PSI Center for Neutron and Muon Sciences

15 Years of Operational Experience with the Ultracold Neutron Source UCN at PSI

ICANS-XXV

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Malmö, Sweden, 13th April 2026

Outline

1. Introduction
2. Main Features of PSI's UCN Source
3. Cryogenic Challenges with handling three phases of deuterium
4. Maximizing the UCN yield
5. Upgrading the UCN source: The UCN EZE Project

Ultracold Neutrons

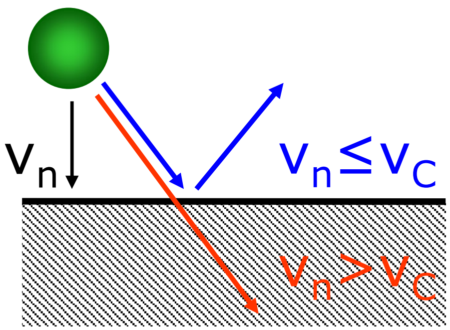
Ultracold neutrons are free neutrons which are reflected on certain materials under <u>any</u> angle of incidence

UCN < 300neV ~ 8m/s ~ 0.003 K !

particularly suited wall materials:

e.g. diamond-like-carbon (DLC),

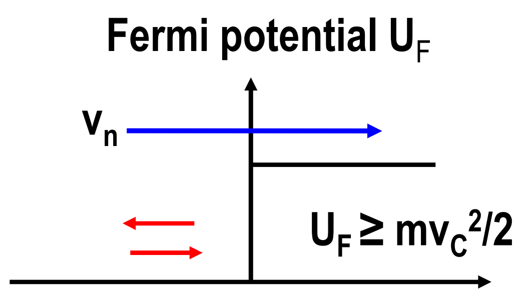
beryllium, nickel



⇒ Neutrons with E_{kin} < 300 neV

can be stored

E. Fermi, 1946 , Ya. B. Zeldovich
Sov. Phys. JETP 9, 1389 (1959)



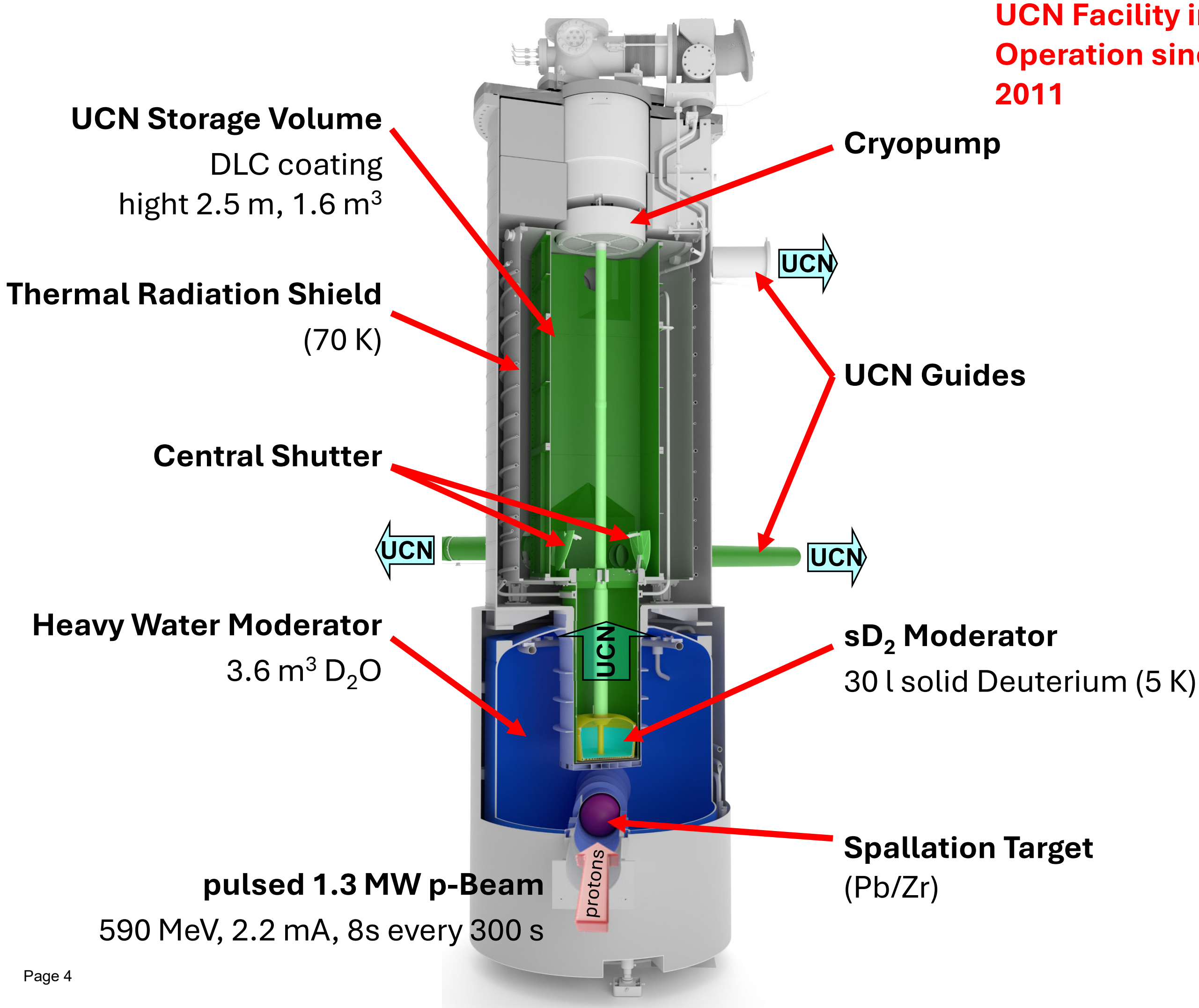
Fundamental neutron physics:

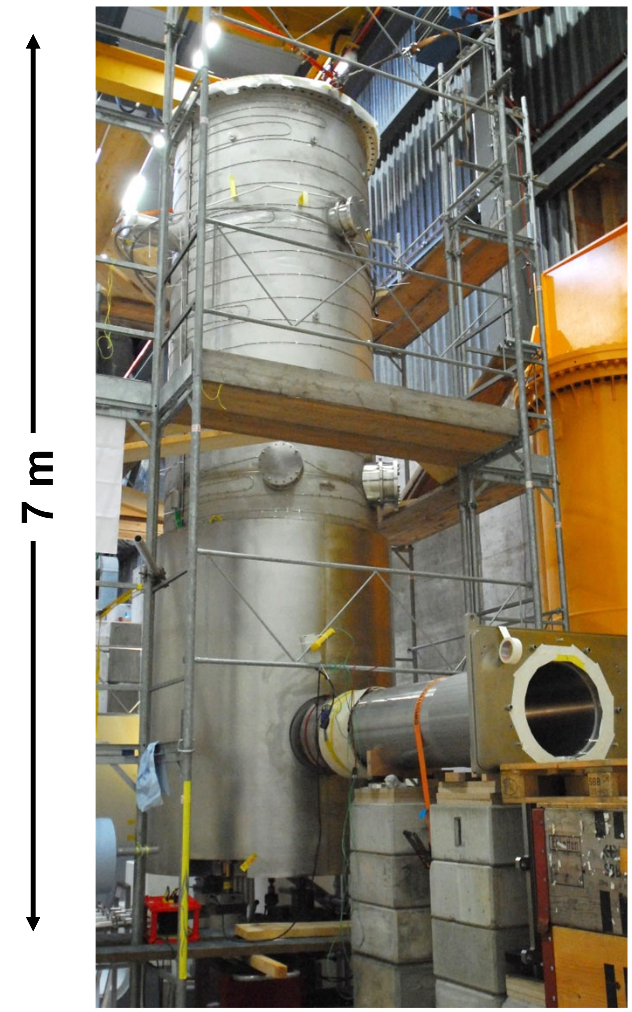
- the search for an electric dipole moment,
- neutron lifetime,

drives the world wide interest in UCN sources with high UCN density.

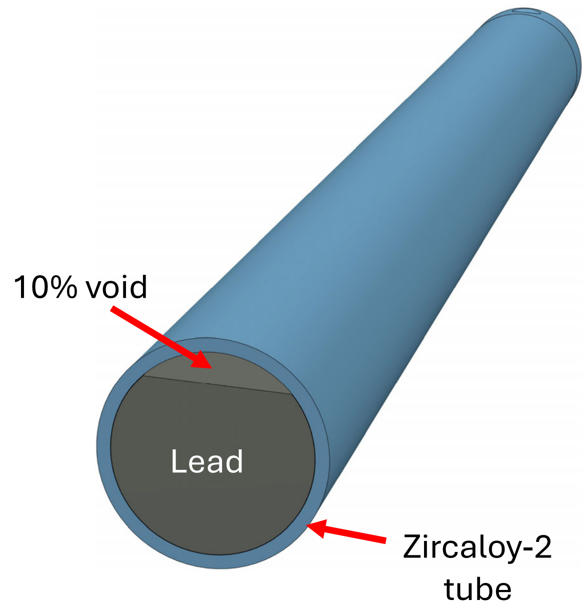
Key Components of the UCN Facility

World's Largest UCN Facility in Operation since 2011





The UCN Target



The UCN target was fully assembled in PSI’s in-house workshop

«Cannelloni»-type target rods: 621 Zircaloy tubes filled with lead (90%)

