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Overview of Comprehensive Research fAcility for Fusion Technology (CRAFT)

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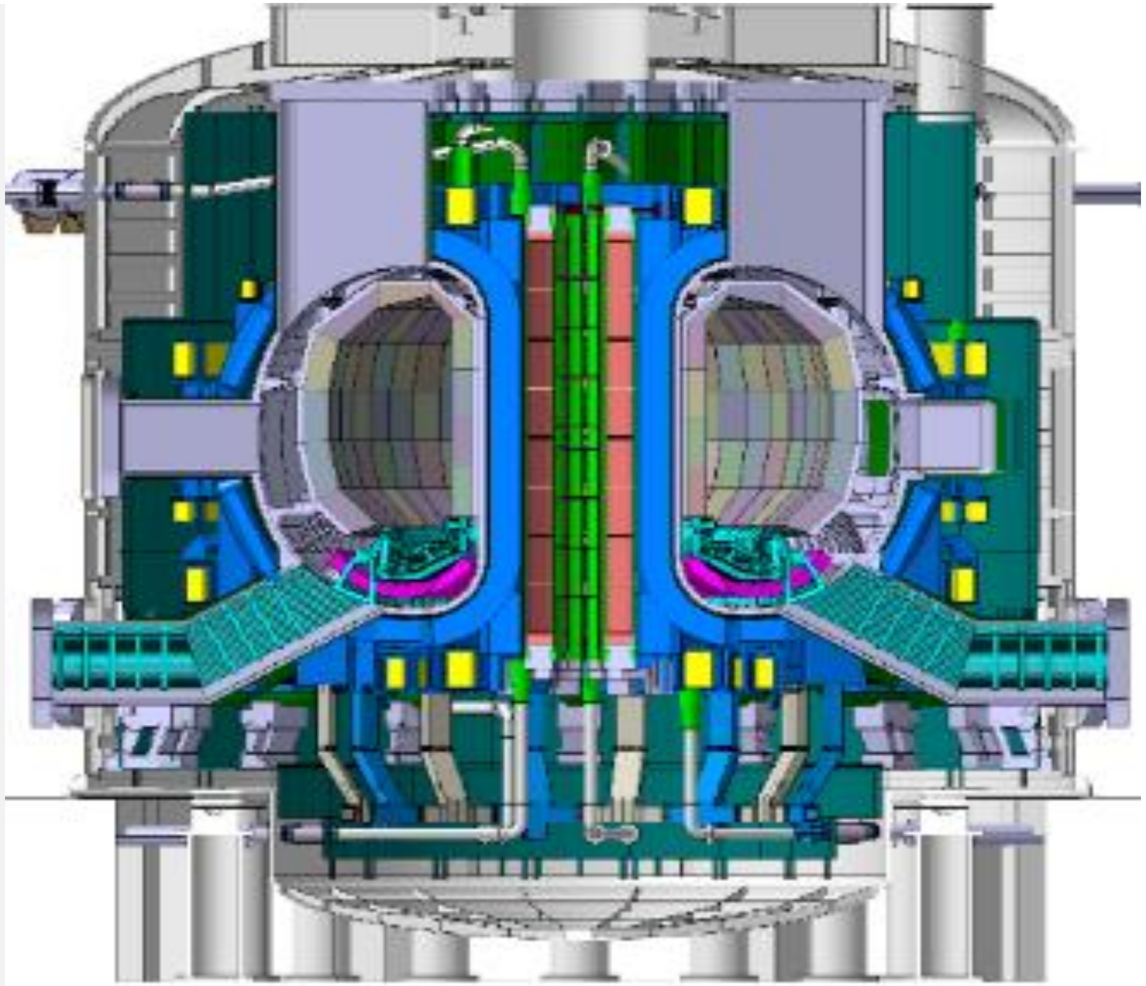
Main Goals of CFETR

DEMO of fusion power plant

- Fusion power > 1500 MW
- Duty time ~50%
- Burning plasma with Q ≧ 10~30
- Tritium self-sustaining （TBR ≧ 1)
- Material and components validation
- Electricity generation



The design is finished. Can we build it successfully?

Chinese Fusion Engineering Test Reactor

R=7.2m, a=2.2m, Bt =6.5T, Pf = 1-2GW, TBR >1, 65000t

Objective of CRAFT

- Explore and master fusion DEMO level key technologies
- Establish the method and standard for manufacture the key material, components and system for CFETR.
- Building key prototype systems for CFETR
- Testing and validating the method, technology and system for a successful construction of CFETR
- Building RAMI for key CFETR systems
- Training next generation of fusion scientist , engineer and mangers.

Lists of systems & facilities of CRAFT

• 1. SC Material testing facility	• 11. CFETR divertor development
• 2. SC Conductor testing facility	• 12. CFETR divertor testing facility
• 3. TF magnets testing facility	• 13. Blankets developments
• 4. CFETR CSMC and testing facility	• 14. Blanket testing facility
• 5. CFETR HTS coil and testing	• 15. NNBI system
• 6. CFETR TF and testing	• 16. LHCD system
• 7. Cryogenic testing facility	• 17. ICRF system
• 8. Power supply testing facility	• 18. ECRH system
• 9. Large Linear plasma testing facility	• 19. VV and installing testing facility
• 10. Mater Control facility	• 20. RH & testing facility

Auxiliary system	1、Power distribution system	3、Campus
	2、Cooling water system	4、Buildings

1.SC Material testing facility

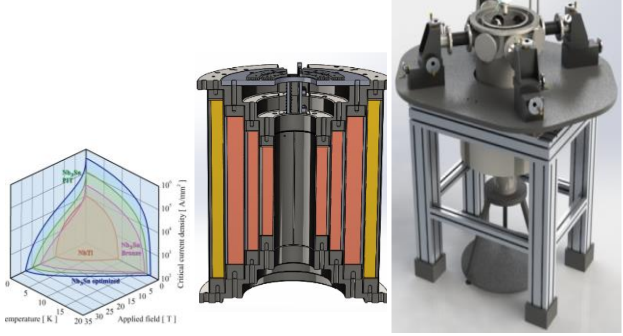
➢ Scientific objectives

- To master scientific and the intrinsic physical properties and service behavior of materials for superconducting magnets in complex and extreme environments, and to carry out engineering application research.

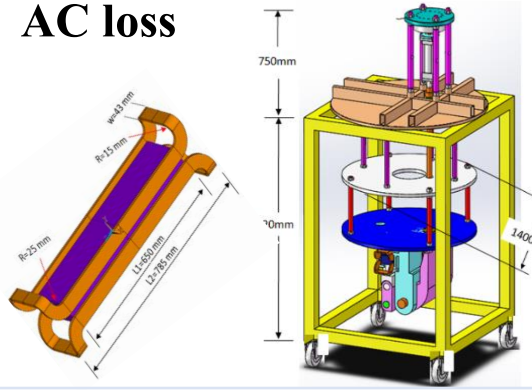
➢ Composition and main parameters

- SC material performance research platform:19 T, 2 kA
- AC Loss research platform: 0.01-0.2 Hz,1500 kN/m
- Structure material performance research platform: 2500 kN
- Thermo-hydraulic research platform: 4-300 K
- NDE technology research platform: 350 kV (X-Ray)
- High voltage research platform: 0-100 kV

