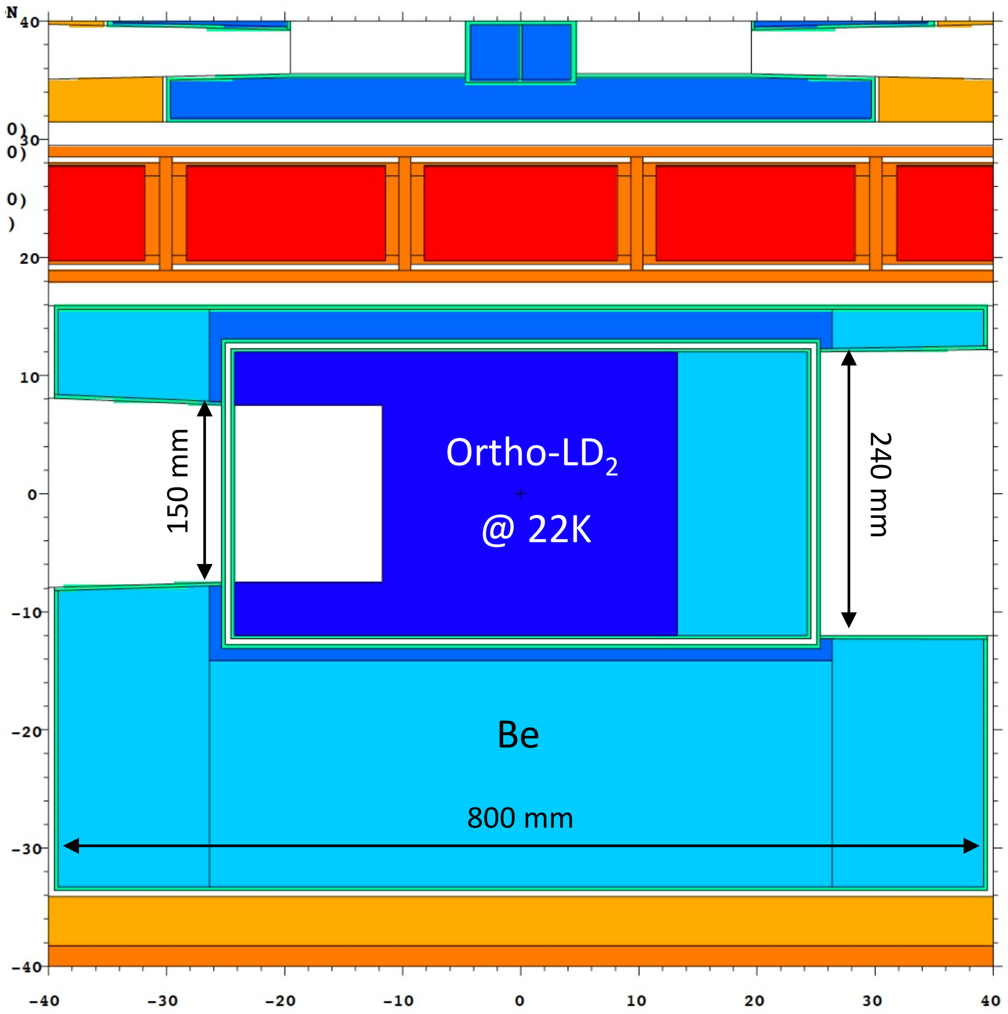
High Intensity

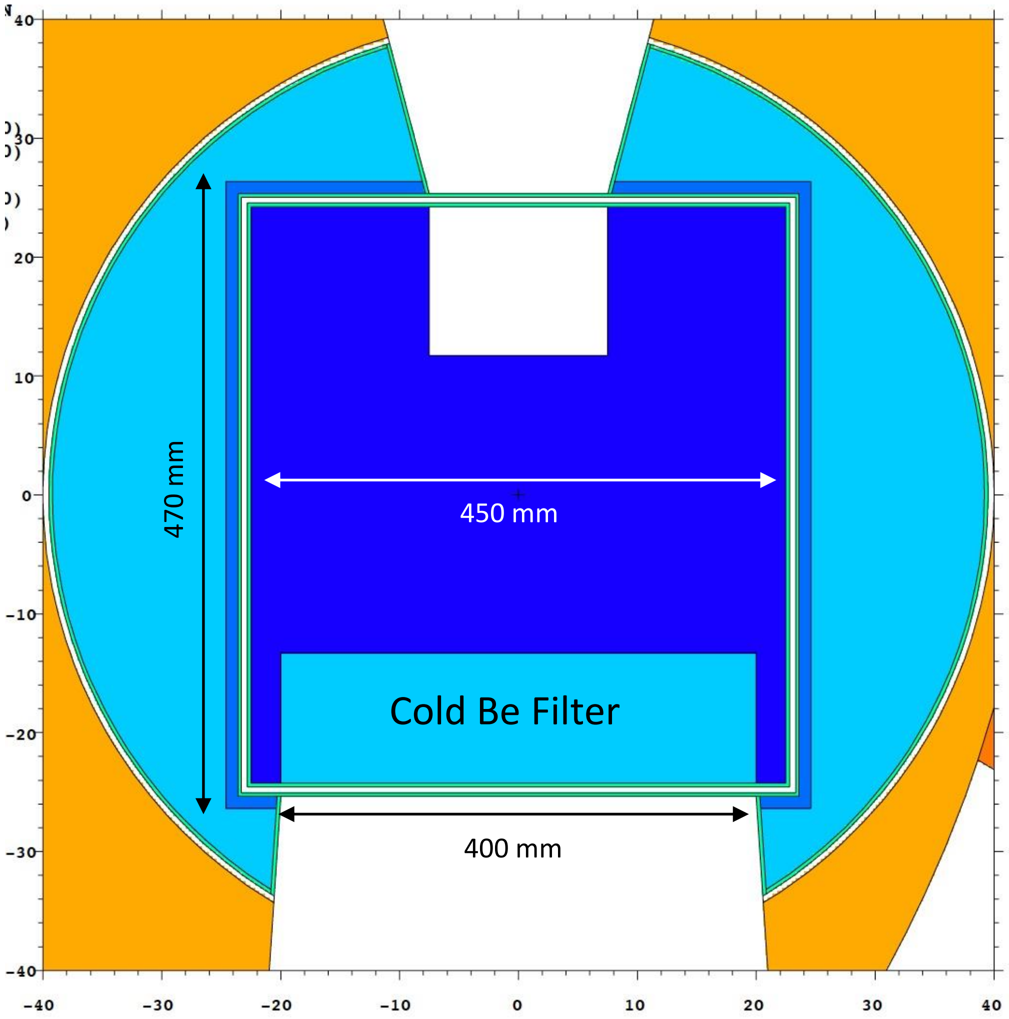
Higher intensity means larger emission surface and bigger moderator