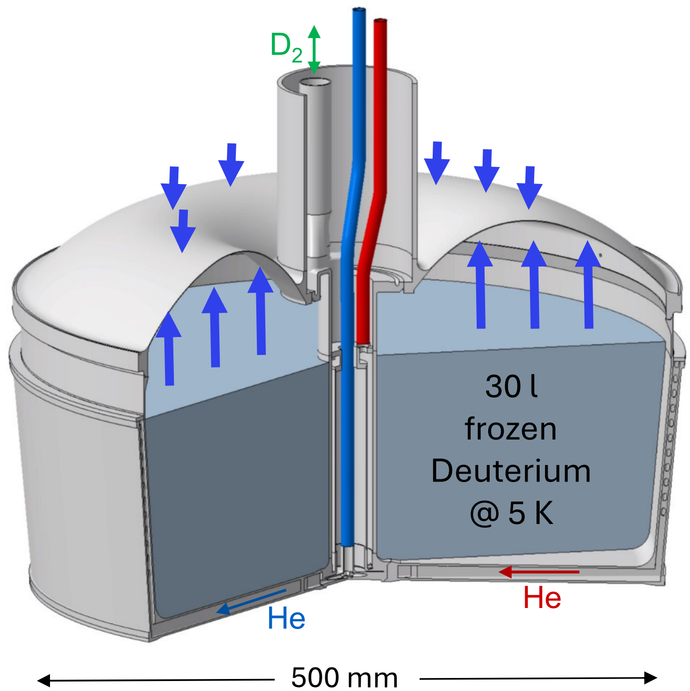
The UCN sD_2 moderator vessel

0.5 mm $AlMg_3$

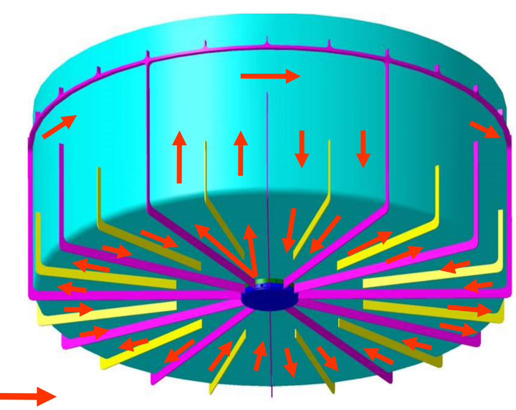
2 × 1.5 mm AlMg4.5Mn

all parts EB welded

at 3 bar inner pressure ⇒ 2 t load

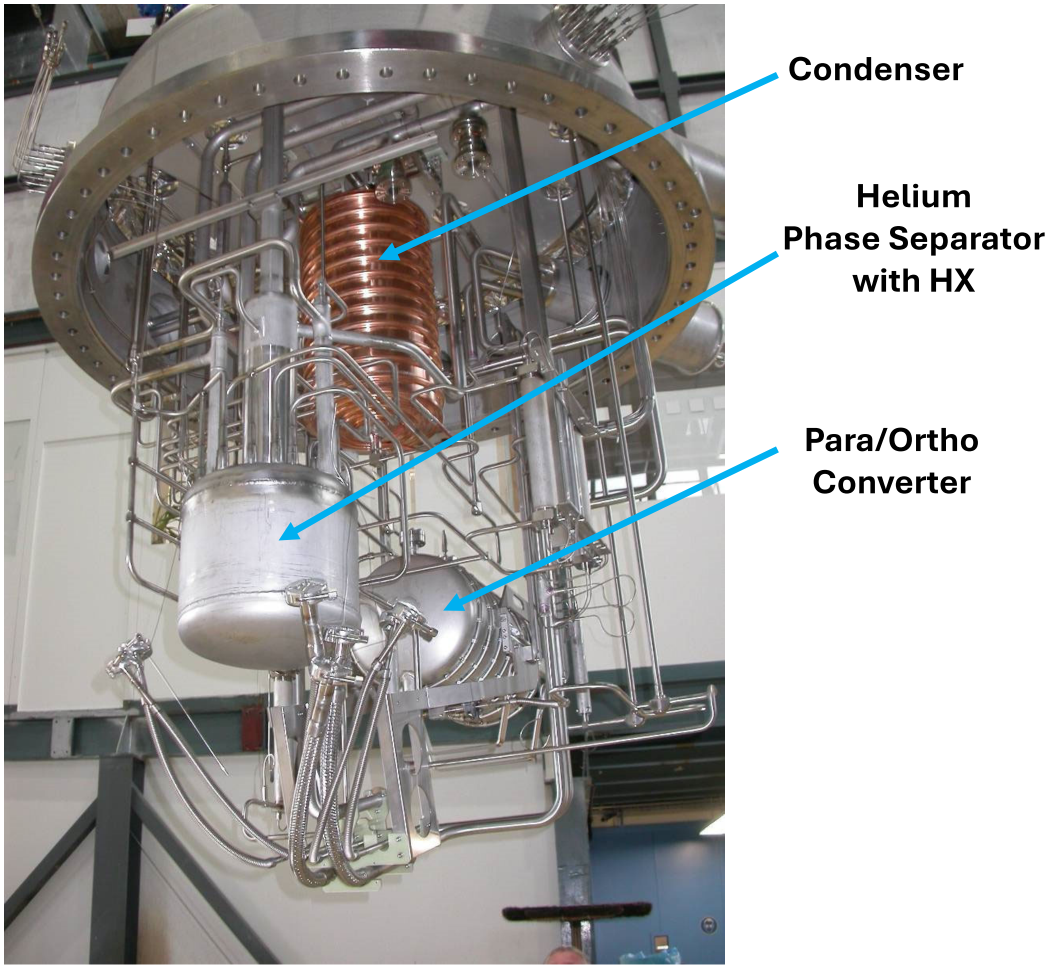


double-walled structure

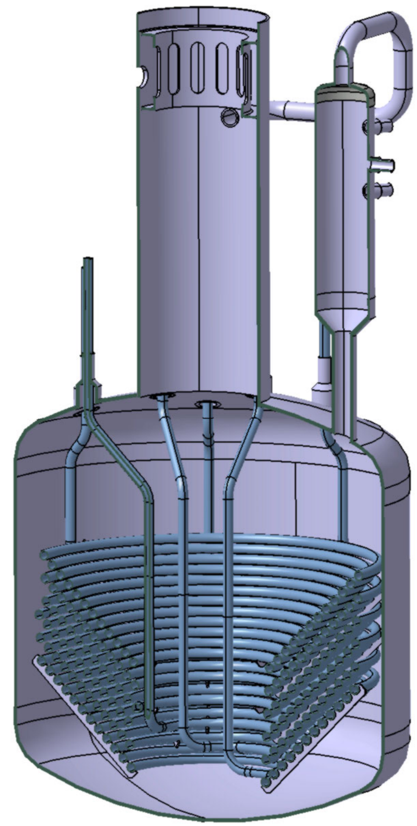


Helium-flow direction

Coldbox for Gaseous/Liquid/Solid Deuterium Handling



Interior of the coldbox without superinsulation



helium phase separator with
6 heat exchangers (7.5m each)

D_2 phase diagram

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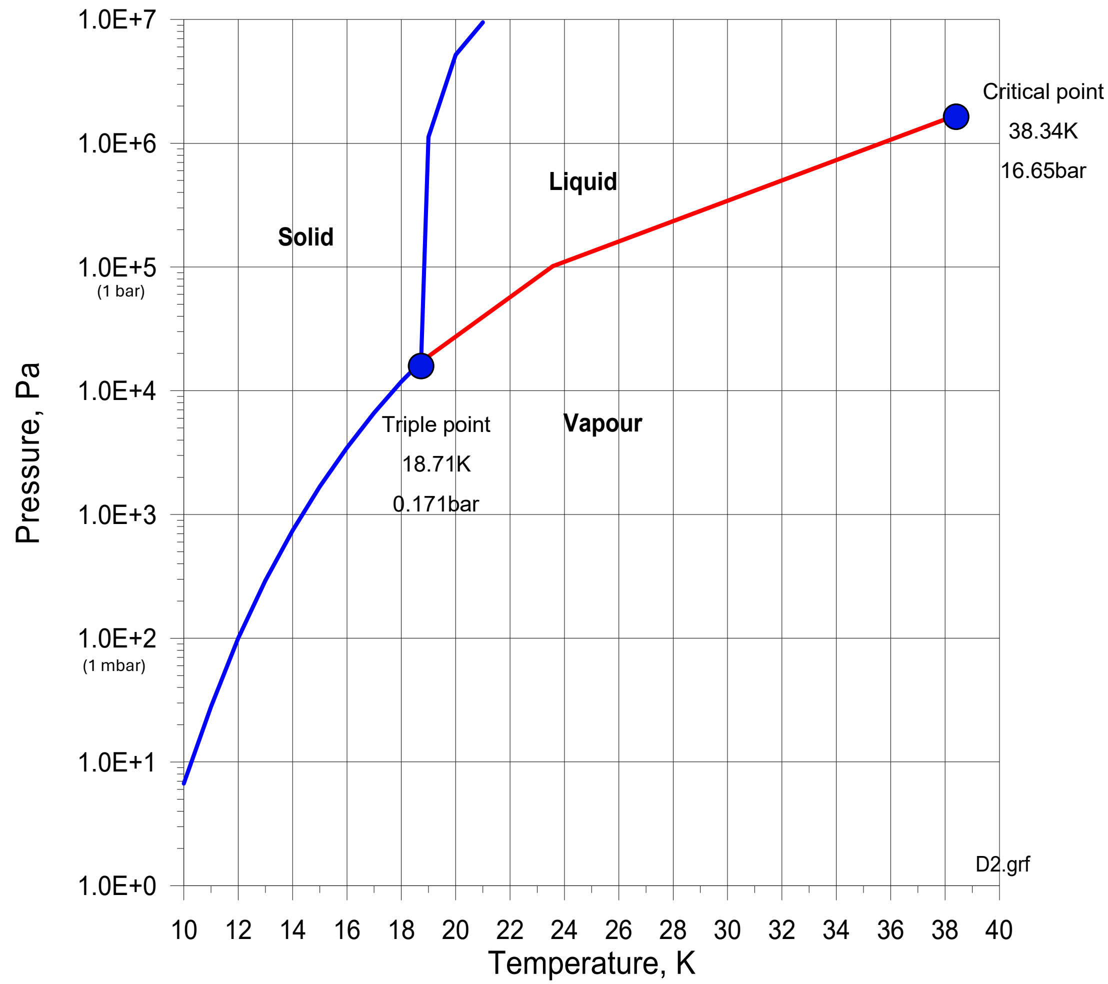
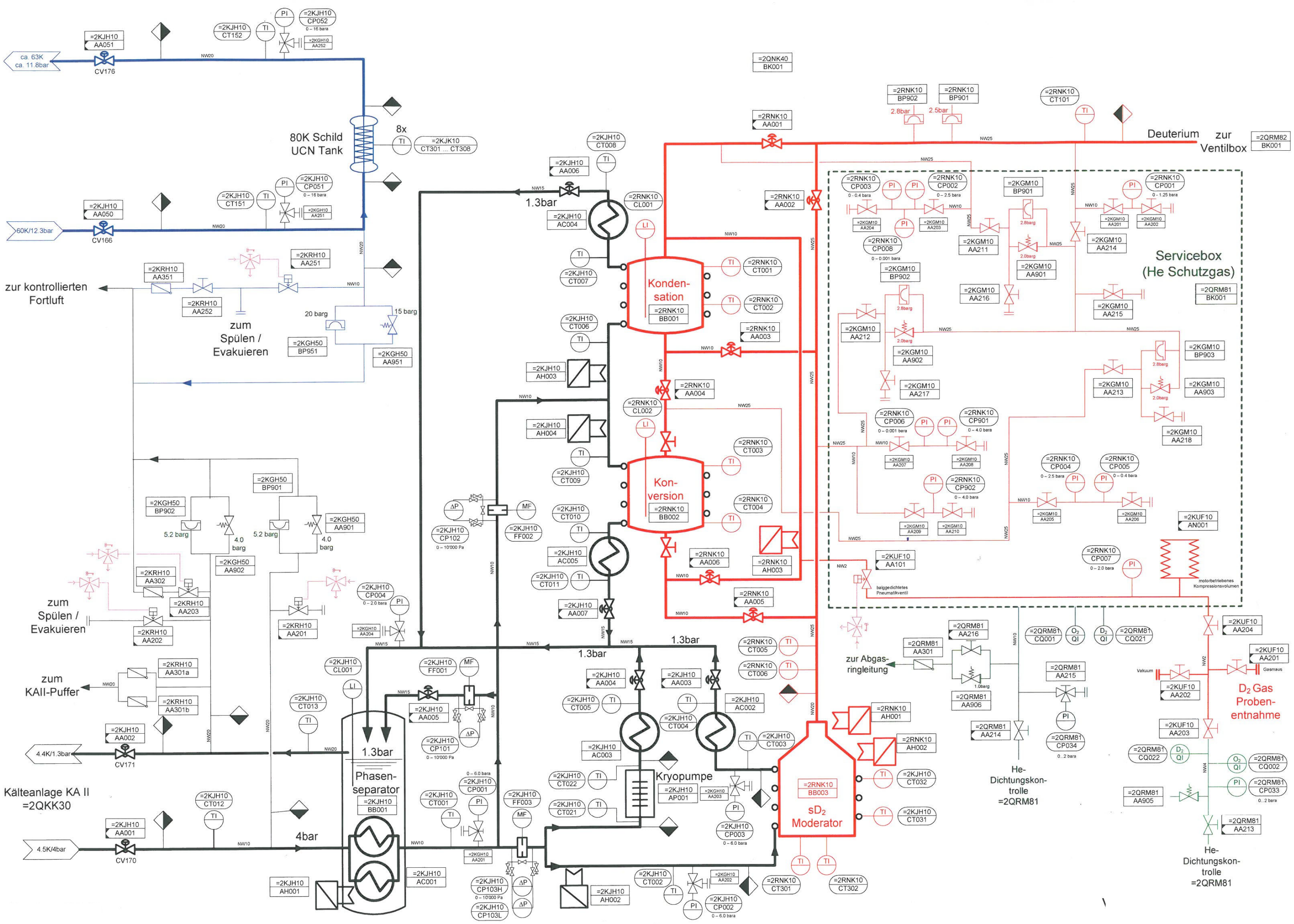
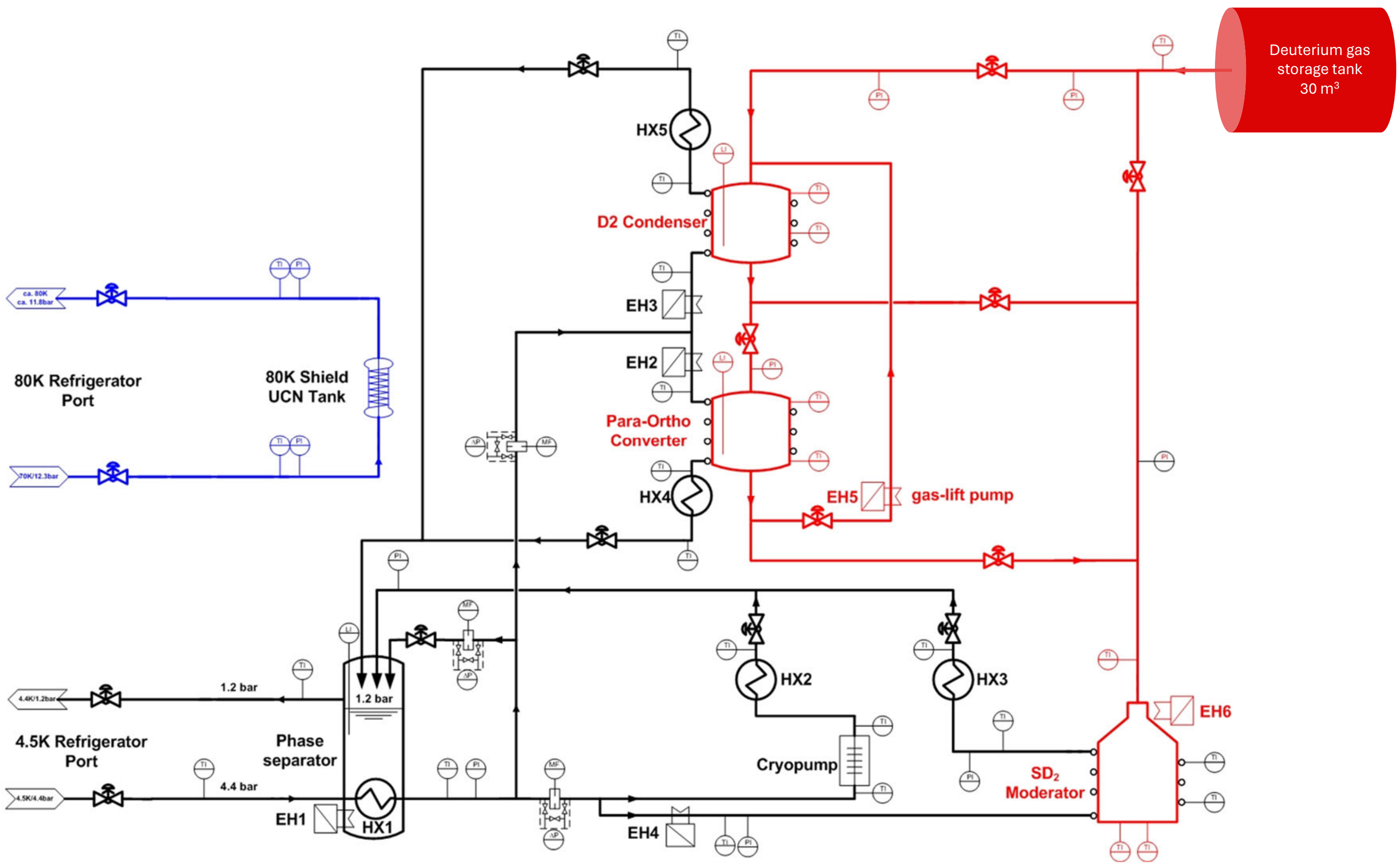