SC material

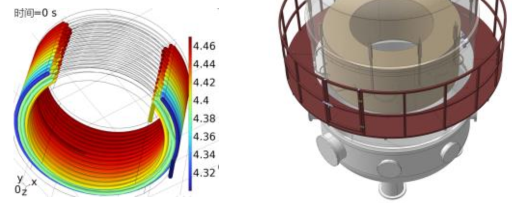


AC loss

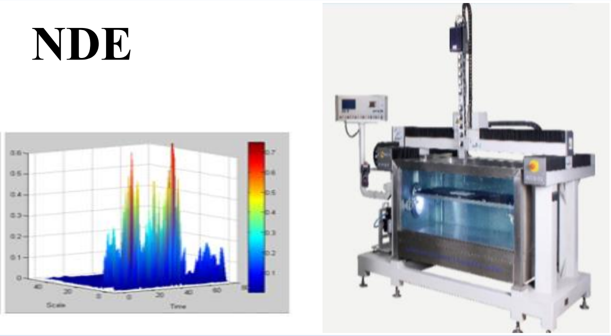


Structure material

Thermo-hydraulic



NDE

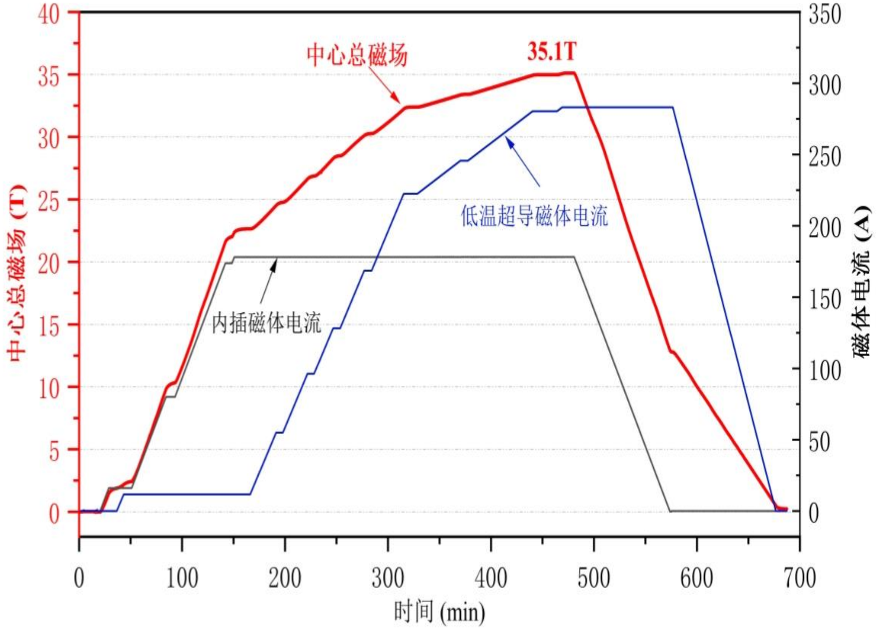


High voltage

1. SC Material testing facility

Having successfully passed acceptance and obtained CNAS certification, the platform is now fully open to global users.

Self-Developed Background SC magnet
(19T&70mm\ 15T&150mm)



35.1T reached

System was be finished on Nov.2024

Thermal-Hydraulic test platform
(D3m*H6.2m, 4.5K@200W)

