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CHINESE ACADEMY OF SCIENCES

The 24th meeting of the International Collaboration on Advanced Neutron Sources (ICANS XXIV)

Current status and CSNS-II progress of CSNS remote handling system

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CSNS Remote Handling & Shielding Group

CSNS-II Remote Handling System

2023-10-30·DongGuan

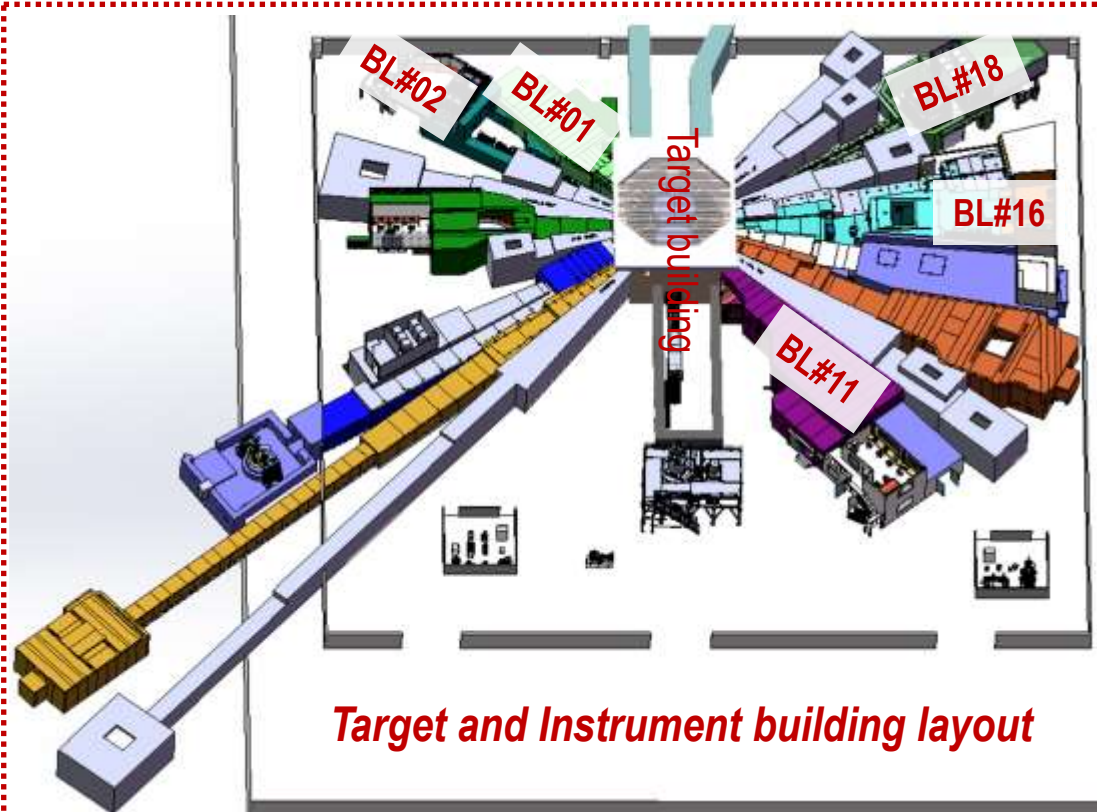
中科院高能物理所东莞研究部



- **CSNS Remote Handling System overview**
- **Operation and maintenance status of Remote Handling System**
 - Shutter system
 - Target replacement
- **Progress of CSNS-II Remote Handling System**
- **R&D on key technology/equipment**
- **Target PIE progress(*see Dr. Chuanggong Zhao's report for details*)**
- **Summary**

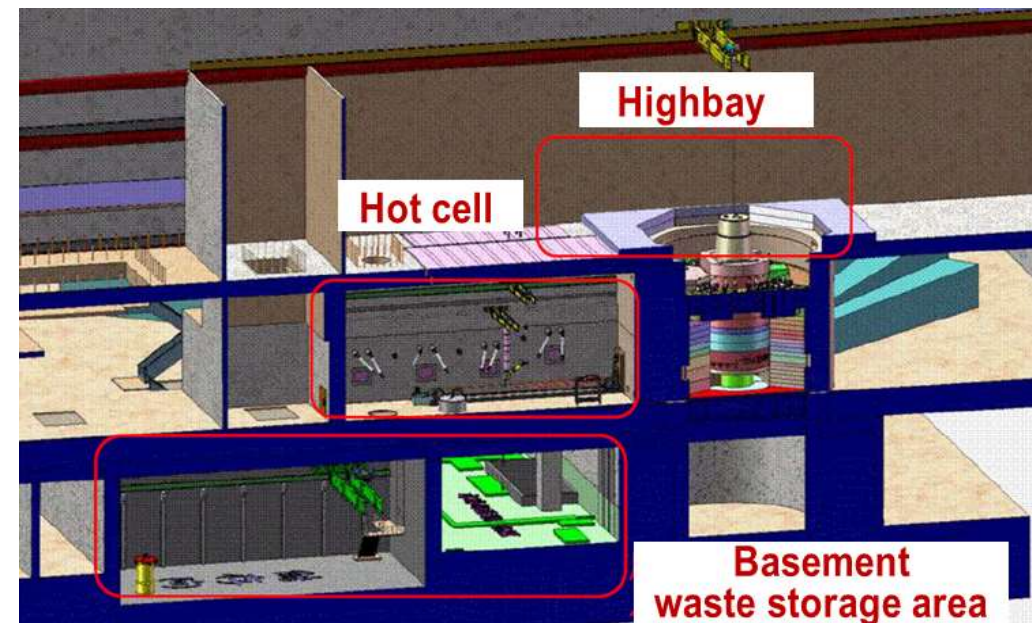
CSNS overview

- The CSNS facility in Dongguan, Guangdong, is an accelerator driven neutron scattering facility for materials research
- **CSNS operates presently at up to 140 KW@25Hz (*will be upgraded to 500KW in the CSNS-II phase*)** proton beam power incident on a solid tungsten target
- **Equipped with 20 neutron beamline/shutters in the target station**
- Presently 5 neutron instruments are operating



Remote Handling System overview

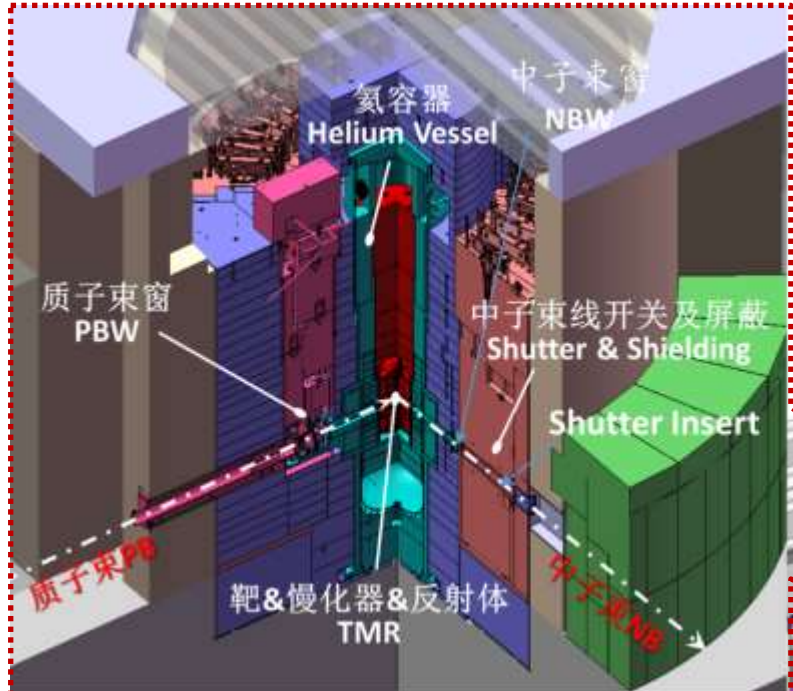
- Remote Handling and Shielding Group members:
 - ✓ Team leader (Prof. Yin)+**5 staff +2 external operators**(Zhouteng Wu, Xi Chen)
 - ✓ Staff: Zhiduo Li, Liubin Yuan, Yuanguang Xia, Chongguang Zhao, Jingjing Ma
- The main task of remote handling system at CSNS:
 - ✓ Operation and maintenance of shielding (shutter) system
 - ✓ Remote handling for maintenance objects at the Target Station
- CSNS Remote handling mainly includes:
 - ✓ Major component replacement (e.g.Target, PBW, Shutter Insert, MR, NBW, Shutter hydraulic cylinder, Ion exchange resin and filter, etc.)
 - ✓ Waste handling operations (Cask loading, shipment, waste volume reduction, waste storage and decommissioning at CSNS campus)
 - ✓ R&D on key technology/equipment and remote handling for potential weak spot maintenance needs of the facility
 - ✓ PIE application and operations development
 - ✓ Emergency handling safeguard for abnormal working conditions(e.g. sudden key component failures, etc.)



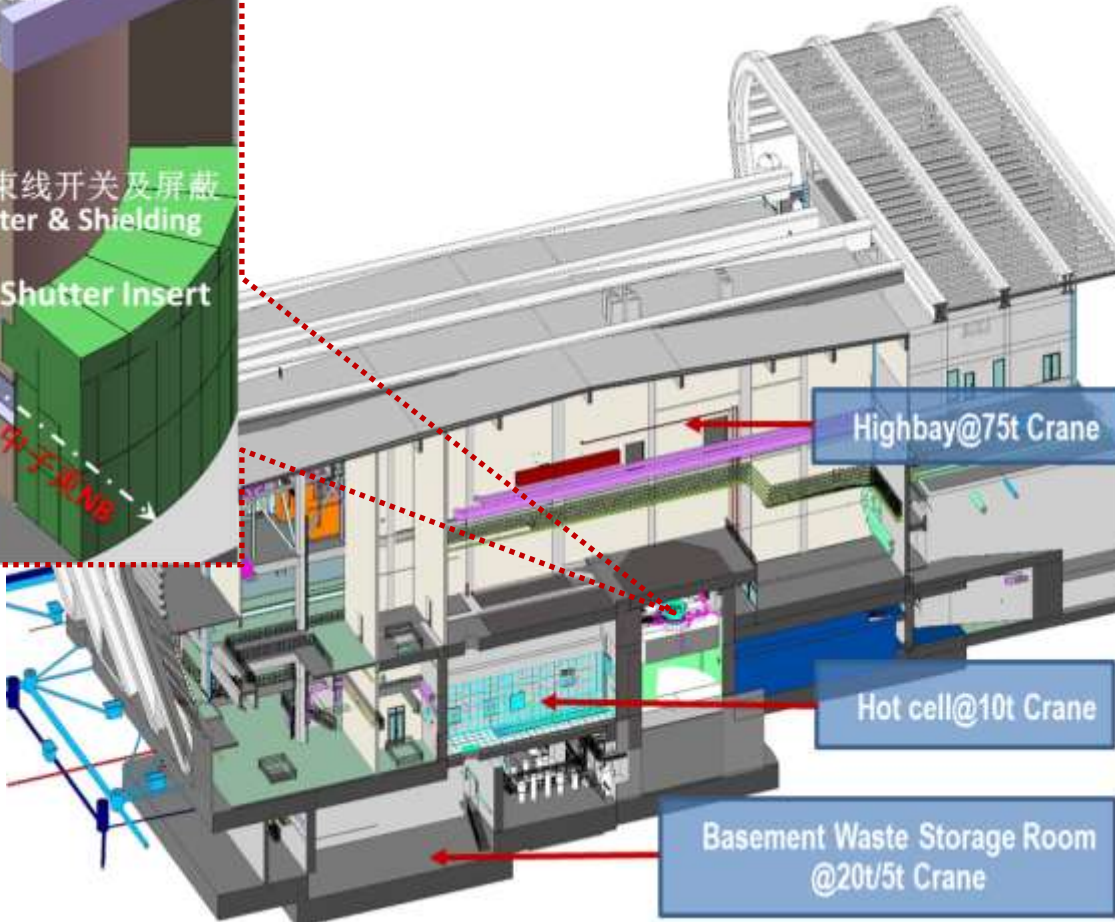
Remote Handling goals&general principle

- Refer to ALARA /time-distance-shielding principle and CSNS Safety Management Regulations
- Safe, reliable, reasonable and effective completion of replacement/disassembly, volume reduction, transfer, storage and decommissioning of radioactive maintenance objects

- Target & trolley system: **Horizontal maintenance**
- MR/PBW/NBW/Shutter insert: **Vertical maintenance**



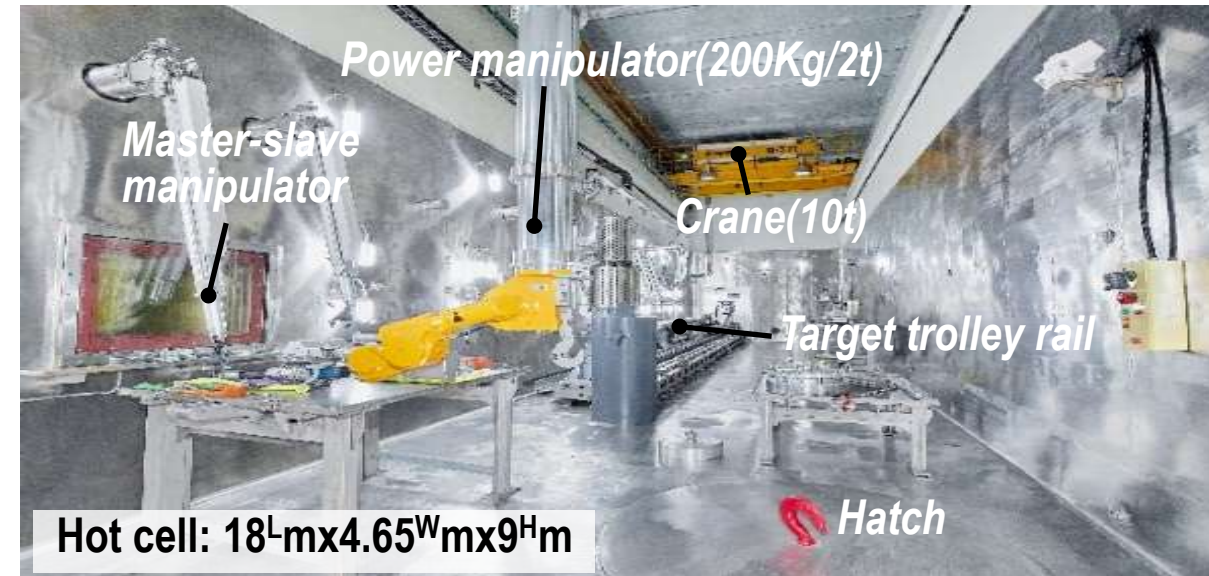
Target station



| Maintenance objects | Expected lifetime | Handling period | Spare parts |
|--------------------------------------------------------|---------------------------------|-----------------|-------------|
| A: High radioactive components | | | |
| Target module | 4-5yrs@CSNS-I 1y@CSNS-II | 10d | Y |
| Target inflatable sealing flange, motor, reducer, etc. | >20y/On demand | 10d | N |
| Moderator | 10yrs@CSNS-I | 25d | N |
| Inner reflector plug | 5yrs@CSNS-II | 25d | N |
| Outer reflector plug | >30yrs/On demand | 25d | N |
| PBW | 4-5yrs@CSNS-I 1-2yrs@CSNS-II | 15d | Y |
| PBW quick seal module | >20yrs/On demand | 15d | Y |
| NBW | >20yrs/On demand | 15d | Y |
| Shutter insert | >20yrs/On demand | 7d | N |
| Outer beamline insert | >20yrs/On demand | 15d | N |
| B: Regular maintenance/Lower radioactive components | | | |
| Ion exchange resin/Filter | 1-2yrs | 30d | Y |
| Shutter hydraulic cylinder | >5yrs/On demand | 7d | Y |
| Shutter hydraulic pump | 1y/On demand | 1d | Y |

