Operation Status of CSNS Target Station

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Outline

Overview of CSNS

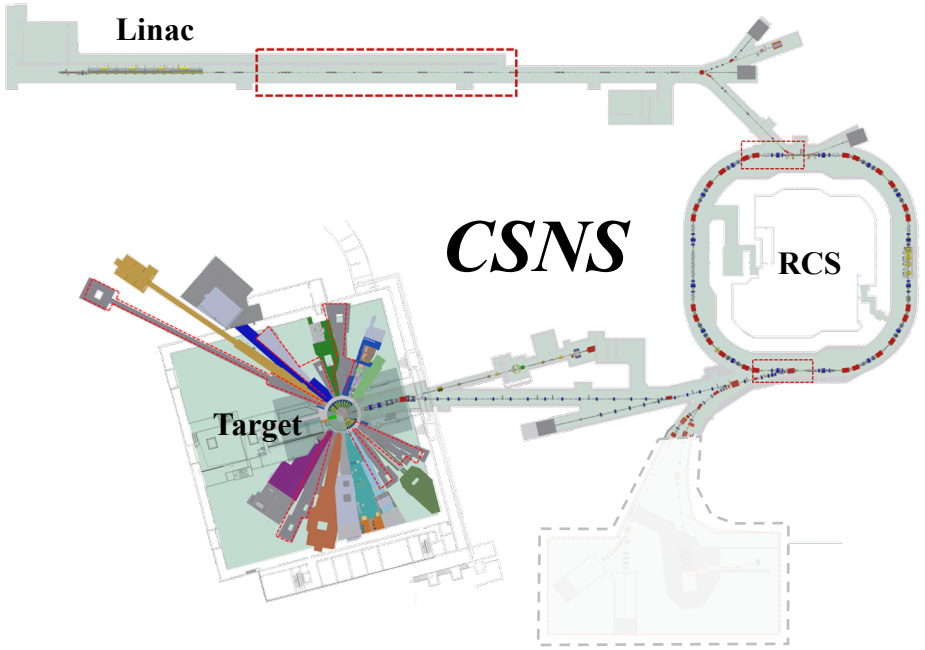
- Location： Dalang town, Dongguan, Guangdong
- Start time： Sept. 2011
- Construction period： 6.5 years
- First beam on target： Aug. 2017
- Ramp up to 100kW： 28th Feb. 2020

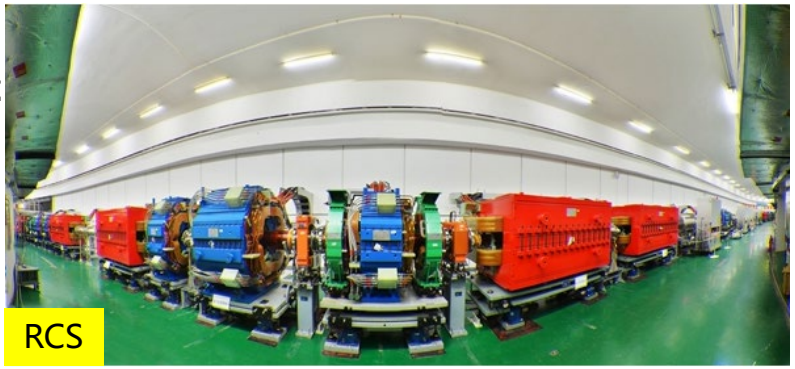
First beam on target (28th Aug. 2017)

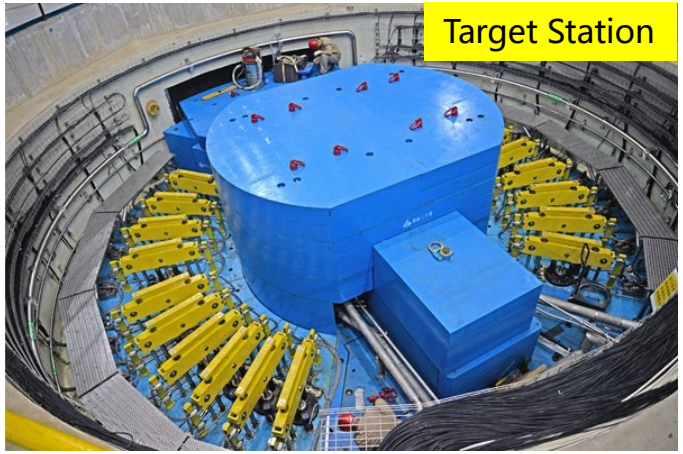
CSNS Aerial View (2024)

Overview of CSNS

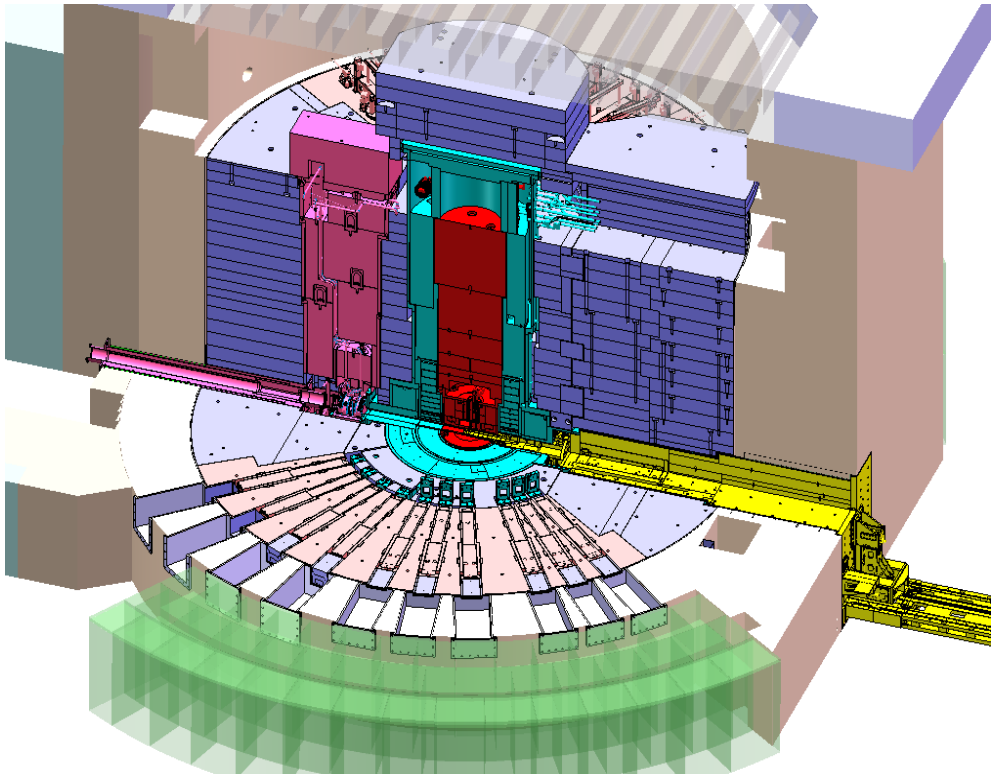
- Linac: 80MeV
- Rapid-Cycling Synchrotron(RCS): 1.6GeV,25Hz
- Target: 100kW(phase-I)
- Instruments: 11







The layout of CSNS Target Station



CSNS Target Station

The main systems in CSNS TS

① Neutronic

② Target Assembly

③ Moderator and Reflector

④ Helium Vessel

⑤ Shielding

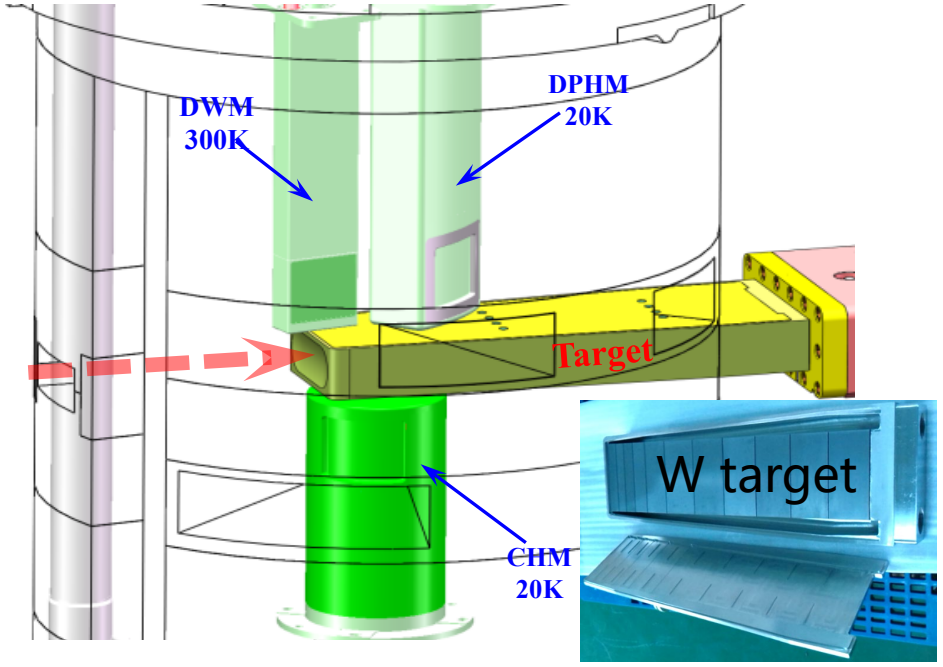
⑥ Remote Handling

⑦ Cryogenic

⑧ Experimental Utility

Parameters of TS at CSNS phase-I

- Tungsten has been chosen as the target material for CSNS.
- Moderators: (1) Decoupled Water (300K)
  (2) Coupled parahydrogen (20K)
  (3)Decoupled poisoned parahydrogen (20K)
- Reflector: Be & SS316



Target-Moderator-Reflector (TMR)

Parameters	values
Beam power	100kW (design goal)
Neutron Efficiency (n/p/sr)	0.1
Target	W plates, Ta Cladding
Moderators	① Water(300K), ② Coupled parahydrogen(20K), ③ Decoupled poisoned parahydrogen(20K)
Reflector	Be/SS316
Coolant	Light water
TMR replacement	Remote-handling

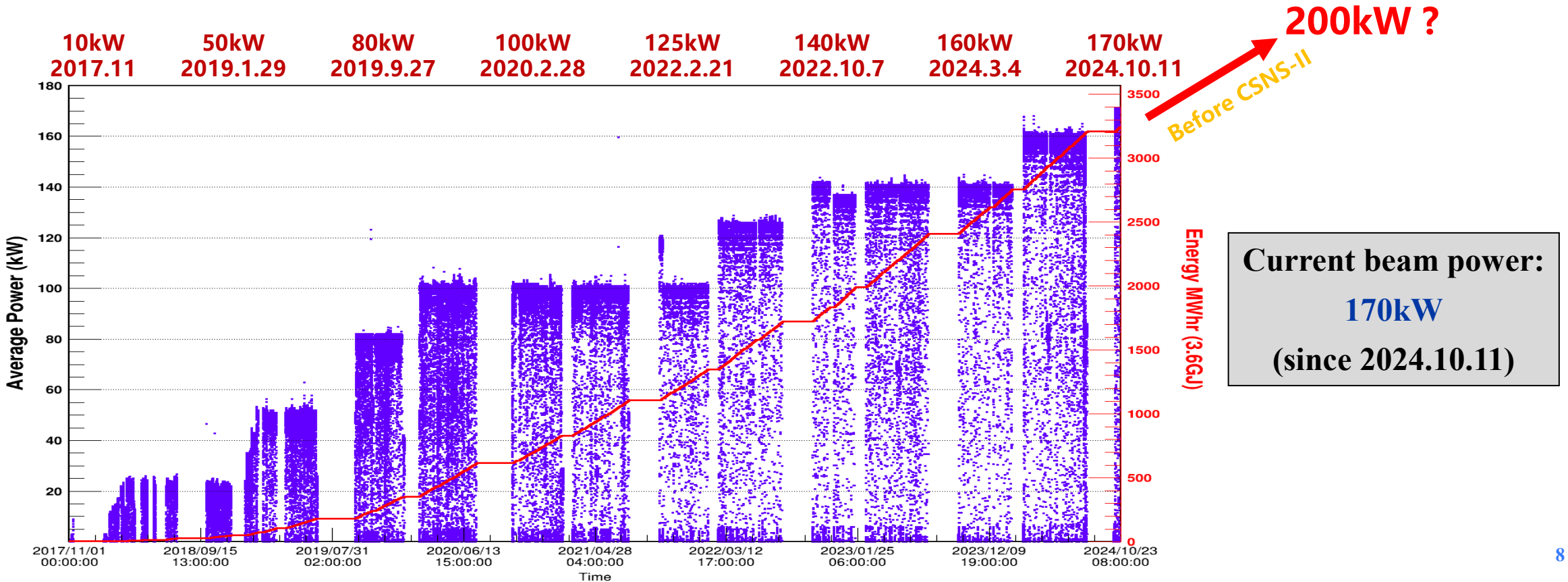
Outline

Beam power

- **In 2023-2024, the target station operated at a power of 140~160 kW for a total of 6936 hours. The neutron beam was available for a total of 5433 hours.**
- **Maintenance plan: Two sessions for each operating cycle.**