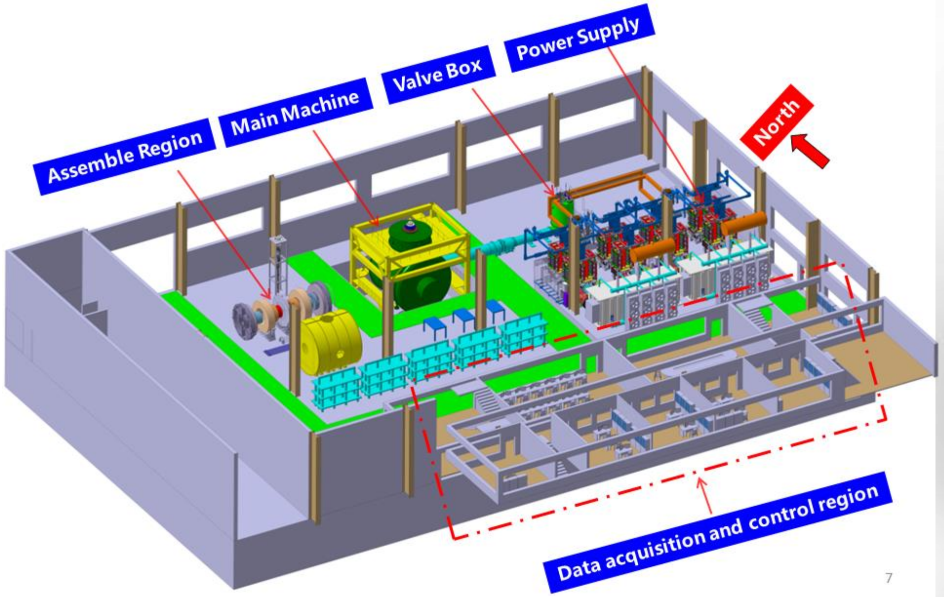
2. SC Superconductor Testing Facility

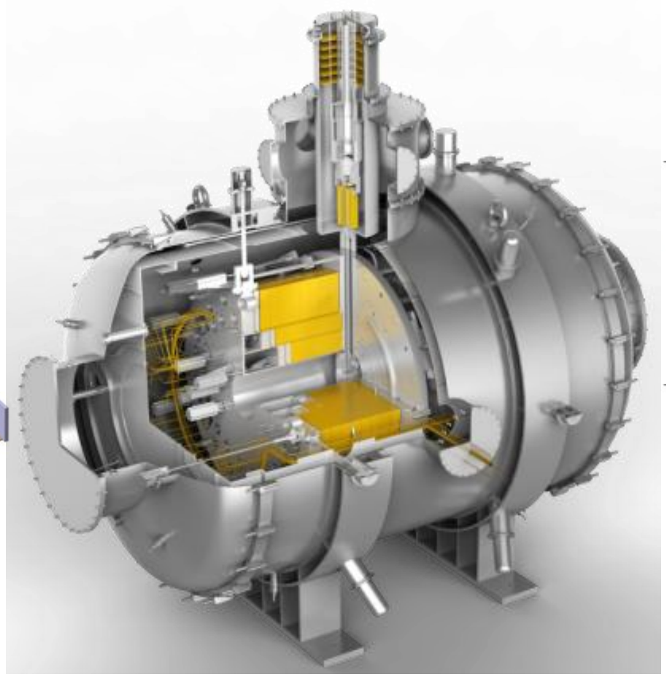
➢ Scientific Objective

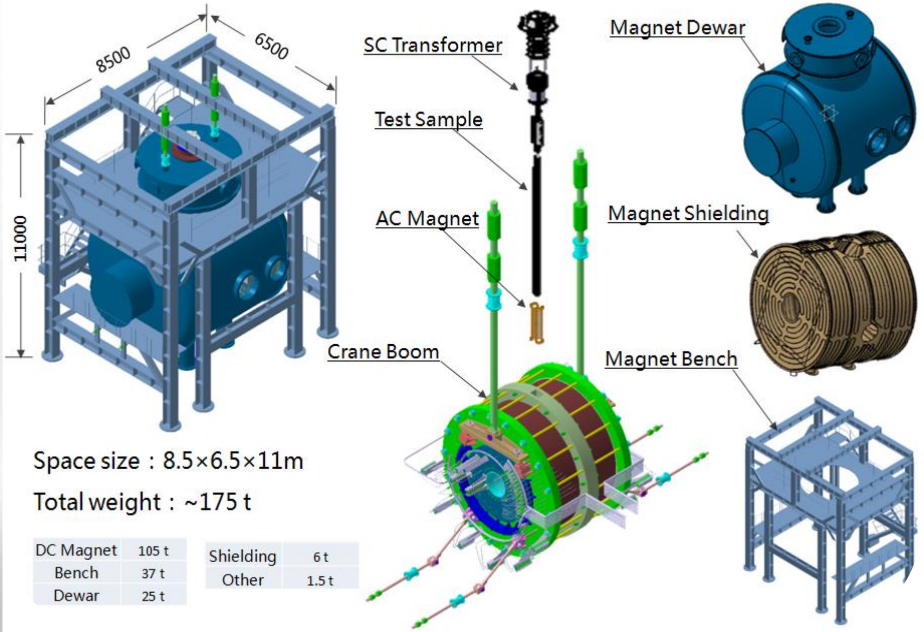
- To study the electro-magnetic behaviors (*T_{cs}*, *I_c*, AC loss, MQE) of superconducting conductor under mult-field coupling condition;
- To evaluate the performance of SC conductor in future fusion reactor operation condition;

➢ Main Technique Parameters

- Maximum magnetic field： 16.5 T (B_{back}=15 T)
- Tested space： 100 × 160 × 550 mm
- Field homogeneity： ≥ 98 % (tested space)
- Maximum tested current： 100 kA







2. SC Superconductor Testing Facility

☐ 15 T DC magnet – Coil Wind

- **HF&MF layer coil winding line**

Length:22 m, Width: 8 m, Working height: 1.8 m

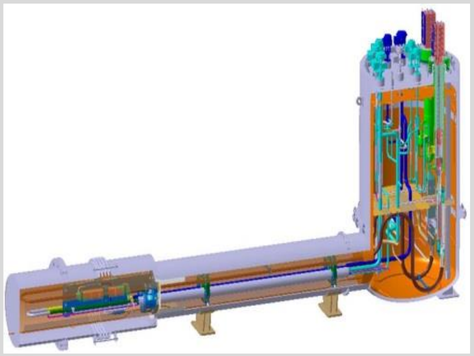
- **LF pancake coil winding line**

Length 32 m, Width 10 m, Working height: 1.8 m

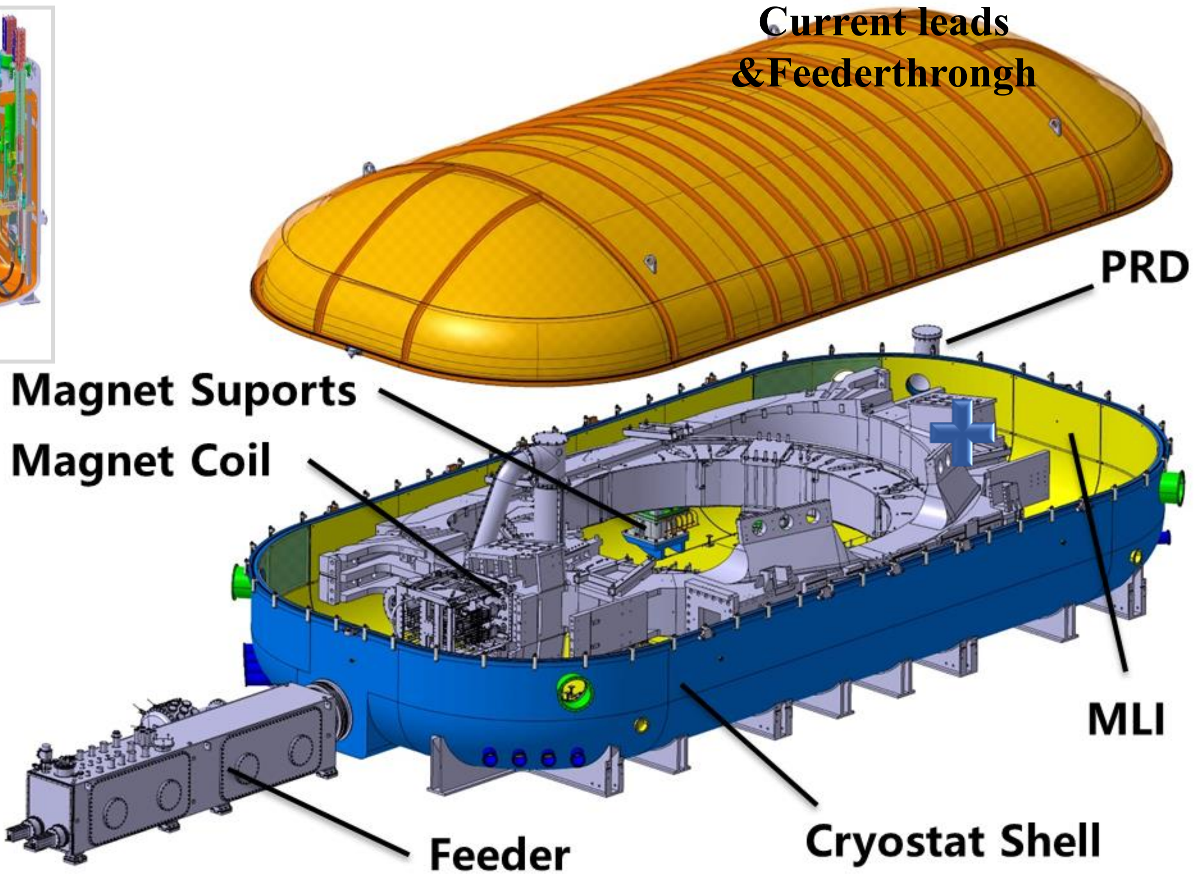
- **All coils were made and assembling starts; Final testing will be next March.**

3. TF magnets testing facility

To perform the DEMO-scale SC magnet research on mechanics, thermology and electromagnetics properties. To evaluate the DEMO SC magnet system compatibility, reliability, stability, and magnet safety in fault state and verify the reliability of magnet engineering technology.