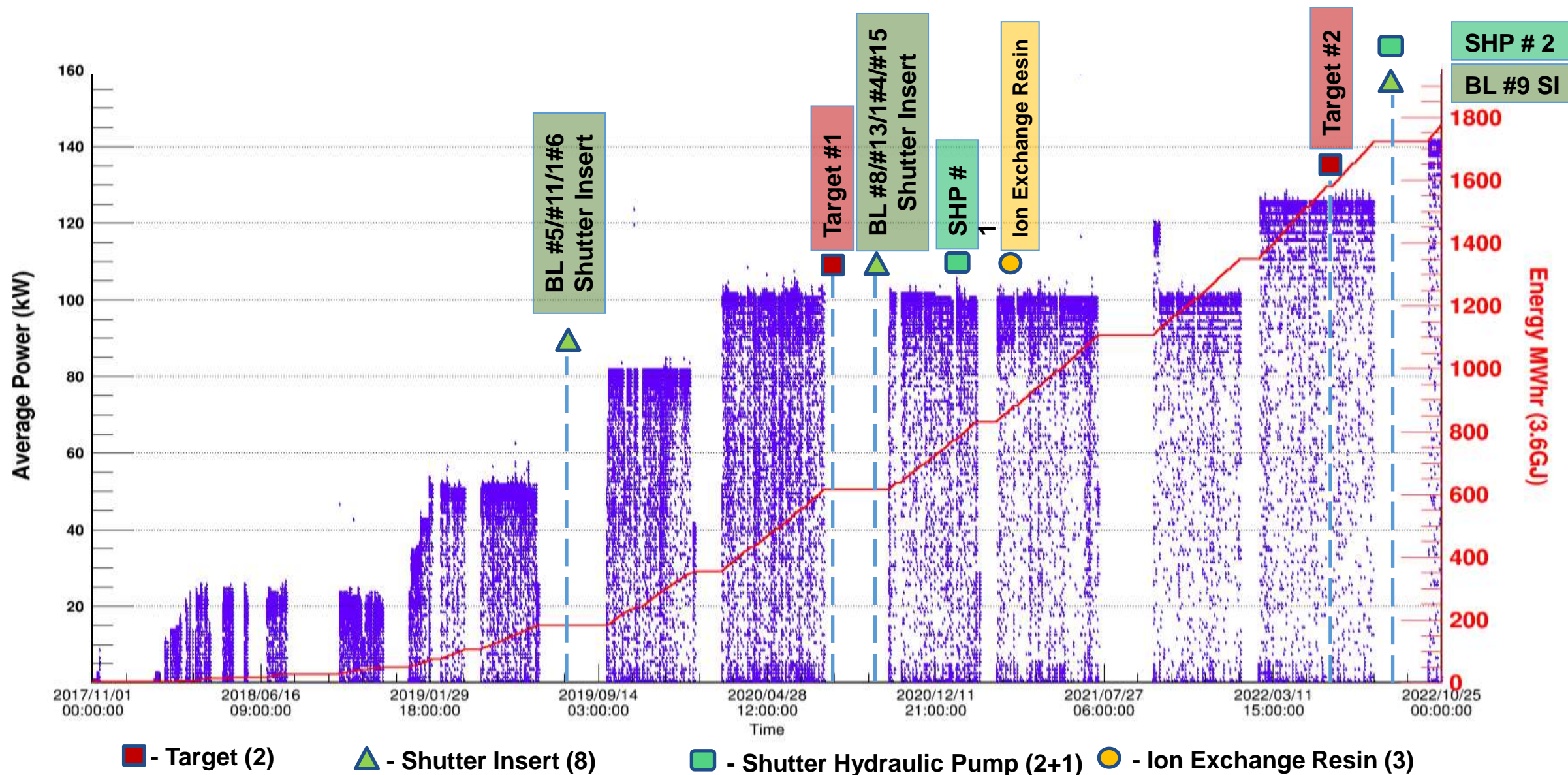
End of life for each item is estimated based on projected beam power, run schedules, availability, etc., and then updated planning with actuals

Remote handling equipment & test platforms

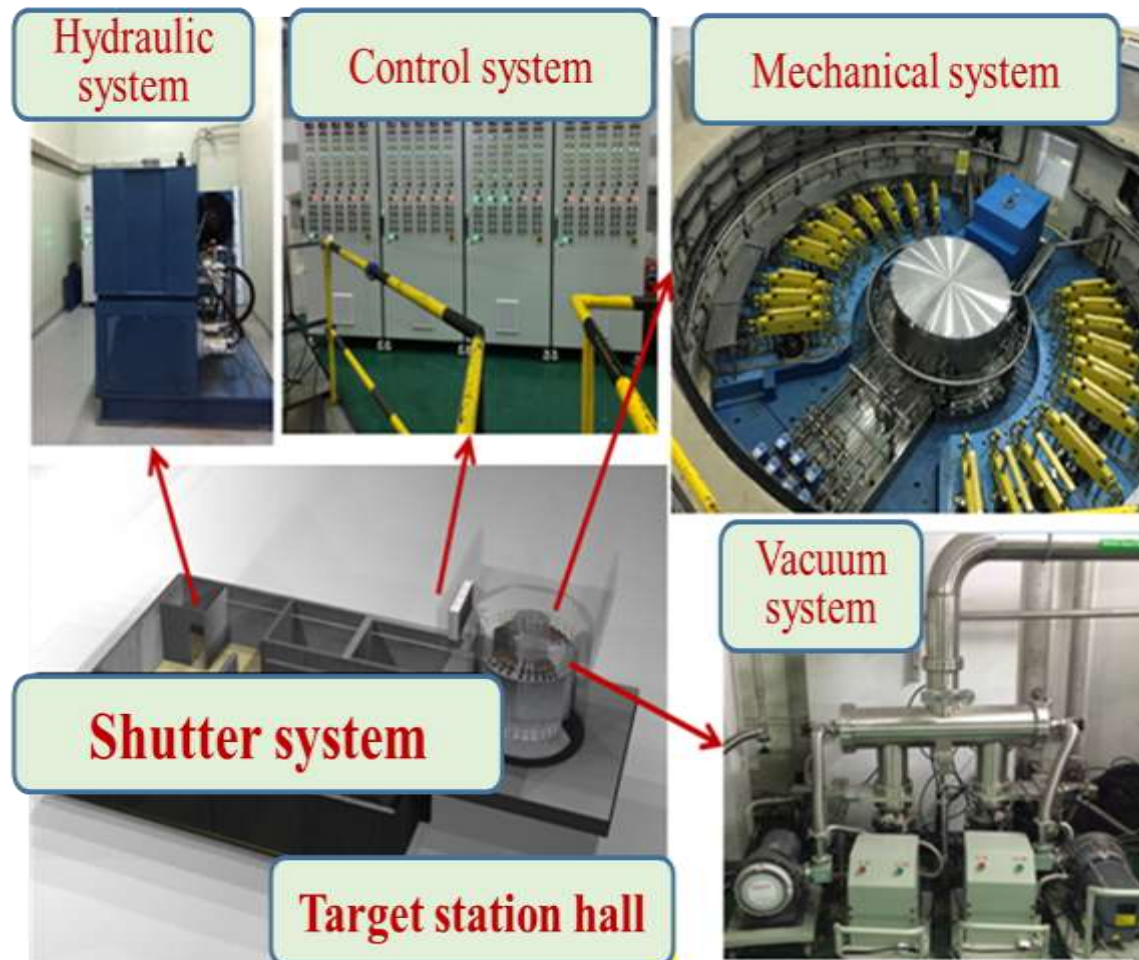


Beam Power & Component Replacement History

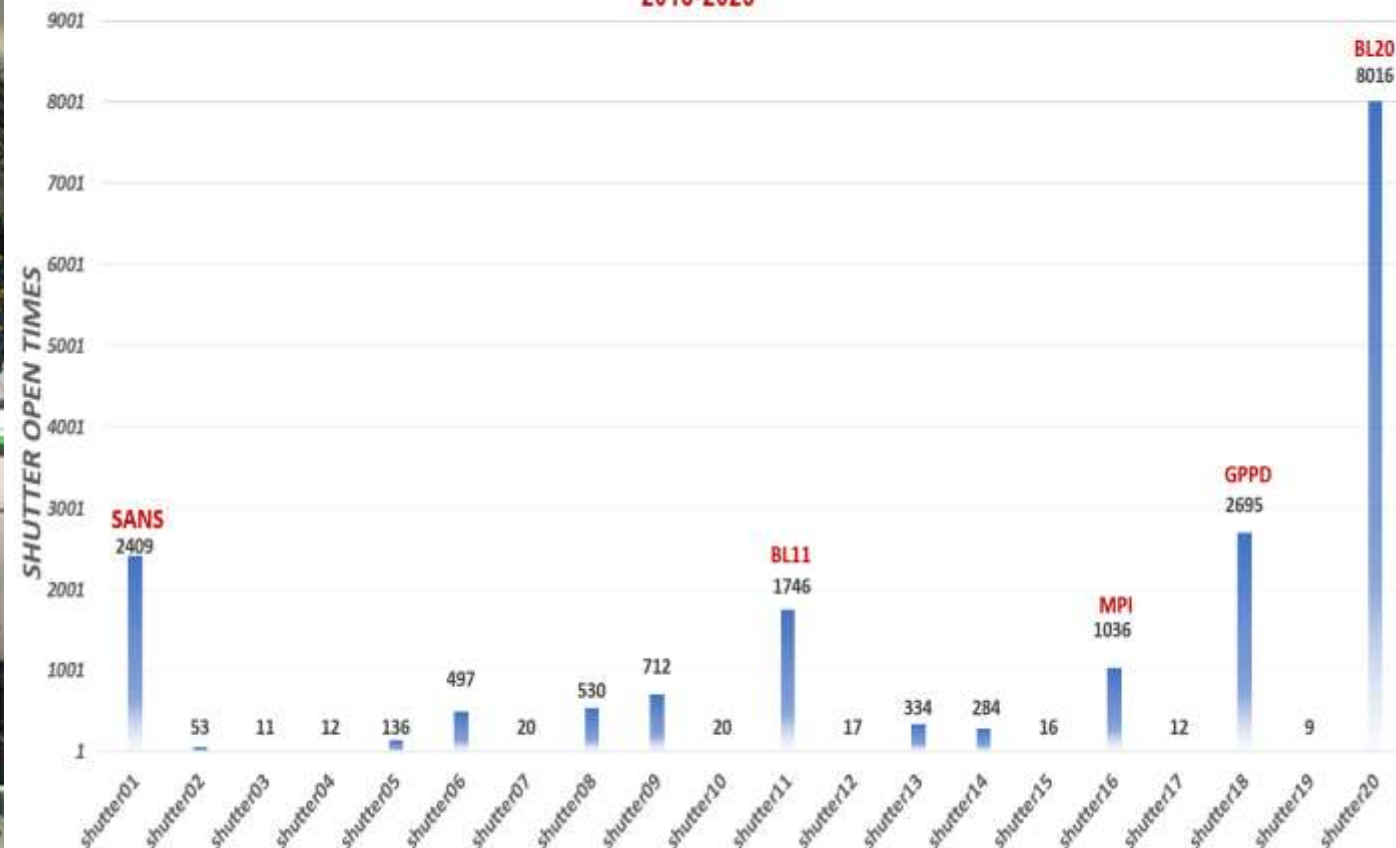
- Since CSNS formal operation began in 2018, a significant amount of remote handling operations have been successfully completed



Shutter system operation status



STATISTICAL TABLE OF SHUTTER OPENING TIMES FOR ALL THE INSTRUMENTS
2018-2023

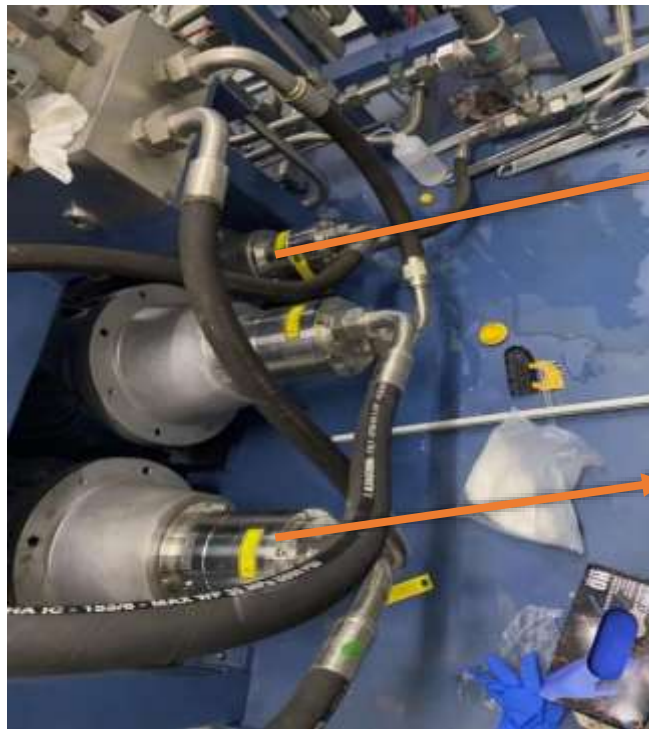


Shutter system has always maintained safe, reliable and stable operation, and has been running continuously for 24 hours (>6000h/y) during the supply beam period for >5 years without failure!