✓ *long-term shutdowns between July and September. (usually, beam on target at the beginning of October)*

✓ *short-term shutdowns between January and February (usually lasting less than one month) .*



Current beam power:
170kW
(since 2024.10.11)

Neutronic measurement

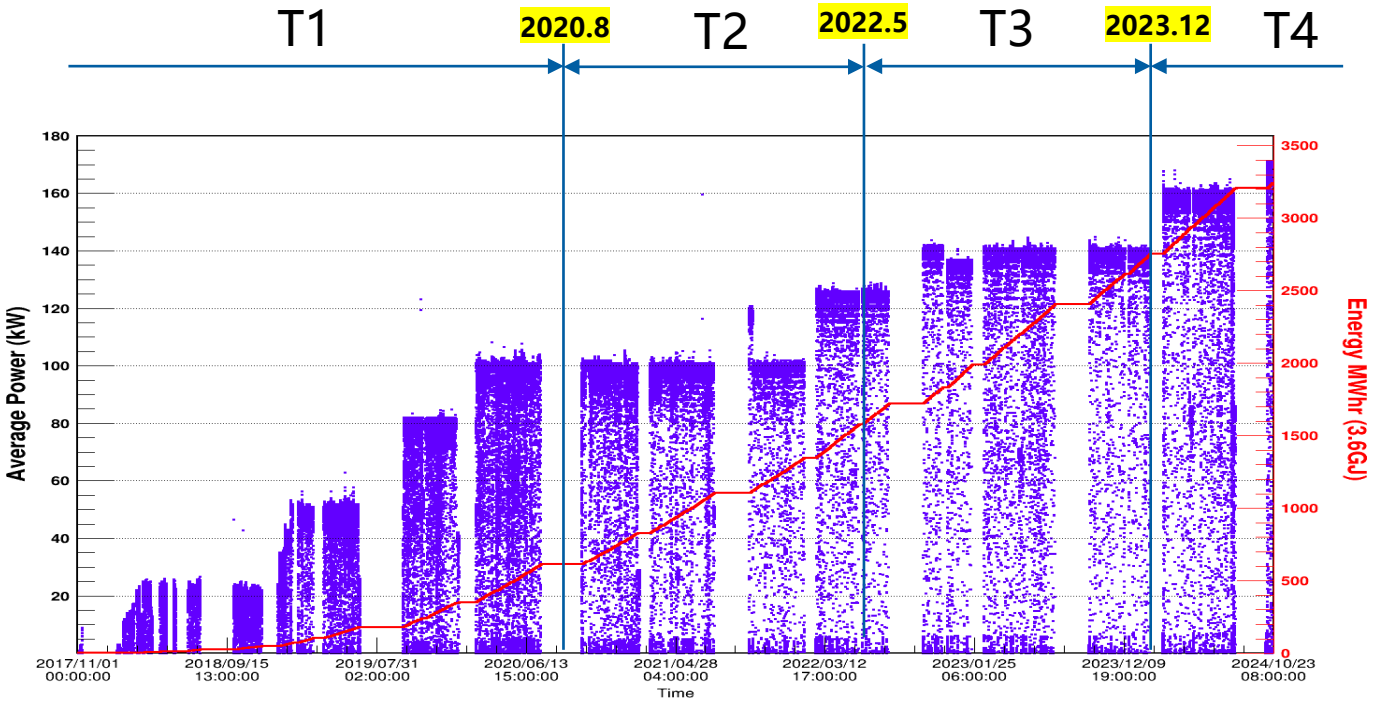
- By measuring the neutron wavelength spectrum, monitor the operational status of the TMR
- Method: CTOF、TOF、Gold foil activation
- Have completed measurements of the neutron wavelength spectrum in the output of DPHM moderator. The neutron wavelength spectrum remains unchanged as power increases. The integrated neutron flux (DPHM) increases linearly with the beam power.

Neutronic measurement

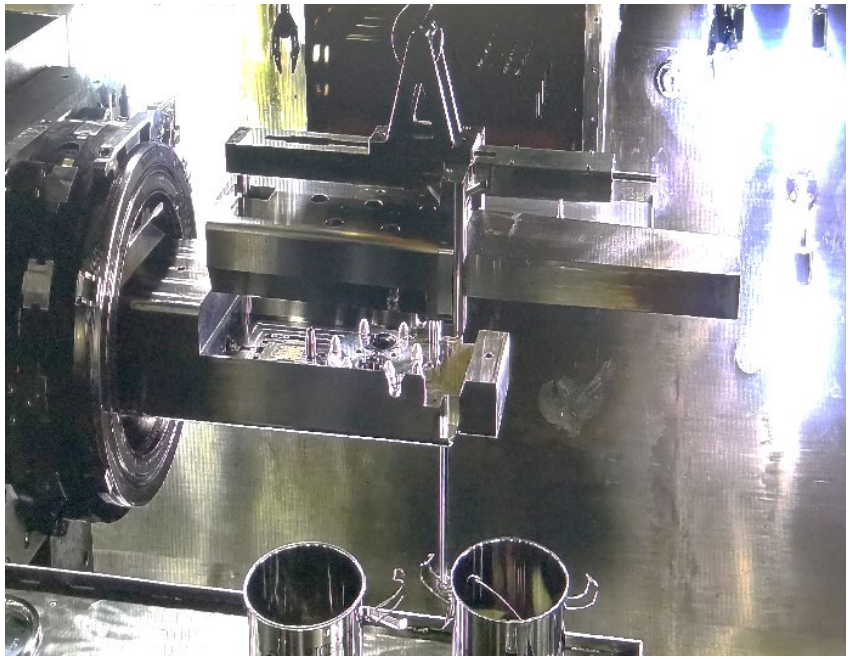
- By measuring the neutron pulse shape, to examine the state of the moderator (decouple/poison layer).
- Complete measurements of the neutron pulse shape in the output of the DPHM moderator. There is no change in the neutron pulse shape during power increase and long-term operation.

Current status of Target Plug

- Current proton beam power is 170kW.
- Three target plugs have been replaced by remote-handing.
- Target Plug No.4 (T4) is in service since Dec. 2023.



Proton beam power of CSNS and service period of the targets



Replace target by remote-handling

Replacement of Target Plug

- **In August 2020, the first target (T1) of CSNS was replaced by remote-handling .**

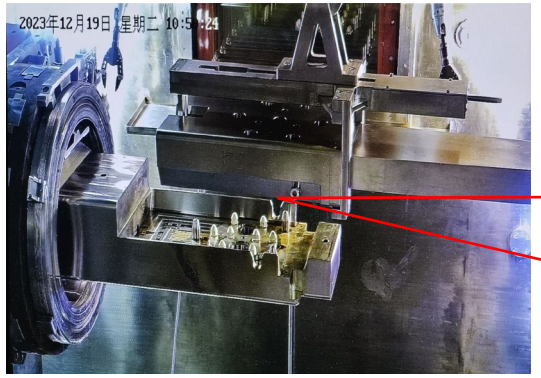
✓ *In serve for ~3 years, from first beam on target (Aug. 28th , 2017) to beam power reach 100kW (since Feb. 28th, 2020).*

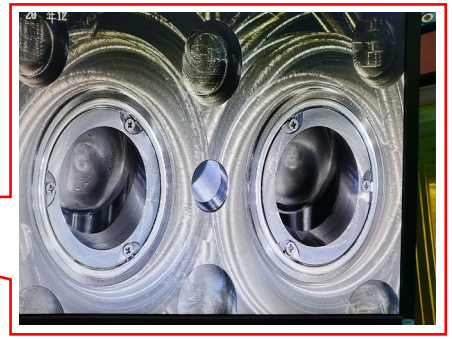
✓ *T1, without thermocouples ; T2, with 6 thermocouples to monitor the temperature of target plates.*

Replacement of CSNS first target

Replacement of Target Plug

- **T2 and T3 leaked unexpectedly and was replaced in advance.**



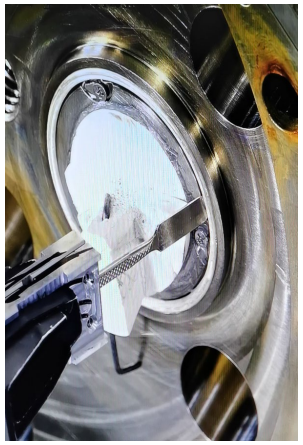


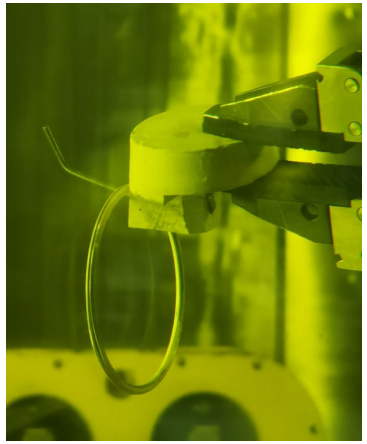
Remote observation of the bottom seal ring T3

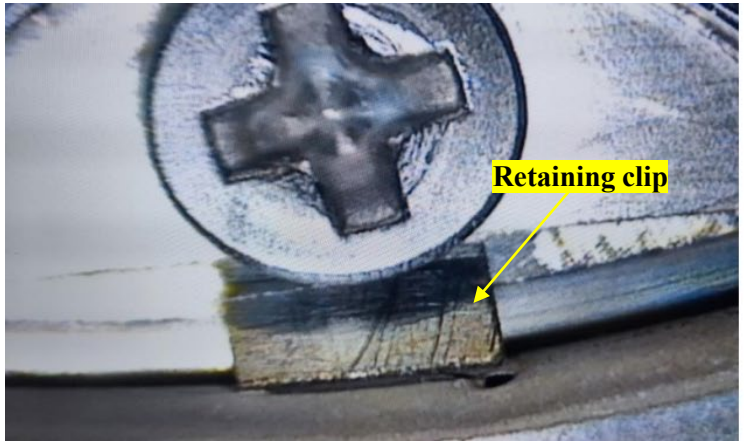
- **The cause of the leak (T2 & T3) is being analyzed.**