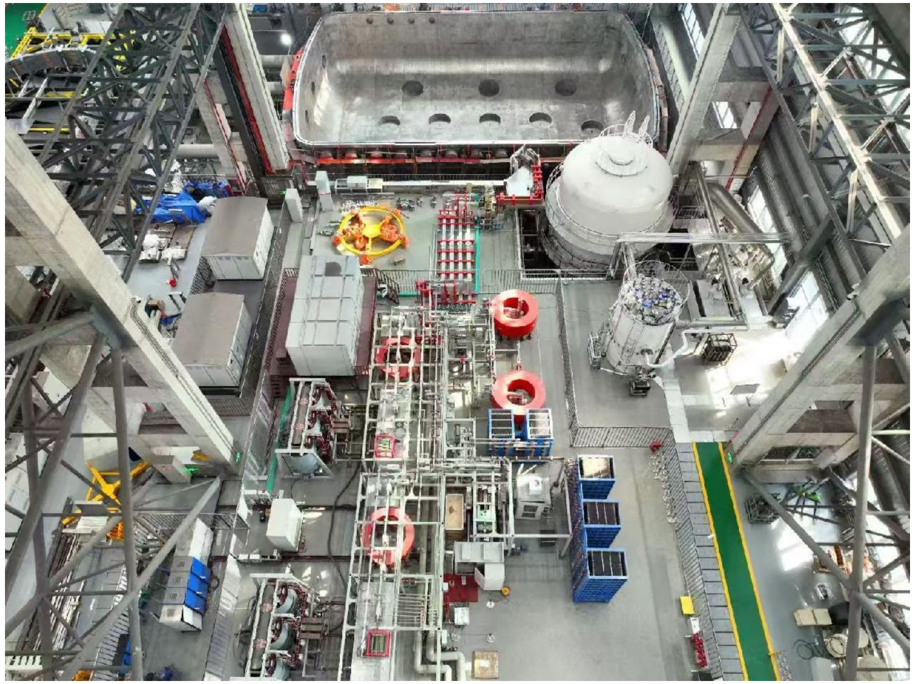
Feeder&current leads



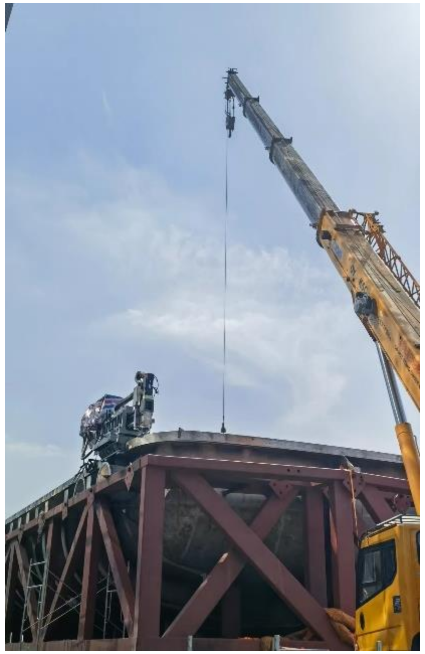
- Quench detection system
- Protection system
- Cryogenic system
- Fast discharge
- Vacuum system

Item	Description
Crystal main dimension	**Length>28.5m; Width>14m; Height>6m**
Operation temperature	4.5K
Current leads operation current	100kA/60kA
SHe pressure	3-6 Bar
SHe mass flow	>500 g/s

3. TF magnets testing facility



Layout of TF testing facility



- TF testing facility have been completed after 4 years efforts.
- A serious technologies have been developed.
- with this experience, ITER TF testing facility was finished within only one year and meets all requirements.

4. CFETR CSMC and testing facility

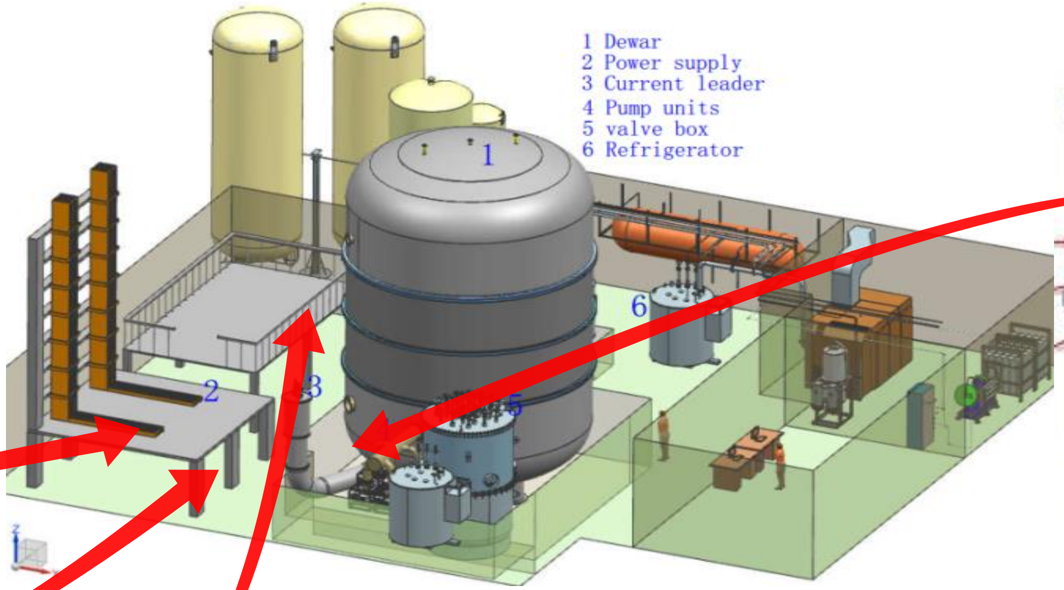
Objective:

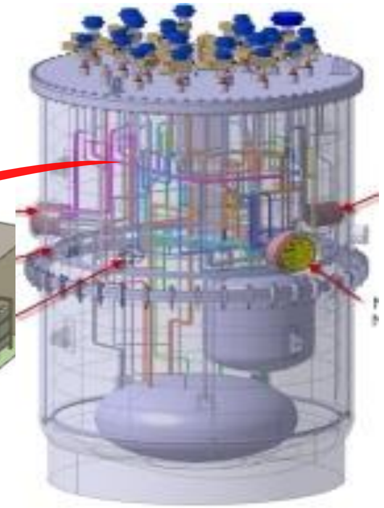
Develop magnet technology of CFETR Nb_3Sn CS

Carry out experiments on electromagnetism, magnetism, thermodynamics performance of magnets under fast magnetic field environment

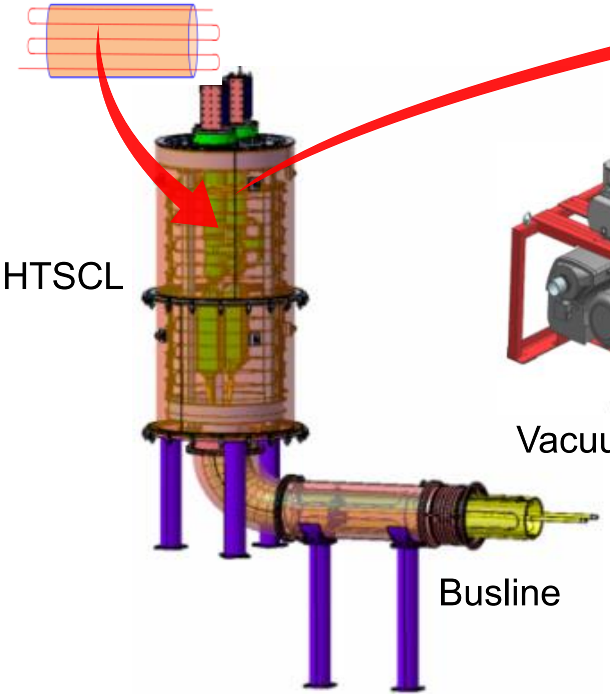
Evaluate the safe operation characteristics of magnets