Shutter hydraulic system operation & maintenance

- Replaced 3 water Hydraulic Pumps and gained the actual operation lifetime from the pump:

- ✓ Rated life: 8000h@ Danfoss pump
- ✓ Water hydraulic pump 01# (PAH63) replaced in 2020 @~16000h
- ✓ Water hydraulic pump 02# (PAH63) replaced in 2022 @~12000h
- ✓ Water Circulating pump 01# (PAH25) replaced on June 5, 2023



PAH25



PAH63

- The self-developed pure water hydraulic cylinder with radiation resistant works very well and has not been replaced yet



Shutter Hydraulic Pump Station

Dose rate: Background level

Shutter Insert Replacement

- Smoothly completed the replacement of 8 sets of Shutter Inserts in total with safety and high efficiency
- ✓ BL #5/#11/1#6 Shutter Insert in 2019@BL#11 Surface dose rate Max. $252\mu\text{Sv/h}$
- ✓ BL #8/#13/1#4/#15 @Shutter Insert in 2020
- ✓ BL#09 used Shutter Insert in 2022@ Surface dose rate Max. $840\mu\text{Sv/h}$



Shutter gate cask lifting & handling

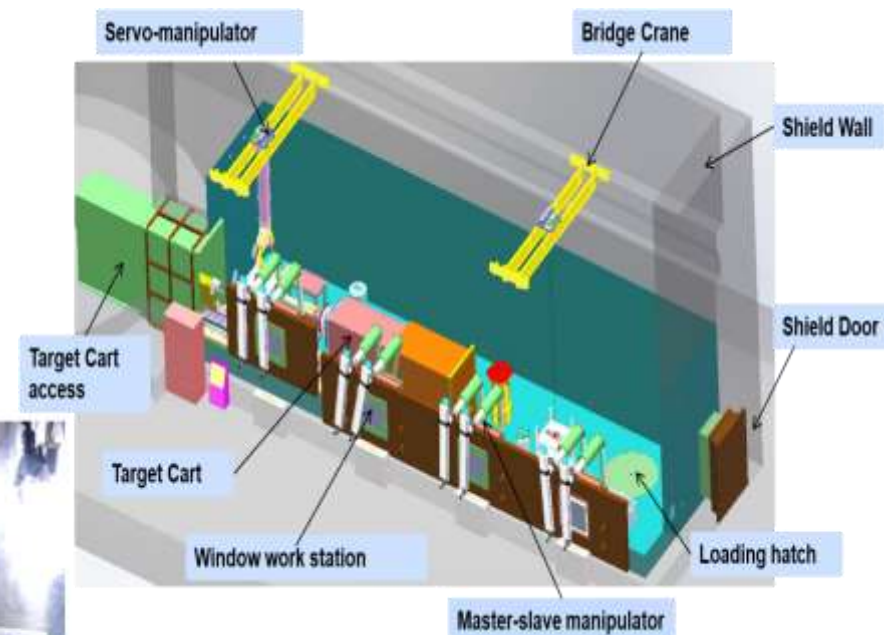


Used shutter insert removal & storage
Net time for replacing a set of Shutter Insert is ~4.5h

- ❑ Gained valuable experience through the replacement of multiple sets of SI
- ❑ Maintenance processes for SI have also gradually been standardized

Target Replacement

- Successful replacement of the target modules is accomplished using only remote handling tooling and procedures in Hot cell
- So far, CSNS has completed the remote replacement of two targets
 - ✓ Replaced the first Target #1 as maintenance panning in 2020
 - ✓ Urgently replaced the 2nd Target #2 for the seal leakage of target module in May 2022
 - ✓ **Typical target replacement requires ~5 days**



Target#1 front end



Target#1 rear end



Target#1 lifting



Seal surface at Helium vessel end
by camera observation



Target#1 removal



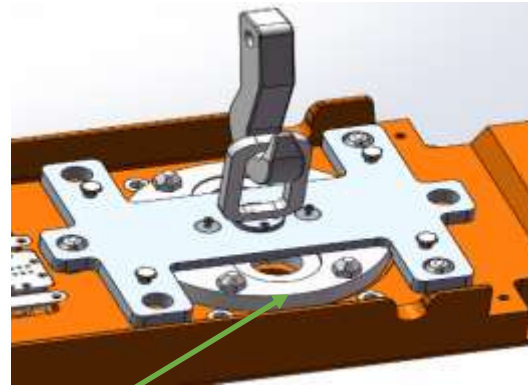
Target#1 cask loading and storage

Target Replacement

- For target#2 sudden leakage failure with a new challenge to uncertain detail location of leak, quickly made a emergency replacement proposal
- Finally, successfully completed the emergency replacement and detection tasks of the target with using 4 days only



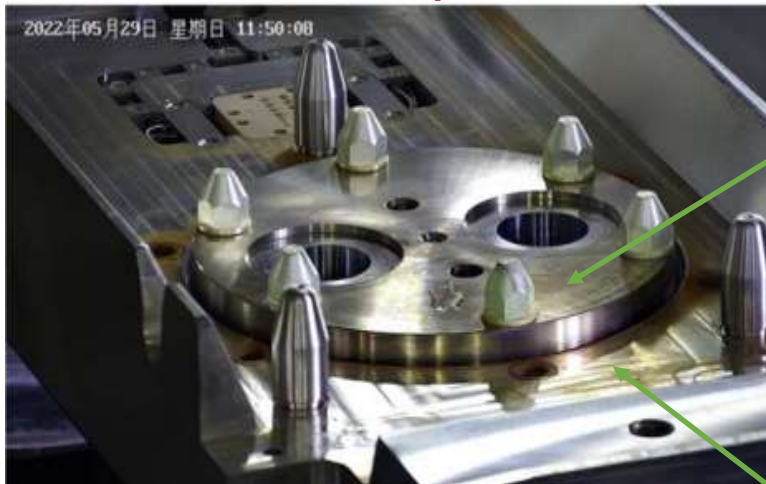
Possible leak points



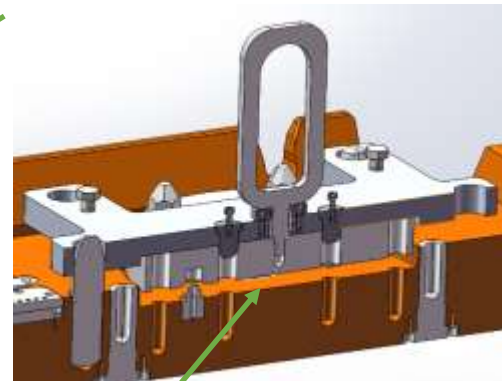
Transitional Plate



Removal tooling



Target Base



Installation tooling



Installation test

Target Replacement

- Target#2 emergency replacement process and effective implement for the seal leakage of target module in May 2022

Clean & Removal



靶体清污



螺栓移除



旧靶水平吊运



旧靶放置翻转平台

Turn over & Observation



翻转



翻转45°

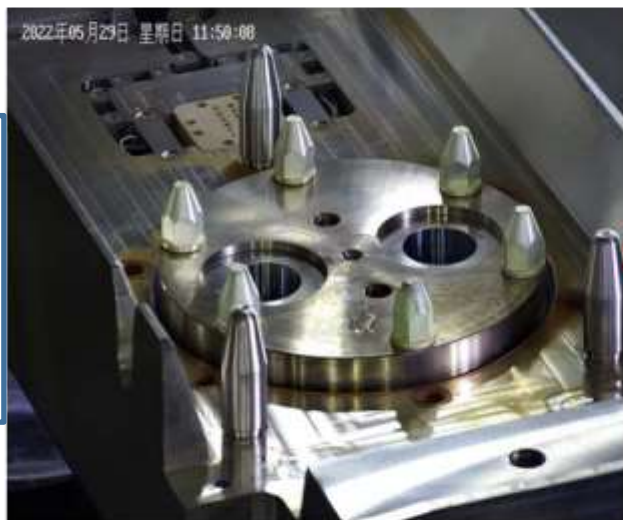


垂直状态

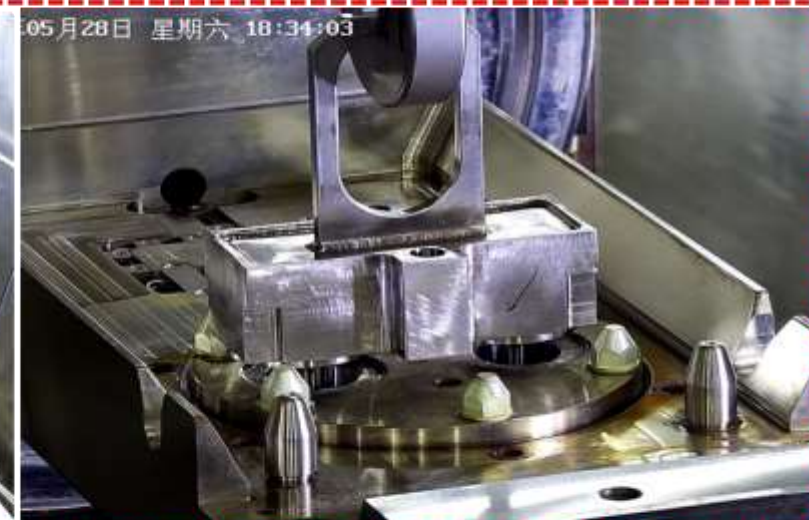


靶体观察

Seal surface & Observation



Transition plate Sealing test



New target lifting



靶体表面清理



吊运至顶部大厅



安装密封圈



密封面清理

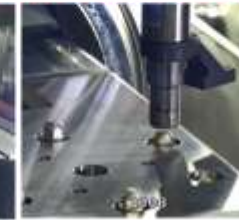
New target installing



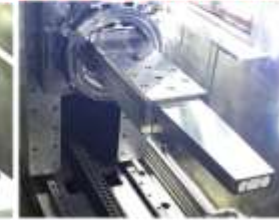
电动抓手抓取



紧固螺栓对准



螺栓紧固

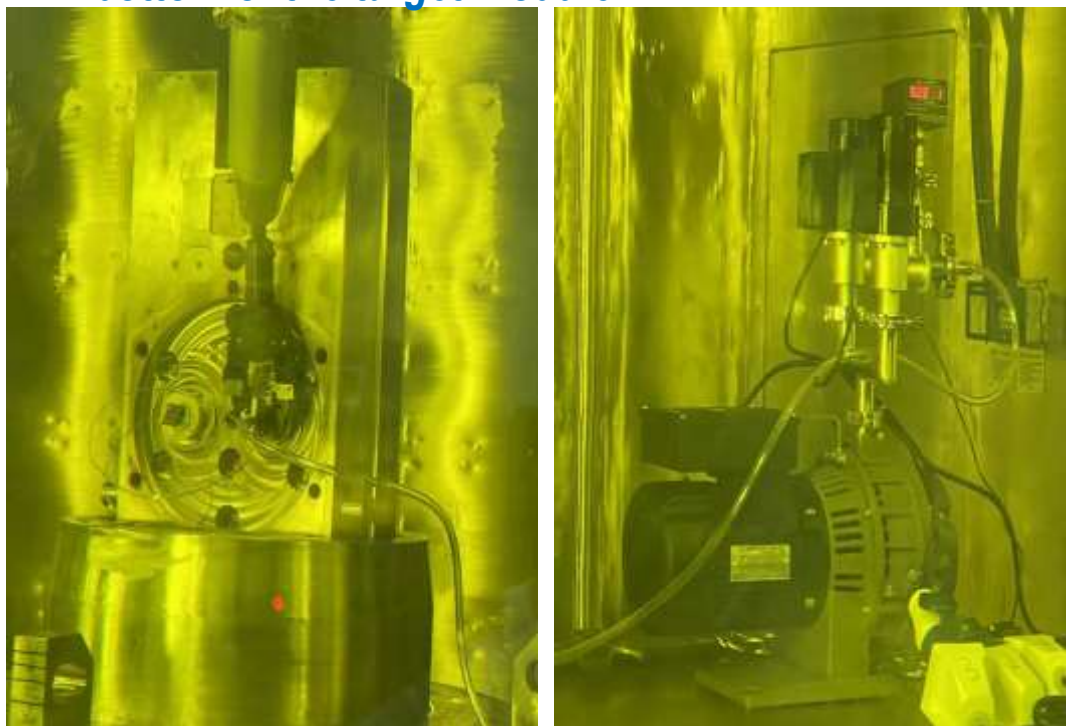


安装完毕

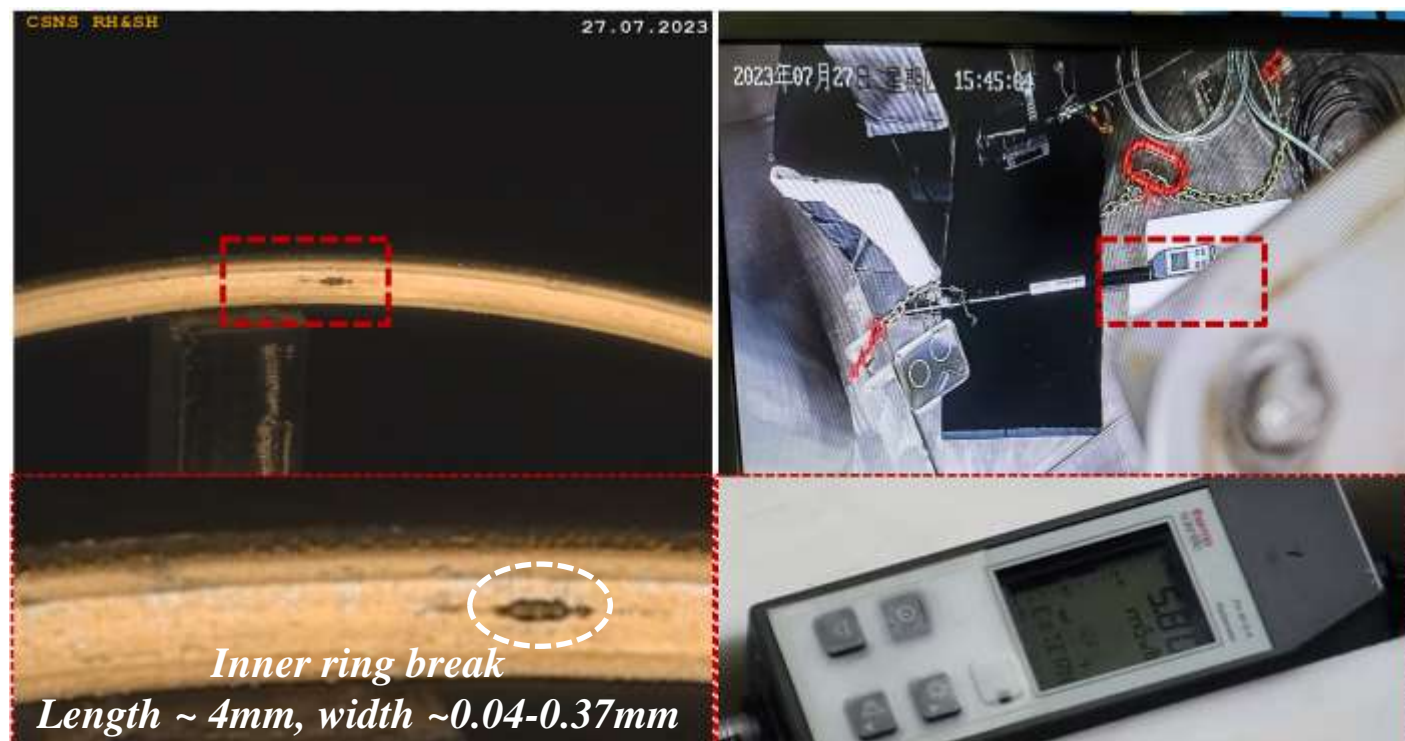
- ✓ Through 2 target replacements, we have accumulated valuable experience in the remote operation of target module
- ✓ Remote operation replacement processes for target module have also gradually been standardized