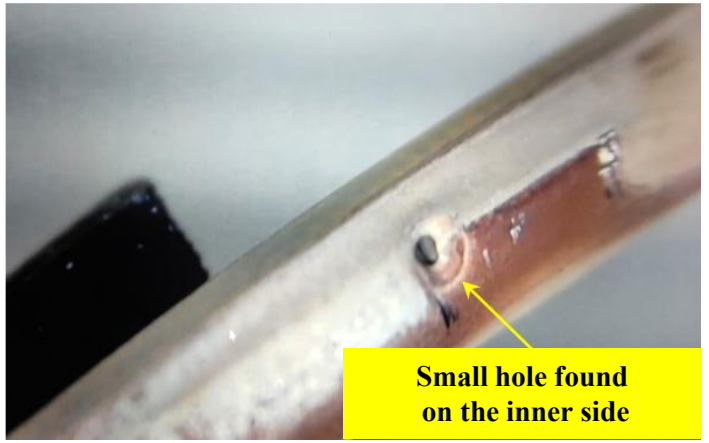
✓ *A small hole was discovered on the inner side of the silver coating layer. It has a high correlation with the retaining clips!*

✓ *The cause of the small hole on the sealing ring is currently being analyzed.*









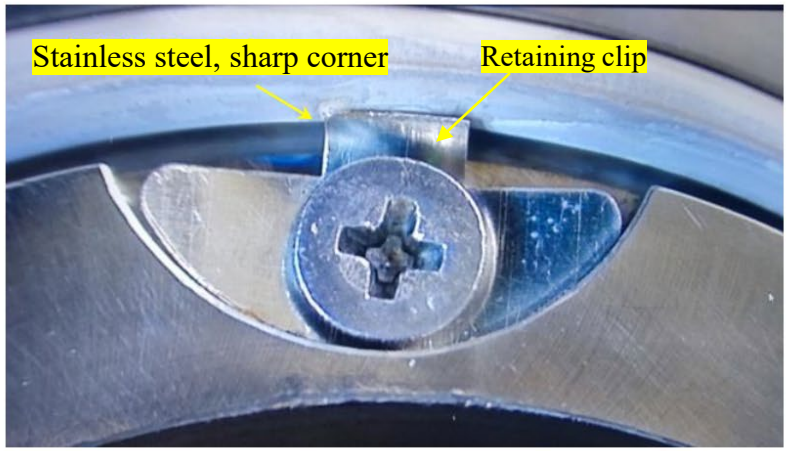
Seal optimization

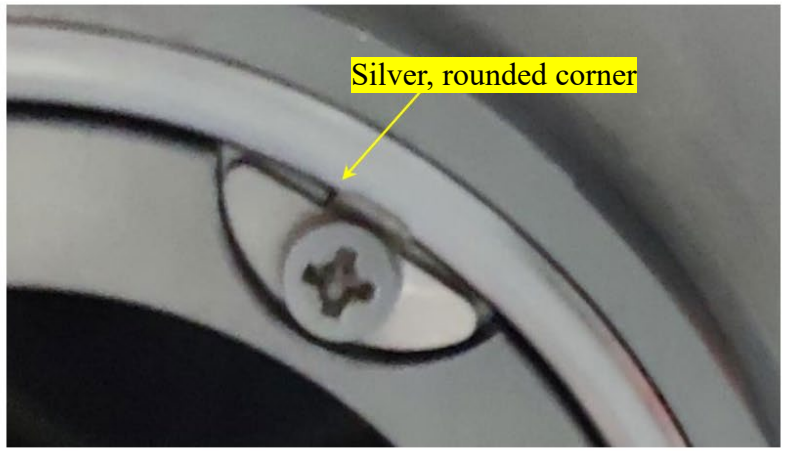
- **The main optimization:**

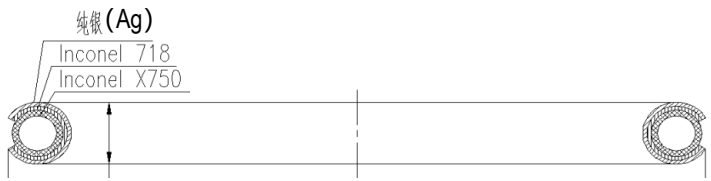
✓ ***Retaining clips:*** *stainless steel → silver, sharp corner → rounded corner .*

✓ ***Seal rings:*** *single layer → double layers. (Being tested, will be applied in T5)*

✓ ***Seal structure:*** *mock-up target is being manufacturing , to test: erosion corrosion, different flange clearance, vibration, etc.*

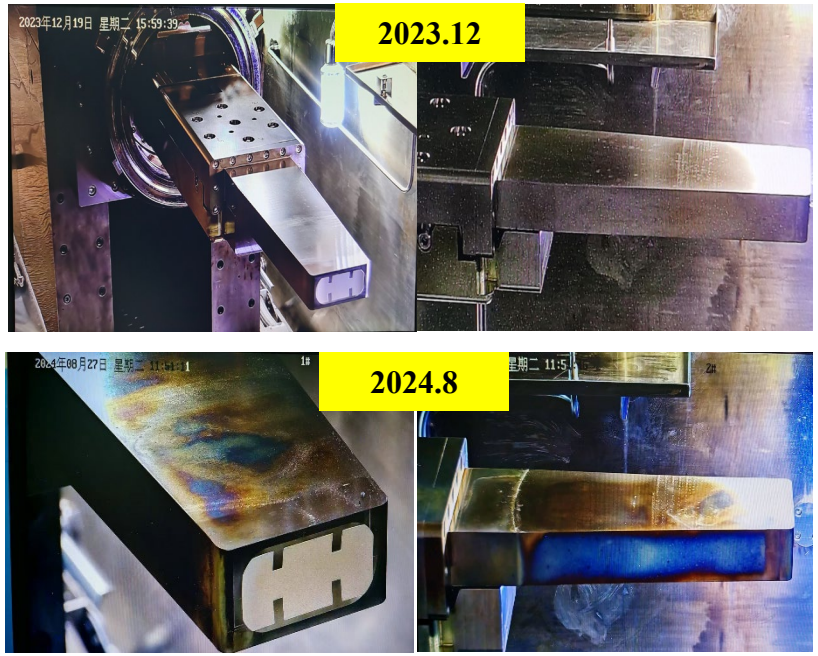




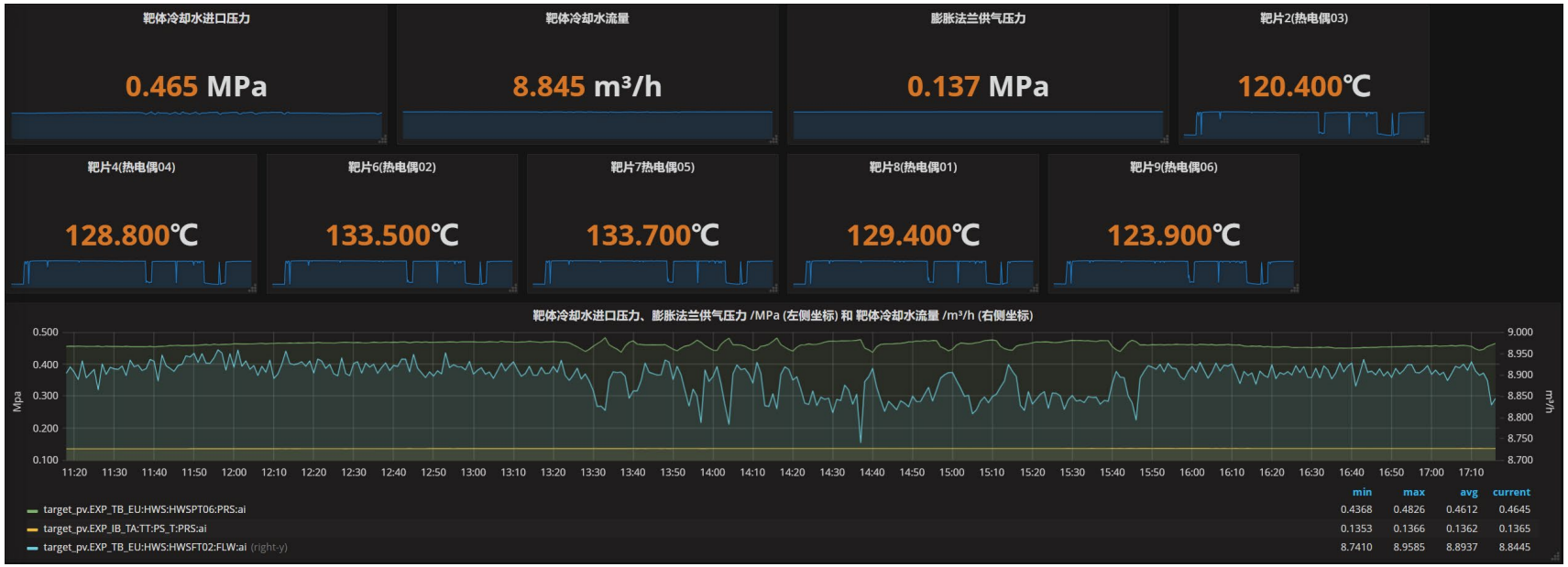


Current status of T4

- T4 has been running stably and normally since its replacement in Dec. 2023.
- The various operational parameters of the target plug are stable.
- The temperatures of the six thermocouples inside the target fluctuate within the normal range.



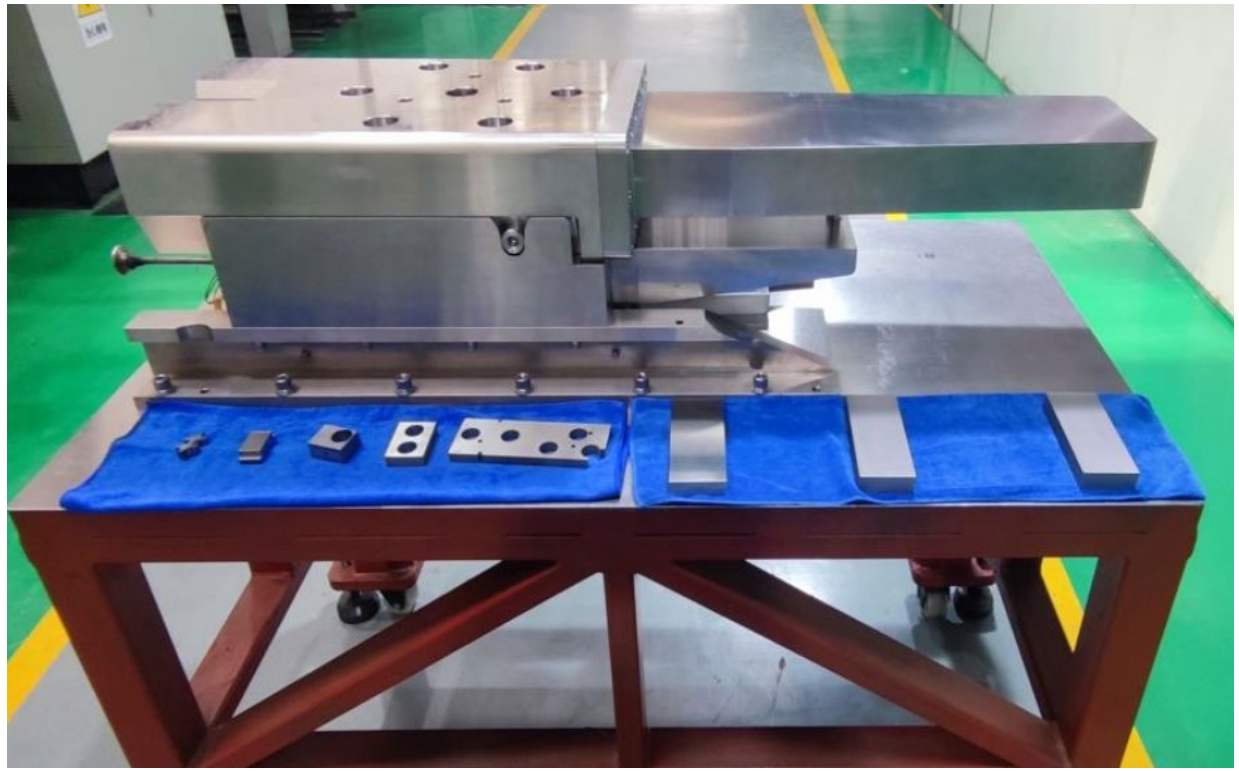
T4 observed through remote camera



Monitoring of target operating parameters

Spare targets

- The manufacturing and test of T5 has been finished.
- The manufacturing of T6 is nearing completion. FAT will be in Dec. this year.
- Strategy for spare target: 1(in service) + 1(ready) + 1(manufacturing)