Longer wavelengths

The main cold source in HighNESS is intended to serve instruments, and secondary VCN and UCN sources

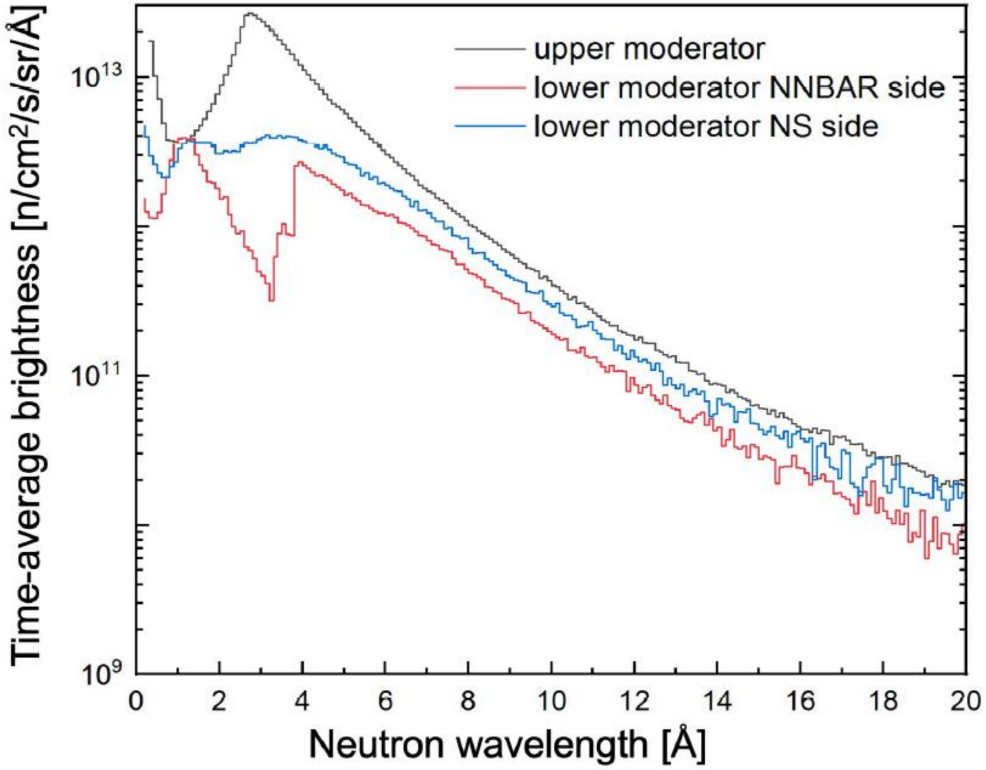
The cold source



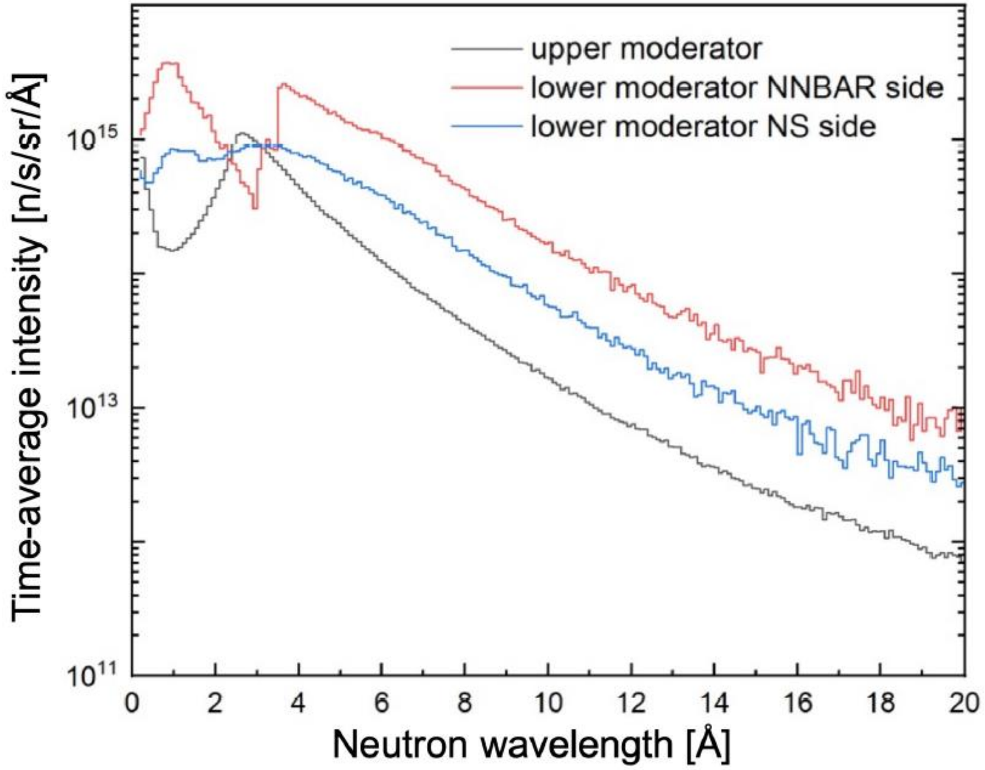


Performance of the cold source

Brightness



Intensity



Possible locations of the VCN and UCN sources

- On 2-4 February 2022, more than 100 scientists and experts from 23 nationalities took part in the workshop