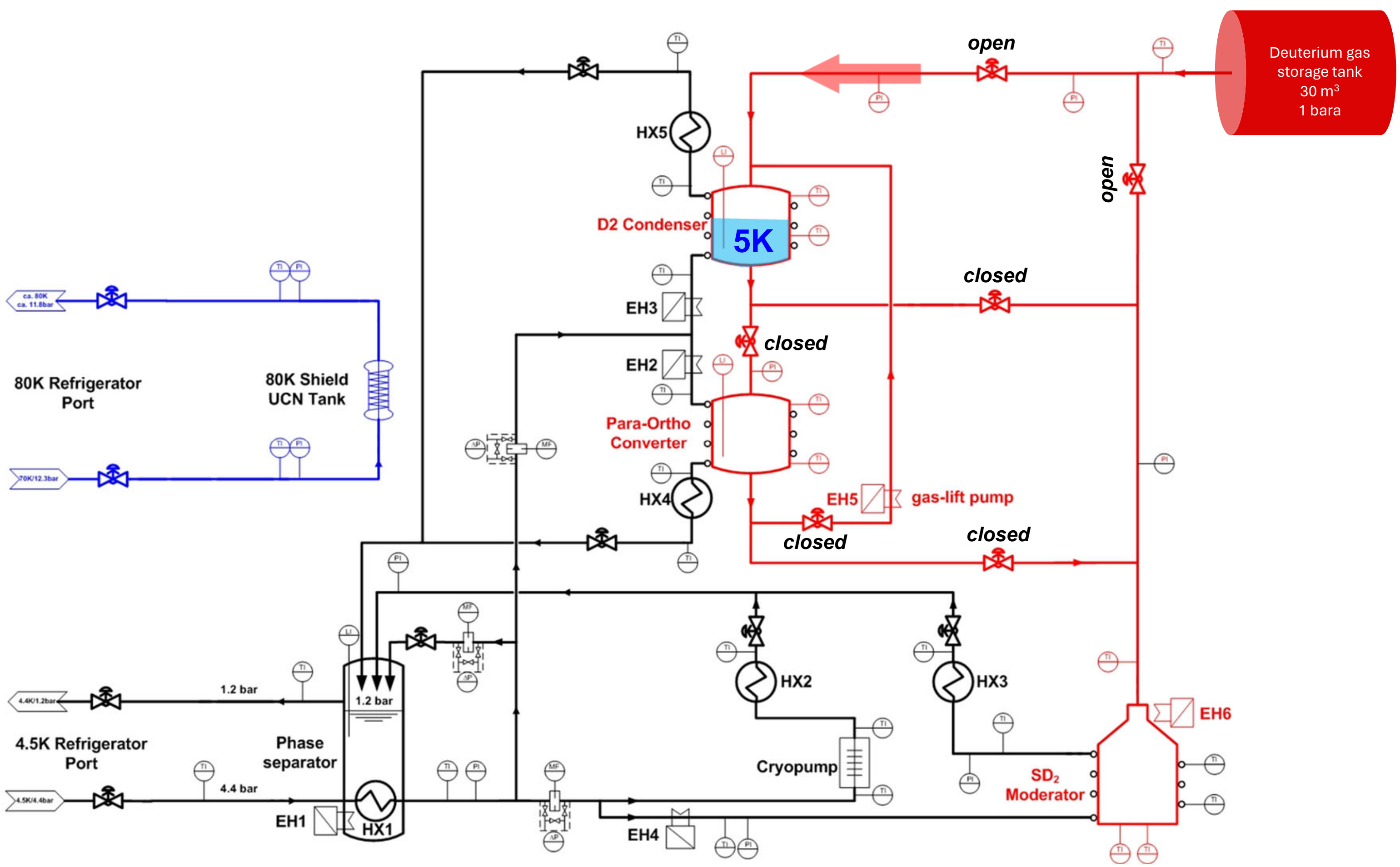
Detailed Coldbox Cooling Scheme



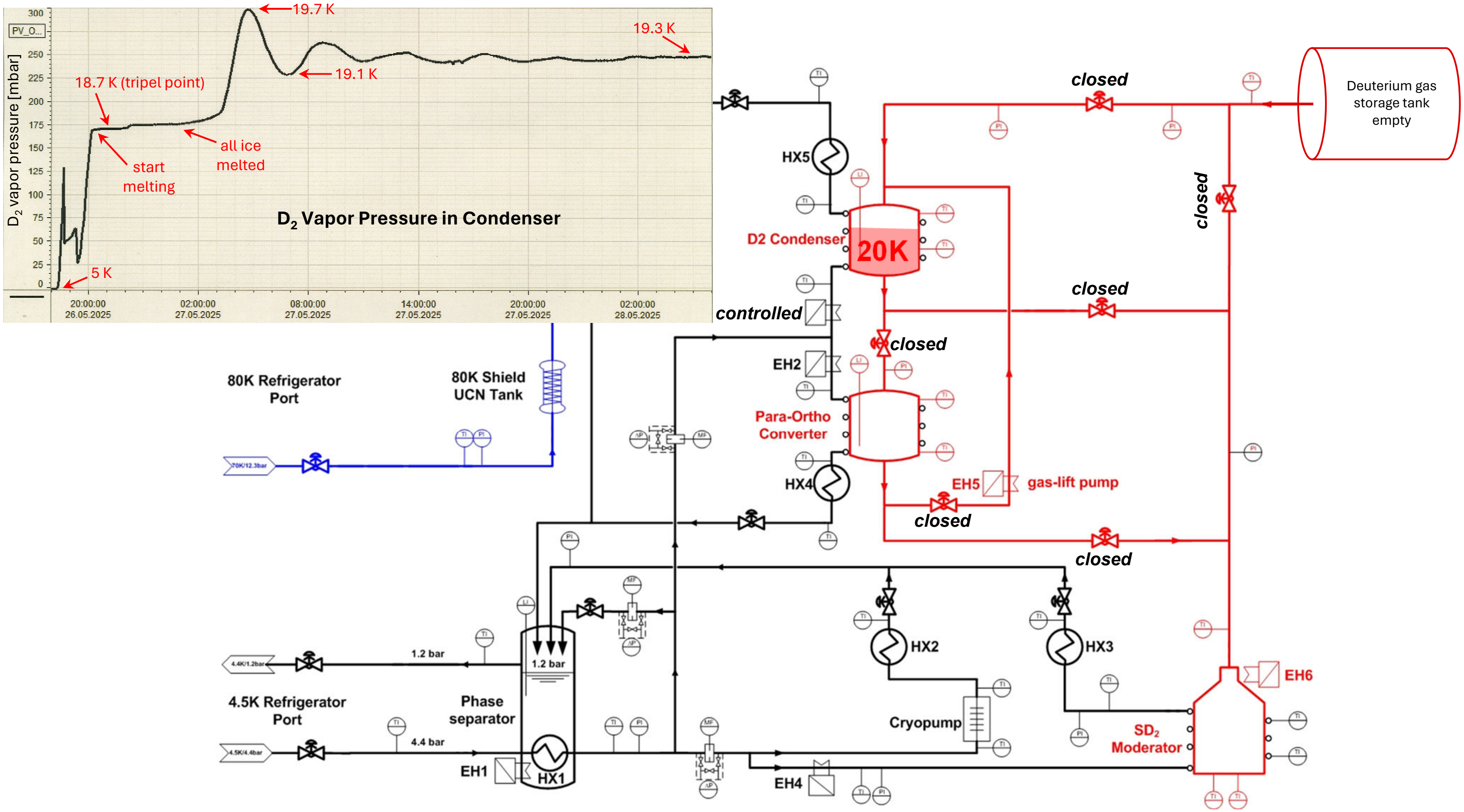
Simplified Cooling Scheme



Condensation from storage tank



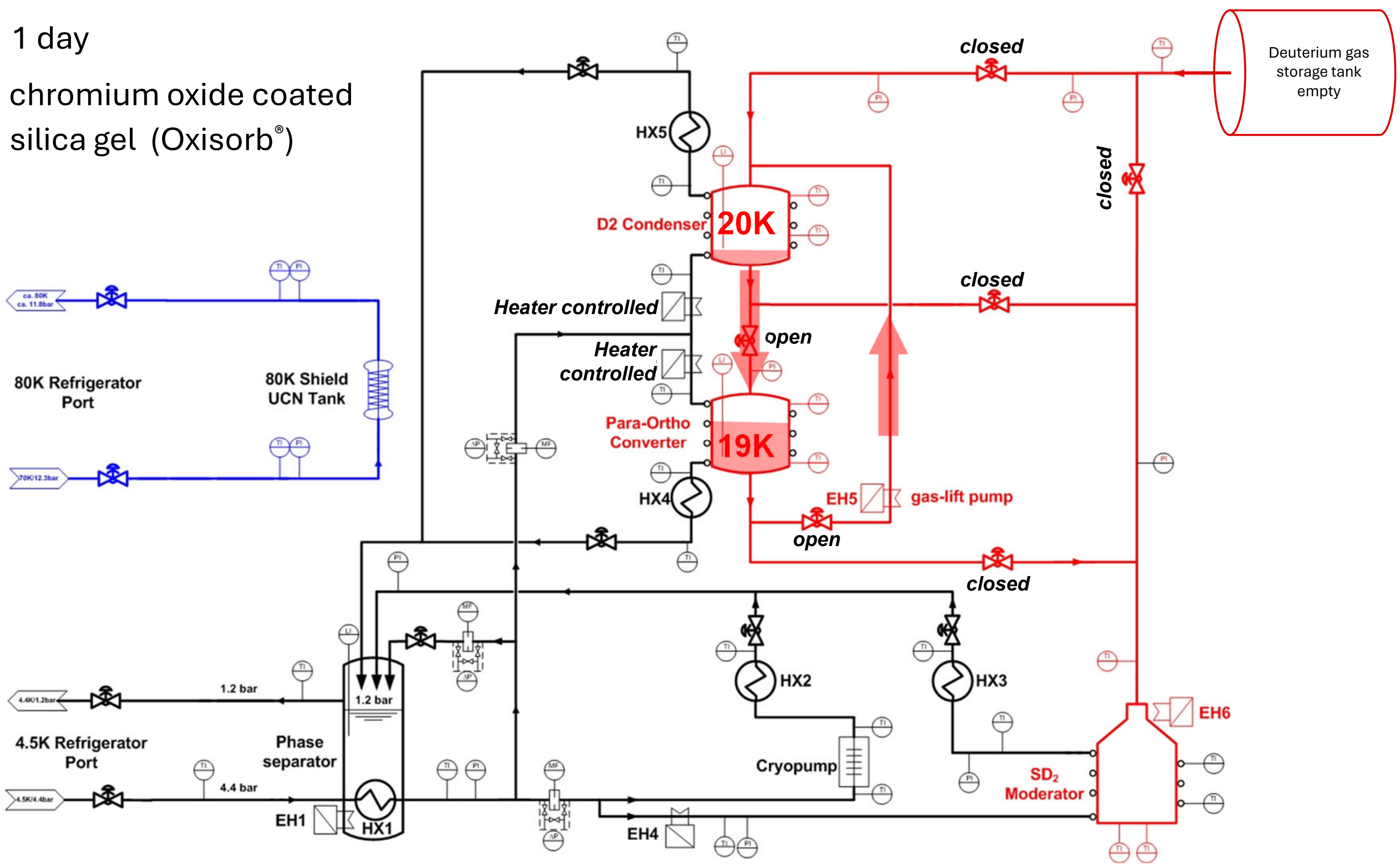
Melting and Keeping at 20K



Transfer and para/ortho Conversion