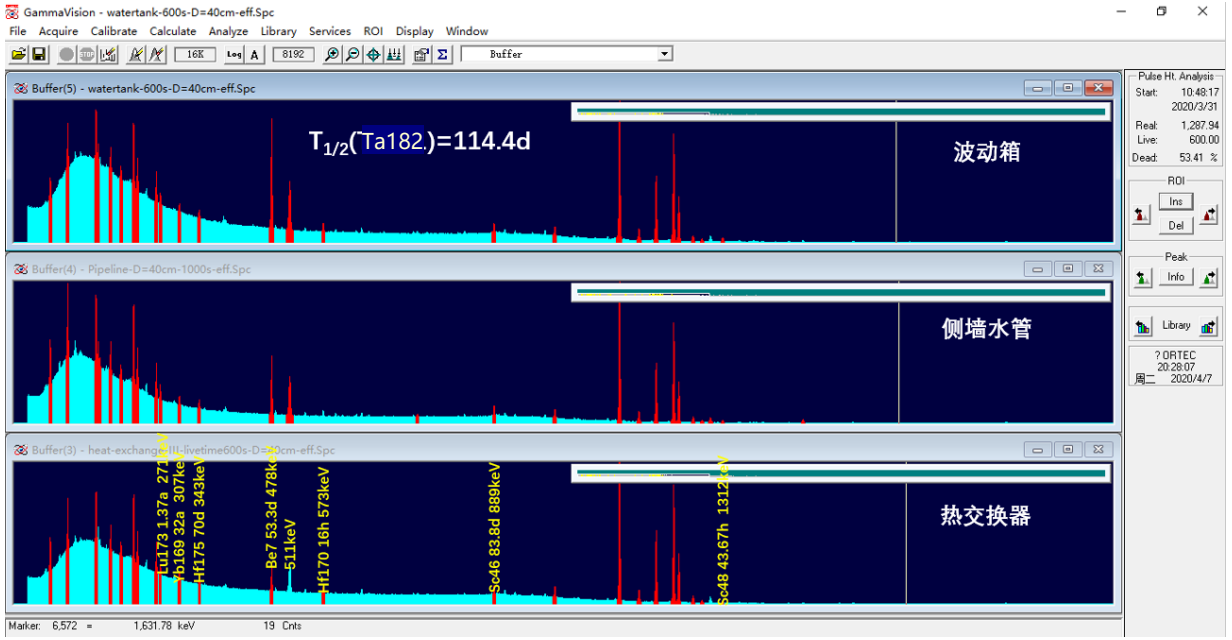


T5

Target PIE plan

- The service environment of the target: high dose proton and neutron irradiation, thermal stress and cooling water corrosion.
- In order to understand the status of the target material and obtain experience for the continuous optimization of the target and power upgrade, CSNS started the target PIE plan.

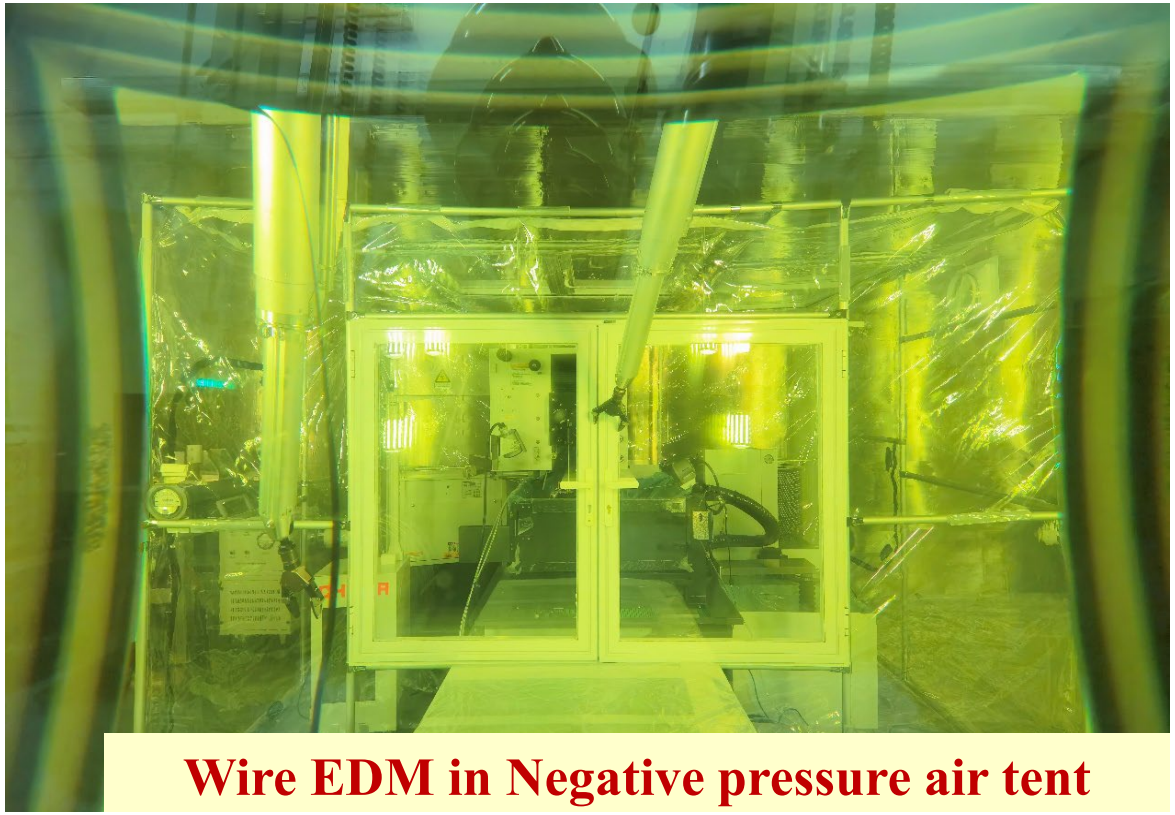
The appearance of the first CSNS target



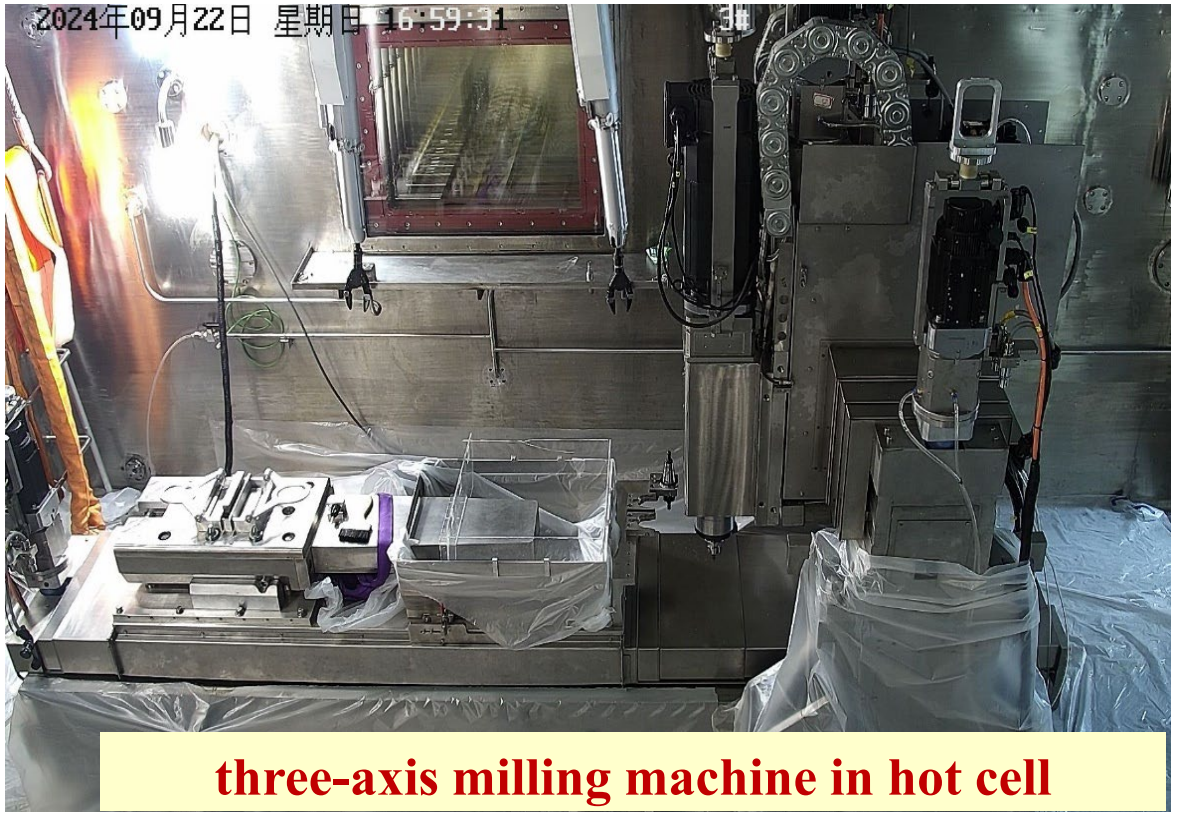
Ta182 was found in the cooling water of the target

Target PIE plan

- The EBW of target vessel and beam windows will be cut and sampled for tensile and compression test and remote observation. A dedicated cutting machine , wire EDM system and test room has been fabricated or built.
- Mock-up target cutting test has been carried out during 2024’s summer maintenance period.