Target Replacement

- **Target #2 failure analysis and detection for remote operations in Hot cell**
 - Carried out target fault detection through remote operation and respectively completed the following in the high radioactive environment:
 - ✓ **Target #2 sealing performance test in Summer maintenance period of 2022**
 - ✓ **Removal and observation of metal sealing ring in Summer maintenance period of 2022 & 2023**
 - ➔ The test results show that the sealing performance of the target container is good (there is no leakage in the vacuum pressure holding test), and it is preliminarily judged that **the leakage is caused by the damage from the silver metal sealing O-ring at the bottom of the target module**



Used target#2 sealing performance test



Removal and observation of metal sealing O-ring

After power upgrade, the activity of core components in target station and the amount of waste storage will increase significantly. The system upgrade mainly includes the preliminary design of key component maintenance proposal, R&D on key technology/equipment, and mockup test.

- **Maintenance design of key equipment in target station**
 - ✓ TMR, PBW, NBW maintenance
 - ✓ Shutter system, water cooling system purification equipment maintenance, etc.
- **Radioactive waste storage design**
 - ✓ Storage of retired components such as TMR and PBWs
 - ✓ Decommissioned ion exchanger reduce volume, storage, etc.
- **Maintenance design of abnormal working conditions for target station maintenance objects**
- **PIE capacity building for retired core components**
- **R&D on Key technology and equipment has been carried out:**
 - ✓ Target station core component handling platform, PIE test room
 - ✓ Power manipulator, remote leak detection, quick lift, hydraulic cutter, etc.



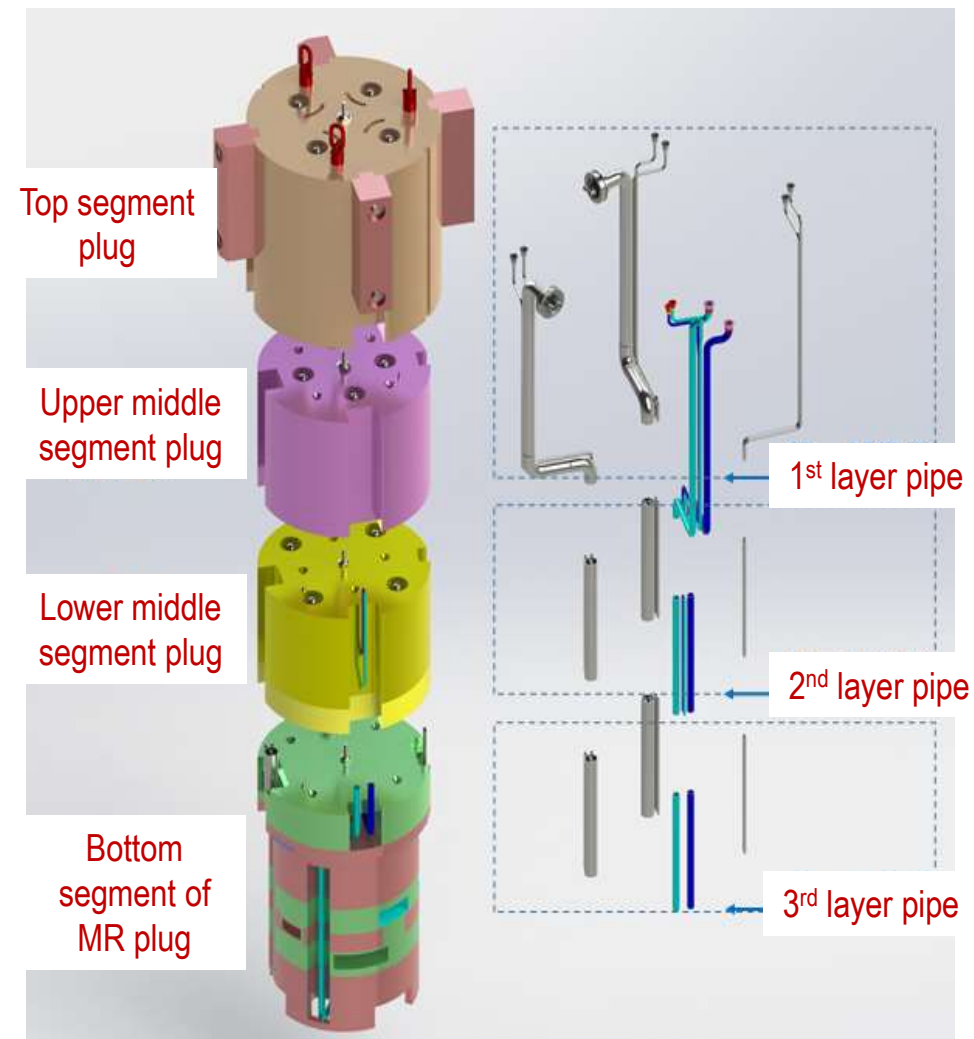
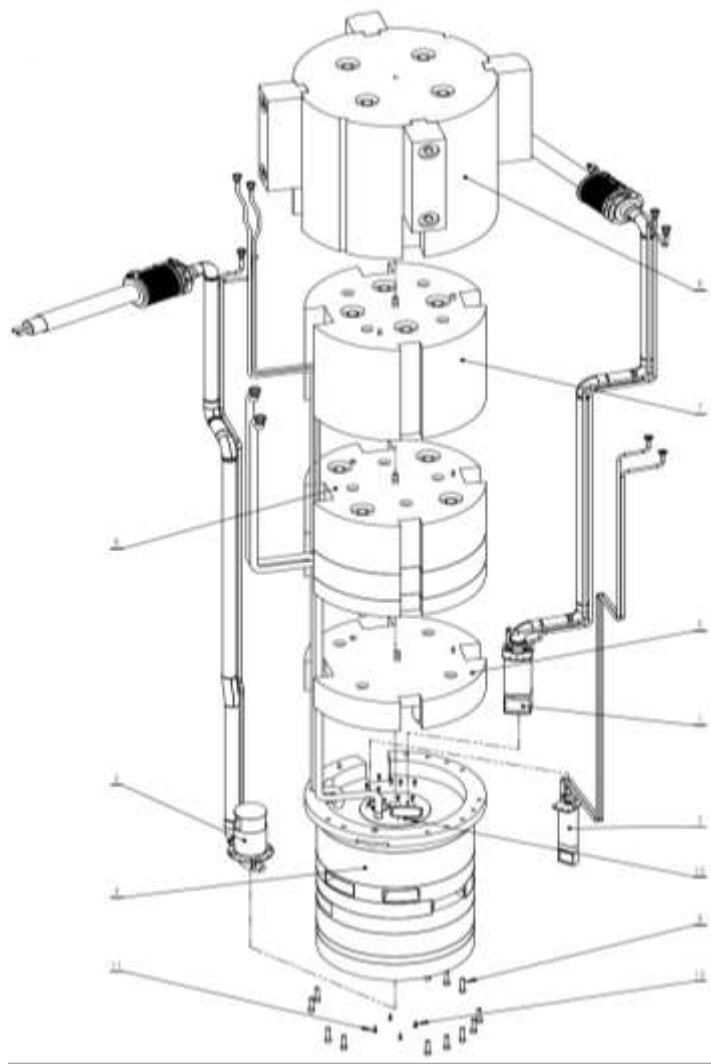
PBW&NBW&MR Mockup Platform

MR replacement process development

- MR plug is large, complex and limited-lifetime(@10y) key component of the target station, the first MR will be replaced in 2027
- MR plug split into four segments and its pipeline split into three segments, each segment will be disposed separately

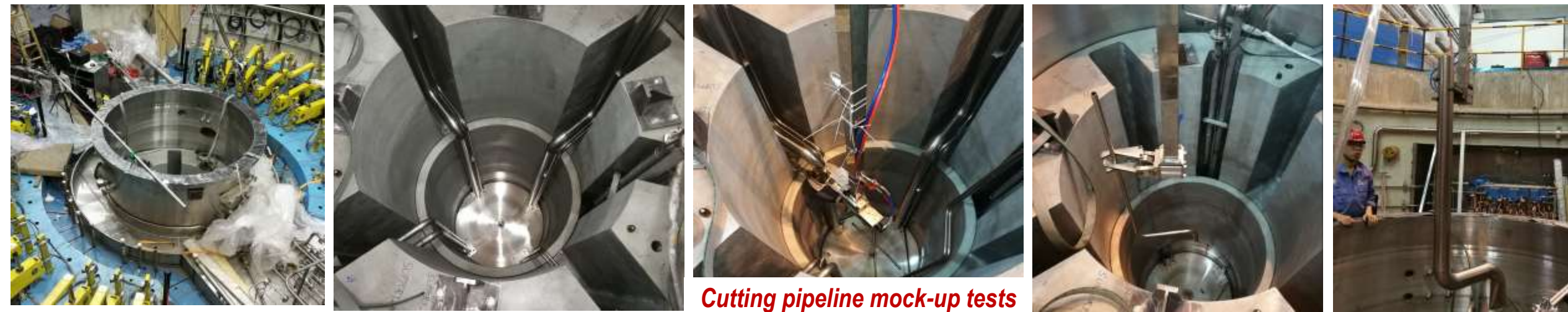


MR plug@~33tons and 5.4m height



MR replacement process development

- Carried out the installation and disassembly tests of each segment before the formal installation of MR plug in target station
- Gained the important operating experience for key remote handling procedure in target station site

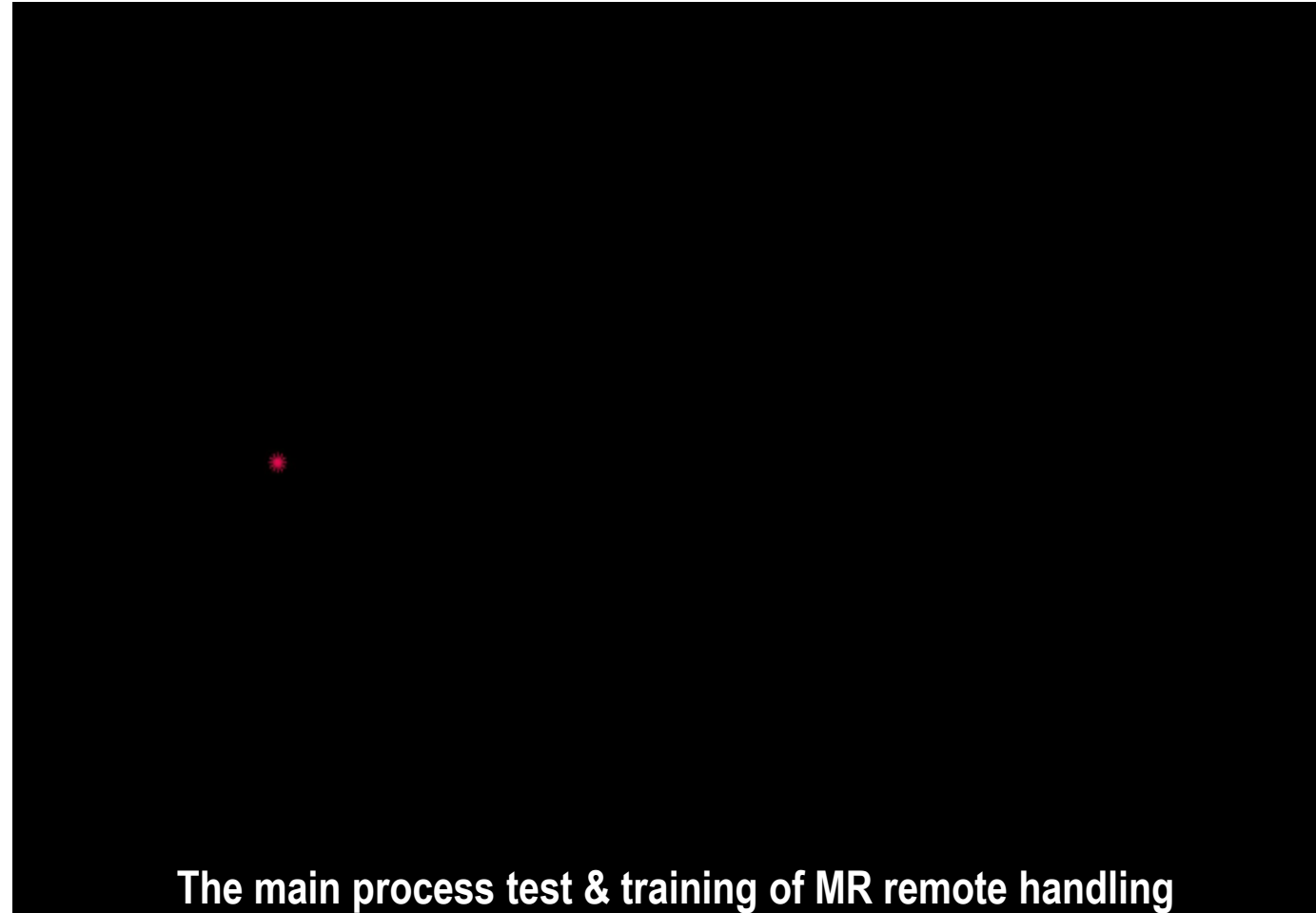


MR replacement process development

- A large number of mock-up test, training and optimizations have verified for the first time that the replacement equipment of the MR plug is reliable and the process planning is feasible