typical duration: 1 day

catalyst: chromium oxide coated silica gel (Oxisorb®)



Transfer of ortho-D_2 to Moderator

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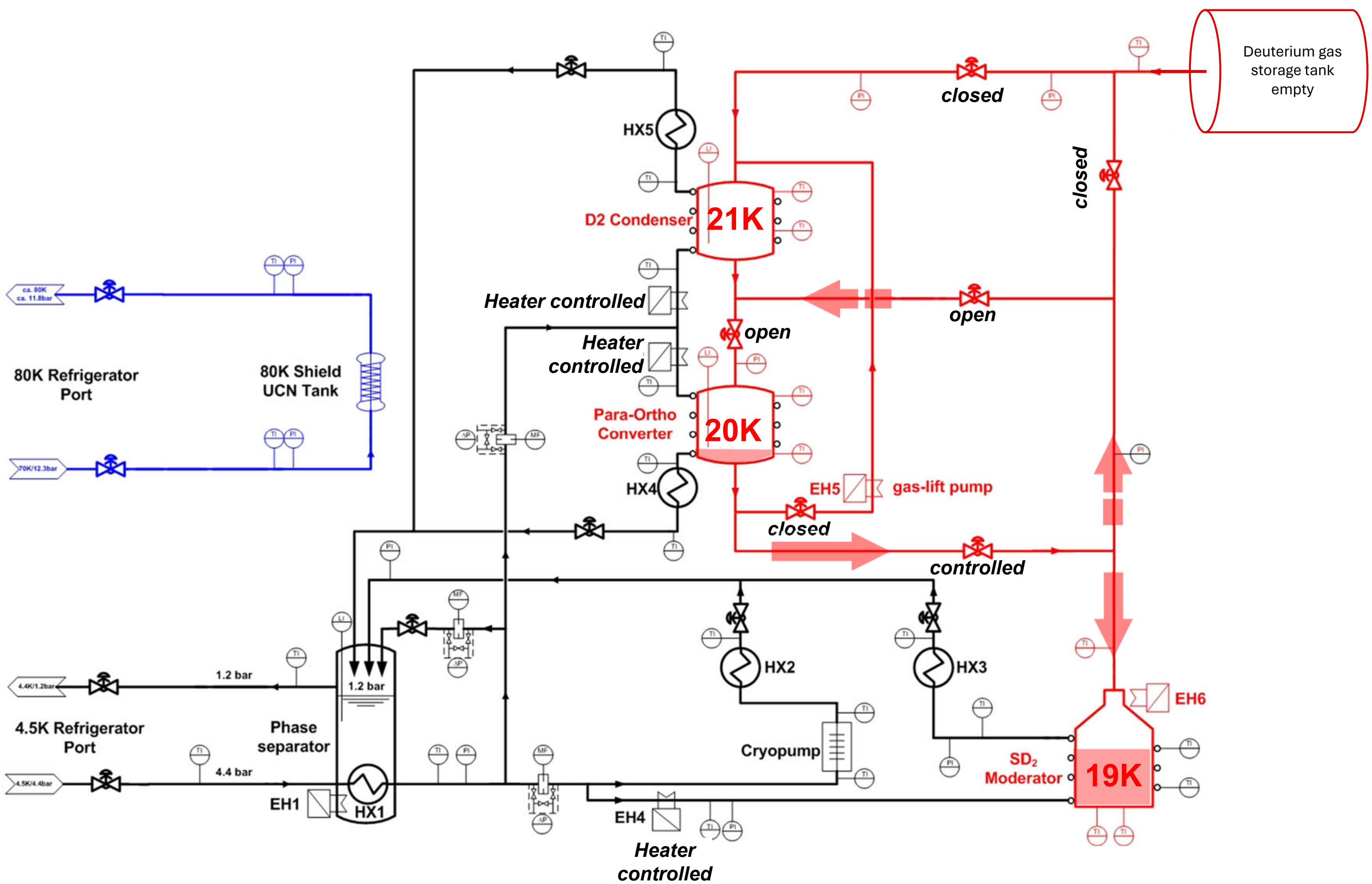
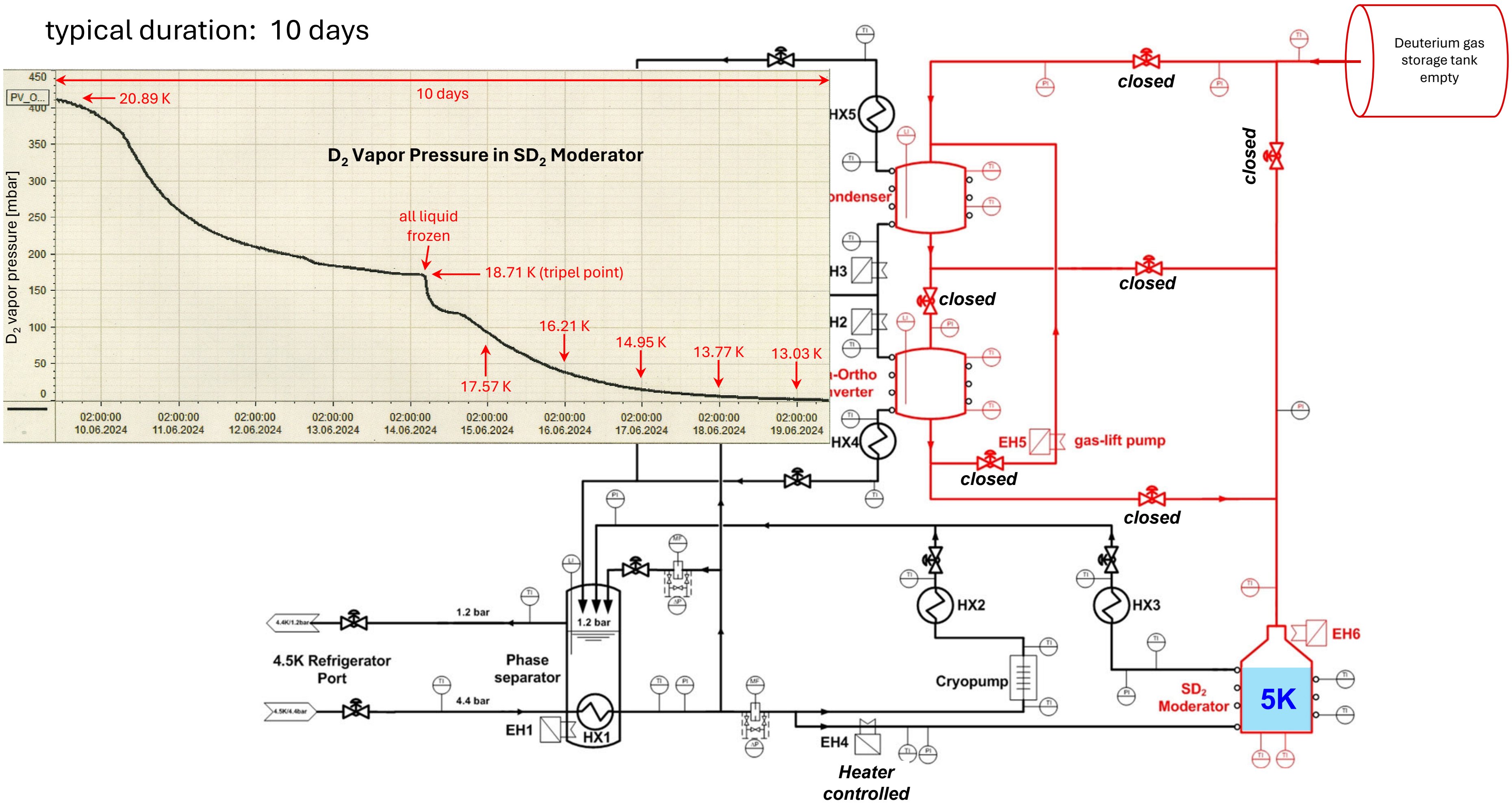