Quench detection&protection



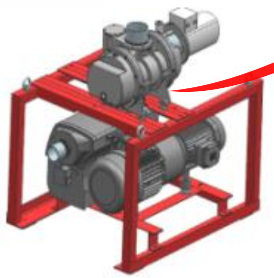


Cryogenic system

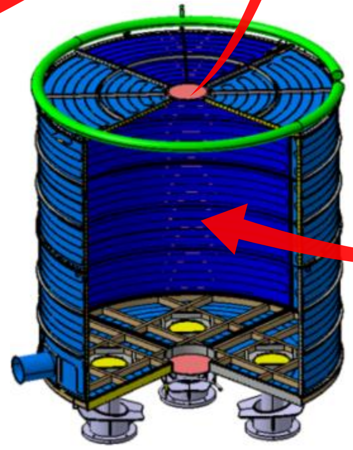


HTSCL

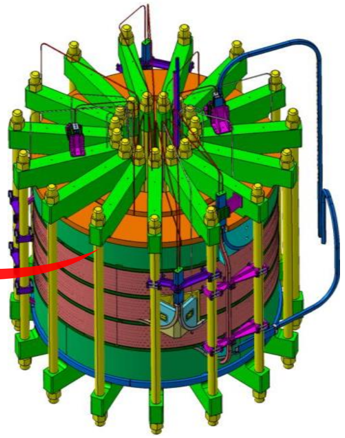
Busline



Vacuum pump



Thermal shield



12T SC CSMC magnet

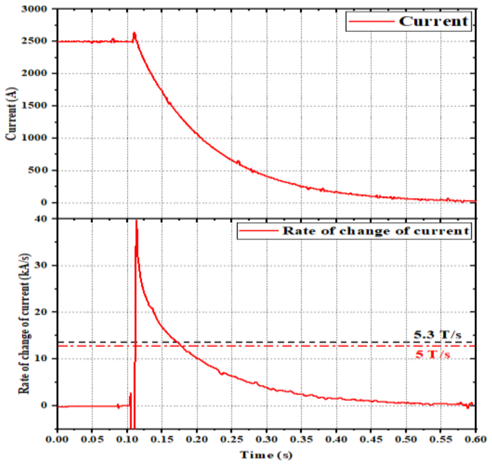
Φ_{in}	1500mm
I_{op}	47 kA
dB_{max}/dt	5 T/s
R_J	< 1 nΩ
T_{OP}	4.5K

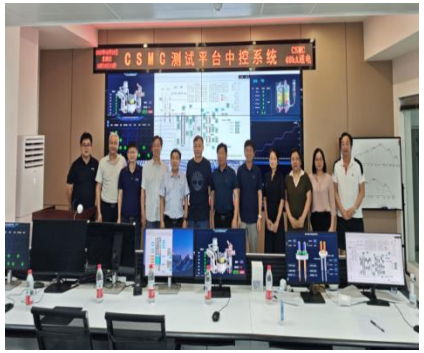
CFETR CS model coil (CSMC) and testing facility

◻ Major progress

- ✓ The maximum current test of the CSMC reached 48kA, Bmax = 15T which is meeting the expected design parameters.
- ✓ The on-site external acceptance testwas completed onAugust 28th 2025.
- The test results show that the magnetic field change rate exceeding 5.3T/s

CSMC of CFETR(1/2 size)





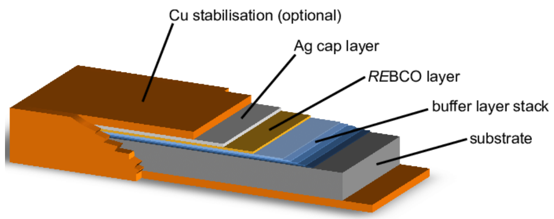
5. HTS magnet technology development

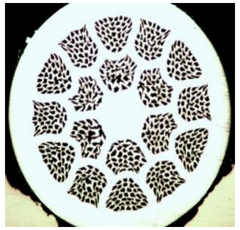
The objectives

- Explore HTS CICC conductor and magnet technologies
- Evaluate operation performance for DEMO device

	Parameters	Values
Coil	Operation current / Io	46.5 k
	Peak field / Max	19.6 T
	Inner radius	475.5 mm
	Outer radius	703.5 mm
	Number of turns / per module	5 x 30 turns
	Conductor length per module	556 m
CICC	Cable OD	32 mm
	Jacket OD	~ 41 mm
	REBCO Tape(width x thickness)	4 x 0.1 mm
	No. of sub-cable	6
	No. of SC tapes	212

design concepts

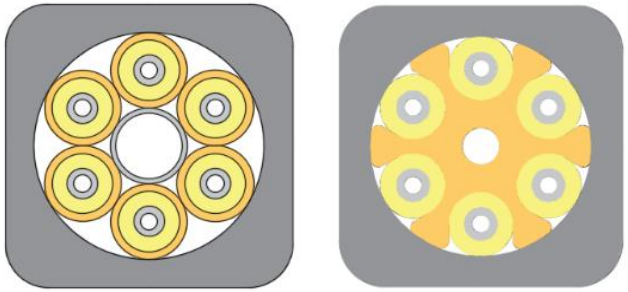




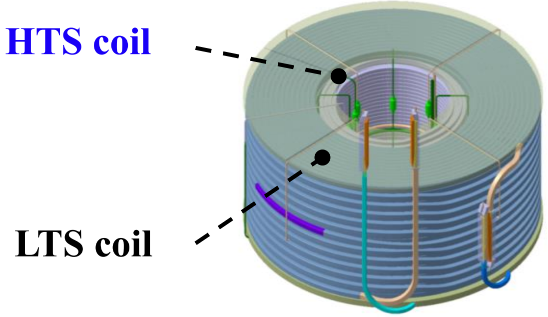
2212 wire

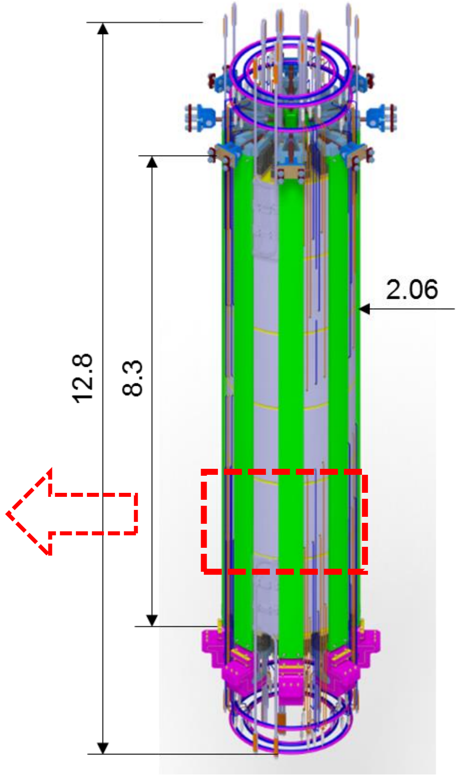
Candidate material: **REBCO tape**

Option I: Option II:



CICC design under developing

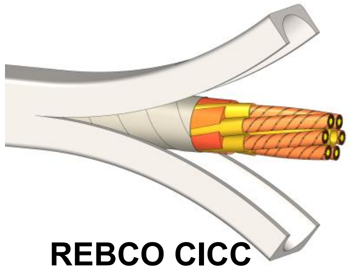


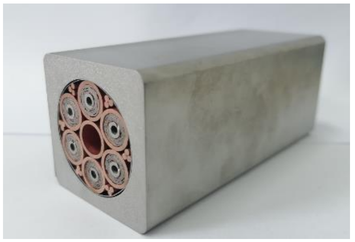


HTS magnet technology development progress

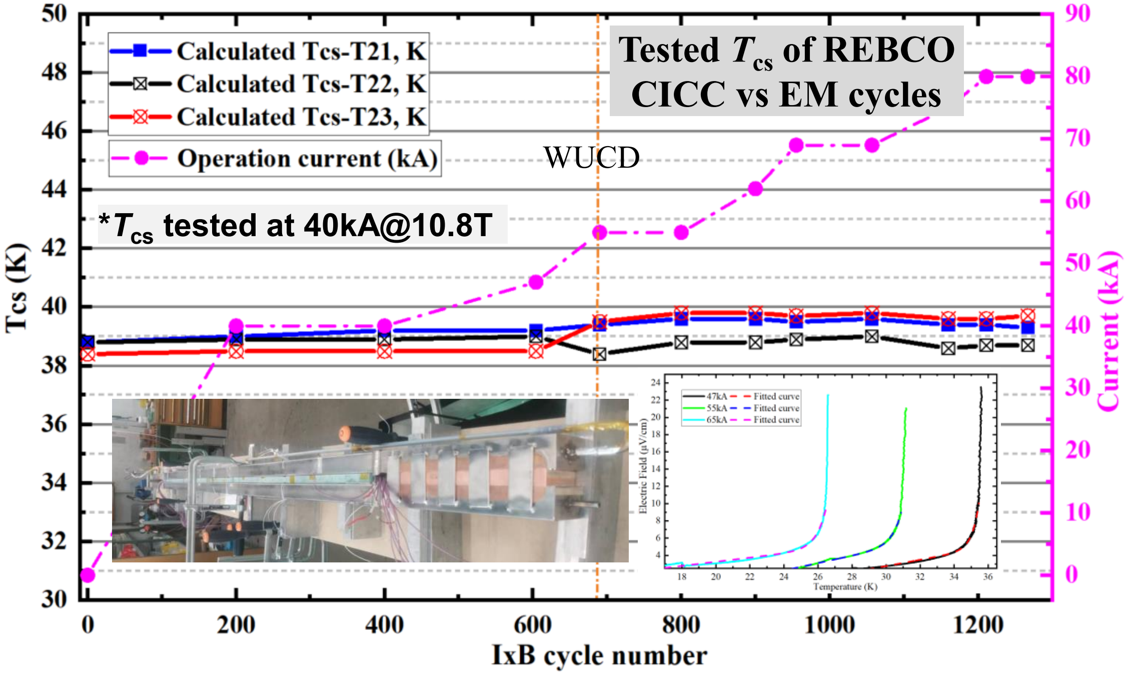
➢ HTS CICC technology development and performance verification

REBCO Tape



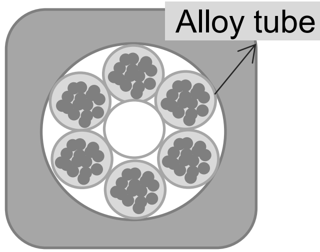


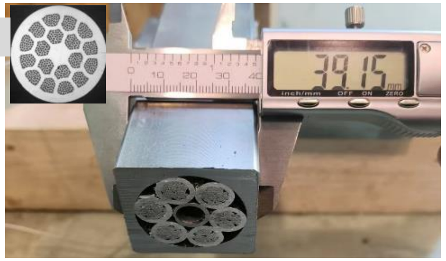
REBCO CICC



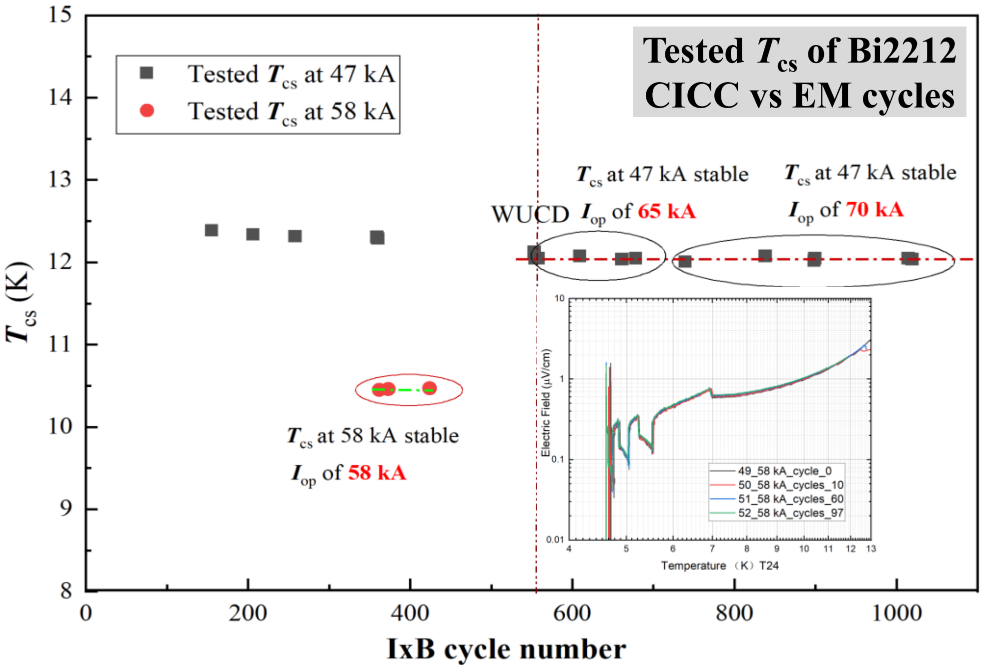
Tested items: 1267 EM cycles (max 80kA @10.8T)
WUCD and Quench (max ~15 μV/cm)

Typical LTS CICC





Bi2212 CICC (Stress Equalization Structure)



Totally ~ 1100 EM cycles (max 70kA @10.8T), no obvious degradation, effects from WUCD will be further analyzed.

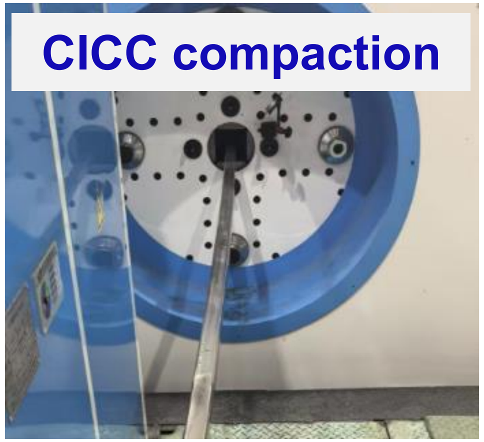
HTS magnet technology development progress