MR replacement test in mock up

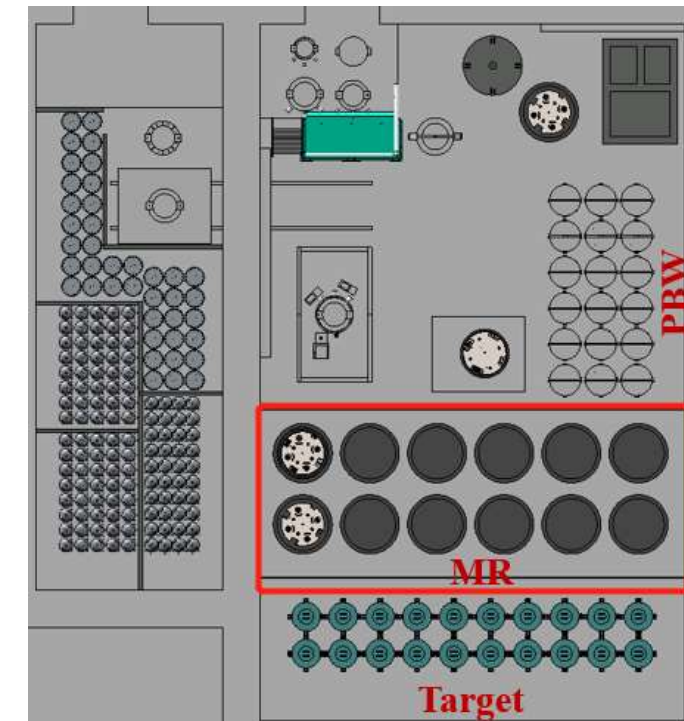
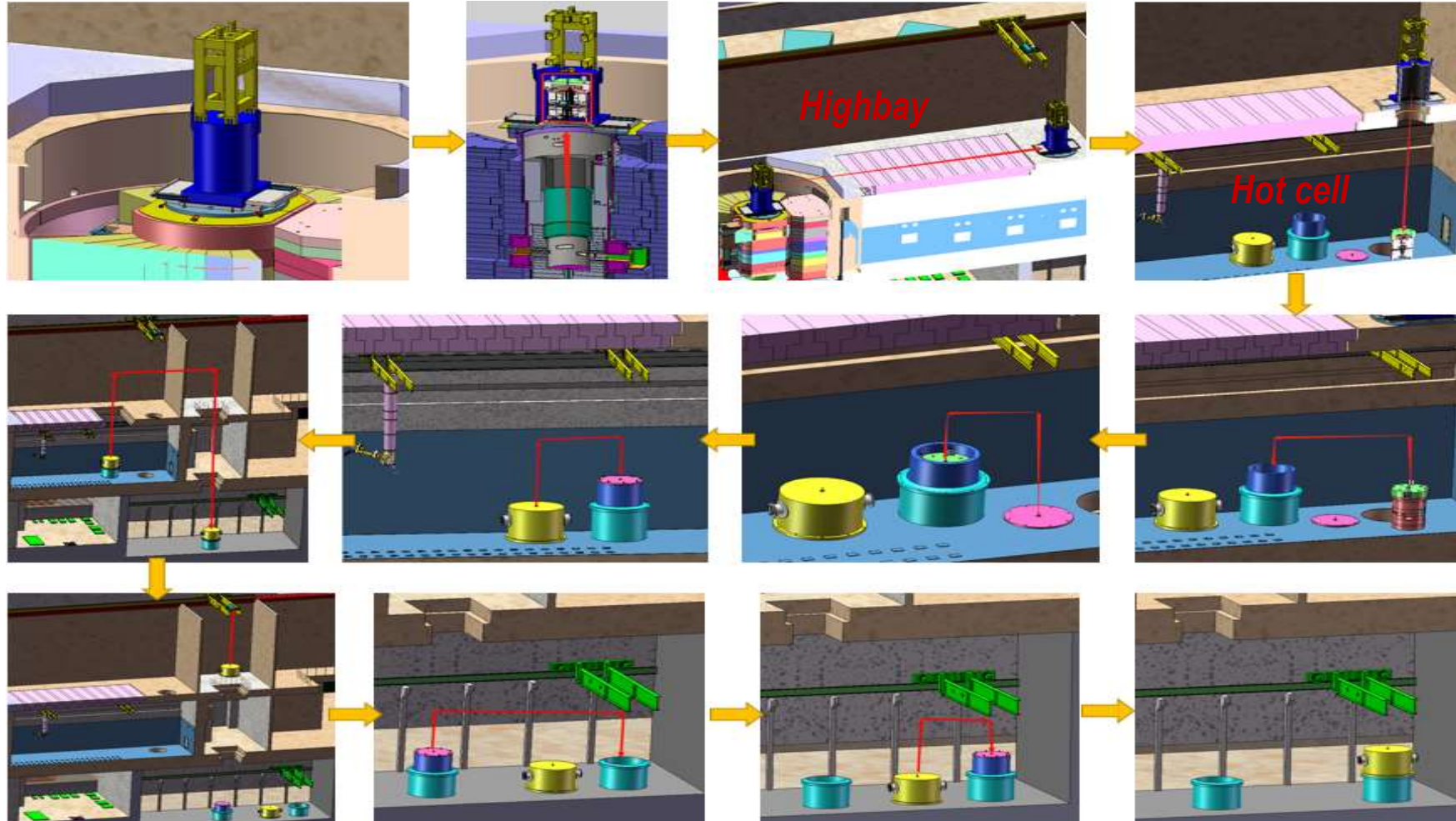


The main process test & training of MR remote handling

- The next step will be to further carry out optimization and improvement tests, based on adding some full-scale components, such as the remaining segmented plug

MR replacement process development

- Difficulties in transfer & storage: the load limit of the Hot cell(10t)/Basement crane(20t) and the size limit of the hoisting port of Hot cell, *the bottom segment of MR plug* with the highest dose(together with shielding cask almost 40t) cannot be directly stored in the basement
- ✓ **Solution:** Based on the existing conditions, comprehensively considering safety & controllability, implementation difficulty and cost, etc., adopt the optimization process design of “*Storage by layer + Transfer by step*” that can effectively solve the above problems

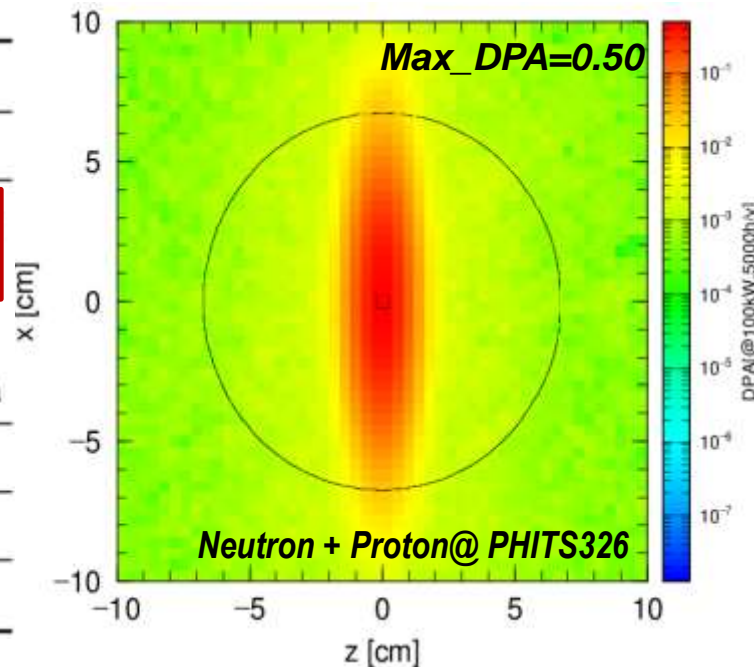


- ❑ The Solid Waste Room in basement can meet the storage space for the bottom segment MR plugs in CSNS-II
- ❑ As surface dose rate $\leq 100\mu\text{Sv/h}$

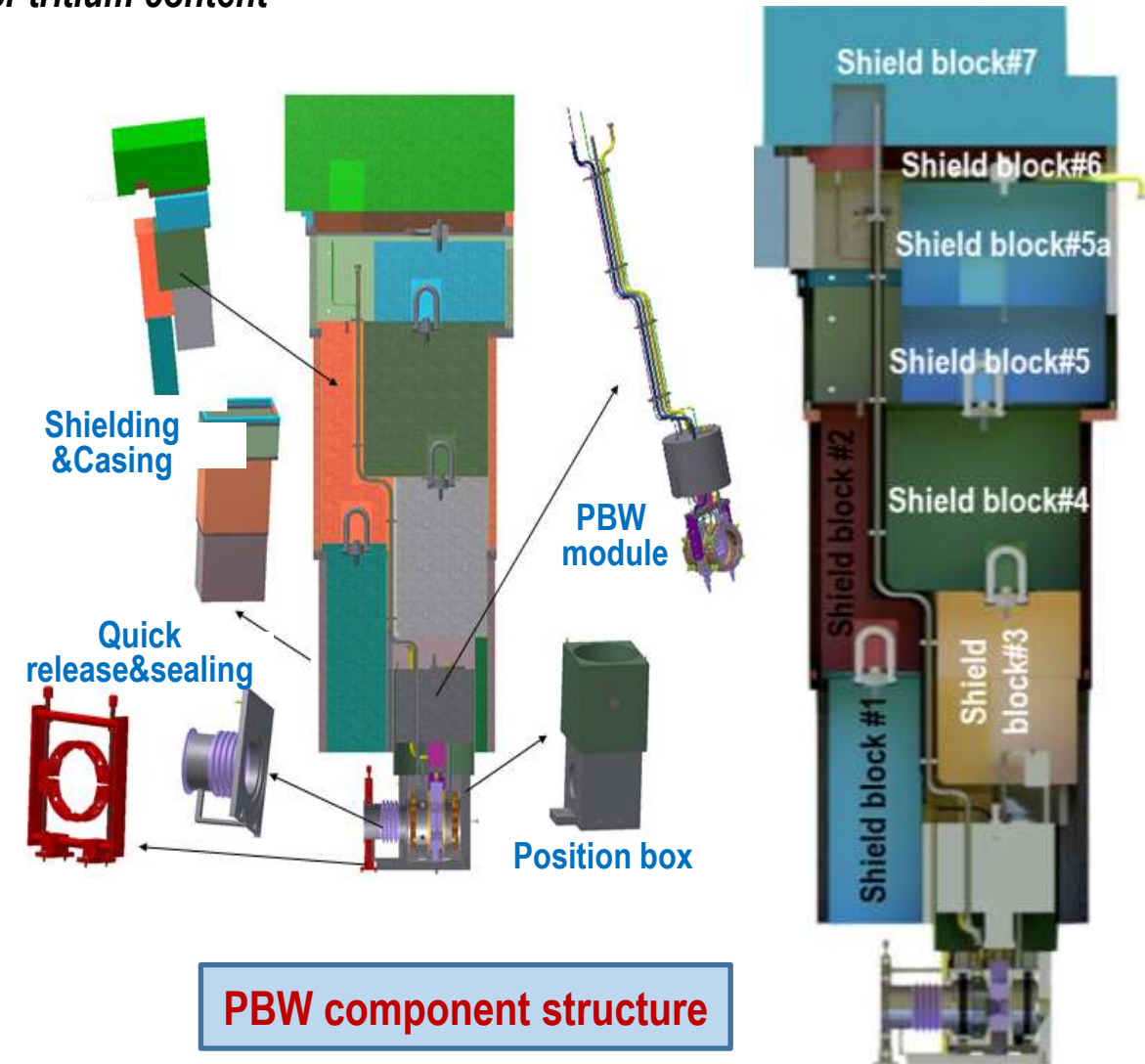
PBW replacement process development

- Completed the process development of the PBW remote handling, and the overall solution was verified to be feasible by the mock up tests
- Replacement of a PBW(A5083-O) module involves the following basic operations:
 - ✓ **Build a negative pressure air chamber to collect activated gas and monitor tritium content**
 - ✓ Removal of 6 shield blocks (reuse)
 - ✓ Drying (water removal) of PBW module
 - ✓ Cutting and removal of activated utility piping
 - ✓ Withdrawal of PBW module from cavity
 - ✓ Installation of new PBW module
 - ✓ Connection of utility piping
 - ✓ Leak testing of inflatable seals and piping connections
 - ✓ Re-installation of shielding

| | |
|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| Beam Power | 100 kW |
| Beam Energy | 1.6 GeV |
| Beam Distribution | Case I: 2D Gaussian distribution $\sigma(27\text{mm}, 6.3\text{mm})$, Case II: X: 12cm, Y: 2.6cm Case III: X: 10.8cm, Y: 2.34cm |
| Repetition Frequency | 25Hz |
| Population per pulse | 1.56×10^{13} |
| Operating time | 5000h/y |