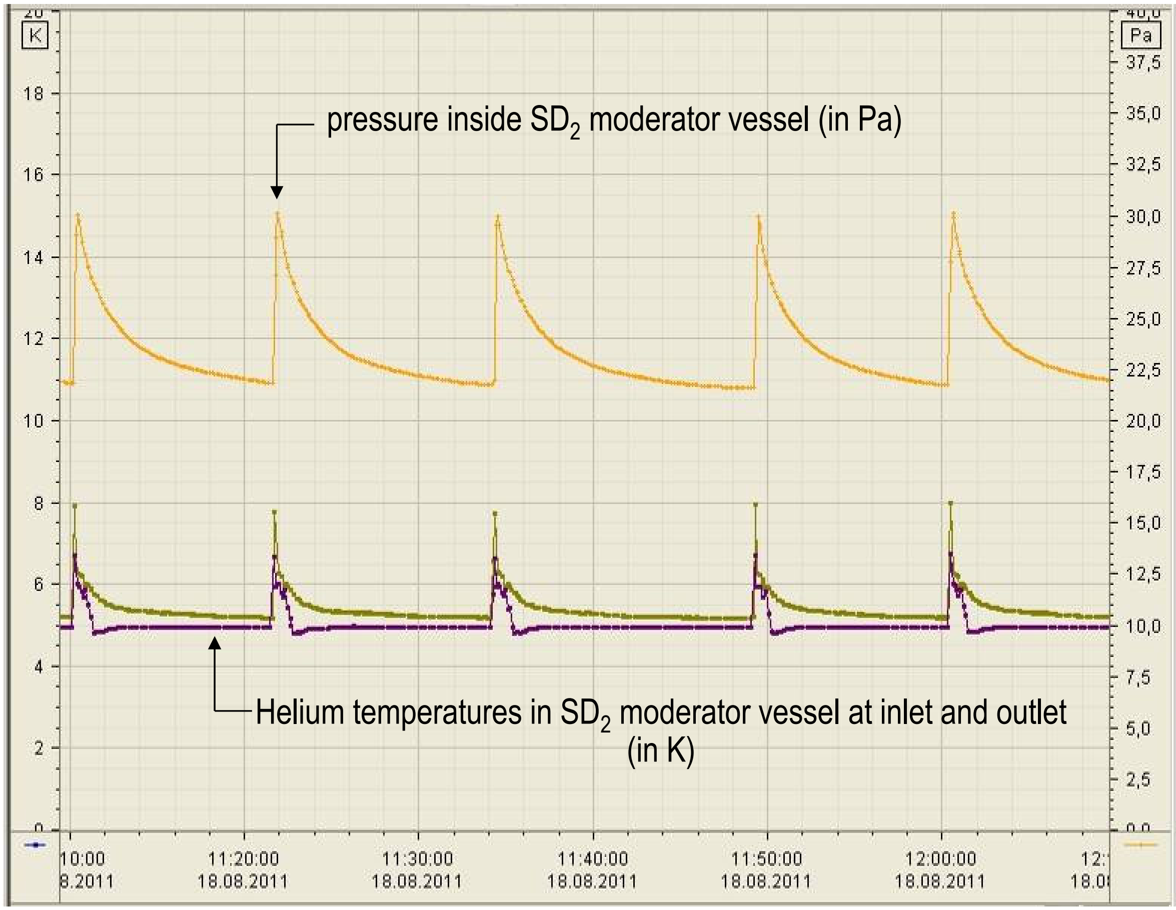
Freezing of Liquid oD_2 in Moderator and Operation

typical duration: 10 days



Periodic p-Beam Kicks onto UCN Target

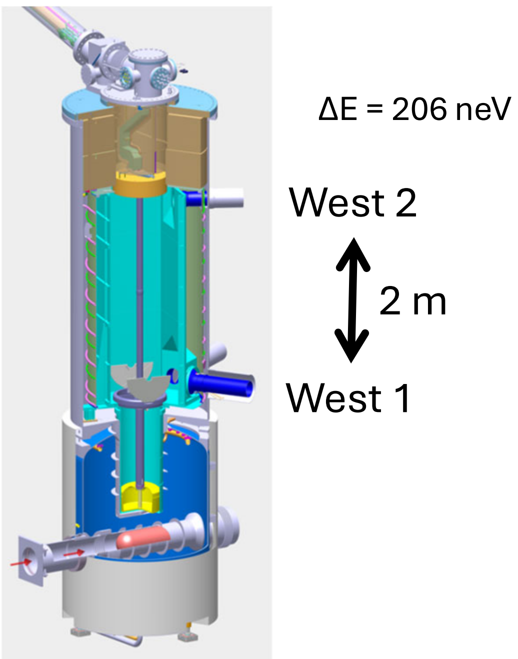
cryo-system copes well with periodic heating due to neutron pulses

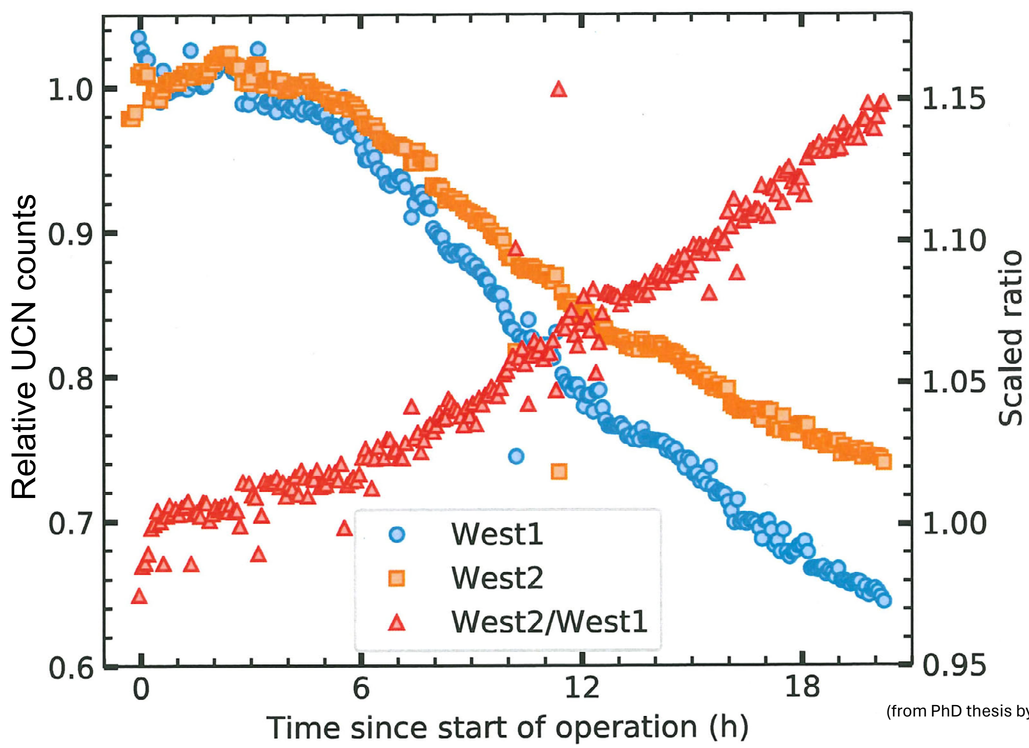


Short-Term UCN Yield Decrease

Continuous pulsed operation leads to a decrease of UCN output

UCN count ratio West2/West1 increases → UCN yield decreases more rapidly for lower energy UCN





(from PhD thesis by N. Hild)

The Frost Model

Published in European Physical Journal A: “Solid deuterium surface degradation at ultracold neutron sources” (2018)

Simplified picture :

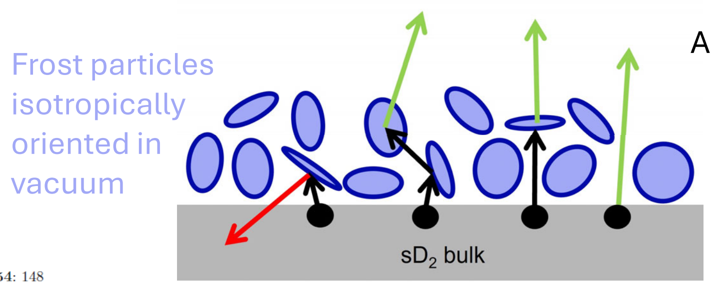
Continuous pulsing leads to built-up of frost layers due to re-sublimation of D_2 vapor

⬇

UCN escaping from bulk surface get scattered on the frost particles which have a neutron optical potential of 102 neV

⬇

The larger the number of frost layers and the lower the UCN energy the higher the probability that the UCN gets reflected



Eur. Phys. J. A (2018) 54: 148

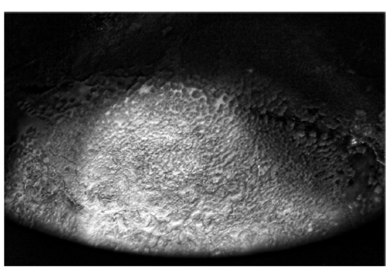
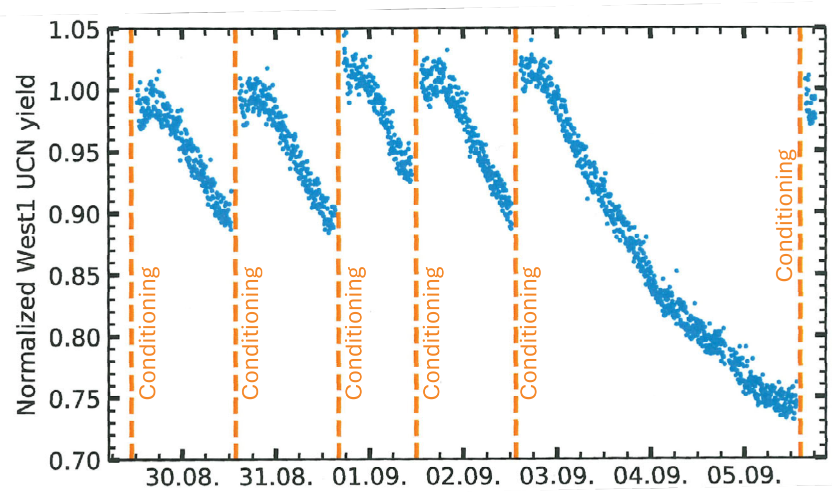


Fig. 15. Zoomed and post-processed image of the sD_2 surface after thermal cycling.