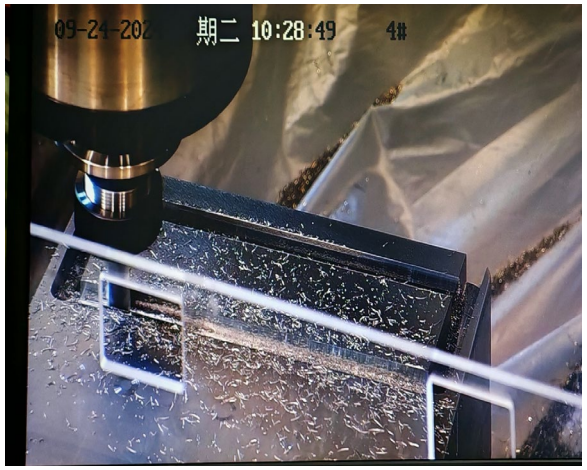


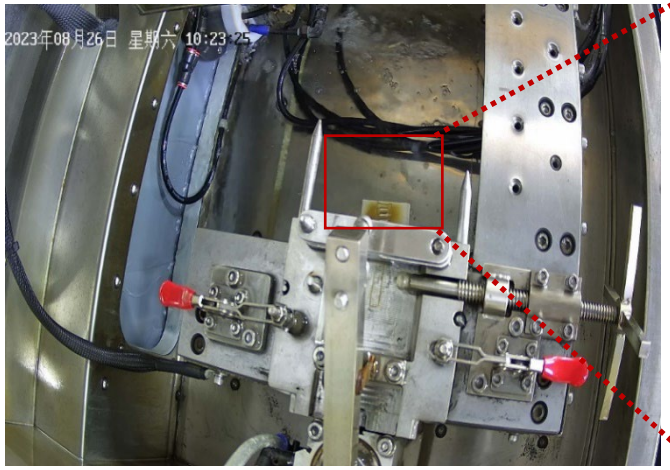
Wire EDM in Negative pressure air tent

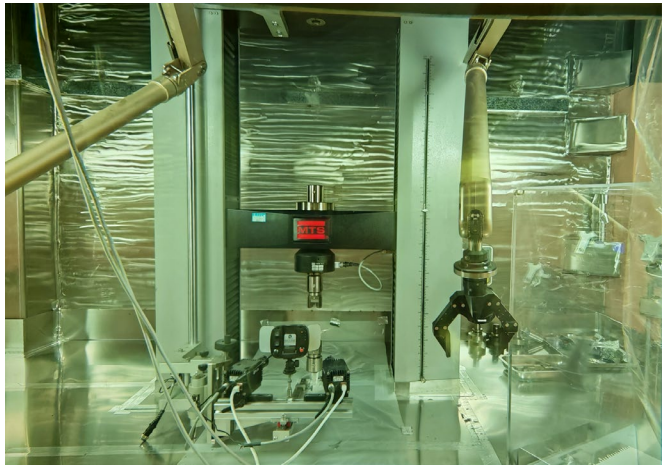


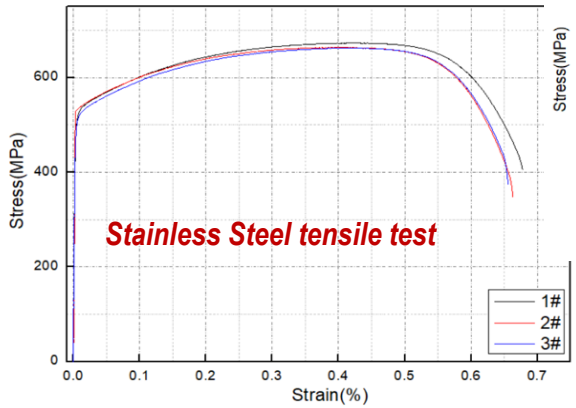
three-axis milling machine in hot cell

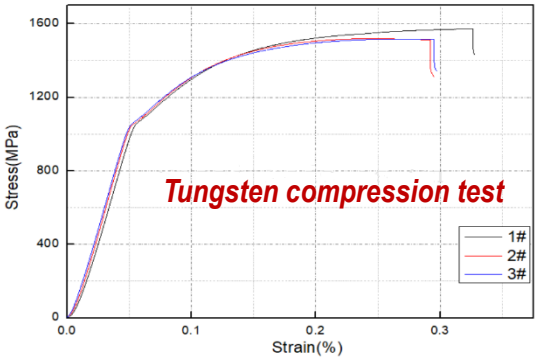
Target PIE plan







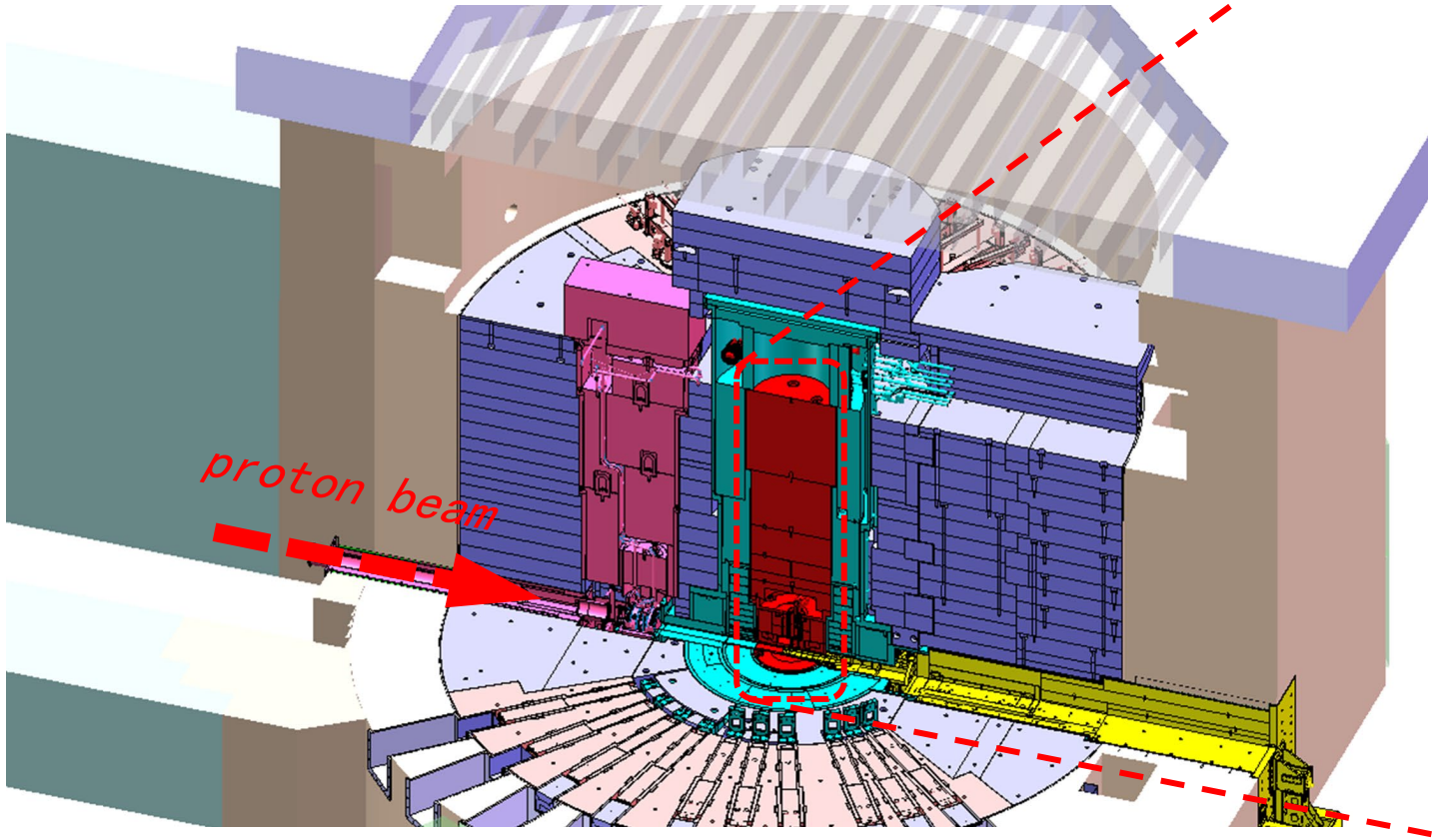


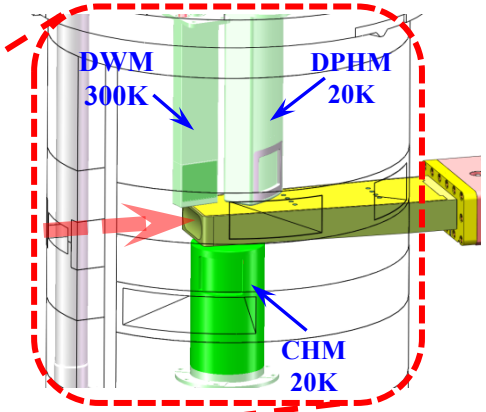


(CSNS remote handling system and PIE plan, by Zhiduo Li)

Moderator and reflector

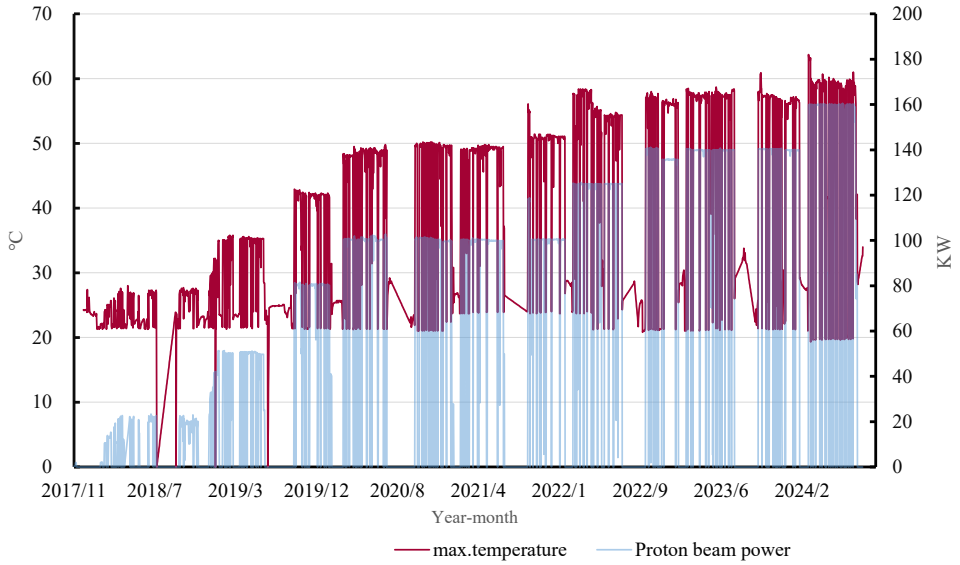
- Includes two liquid hydrogen moderators and one water moderator
- Continuous operation for 6 years without failure



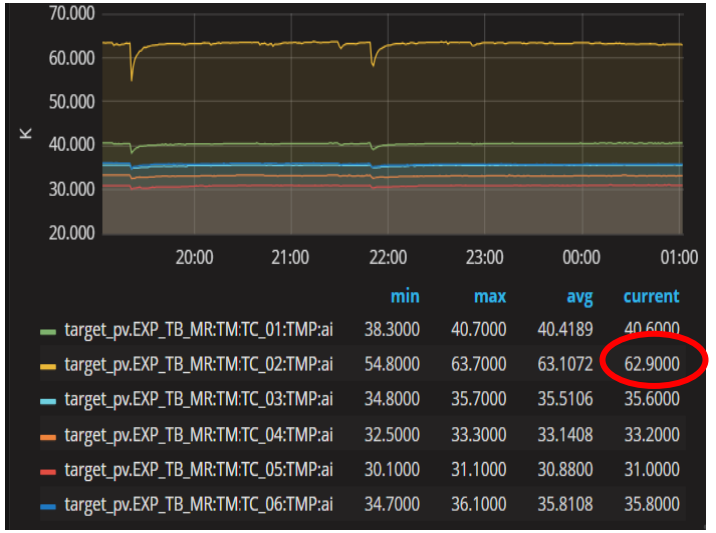


Moderator and reflector

- Max temperature of the aluminum container is 62.9℃@170KW
- Long-term use limit temperature of 5083 aluminum alloy is 65℃
- As the power increases to 170KW, the maximum temperature monitored by the TC02 thermocouple on the reflector is approaching the allowable temperature limit.
  As power may increase(→200kW), the temperature will inevitably exceed the limit.
- Solutions: 1) increase the flow rate of cooling water; 2) decrease the inlet temperature.
  (The temperature of secondary water is planed to be decreased in next summer)