➢ HTS magnet components mass production technology development

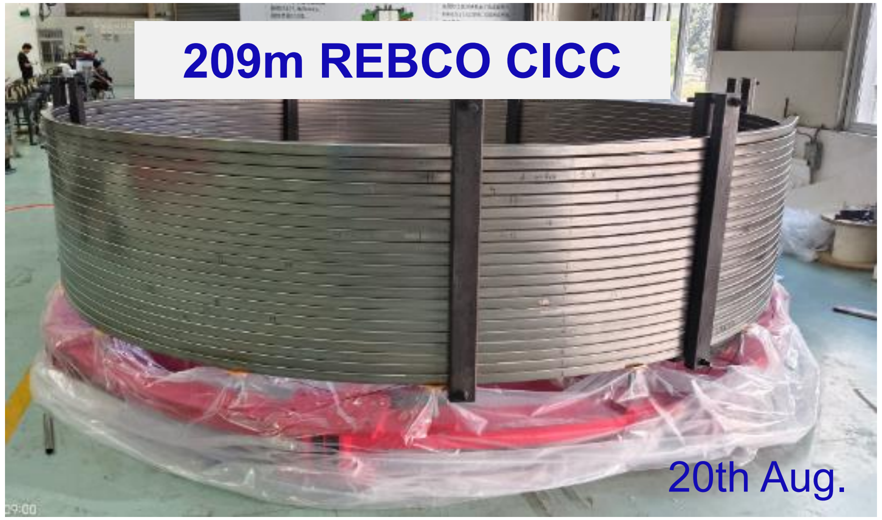
Sub-cable winding

CICC cable twisting

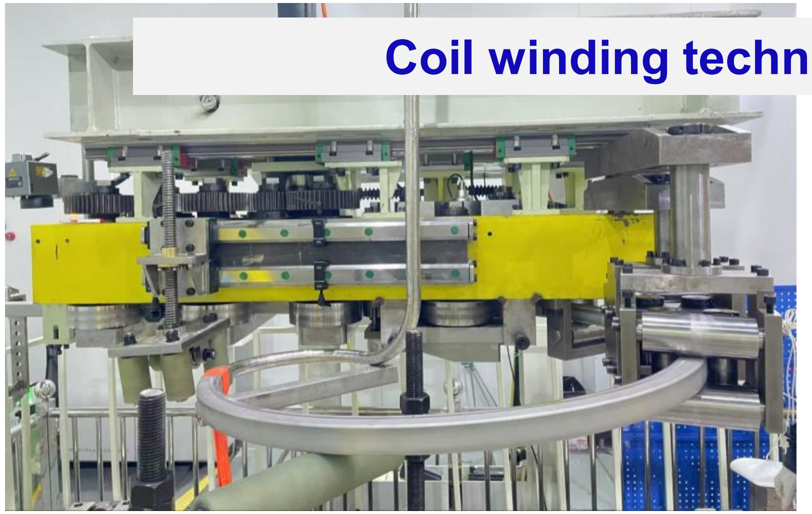
CICC compaction



209m REBCO CICC



Coil winding technology verification



6. CFETR TF and testing

➢ Objective:

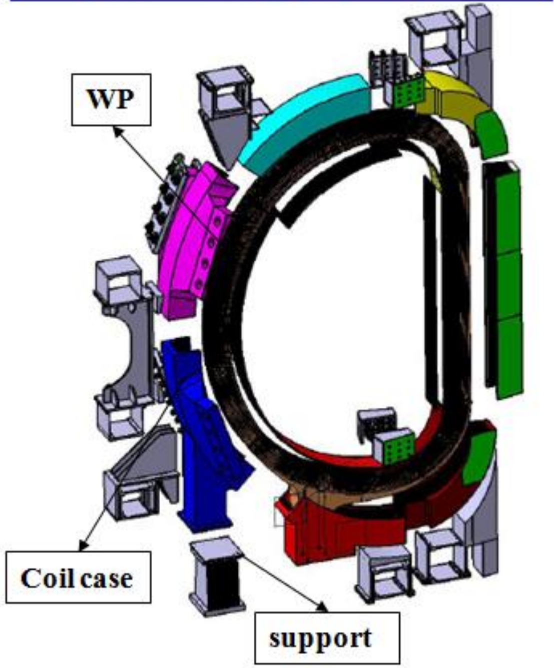
- To develop and validate of fusion reactor large-scale superconducting coil manufacturing technologies and standards.
- To construct a prototype TF coil meeting the physical and engineering requirements of CFETR

➢ Main Technique Parameters:

Items	Value
Io	95.6 k
Max	~14.5 T
Total Storage Energy of 16 TF coils	~120 GJ
Total Inductance of 16 TF coils	26.3 H
T_{op}	4.5 K
Insulation Voltage	＞10 k
Height × Width	21.7 × 12.3 m
Total weight	~643 t

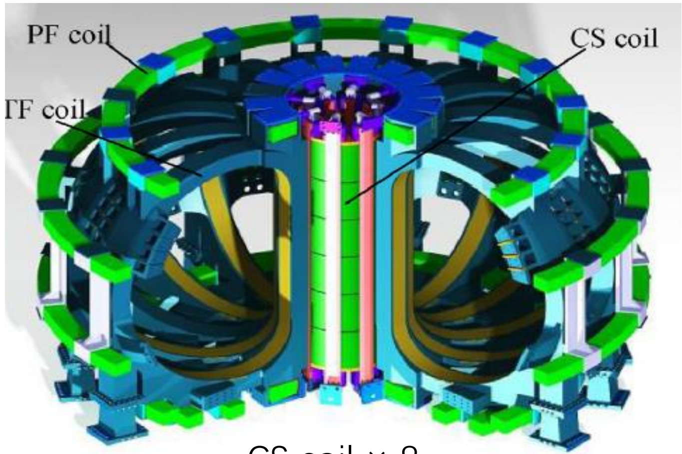
➢ System Description:

✓ Preliminary design model



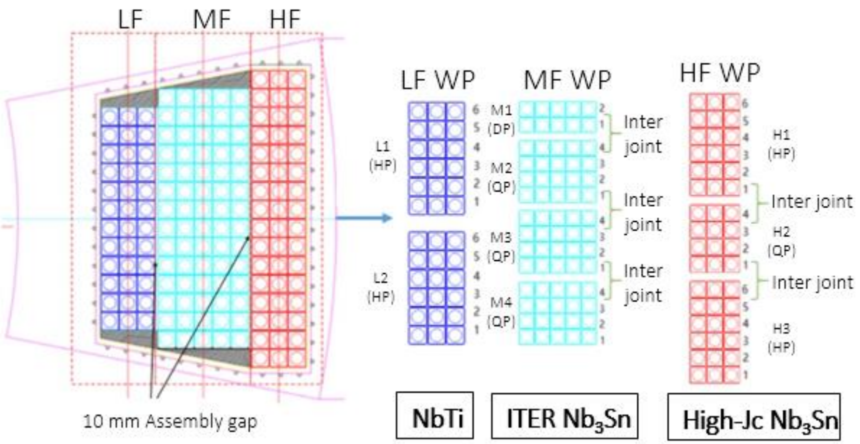
WP, coil case, coil support

✓ CFETR magnet system



- CS coil × 8
- TF coil × 16
- PF coil × 7

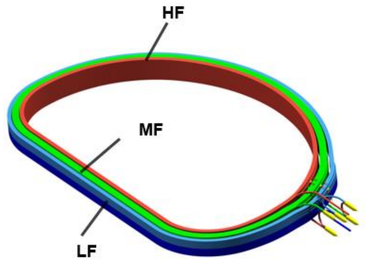
- 3 grades conductors has been adopted

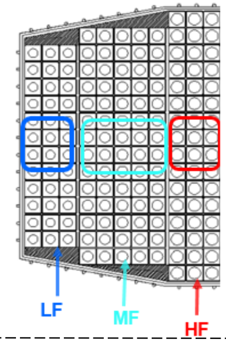


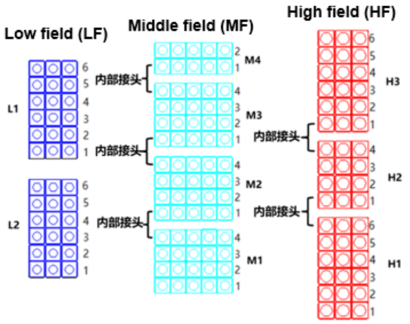
Key Technologies Qualification of TF Coil

Hybrid Graded Winding of Coil Design

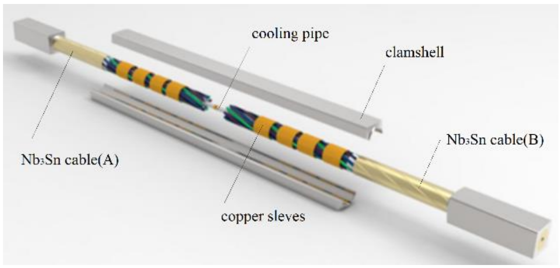
- ✓ Strands with 3 grades : **high performance Nb_3Sn, ITER grade Nb_3Sn and NbTi.**
- ✓ Internal superconducting **joint technology** is adopted to realized winding packs connection.