By Zhiliang Hu



PBW component structure

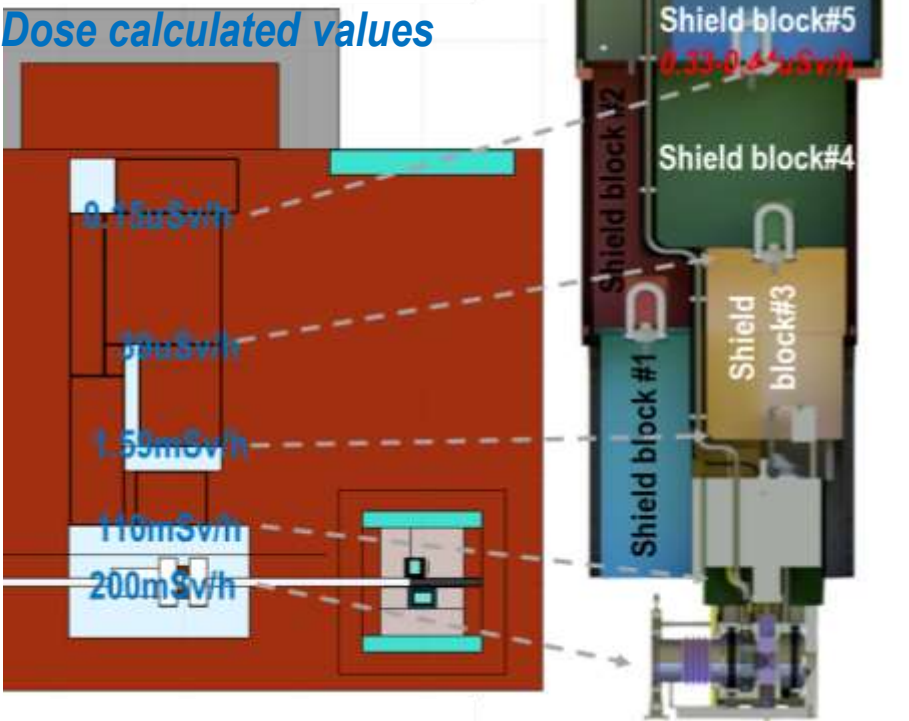
PBW replacement process development

- Scheduled for the first PBW replacement during summer maintenance of 2024
- ✓ Carried out relevant handling tests and training in target station in this summer maintenance period

| Beam power | 50Kw | 80Kw | 100Kw | 125Kw | 2023.8 (125kW+170kW) | 2024.8(200kW) |
|-----------------|-------|-------|-------|-----------|----------------------|---------------|
| Service time /h | 5655 | 2030 | 9885 | 3700(Now) | 2000+5000 | 5000 |
| DPA | 0.145 | 0.084 | 0.509 | 0.238 | 0.129+0.437 | 0.514 |
| Accum. DPA | 0.145 | 0.229 | 0.738 | 0.976 | 1.542 | 2.056 |

By Guangyuan Wang

▣ DPA accumulated situation from the operation of the in-service PBW to the present



PBW remote handling training in mockup

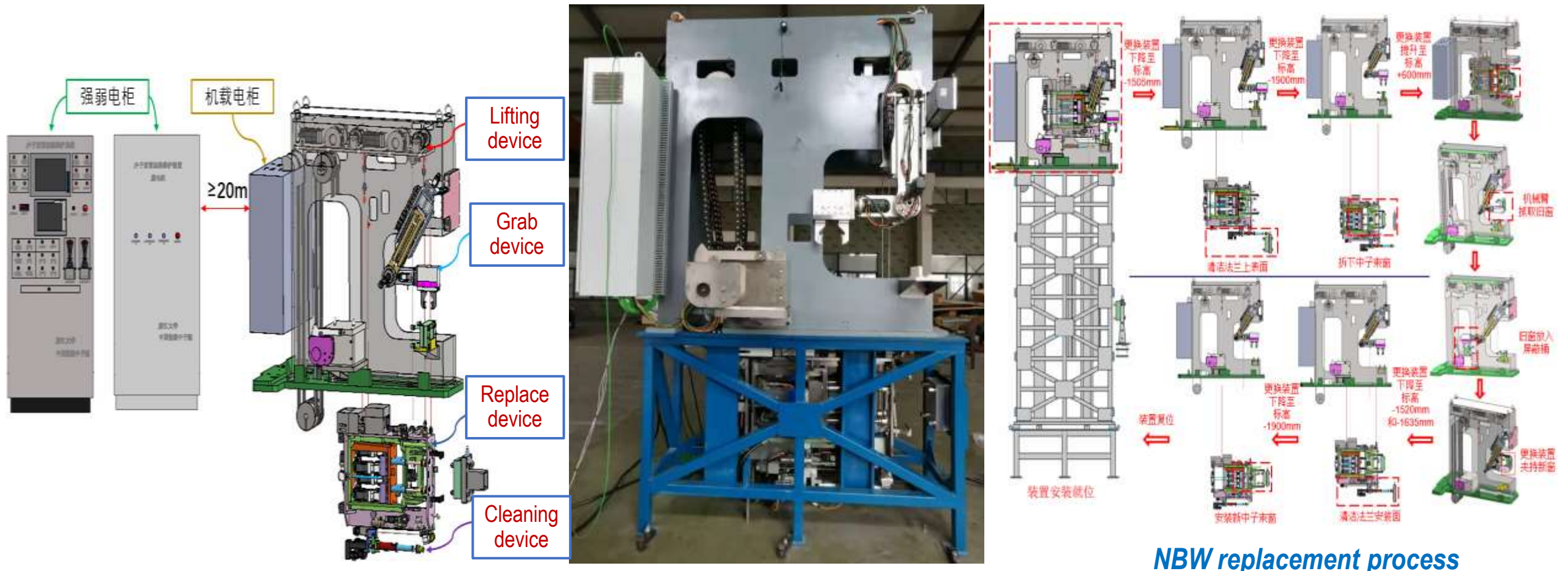
PBW remote handling training in T.S.

- ✓ Shielding blocks/Utility pipeline joints disassembly/recover
- ✓ Water and vacuum leak detection test

Dose measurement of activated shielding blocks in PBW plug cavity

NBW replacement process development

- Completed the development of a functional prototype of **NBW replacement device**
- ✓ *Material: Aluminum alloy 6061, and NBW has a long expected lifetime, then once broken, it must be able to be replaced quickly*
- ✓ *20 NBWs in total and located at neutron beamline channels of Helium/Core vessel*
- Next step will be to carry out testing and improvement work in the large component Mock up

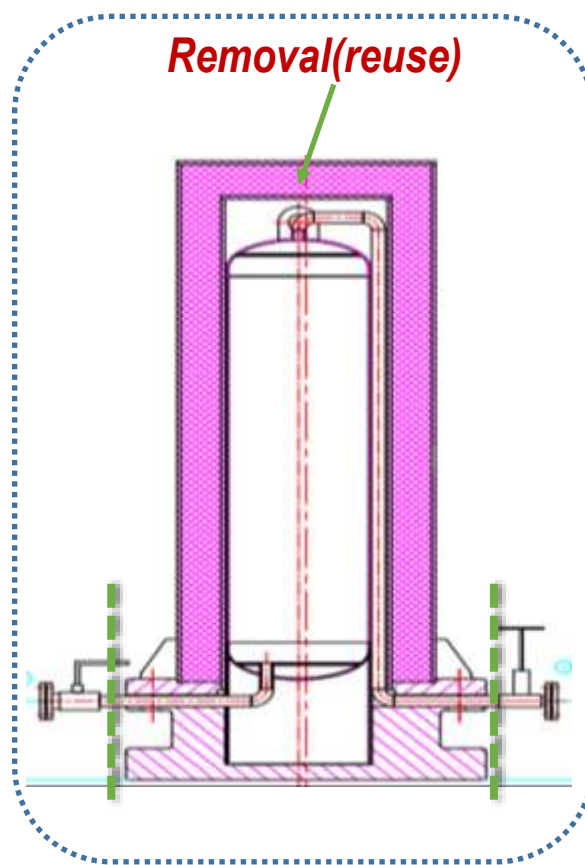


Other equipment replacement operation

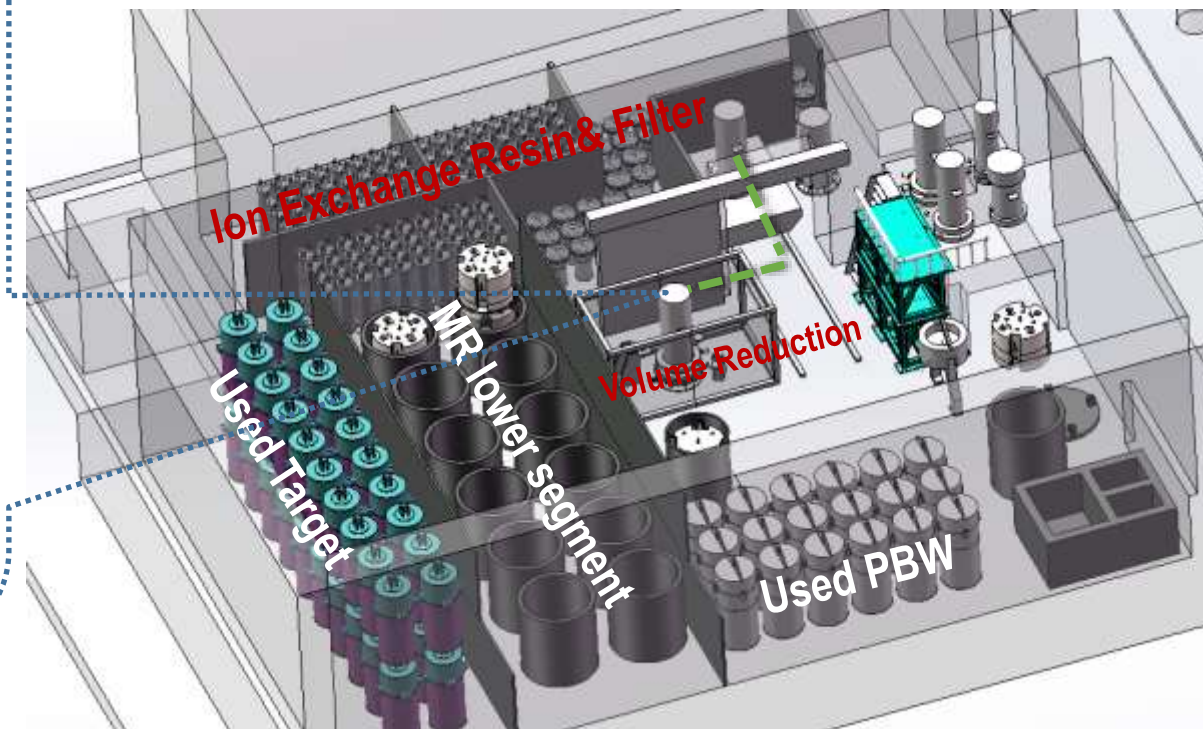
- First replaced 3 Ion Exchange Resins(IER) by using transfer trolley for cooling water system of target station in 2020
- Ion exchange resins and filters will be replaced during next summer maintenance period



- ✓ The surface dose rate < $1\mu\text{Gy/h}$ in 2020
- ✓ Surface contamination and air tritium concentration less than exemption value



- Volume reduction handling design for CSNS-II phase:
 - ✓ Cut pipes and plug the tubing remaining on the device
 - ✓ Remove the outer lead shielding case(reuse)
 - ✓ Centralized storage at basement after volume reduction
- **NOT** consider dealing with the resin itself for the time being



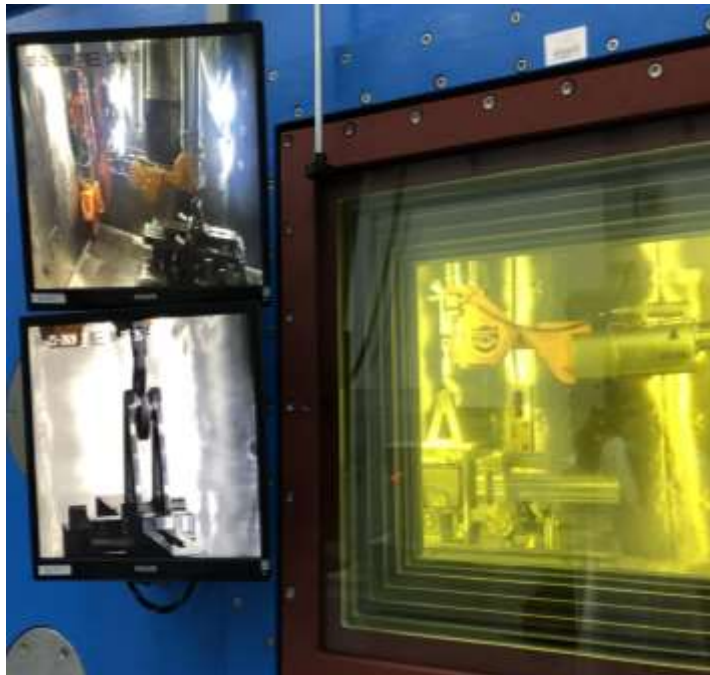
Preliminary design of basement waste storage room layout & water cooling system purification equipment maintenance

Progress of R&D on key technology/equipment

- Handling of main abnormal working conditions during target change

❑ **CASE#1:** if overhead power manipulator is failure during remote handling, especially for lifting and transferring the target module

- ➔ Strengthen maintenance and spare parts guarantee in regular maintenance period
- ➔ More importantly, develop a movable power manipulator system in the hot cell, when the overhead power manipulator fails, the radioactive source can be removed in time, and then the power manipulator can be repaired.