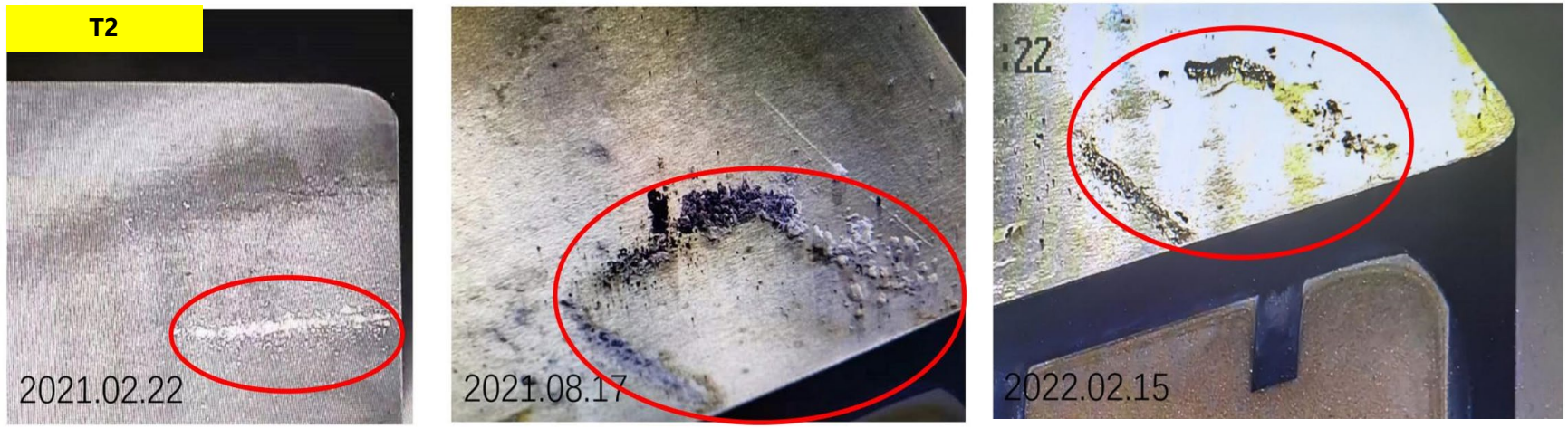
The highest temperature of the aluminium container in the past years



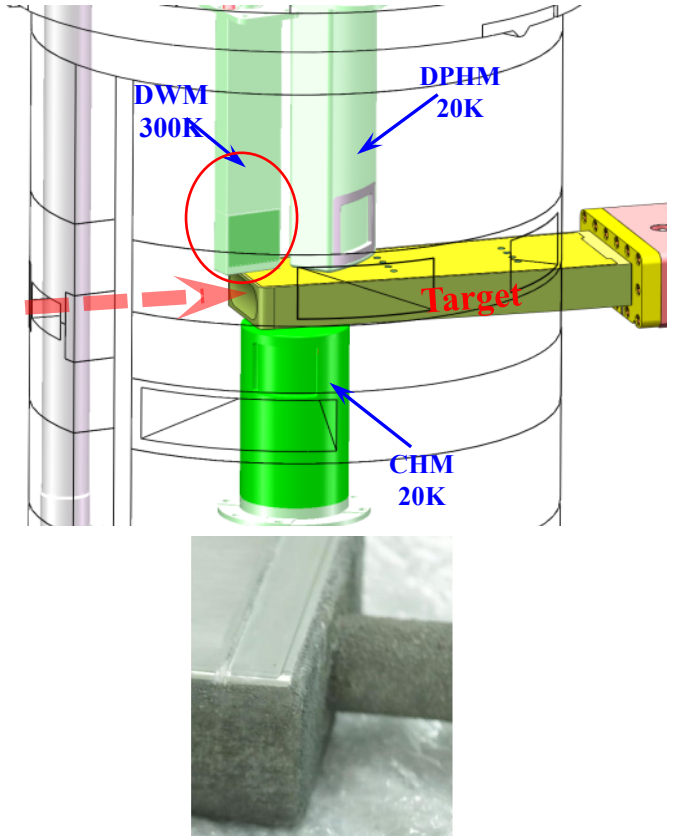
The current maximum temperature of the aluminium container

Moderator and reflector

- Since its first discovery in February 2021, the cadmium decouple layer of the water moderator has gradually decreased after reaching its peak in August of the same year.
- No significant changes have been observed in the neutron spectrum.



The decoupled cadmium layer powder on the surface of the target



Electroplated cadmium layer of DWM

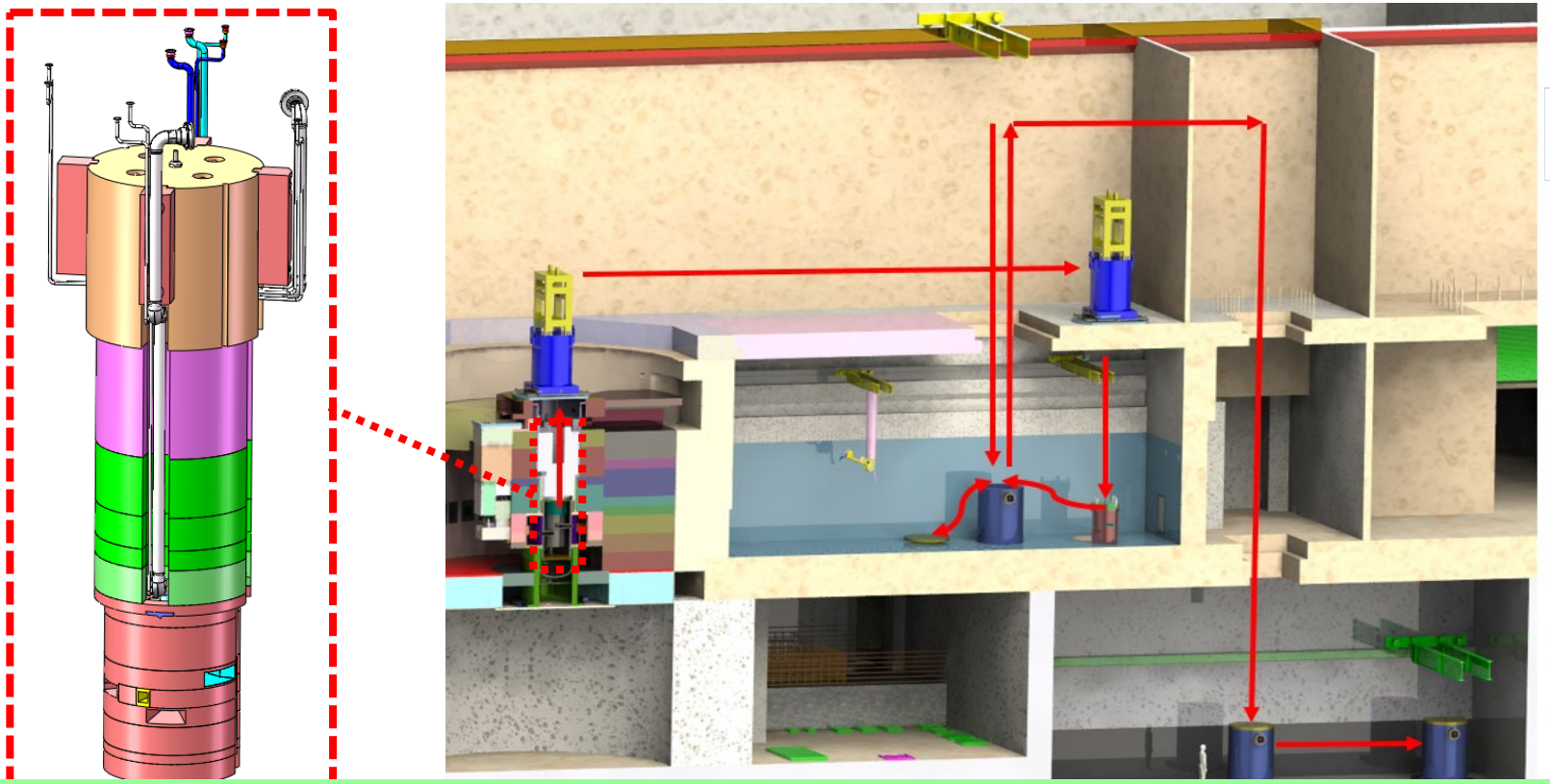
Moderator and reflector

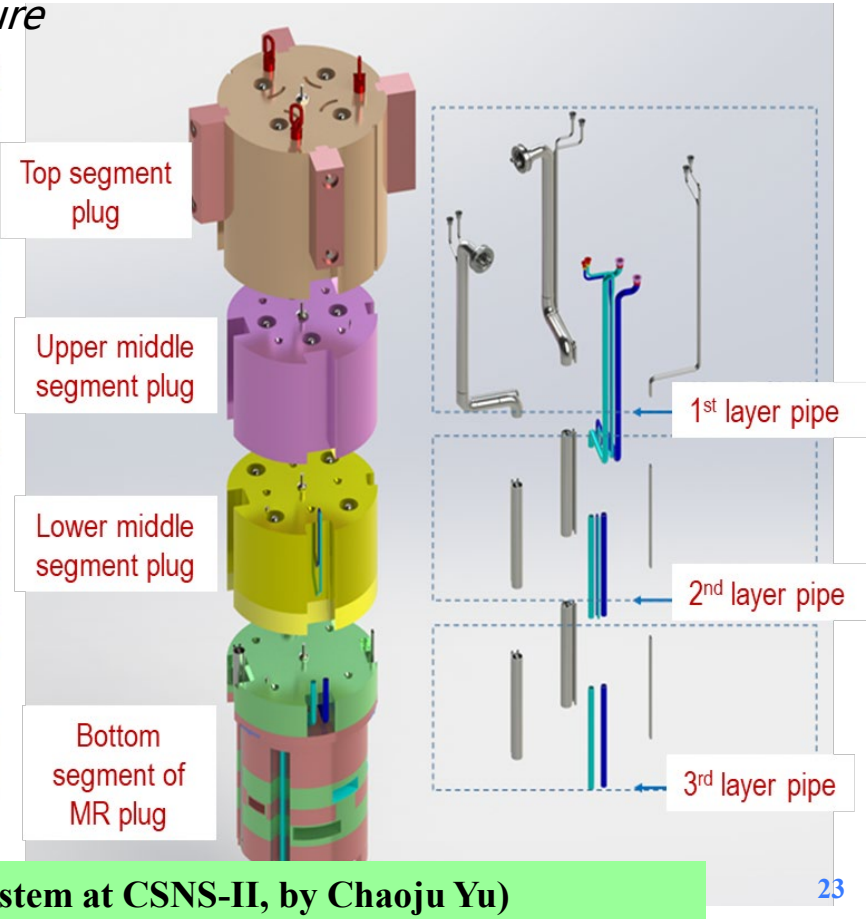
- **Plan of MR replacement: January to April 2028, for CSNS-II (500kW)**

✓ *MR plug split into four segments and its pipeline split into three segments, each segment will be disposed separately*

✓ *Use lifting and transport containers to transport plugin and pipeline to storage containers in the hot cell, and then lift them into the basement to store*

✓ *Detailed scenario design and mock-up test will be the focus of work in the near future*



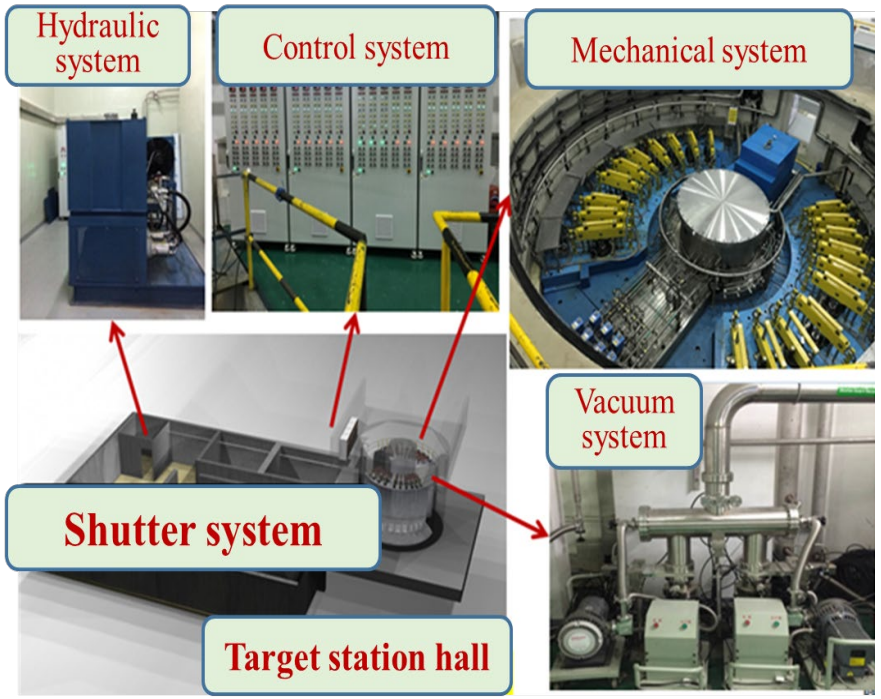


(Structural Optimization Design and Manufacturing Technology Development of Moderator Reflector System at CSNS-II, by Chaoju Yu)