- HighNESS teams working on several concepts on VCN and UCN sources

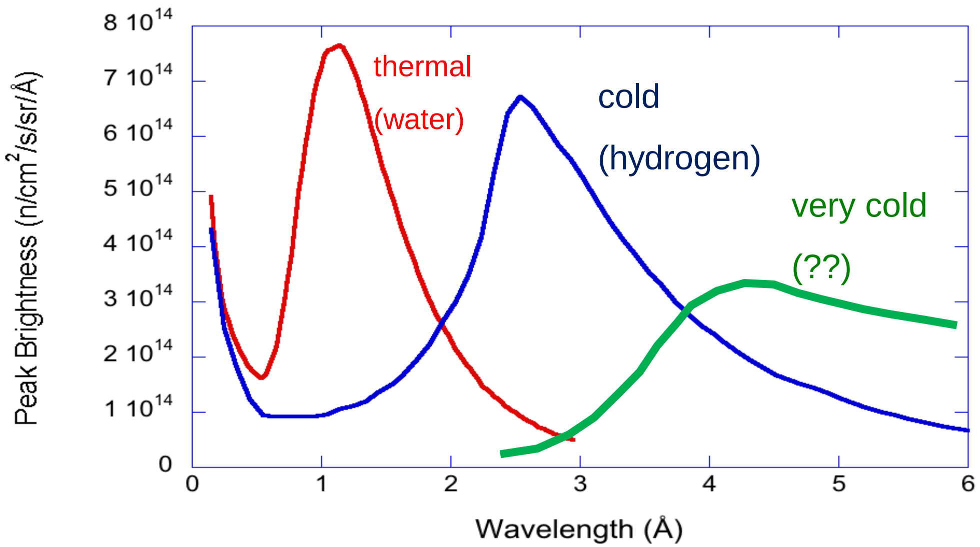
- Workshop proceedings published in a special issue of the Journal of Neutron Research in 2022

Very Cold Neutrons applications

VCN imply Increase in observation time for fundamental physics and expansion of dynamic range in neutron scattering.

cold	2-20 $\AA$
very cold	10–120 $\AA$
ultracold	$>$ 500 $\AA$

- Fundamental physics
  - NNBAR (FOM proportional to λ^2)
  - Possible applications in interferometry, nEDM, neutron life time measurements.
- Neutron scattering
  - Up to 20 Å: benefits for SANS and Spin-echo
  - Above 20 Å: Attractive region to be explored in SANS, spin-echo, reflectometry.



Possibilities for VCN source at ESS

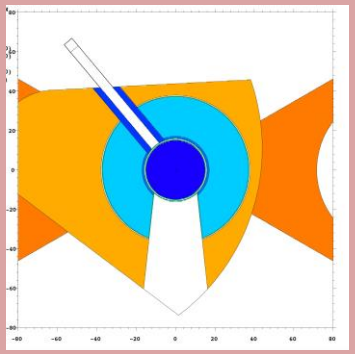
In the original HighNESS proposal

Advanced reflectors to increase transport of VCNs from the main cold source

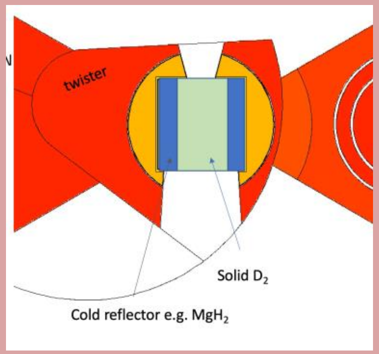
Dedicated in-pile VCN moderator

Recent concept by V. Neshvizevsky

Combined use of LD_2, SD_2 and nanodiamonds



1



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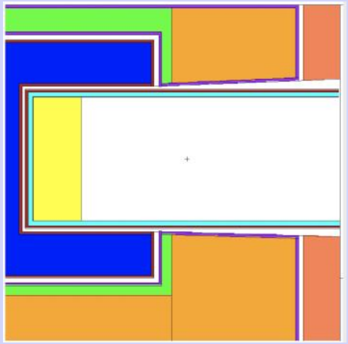
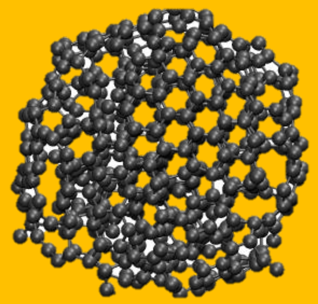


3

Novel reflector materials under study

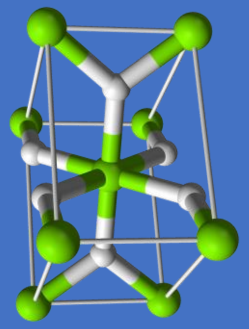
Nanodiamonds

- VCN reflector
- Thermal scattering library developed within HighNESS



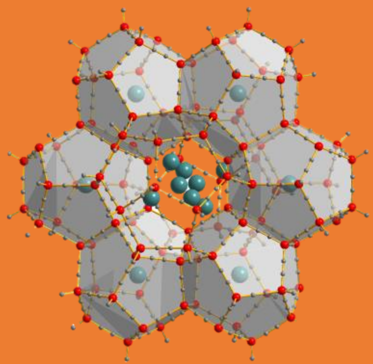
MgH_2

- CN and VCN reflector
- Thermal scattering library available



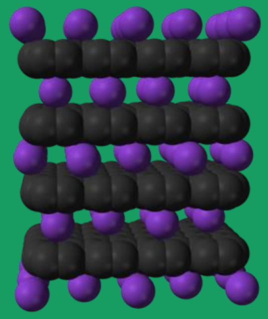
Clathrates hydrates

- Possible VCN converter or VCN reflector
- Cross section measurements and thermal scattering library within HighNESS



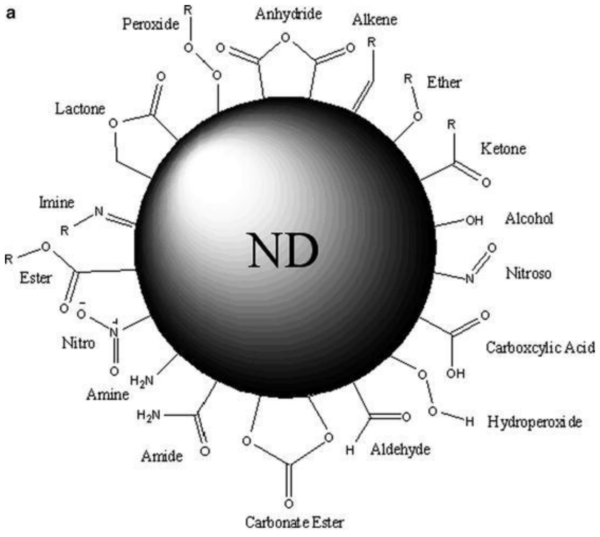
GIC

- Possible VCN reflector
- Cross section measurements and thermal scattering library determination within HighNESS