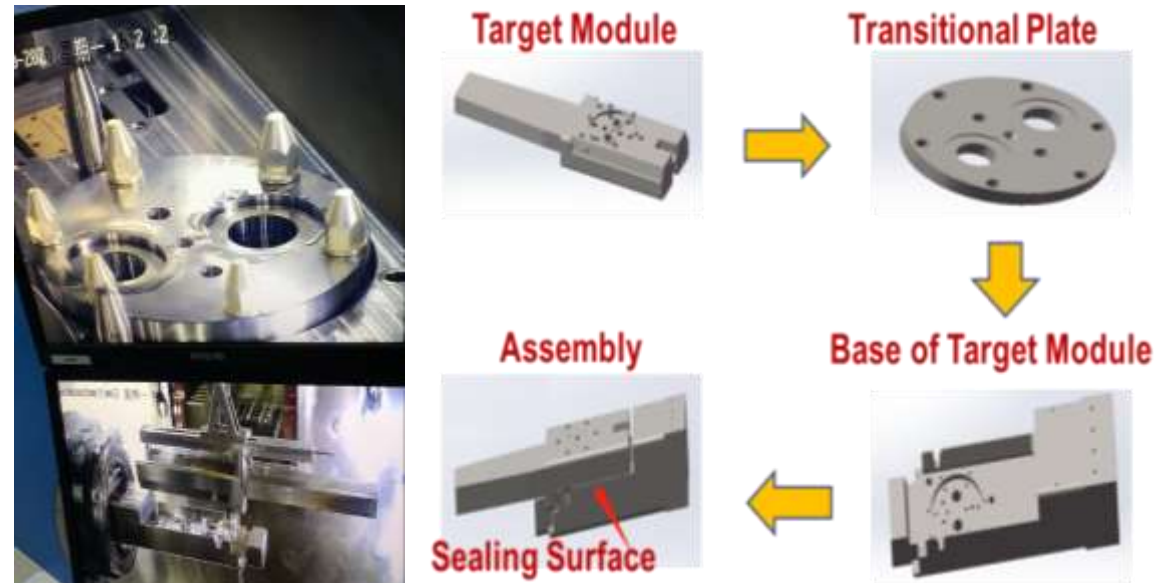


- Plan to develop a set of radiation-resistant water hydraulic heavy-duty mobile robot(single arm) at CSNS-II
- ✓ Radiation dose resistance of key components $\geq 1.0E6Gy$
- ✓ Heavy load: $\geq 700Kg$
- ✓ Overall dimensions after retraction $< \Phi 1380mm$

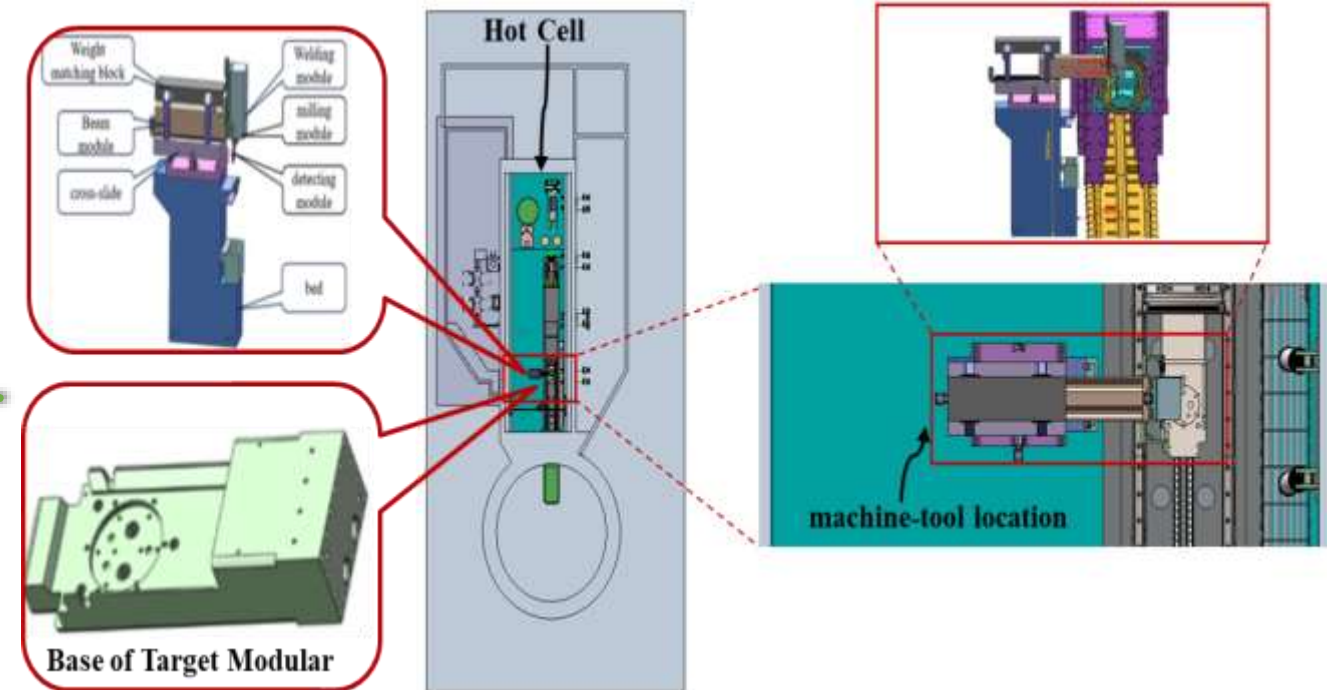
We have also accumulated good experience in the development and operation of pure water hydraulic drive equipment based on shutter system

Progress of R&D on key technology/equipment

□ **CASE#2:** If the sealing surface of the target base is damaged and affects the sealing performance of cooling water



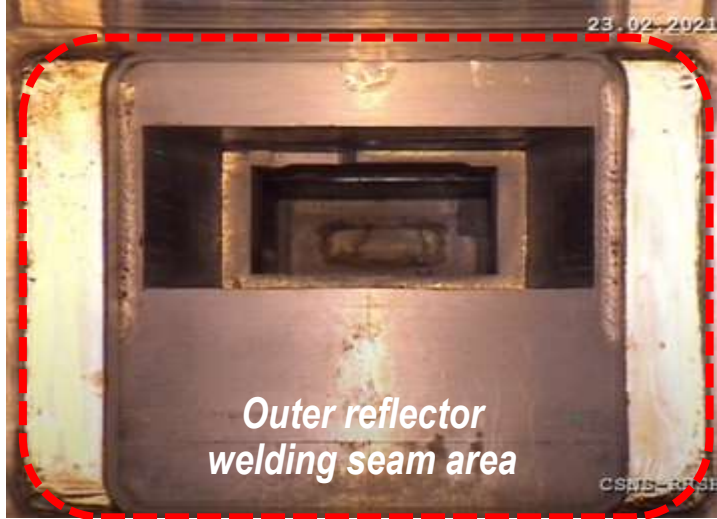
□ **CASE#3:** if the sealing bolt of the target is seized/broken or screw hole is damaged during the process for removing or installing bolts



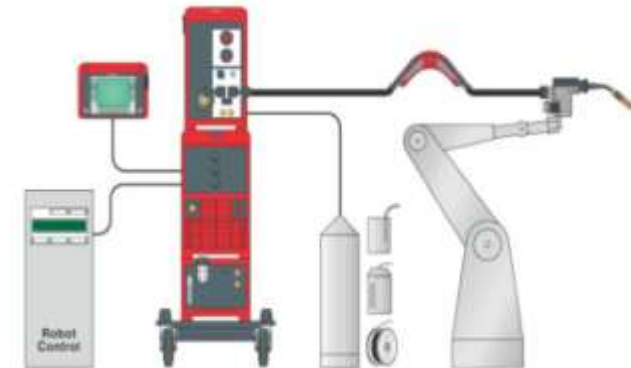
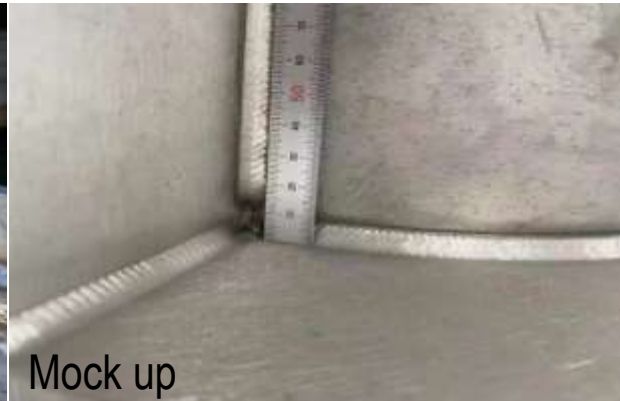
- Designed an set of integrated special machine tools to solve the above abnormal working condition problems **as a key technical reserve to develop**
- Repair the defect damage of the sealing surface of target base
- Remove the broken bolts and repair threads

Progress of R&D on key technology/equipment

- Remote Operation Observation, Helium Leak Detection and Repair Welding System for Outer Reflector close to the hot cell side
 - ✓ Completed the development of the five-axis leak detection trolley prototype, and carried out the tests (remote operation hoisting, rail motion, leak detection test). However, durability testing still needs to be continued to ensure the reliability of actual operation



- The development of remote operation repair welding system is being carried out, and relevant key technology and process verification experiments are ongoing. ***This is a huge challenge work and is currently being developed as a technical reserve***



Progress of R&D on key technology/equipment

- Traditional remote operations in the Hot cell only relies on cameras and lead glass windows for observation, which can easily cause certain limitations, and also requires a higher level of operation for the operator
- Developed a prototype system that is a *vision system for remote handling based-on posture tracking and digital twin technology in Hot cell, and initially realized the basic expected functions*
 - ✓ Providing 3D distance/position measurement and motion collision detection/alarm
 - ✓ Multi-angle observation(e.g. rotation, scaling & alarm prompt, etc.) in virtual & reality mapping system for assisted guiding the operation is more reliably and easier



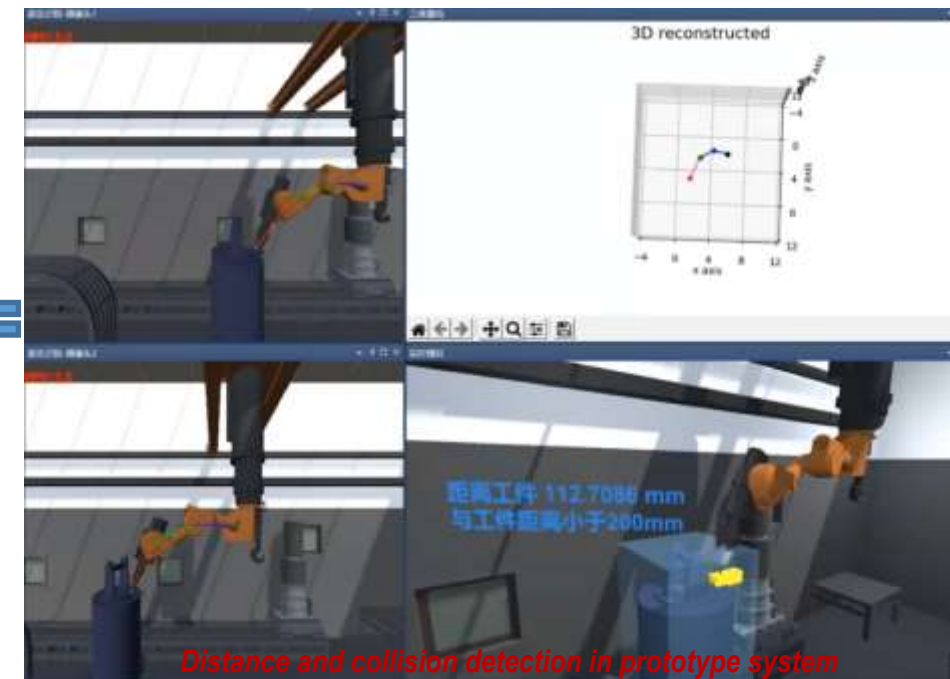
Developed the Virtual Reality Simulation System of Hot Cell



Pose Estimation(PE)



Digital Twin(DT)

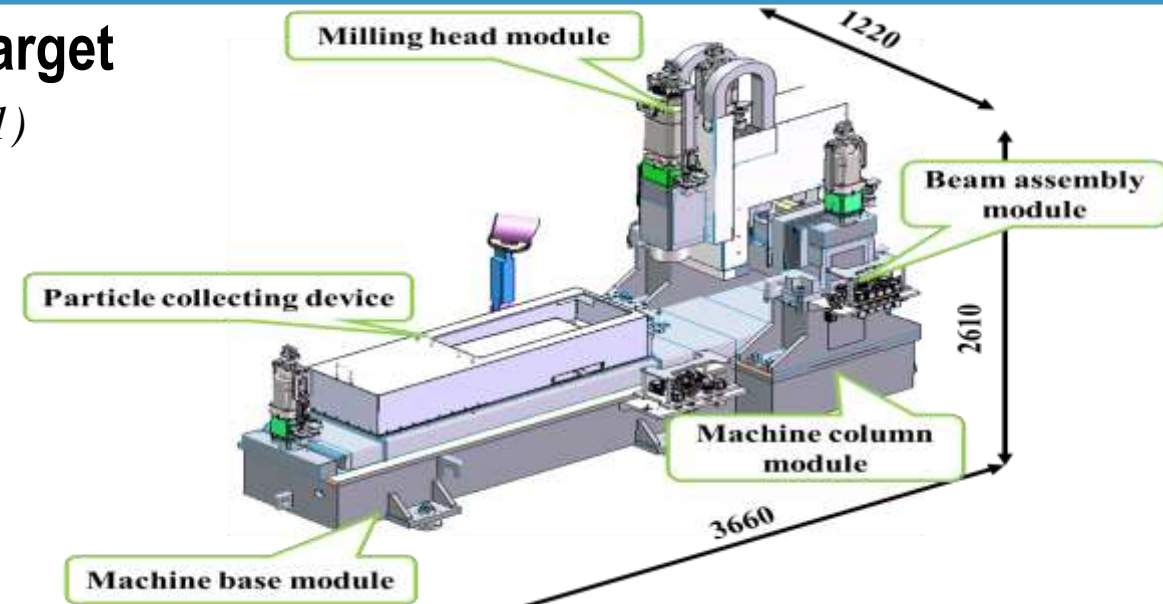
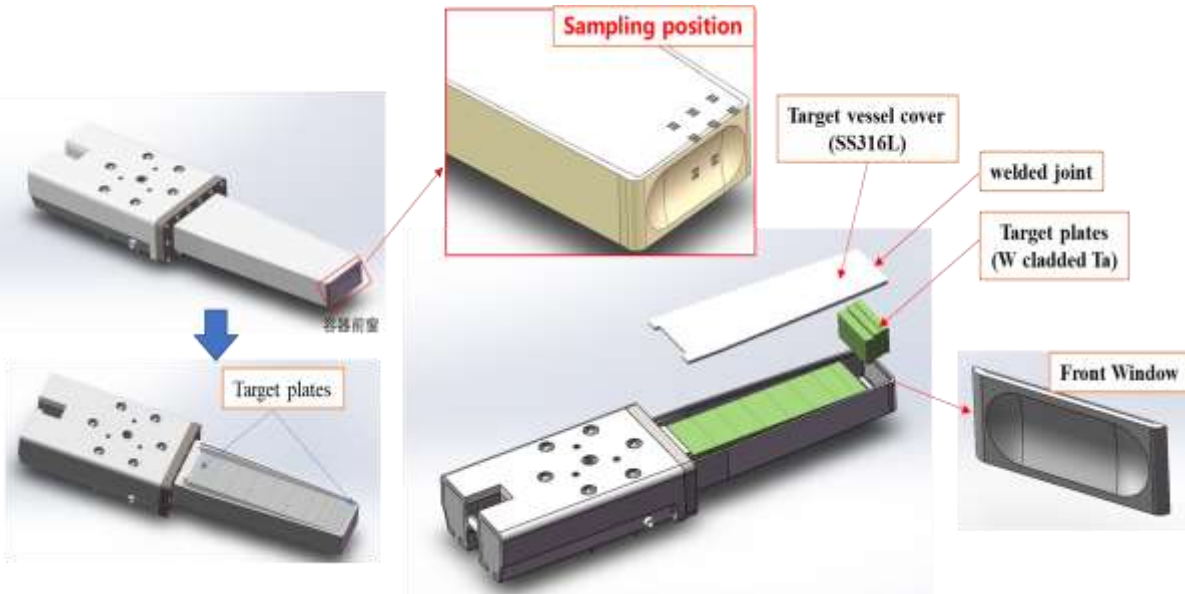