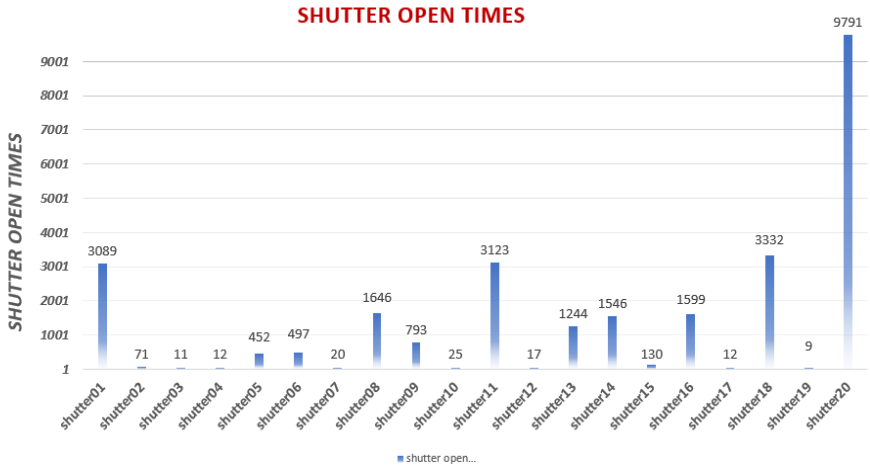
Shutter operation status and maintenance

CSNS shutter system

- ✓ Pure water hydraulic pumping station
- ✓ Mechanical and hydraulic drive parts
- ✓ Vacuum system
- ✓ Control system



- ✓ **Eight sets of shutter inserts have been replaced from 2018 to 2022**

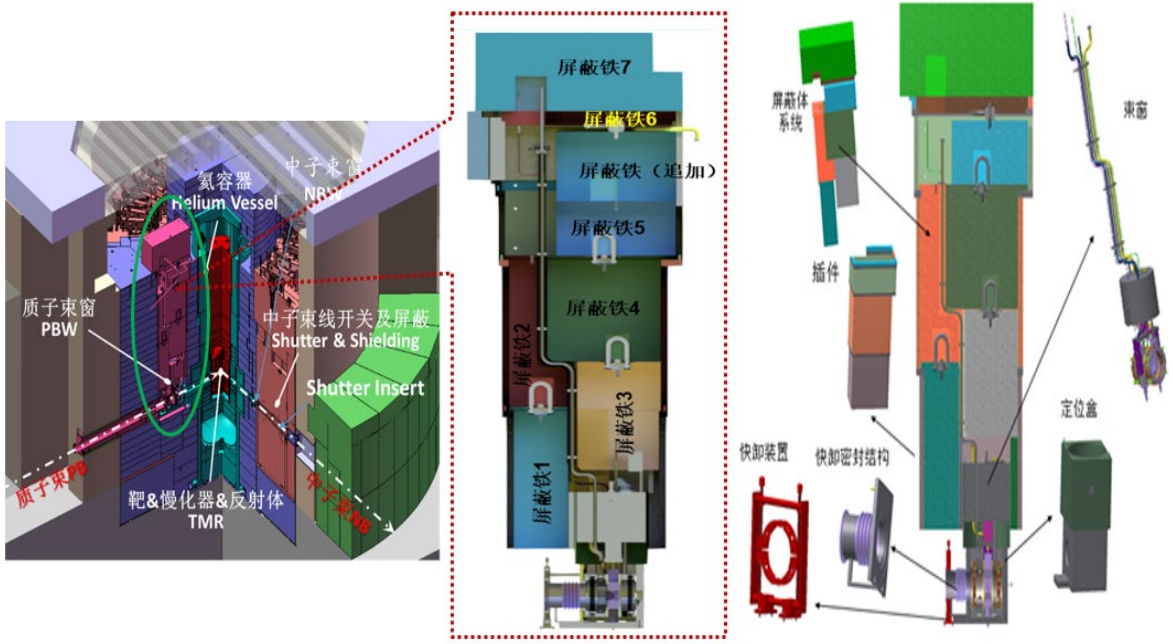


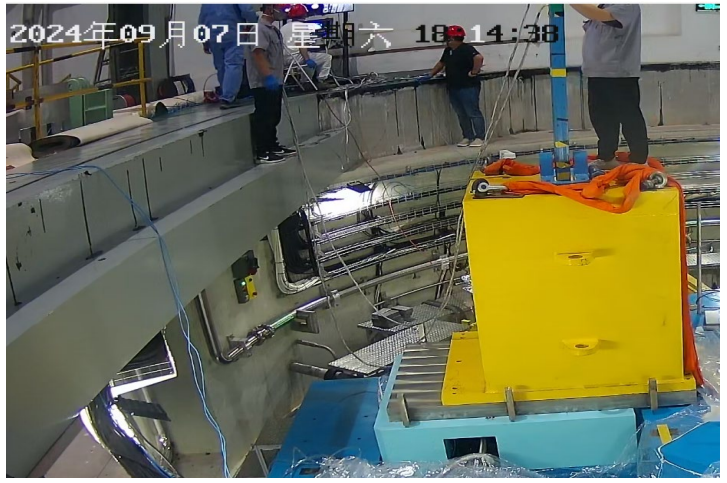
Maintain a high level of efficiency and stability in operation!

PBW replacement

Remote replaced the PBW

- ✓ *Shielding blocks removal*
- ✓ *Water and vacuum pipe cut and connect*
- ✓ *PBW lifting transport and storage*
- ✓ *New PBW install ,*
- ✓ *Seal performance test*
- ✓ *System recovery*

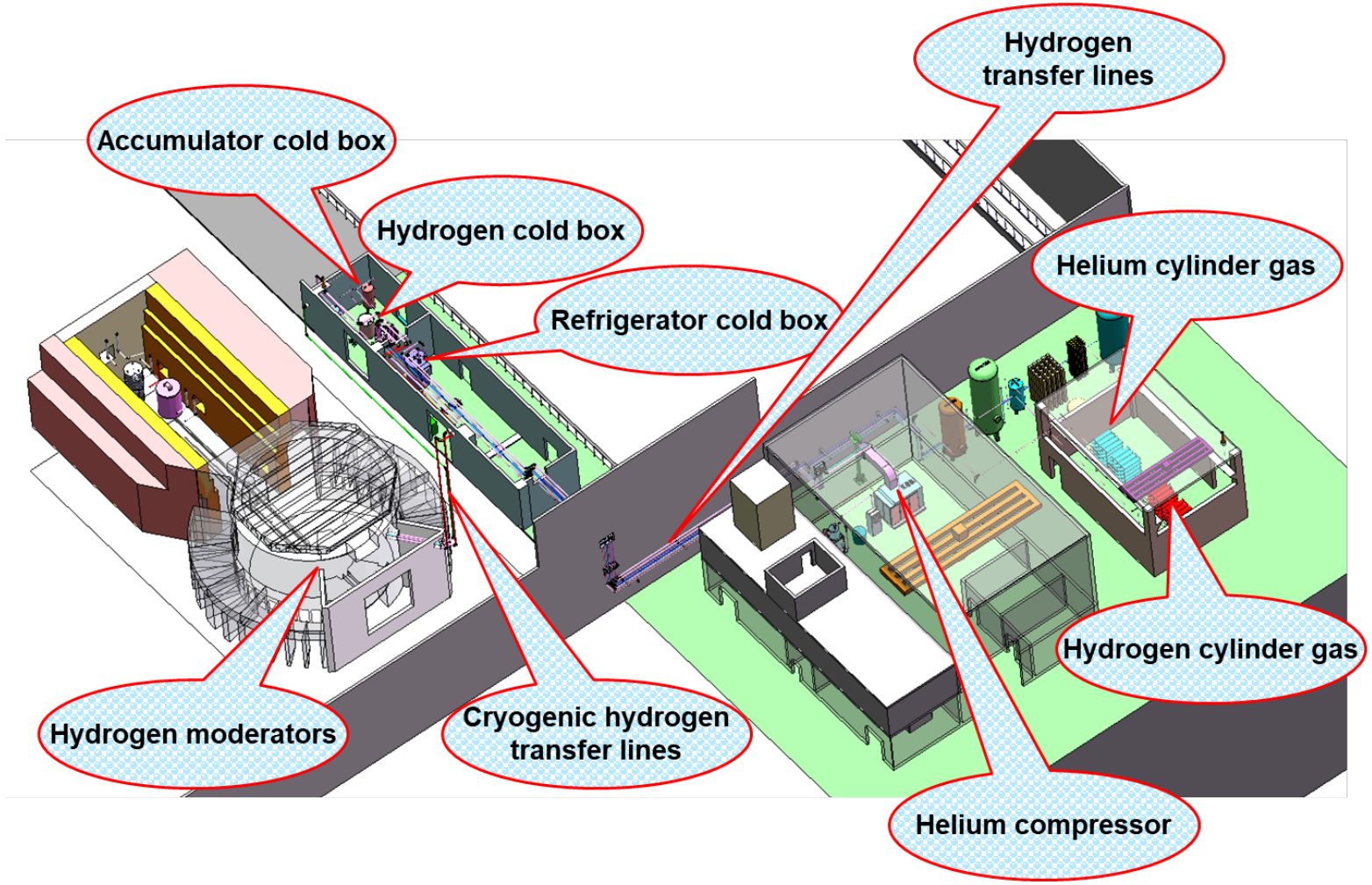




Successfully replaced PBW for the first time in 2024's summer maintenance period!