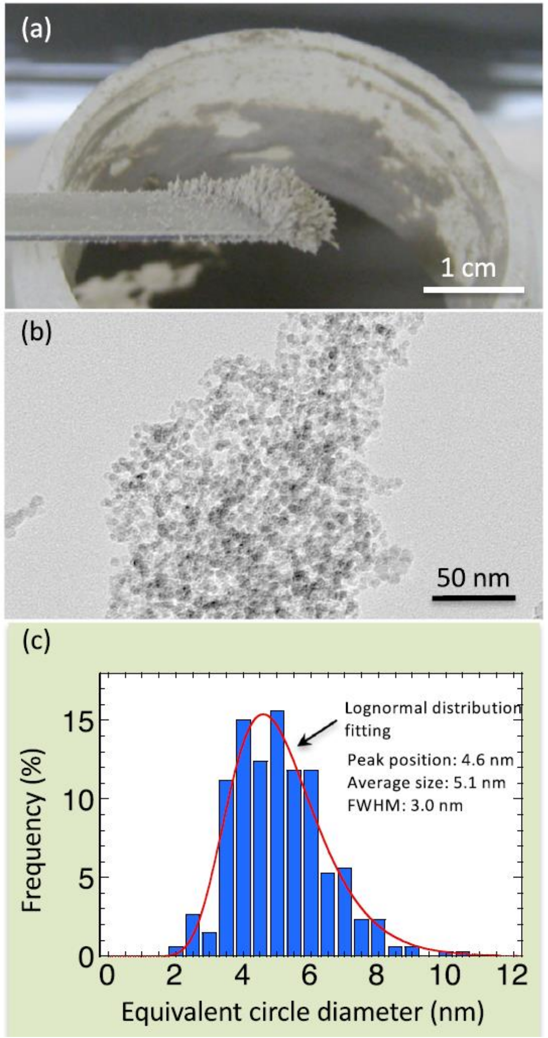


What are nanodiamonds?

- A diamond nucleus within an onion-like shell measuring few nanometers
- The outer surface is a shell with complex chemical composition, consisting of impurities such as carbon, oxygen, nitrogen and hydrogen

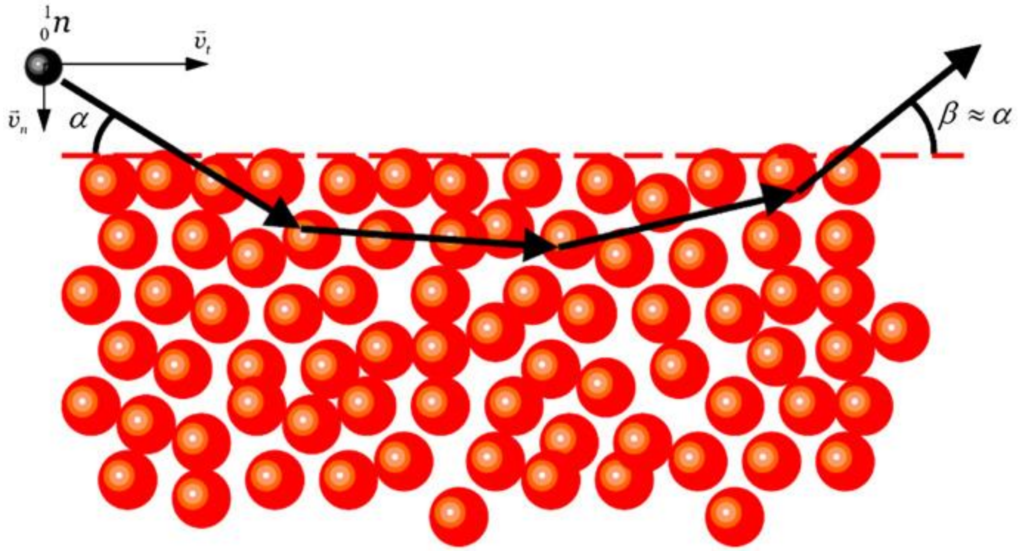


Ref [1]



Why do we need them?

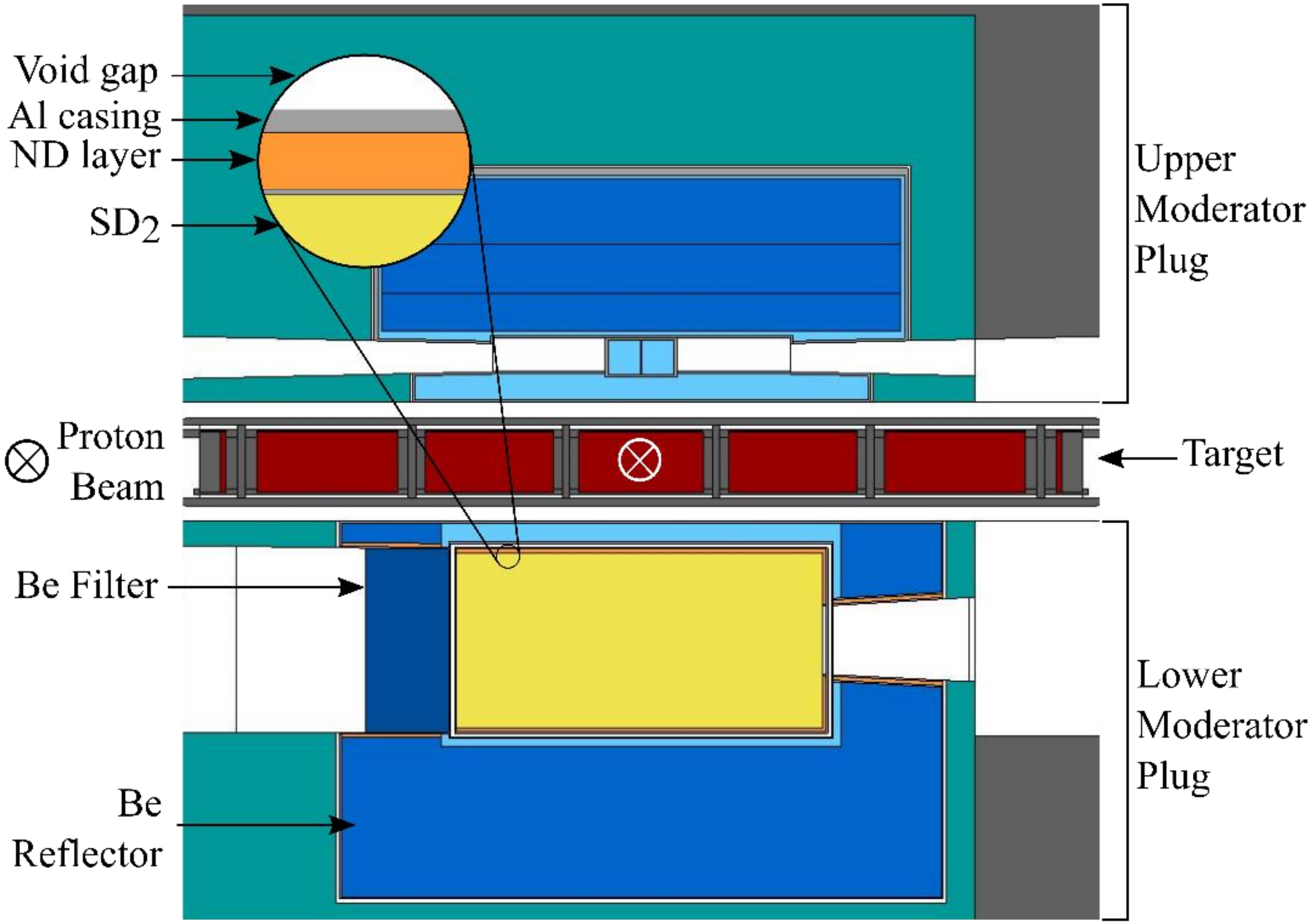
- Nanodiamond Powder samples showed efficient reflector properties for very cold neutrons (VCN) up to 10^{-4} eV [2]
- Good quasi-specular reflectivity for cold neutrons [3]
- Nanoparticles provides a sufficiently large cross-section for elastic scattering on a spatial scale comparable to the VCN wavelength
- Carbon has a low absorption cross-section