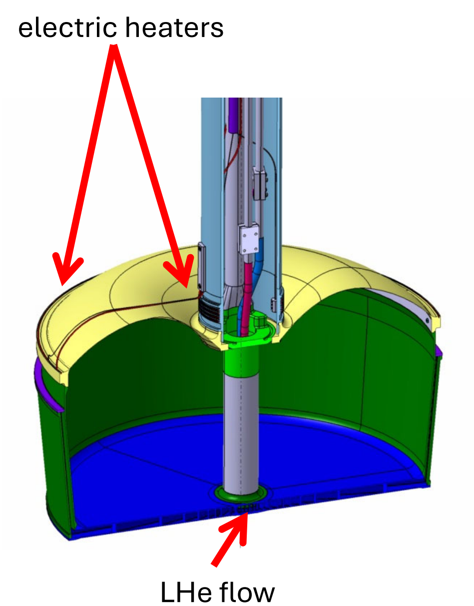
A recovery process for the bulk ice surface is needed to keep the UCN output high:

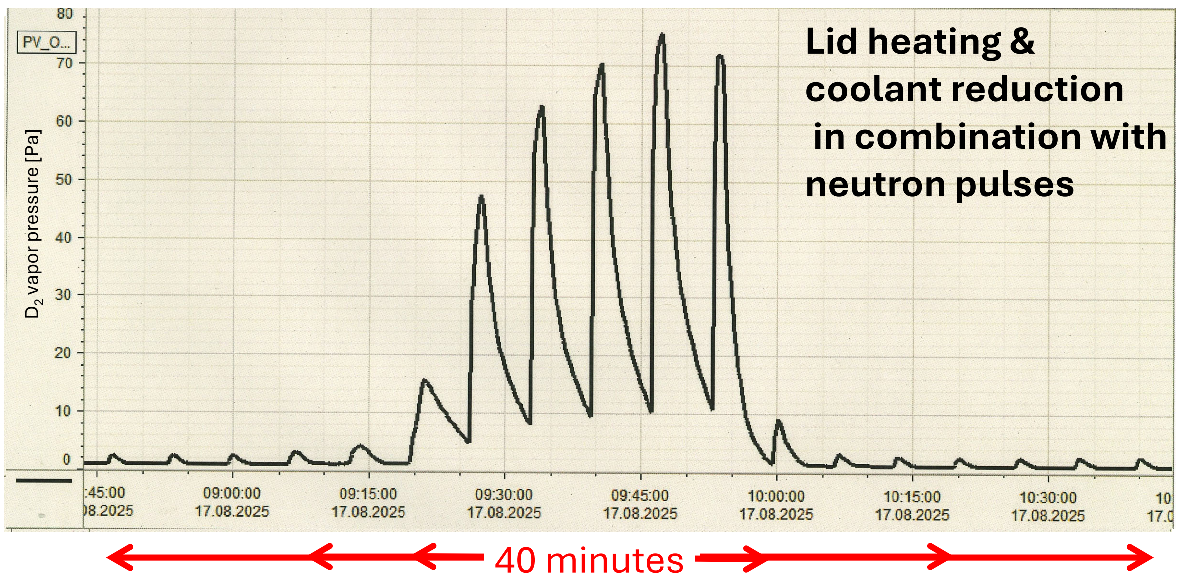
“Thermal Conditioning”



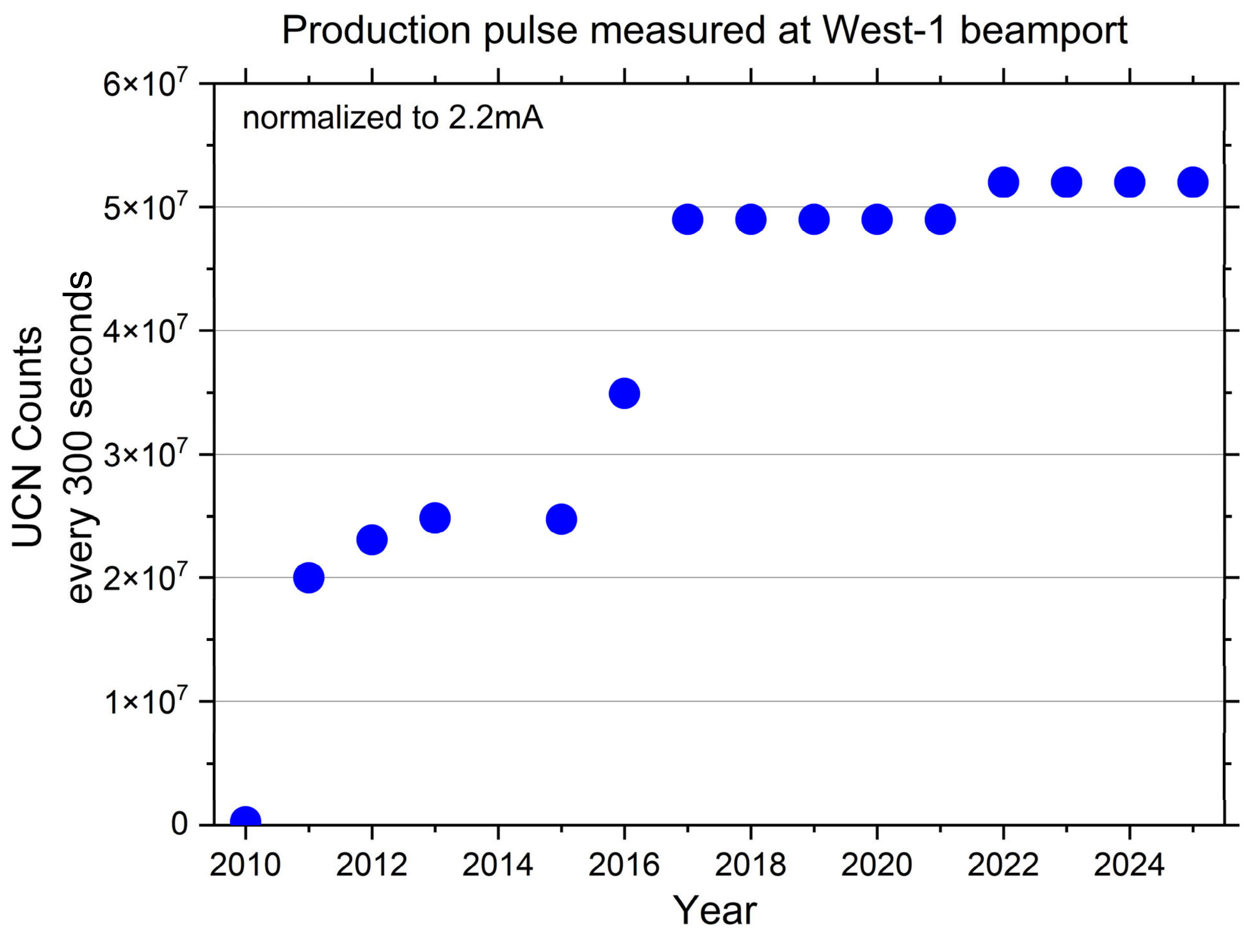
Evolution of the Conditioning process

- ✓ Development of surface treatment called ‘’conditioning’’ to recover output:
  Reduce He cooling of moderator vessel with additional heat input using heating wires
- ✓ <u>but</u> conditioning interrupts operation → time needed for output recovery must be minimized



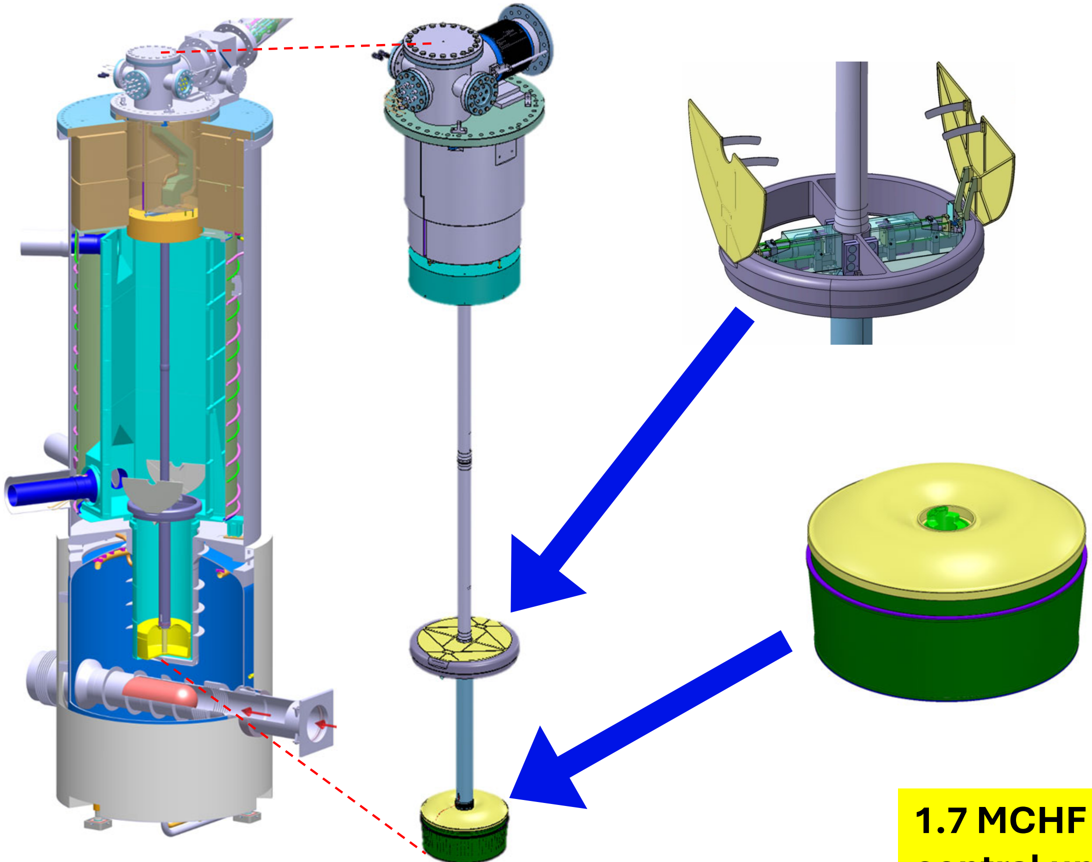


Maximum UCN Yields versus Operating Years



Refurbishment & Improvement Project: UCN EZE

central insertion unit



Situation after 15 years of operation:

☹ one of the two central shutters is not functionable anymore. Shutter is permanently closed now

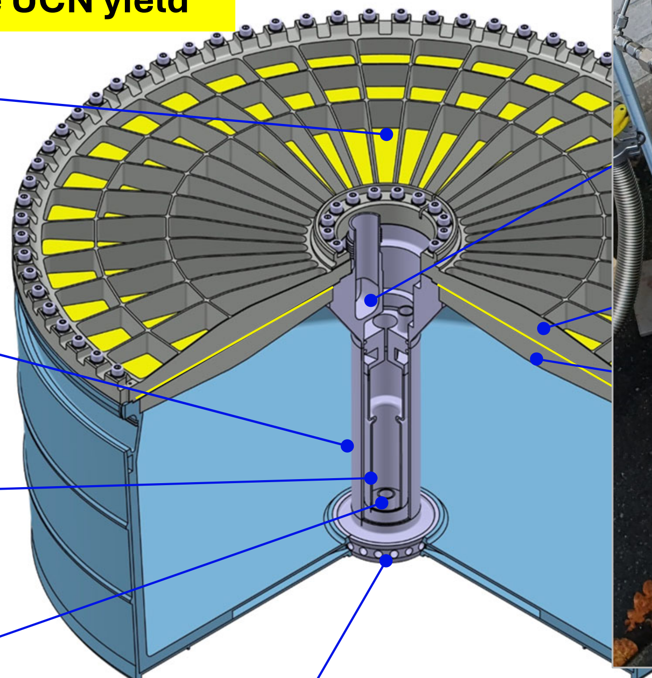
☹ sD_2 moderator vessel developed a small He cold leak (< 20K) over time causing deterioration of the vacuum of the UCN storage volume

☺ with a thinner moderator lid the UCN yield could be higher

1.7 MCHF project to replace and improve the existing central unit including the sD_2 moderator vessel by 2028

New UCN Moderator Vessel

Half the thickness ⇨ ~20% more UCN yield



Details will be presented in the talk «*Design and Validation of a Thin Aluminium Lid for a new Solid Deuterium Moderator Vessel at the UCN Facility at PSI*» given by D. Schori

Comparison to Old Moderator Lid

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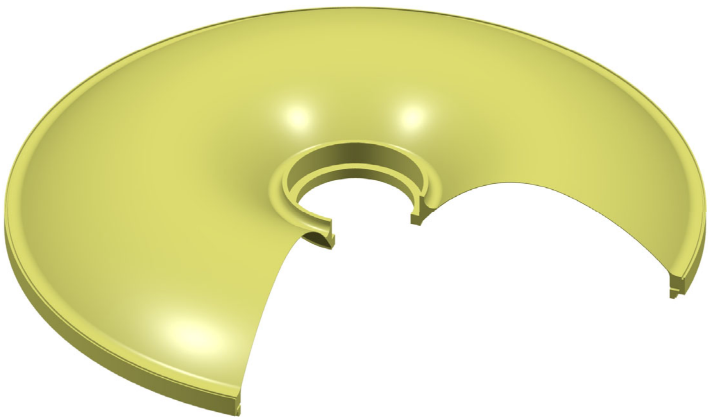
OLD

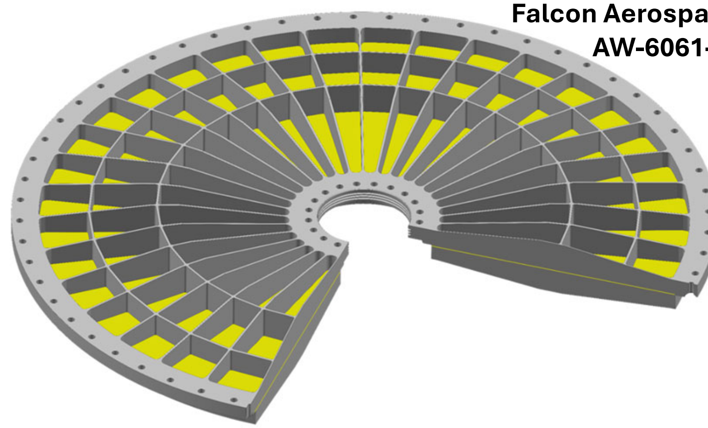


foil thickness: 500 μm

neutron-transparent area: 164’333.8 mm^2

NEW

Supplier:
Falcon Aerospace (USA)
AW-6061-O



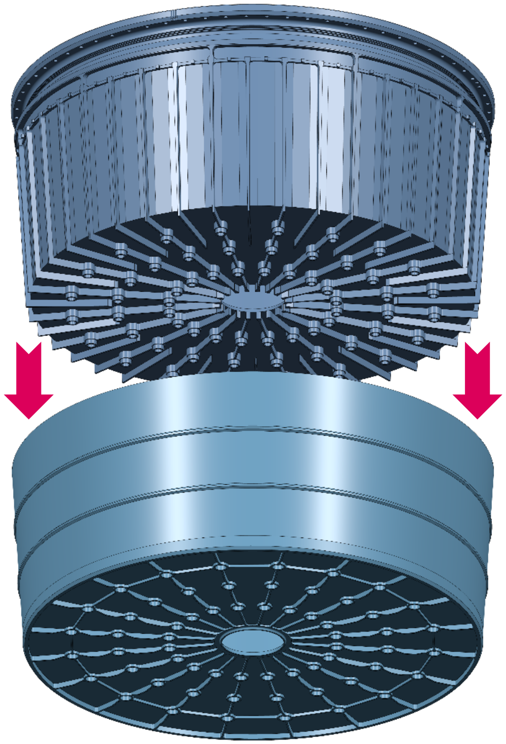
foil thickness: 250 μm

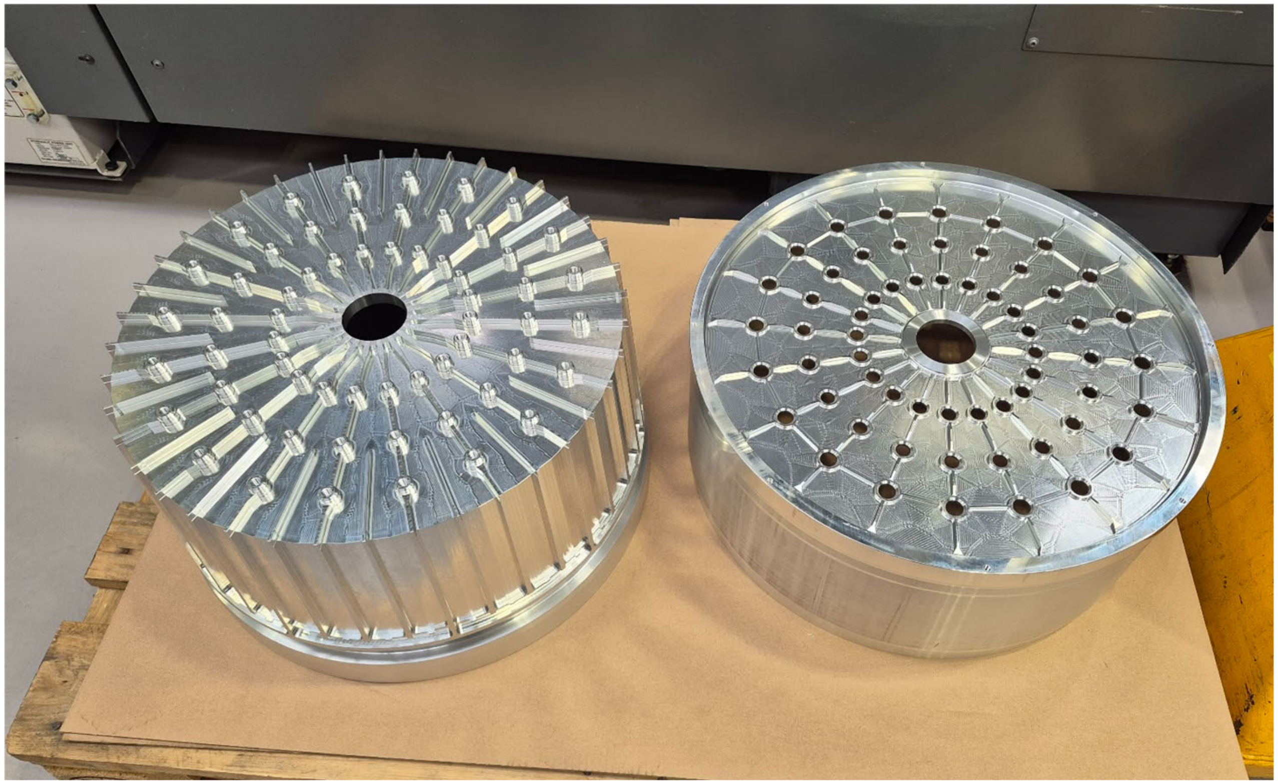
neutron-transparent area: 154’017.7 mm^2 (-6.3%)

neutron gain: ~10 – 20%

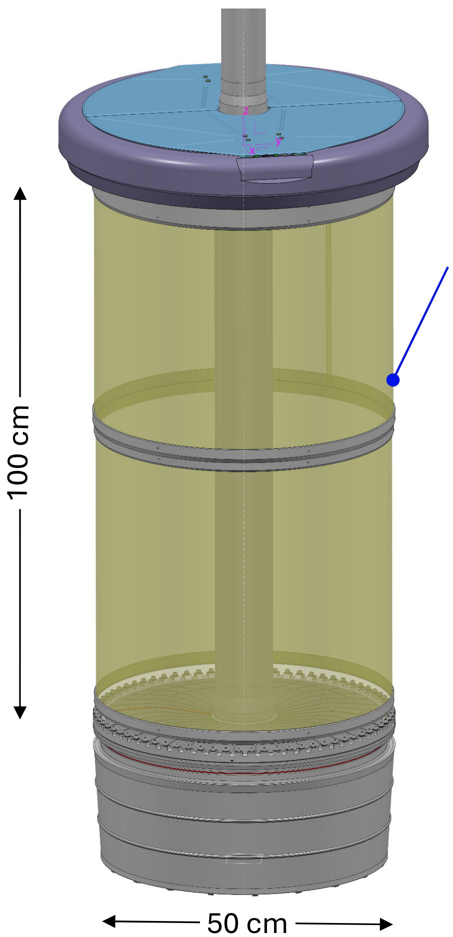
Double-Walled Lower Part of Vessel

- Both shells have a wall thickness of 2.5 mm thick after maschining. The slugs were forged to avoid micro leaks.
- 60 welding nozzles (EBW)