(Proton beam window replacement in CSNS, by Yuanguang Xia)

Cryogenic system



The Layout of the cryogenic system

Cryogenic system

- **CSNS cryogenic system provides hydrogen at 18~21K@15bar to keep the average temperature of two moderators below 20K. Concentration of para-hydrogen is higher than 99%.**

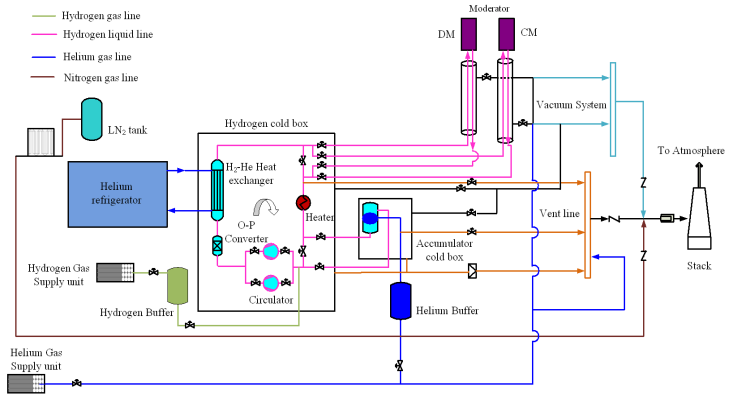
✓ *Provide 1L/s of supercritical liquid hydrogen for two moderators*

✓ *Dual hydrogen circulators hot standby*

✓ *Use welded bellows to compensate for pressure fluctuations*

Hydrogen Loop(1.5 MPa@18~21K)

Helium Refrigerator(2.2kW@20K)



Flow diagram

Cryogenic system

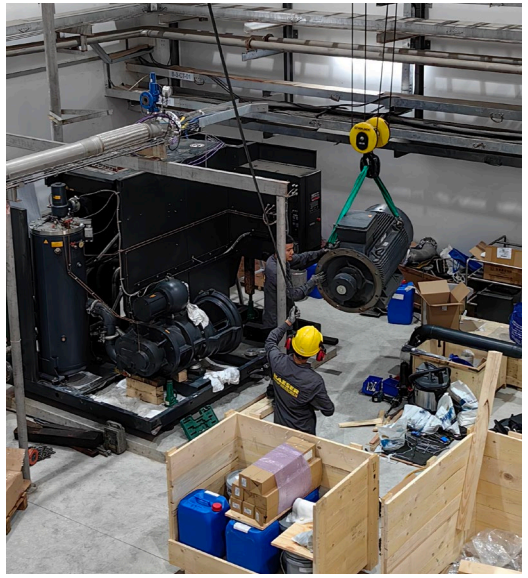
Operation

- ✓ *The hydrogen circulators once became the main failure restricting operation, but with improvements in maintenance methods, the failure rate has been steadily decreasing.*
- ✓ *The failure rate of the control system has been relatively high recently, and we plan to shorten the replacement frequency of the components.*

Year	Operation time	Failure	
2018	6192h	0h	Compressor incoming line overheat protector
2019	6185h	73h	Hydrogen supply valve stem fracture
		70h	Hydrogen circulator bearing damage
		70h	Hydrogen circulator bearing damage
2020	6900h	0h	/
2021	6840h	50h	Hydrogen circulator spindle fracture
2022	6480h	30h	Control system UPS damage
2023	7080h	26h	Helium supply valve controller damage
		50h	Control system CPU control panel damage

Cryogenic system

- **Maintenance**



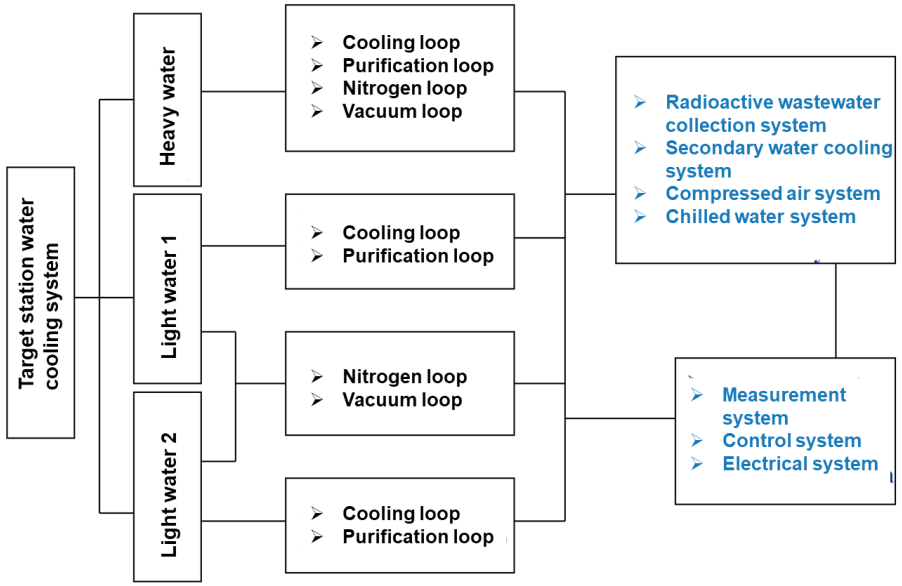
2023
Replacing the motor and rotor of the compressor

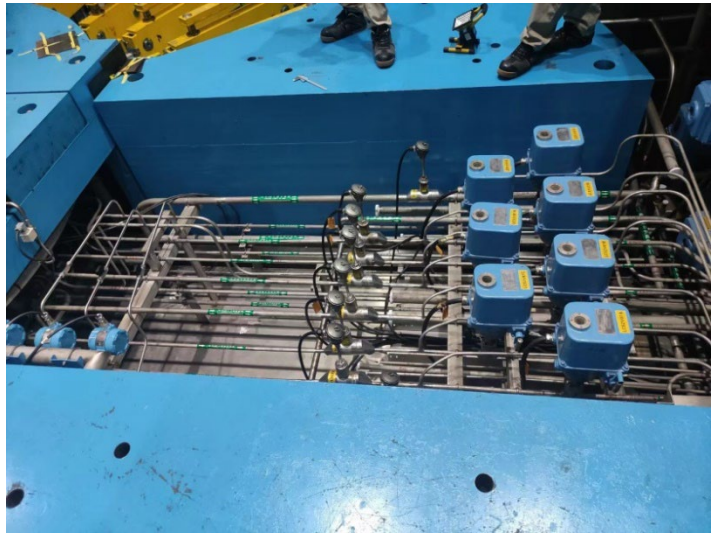
> 40,000 hours of operation

2024
Replacing the O-P hydrogen converter

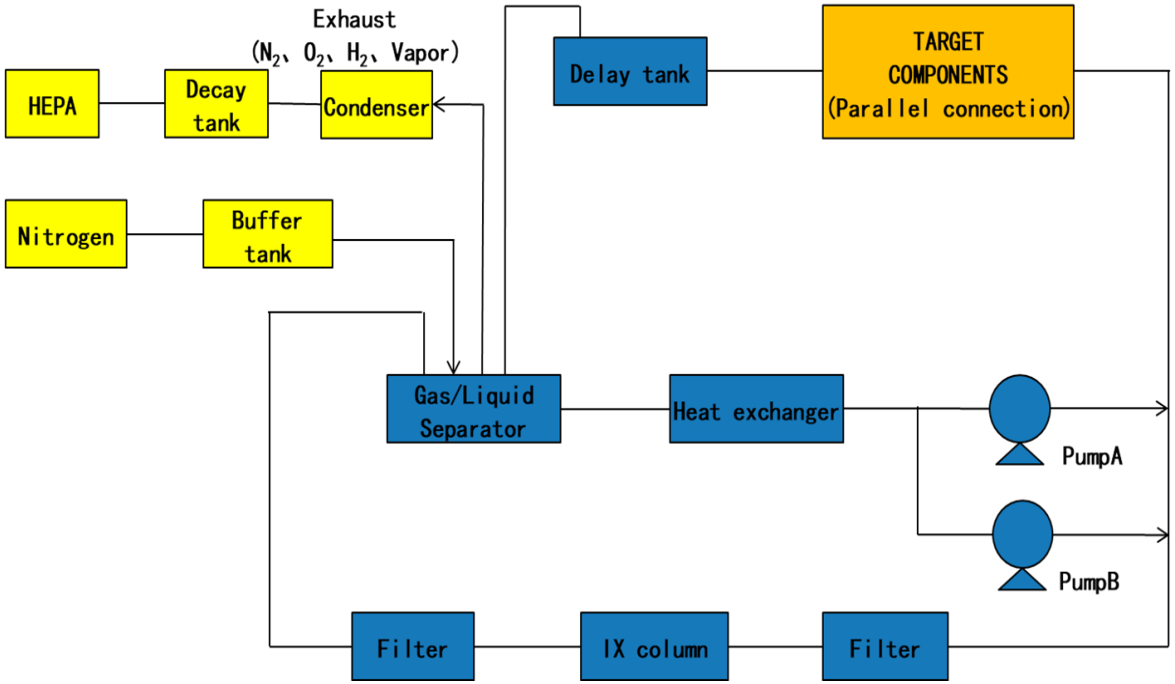
- **After 5 years, the catalyst particles have become powdered**
- **Filters have been added to both the inlet and outlet of the new structure.**

Water Cooling System





Water Cooling System



Flow diagram of water cooling system

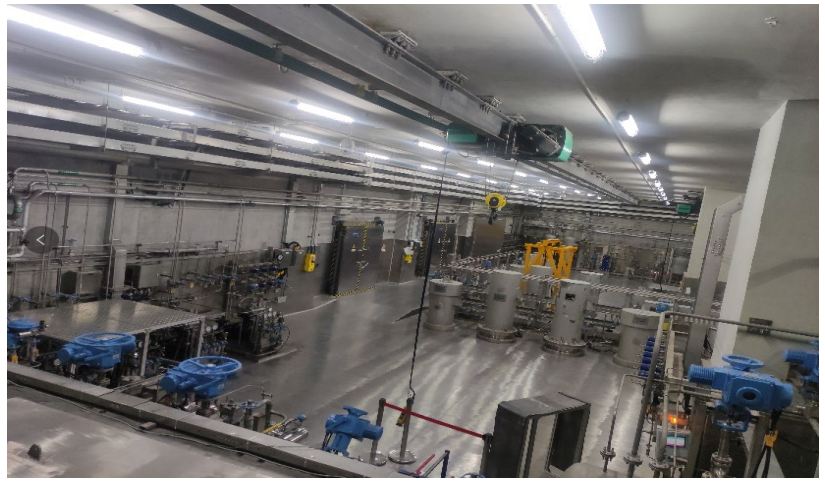
Main operation parameters

Water Cooling loop	Main component (s) served	Flow Rate (m^3/h)	Inlet Pressure (bar)	Temperature rise(°C)
Heavy water (light water)	Target	8.95	4.8±0.1	9.6
	Reflector	4.68	4.1±0.1	6.6
Light water1	Decoupled water moderator	0.66	2.7±0.05	0.7
	Pre-moderator	0.78	2.8±0.05	2.2
	DPHM water cooling layer	0.42	2.5±0.05	3.1
	Proton beam window	1.13	2.3±0.05	0.1
Light water2	Center section(helium vessel)	0.49	3.5±0. 1	4.9
	Lower outer reflector plug(helium vessel)	1.57	4.2±0. 1	6.3
	Intermediate reflector plug	0.42	3.5±0. 1	1.1

Notes： DPHM: Decoupled & poisoned hydrogen moderator
Proton beam power :170kW

Water Cooling System

- **Thermal-hydraulic operation parameters satisfy the physics requirements.**
- **Pressure boundary is completed, no seal failure.**
- **Cooling Loop Chemistry**
  - ✓ *Water quality is maintained with mixed bed resin and filters*
  - ✓ *Water conductivity is maintained lower than 0.5μs/cm.*
  - ✓ *pH –loops initially analyzed at 6.5; weakly acidic at present.*
  - ✓ *Main cations (chemical corrosion from structural materials) are Fe^{2+},Fe^{3+},Al^{3+}. Main anions are Cl^{-},NO_3^{-},SO_4^{2-}.*
- ➢ **The concentration of explosive gases (hydrogen and oxygen) maintained below its lower explosive limit.**
  - ✓ *Nitrogen is used as the carrier gas to dilute and exhaust gases (hydrogen and oxygen)*



Summary

- The beam power of CSNS has exceeded the design goal and reached 170 kW.

  The overall operation of the Target Station in CSNS Phase-1 is stable.
- There was an unexpected water leakage in T2 and T3, which required unplanned replacement. However, due to quick response and resolution, it did not have a significant impact on the facility’ s operation.
- Remote maintenance capability is gradually improving. With the increase in operating years and the engineering requirements of Phase II, more maintenance and replacement work needs to be carried out.
- The Cryogenic system and water cooling system operates normally at 170kW, and it still needs to withstand higher power (200kW?) before completing CSNS-II upgrade.
- Target Station division is currently carrying out the design and optimization work for the CSNS-II.

Thank you for your attention!