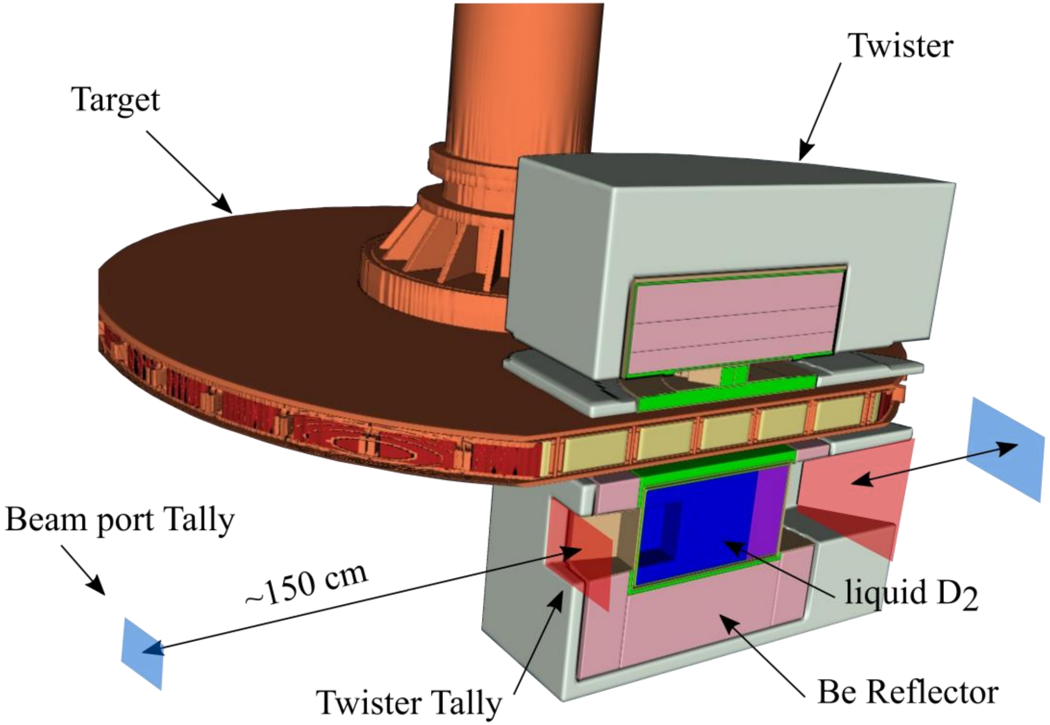
Ref [4]

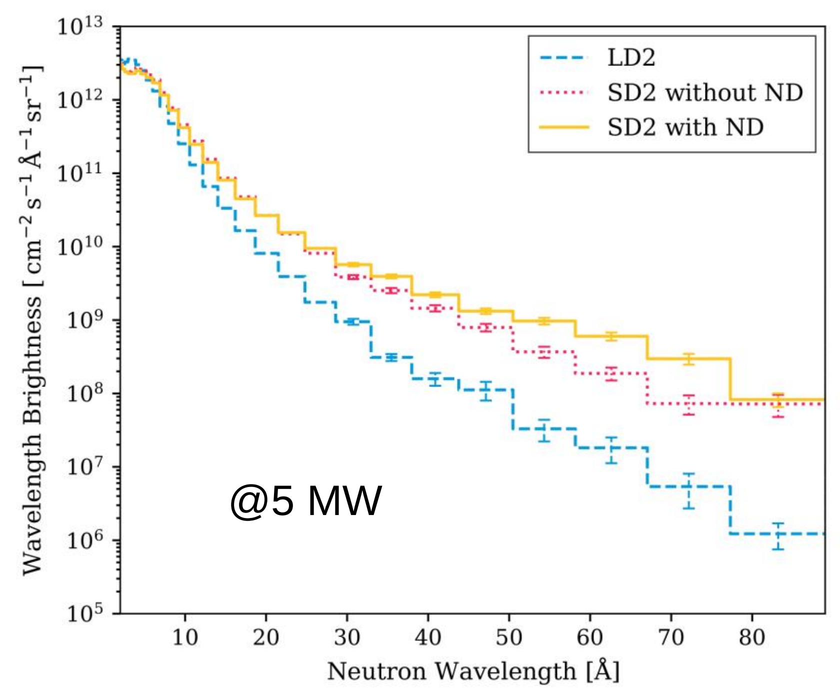
SD_2 VCN moderator

- 45 x 49 x 24 cm^3 box shape
- 50 L of solid-D_2 at 5 K
- Reflector layer made of ND, 5 mm thick
- 10-cm Be filter at 20 K on the NNBAR side