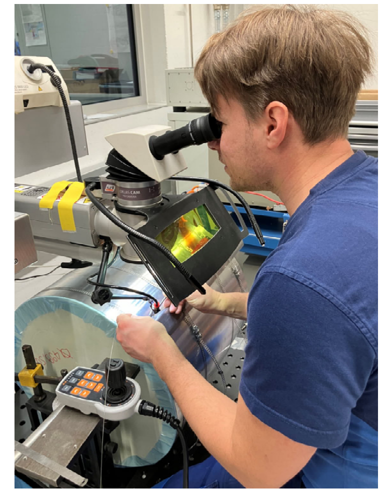
New Vertical Neutron Guide



Highly polished
(and Ni-coated)
0.5 mm Al foil
(EN AW 6082)

Al sheets: 0.5 x 500 x 2000

dummy cylinder for testing



Laser welding test
of dummy cylinder

Inner surface roughness : $R_a \leq 10$ nm !! (Japanese supplier)

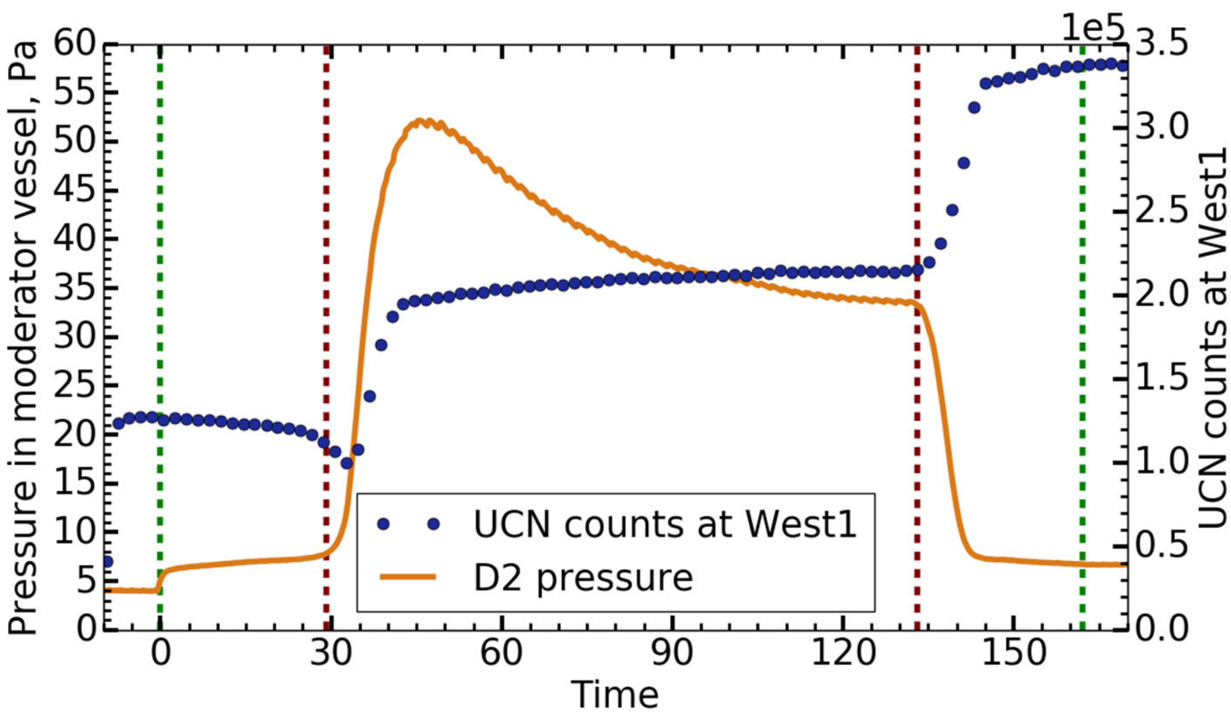
Summary

- PSI operates the world’s most intense source for ultracold neutrons
- Preparation of the solid deuterium moderator takes up to 3 weeks
- Conditioning time could be reduced from 2 days to 40 min to maintain a high UCN yield
- A major refurbishment & upgrade project, UCN EZE, is underway
- The goal is to improve the UCN yield by ~50%

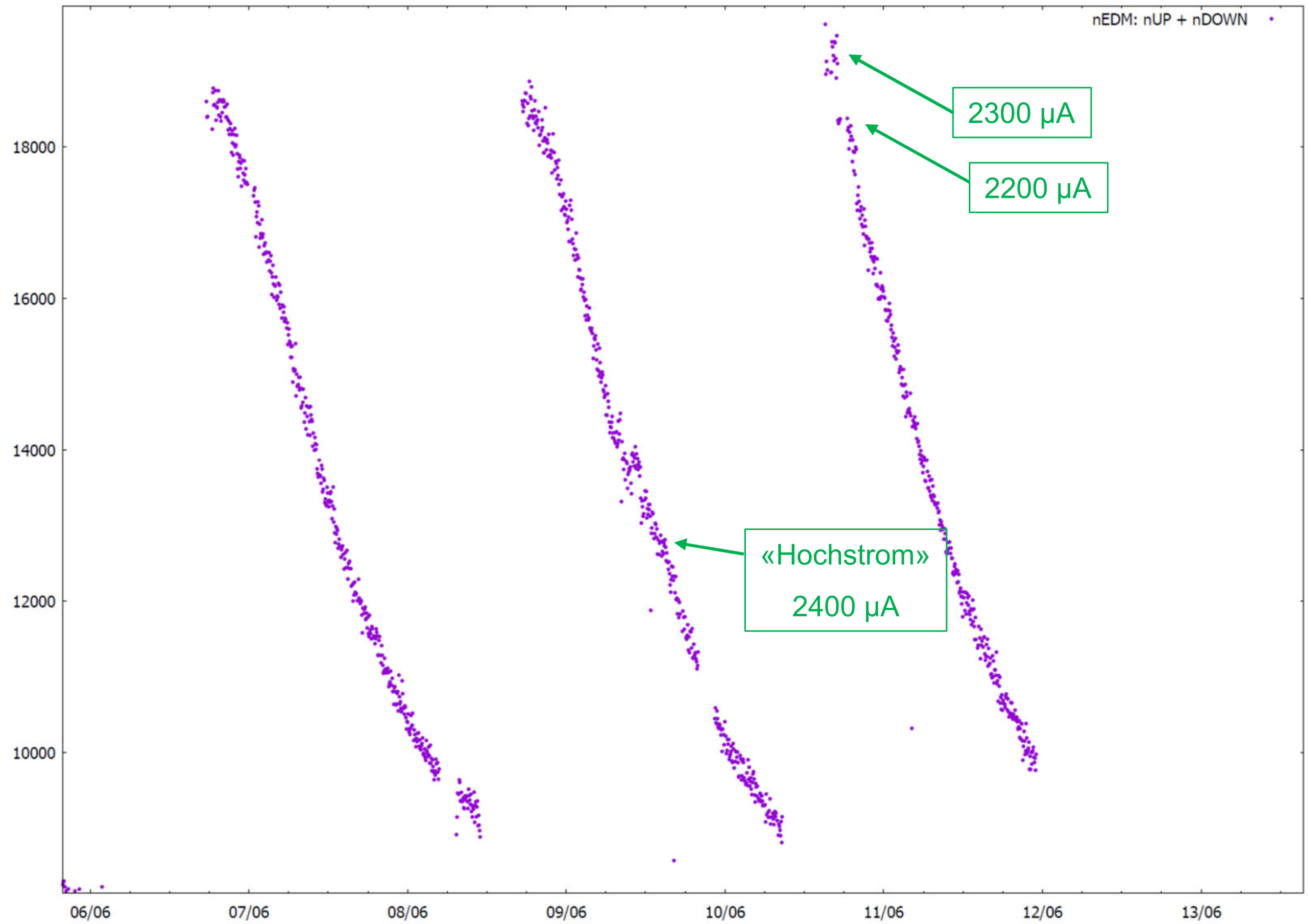
Thank you for your attention!

Probing UCN Output

Probe UCN output during conditioning with short 0.1 s pulses at 1.4 mA in quick 2 min succession
→ minimal interference with conditioning process

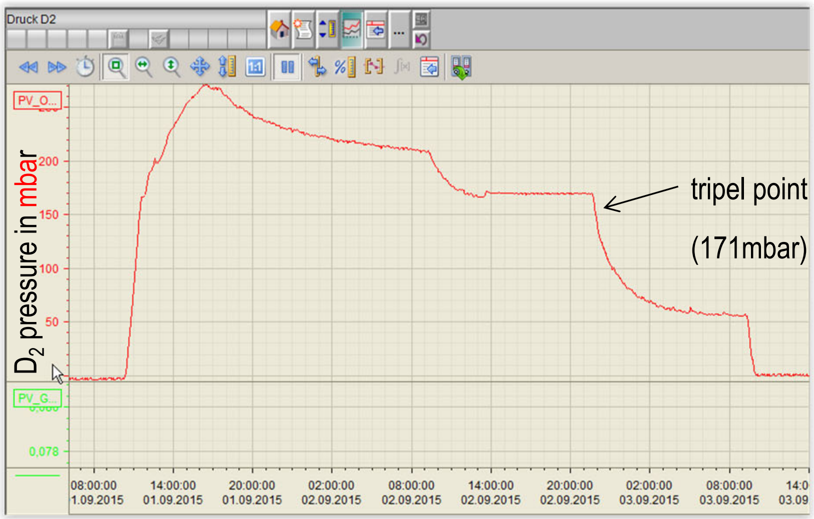


3x Conditioning letzte Woche



SD_2 Moderator Annealing Cycles

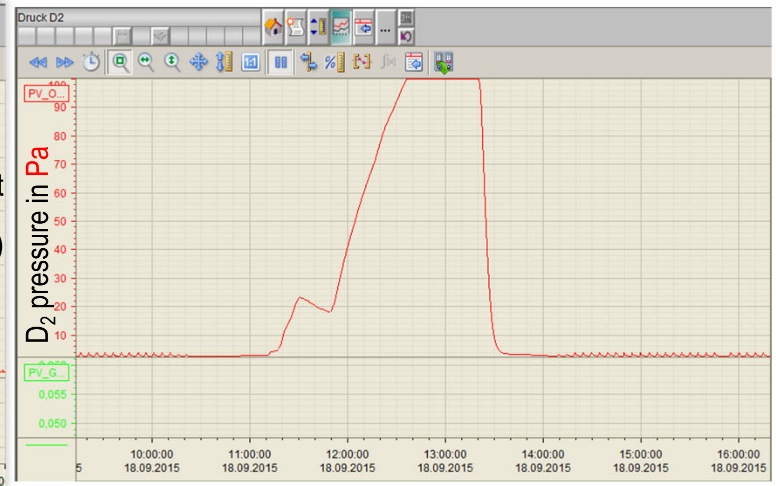
normal annealing cycles



~ 3 days

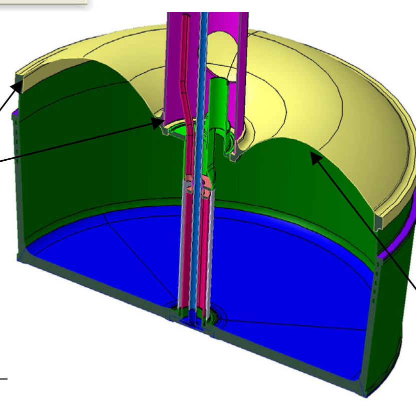
ultrashort annealing cycles

lid heating only



~ 3 hours

lid heaters



snow (?)