Developing the Assisted Operating System of Hot Cell

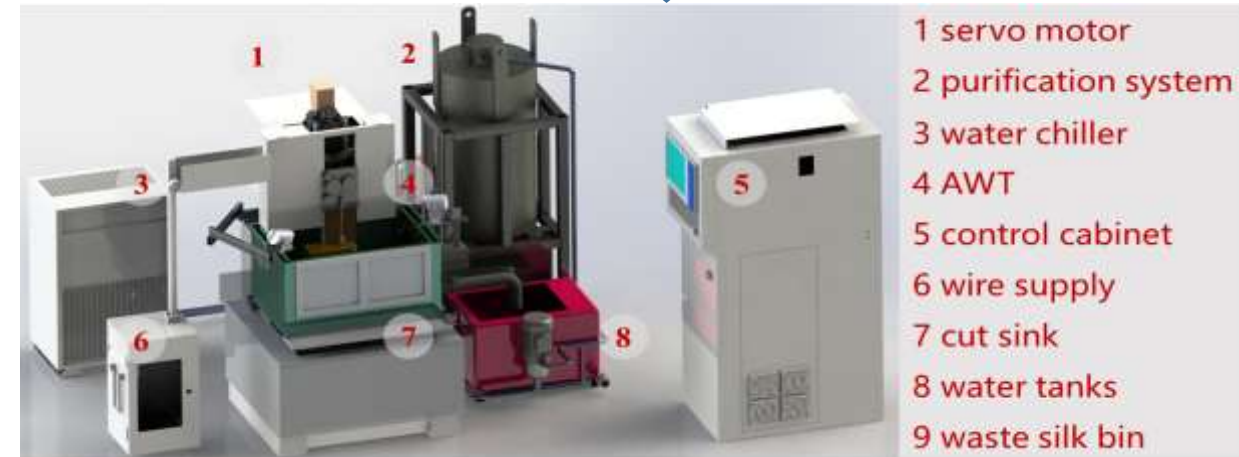
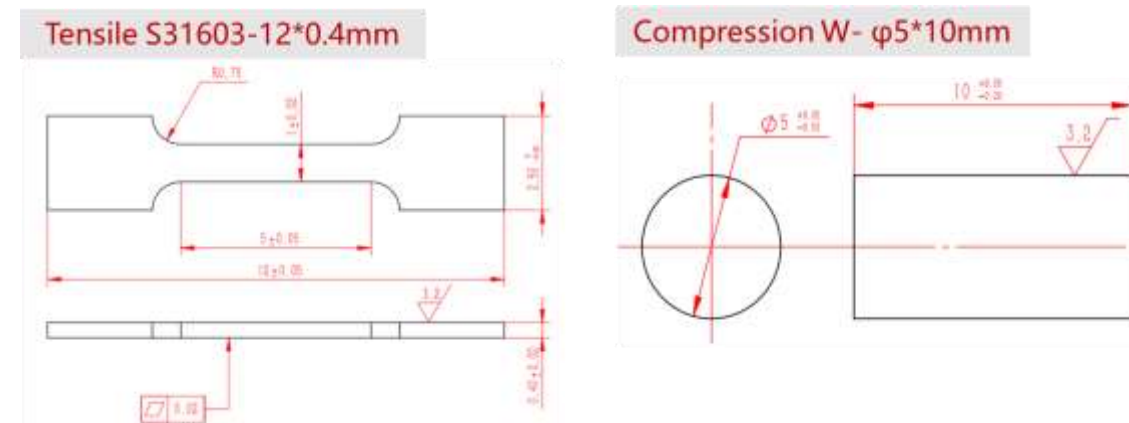
Target PIE progress-overview

Overall solution of sample preparation for Retired Target

CSNS Hot-Cell Renovation Project, CAS (2020/12/31-2022/12/31)



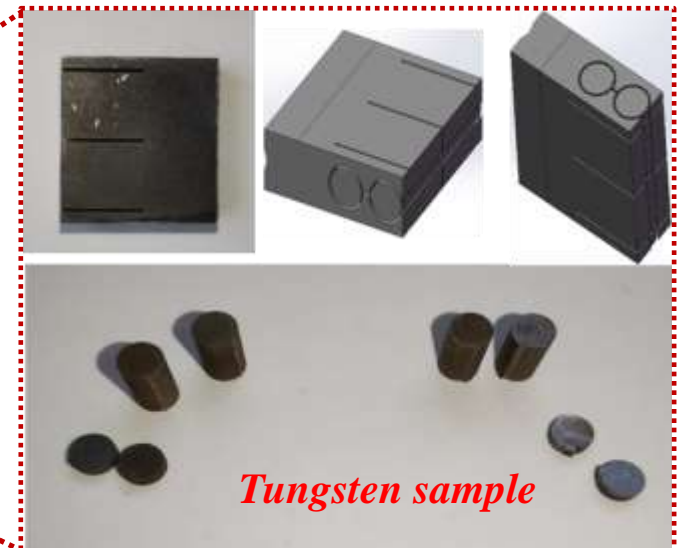
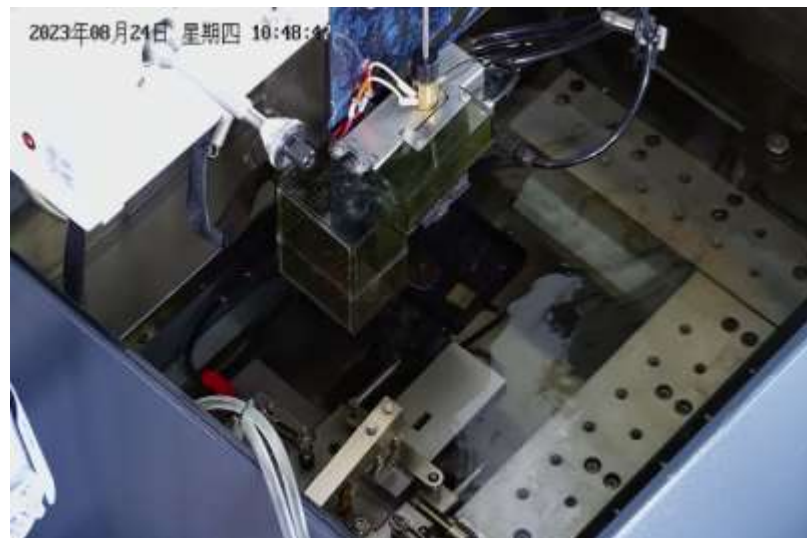
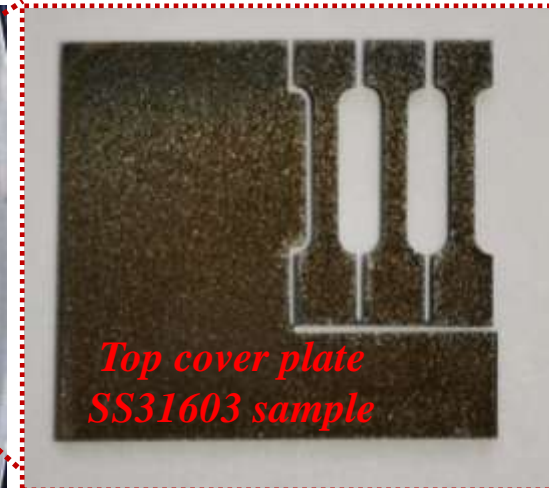
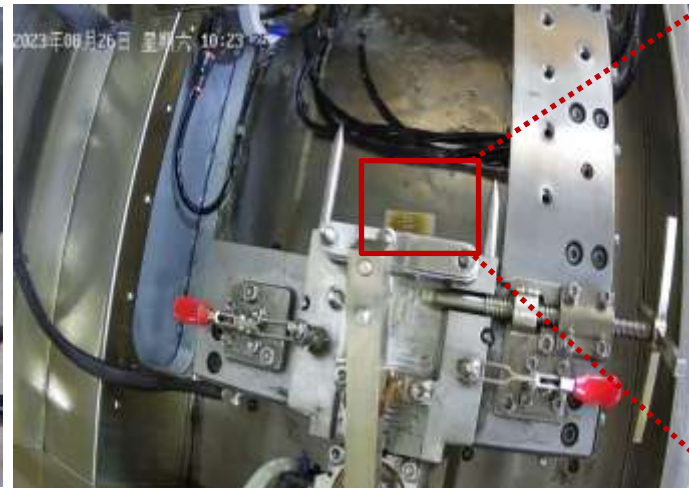
Development of Special Planomiller for Sampling



Development of Wire EDM system for Sample preparation

Target PIE progress-Small sample preparation

□ In the hot cell, the tasks of cutting sampling and sample preparation were completed by using the mockup target during this summer maintenance period



Target PIE progress-performance test

□ In test room, the mechanical performance testing was completed by using the cold sample



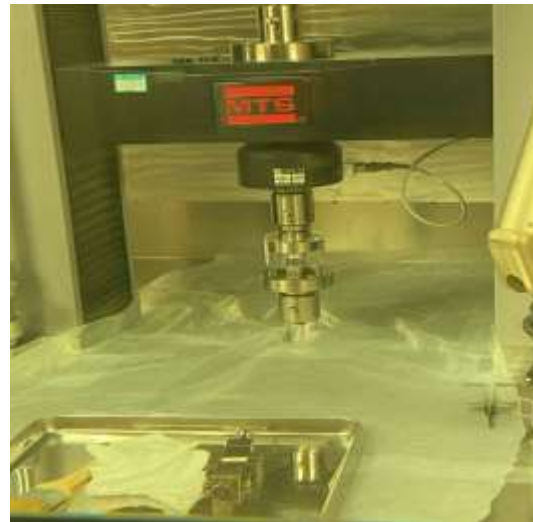
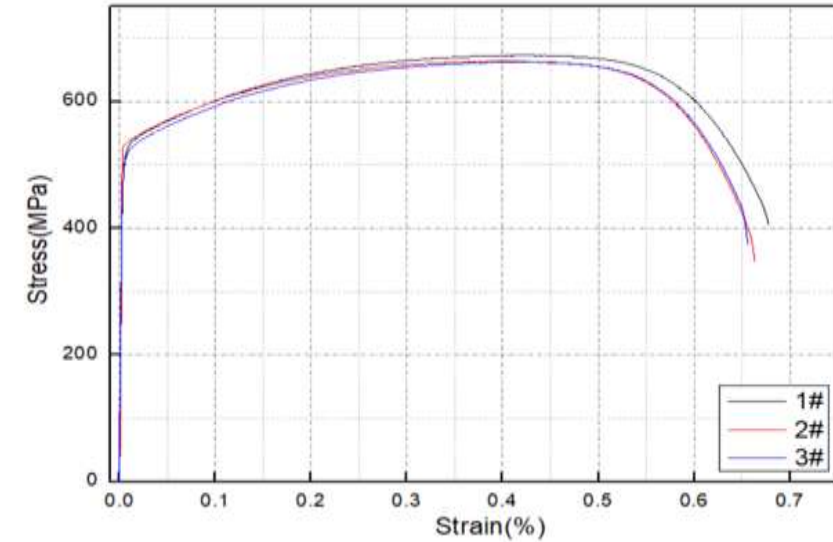
Inside and outside the test room



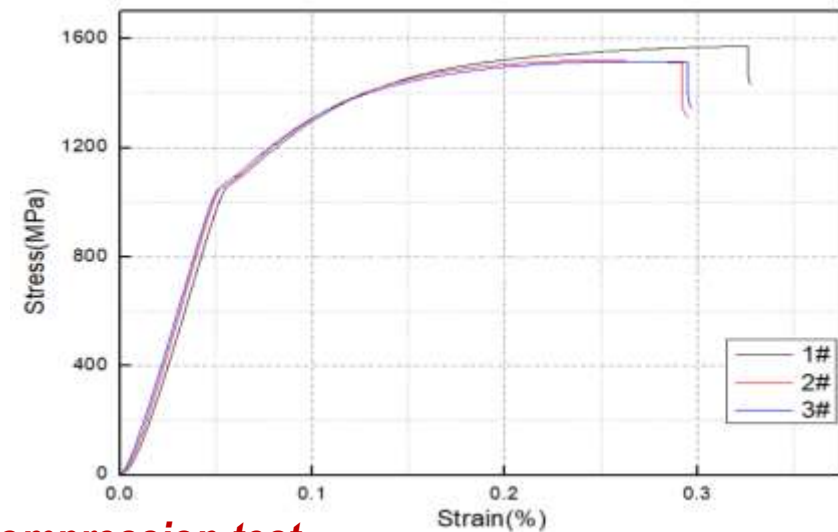
Mechanical testing platform



Stainless Steel tensile test



Tungsten compression test



- Since the beginning of CSNS formal operation, shutter system has maintained stable operation all the time and a significant amount of remote handling has been accomplished
 - ✓ Effective remote handling design and mock up testing and significant planning and training operators has ensured success of these critical operations, and also accumulated valuable handling experience, especially for target/shutter insert replacement
 - ✓ The scope of remote handling continues to increase with the construction and development of PIE capabilities
- A concerted effort of continuous improvement has resulted in increased efficiency, reliability and reduced risk in operations.
- From the perspective of long-term stable operation of the target station, remote handling still faces some new challenges that need to be overcome. Keep improving, keep moving...

***FOR REMOTE HANDLING,
NO BEST, JUST BETTER!***

Thank you for your attention!