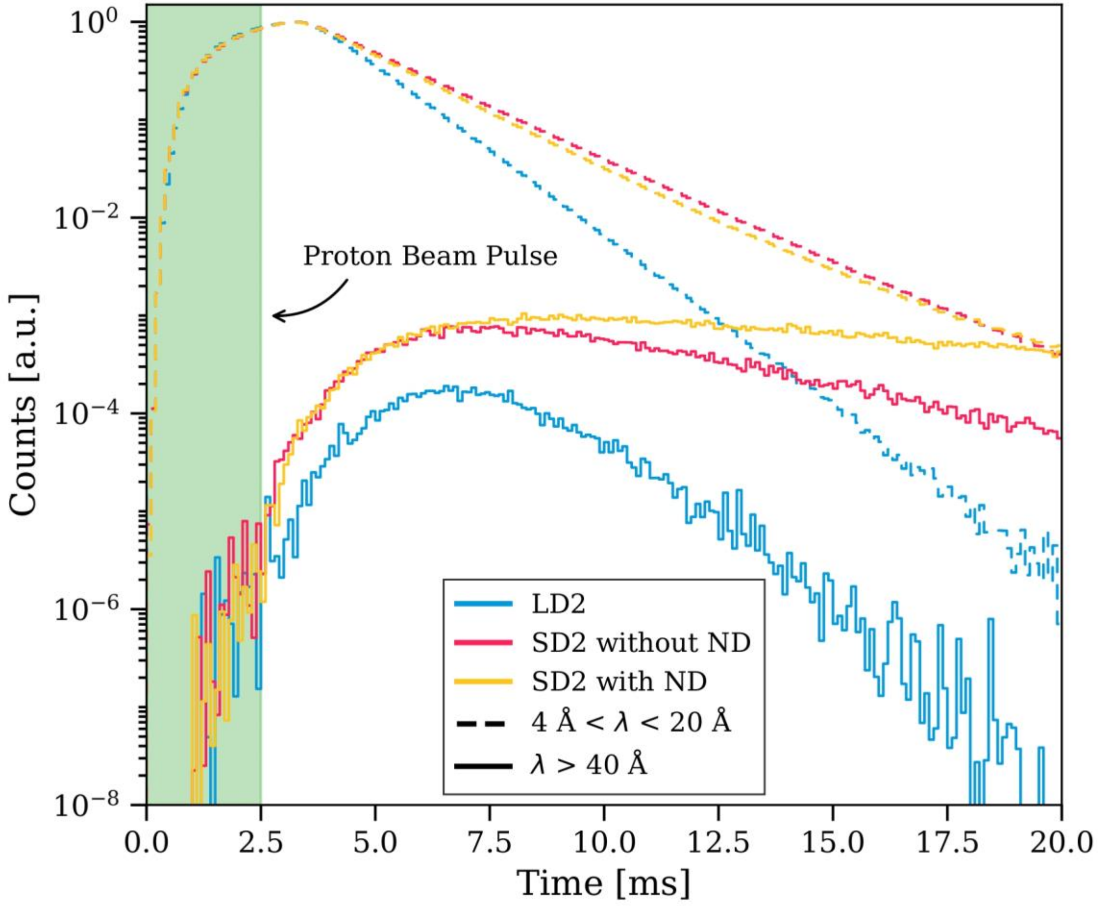
Performance





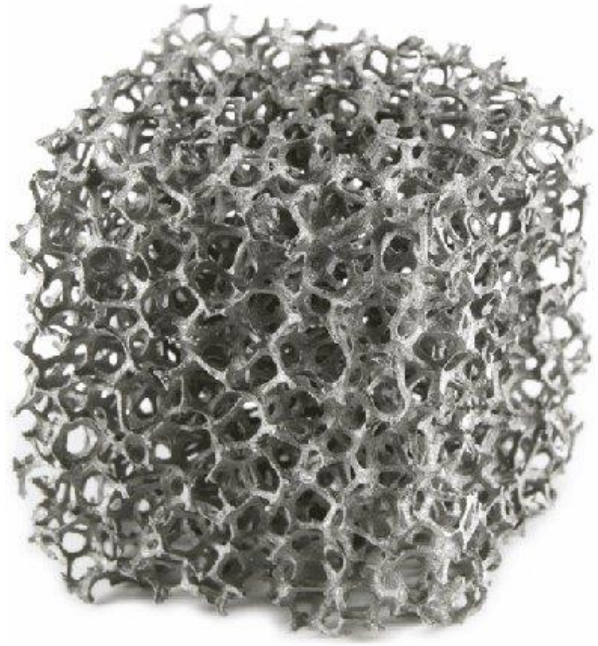
	> 40 Å	10 Å to 40 Å	4 Å to 10 Å	2.5 Å to 4 Å
N.S.	19.0	2.4	1.2	0.7
NNBAR	14.3	2.3	1.3	0.6

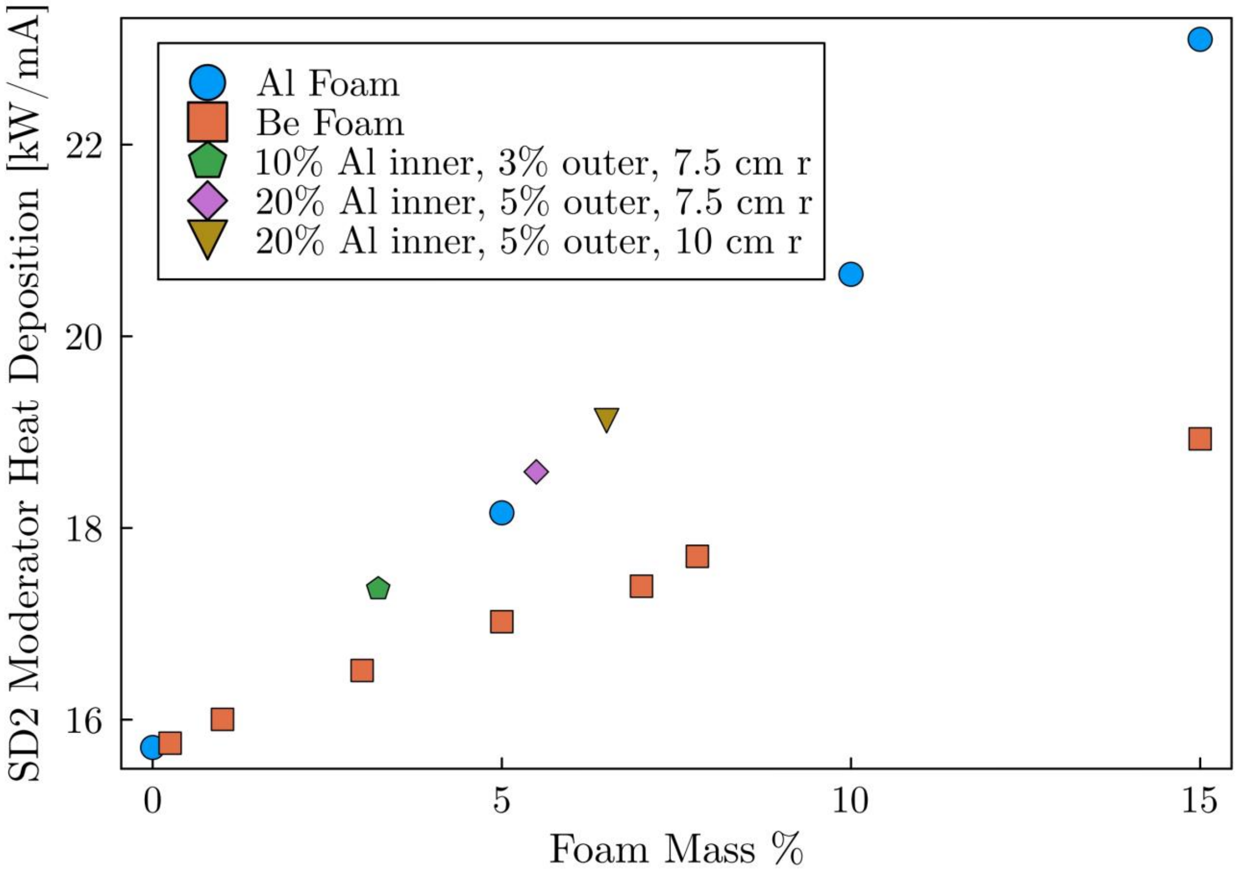
Emission time



How do we plan to cool it?

- Preliminary calculations show it is possible to cool it within the ESS environment **at 2 MW** beam power by use of metallic foam and conventional liquid-He channel

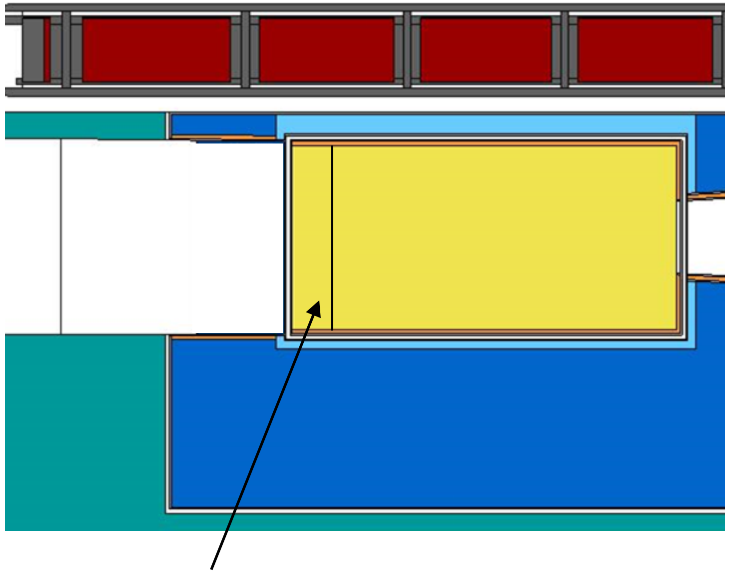




UCN Production

- Solid-D_2 can be used for UCN production
- Only last few centimeters will be effective
- No foam should be put here
- Cooling still a problem

The future of the NNBAR beamline after the experiment could be UCN



UCN production density in the last 5 cm:

- 9.13E5 UCN/cm^3/s

UCN converter

- Thin-film 2-cm SD_2 converter
- Al vessel with 2 mm walls

UCN production density

3.07E5 UCN/cm^3/s

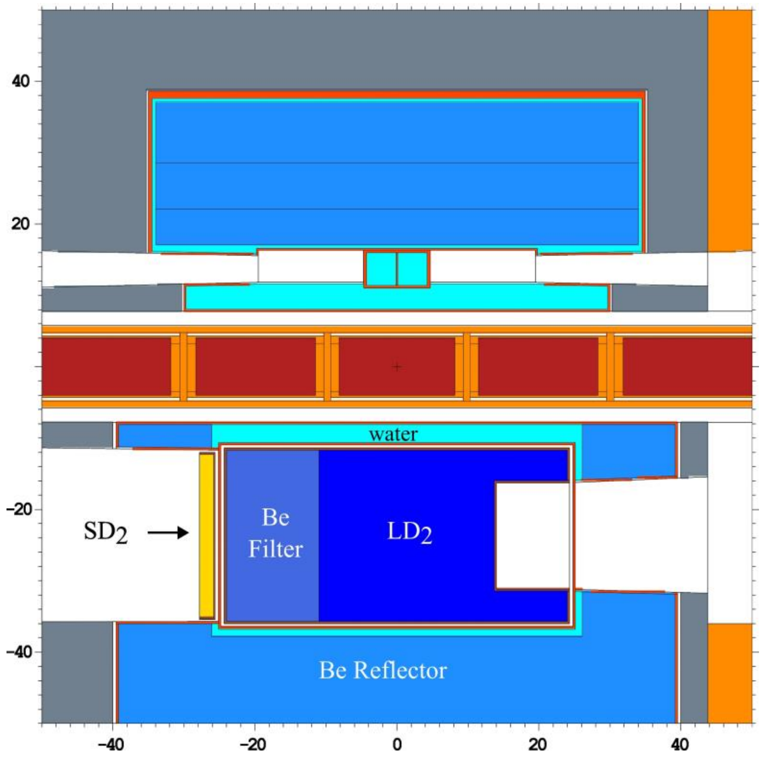
No cold Be Filter

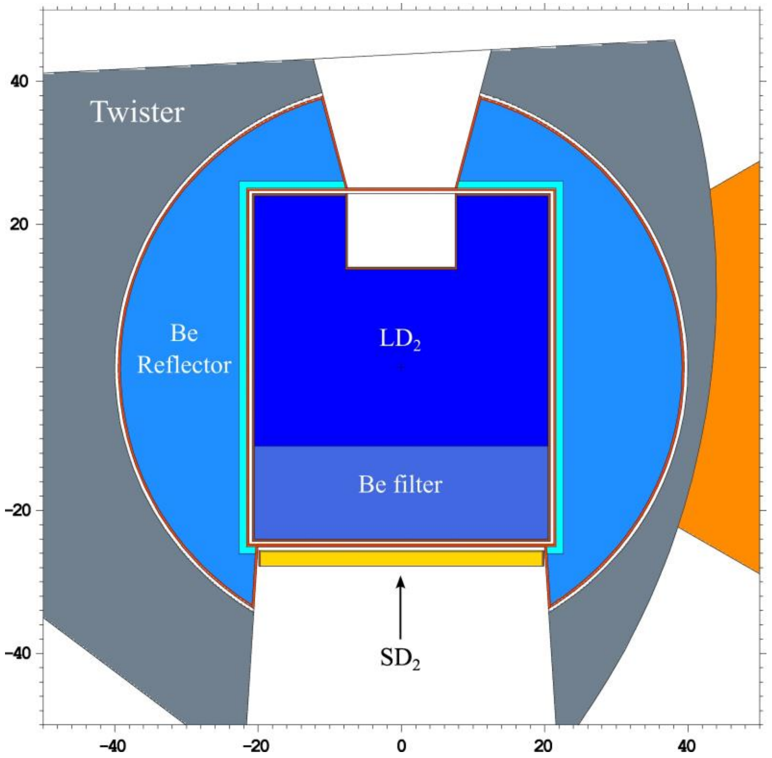
UCN production rate density

4.70E5 UCN/cm^3/s

Heat-load

760 W





3-in-1 moderator

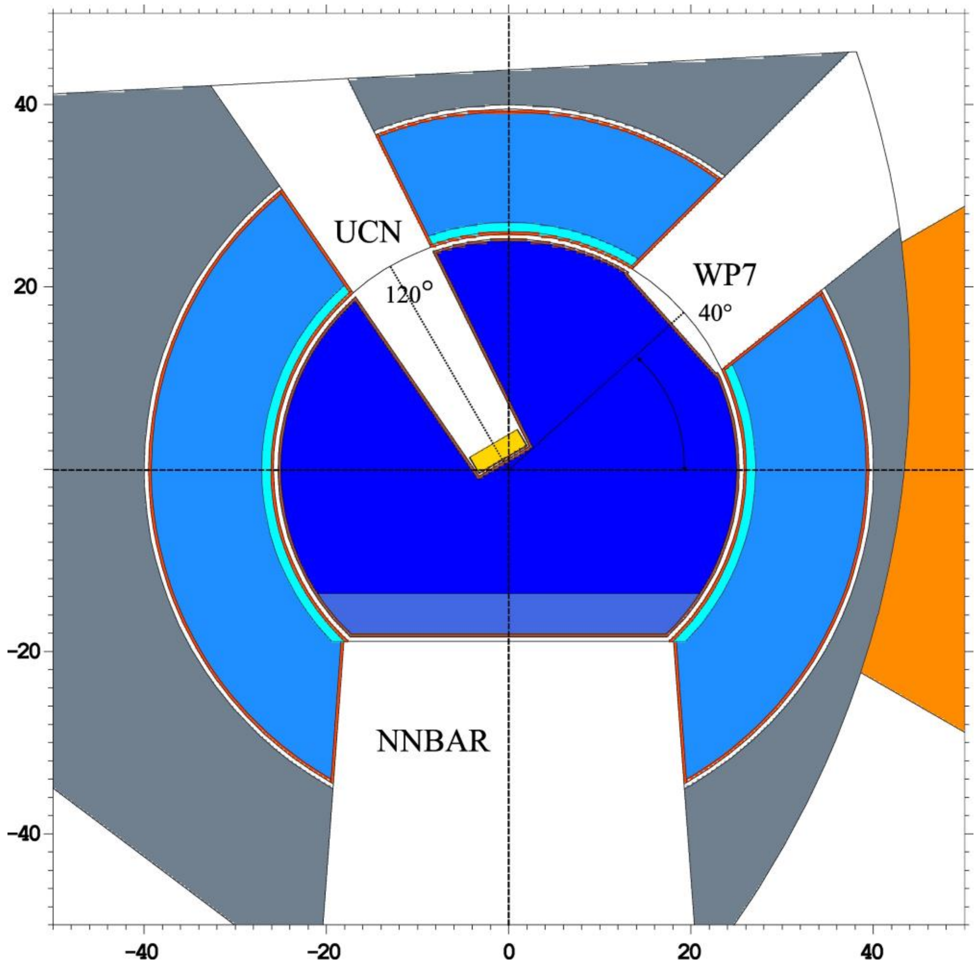
- Cylindrical moderator 45 cm diameter
- 3 openings
  1. 24x40 NNBAR opening with flat surface and Be filter
  2. 10x10 UCN opening with a deep reentrant hole and a thin-film SD_2 moderator at the bottom
  3. 15x15 neutron scattering opening

UCN production rate density

2.34E6 UCN/cm^3/s

Heat-load

550 W



Conclusions

- We found that solid-D_2 could be used to build a high-intensity VCN source
- Nanodiamonds are almost transparent in transmission for cold neutron, but at lower energies they show optimal properties as reflector material
- Cooling is going to be challenging, but:

1. A VCN source could operate at higher temperature than 5 K
2. We should not give up on the possibility to innovate

- In any case, solid-D_2 could play a role in the future of the ESS. With the right amount of effort and expertise there is fertile ground for designing the first high-intensity UCN source

Thank you
for the attention

References

1. **Teshigawara, M.**, Y. Tsuchikawa, G. Ichikawa, S. Takata, K. Mishima, M. Harada, M. Ooi, et al. “Measurement of Neutron Scattering Cross Section of Nano-Diamond with Particle Diameter of Approximately 5 nm in Energy Range of 0.2 MeV to 100 MeV.” *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 929 (June 11, 2019): 113–20.
2. **Nesvizhevsky, V. V**., E. V. Lychagin, A. Yu. Muzychka, A. V. Strelkov, G. Pignol, and K. V. Protasov. “The Reflection of Very Cold Neutrons from Diamond Powder Nanoparticles.” *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 595, no. 3 (October 11, 2008): 631–36.
3. **Granada, J.** Rolando, J. Ignacio Márquez Damián, and Christian Helman. “Studies on Reflector Materials for Cold Neutrons.” *EPJ Web of Conferences* 231 (2020): 04002.
4. **Cubitt, R.,** E. V. Lychagin, A. Yu. Muzychka, G. V. Nekhaev, V. V. Nesvizhevsky, G. Pignol, K. V. Protasov, and A. V. Strelkov. “Quasi-Specular Reflection of Cold Neutrons from Nano-Dispersed Media at above-Critical Angles.” *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 622, no. 1 (October 1, 2010): 182–85.
5. **Borovinšek, Matej & Vesenjak, Matej & Jože, M & Ren, Zoran**. (2008). Computational reconstruction of scanned aluminum foams for virtual testing.