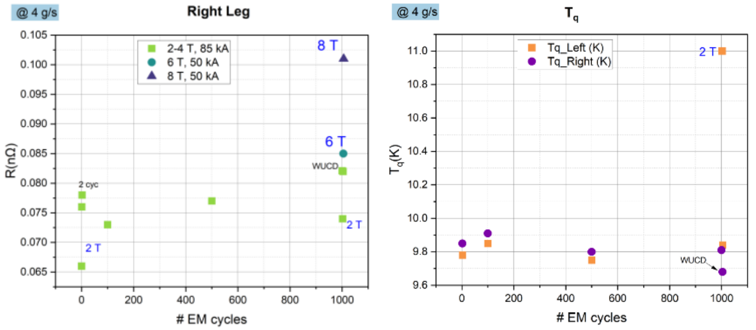




Internal Joint in WP



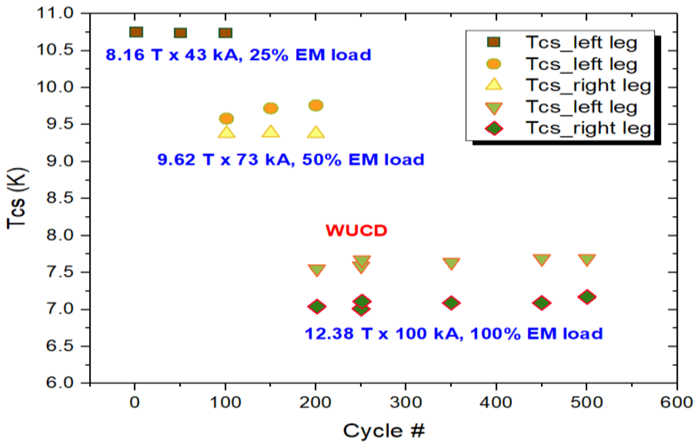
Overview of internal joint structure

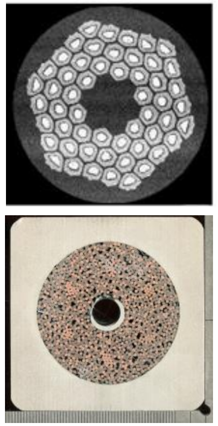


Performance test results of internal joint from SPC

- ✓ DC resistance can reaches to the level of **0.08nΩ** at 4T field after WUCD and 1000 EM cycles.
- ✓ **NO clear degradation** of the quenching temperature is visible after increasing EM cycles.

High-performance Nb_3Sn Sc Wire

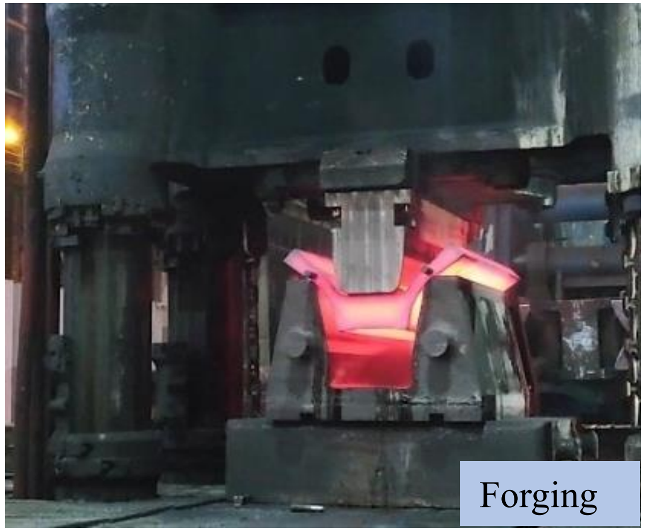




- ✓ **100kA-class** cable-in-conduit conductor has been successfully developed with WST high-J_c Nb_3Sn strand (**J_c>2200 A/mm² @ 12T,4.2K**)

316LMn Stainless Steel (JJ1) Forging Material for Coil Case

- ✓ Successfully developed for the **inner straight part of case**



Test Item	Fail or Pass
Chemical composition	Pass
Grain size	Pass (Level 2-3)
Inclusion, ferrite, intergranular corrosion	Pass
tensile property@4.2K	Pass (average:YS~1100MPa)
fracture toughness @4.2K	Pass (average:~200MPa·m$^{1/2}$)

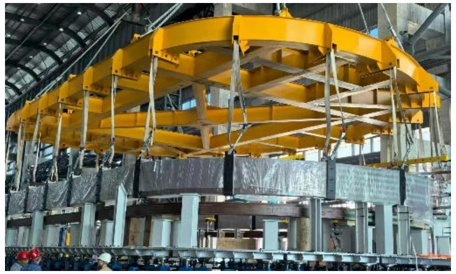
CRAFT TF Coil Progress

Winding Pack

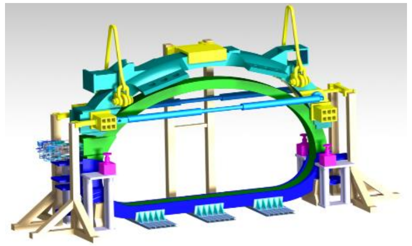
- ✓ **Winding** of 9 HF&MF&LF sub-windings —Completed
- ✓ HF&MF&LF **internal joints and terminations** fabrication —Completed
- ✓ **Heat trinsulation wrapping** of HF&MF&LF windings —Completed
- ✓ **VPI** of HF&MF&LF heatment of MF&HF windings —Completed
- ✓ **Turn windings** —Completed
- ✓ **Embedding trial** of HF&MF&LF —Completed





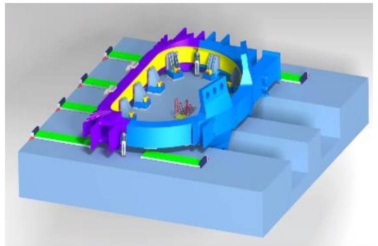



Coil Assembly



Vertical way

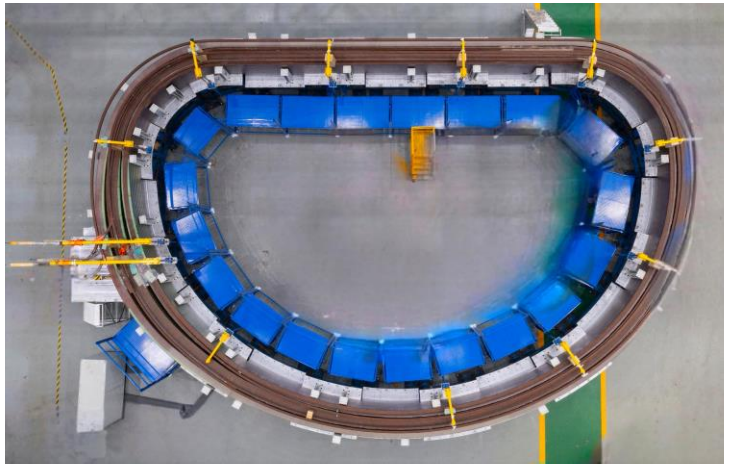
Assembly strategy Optimization



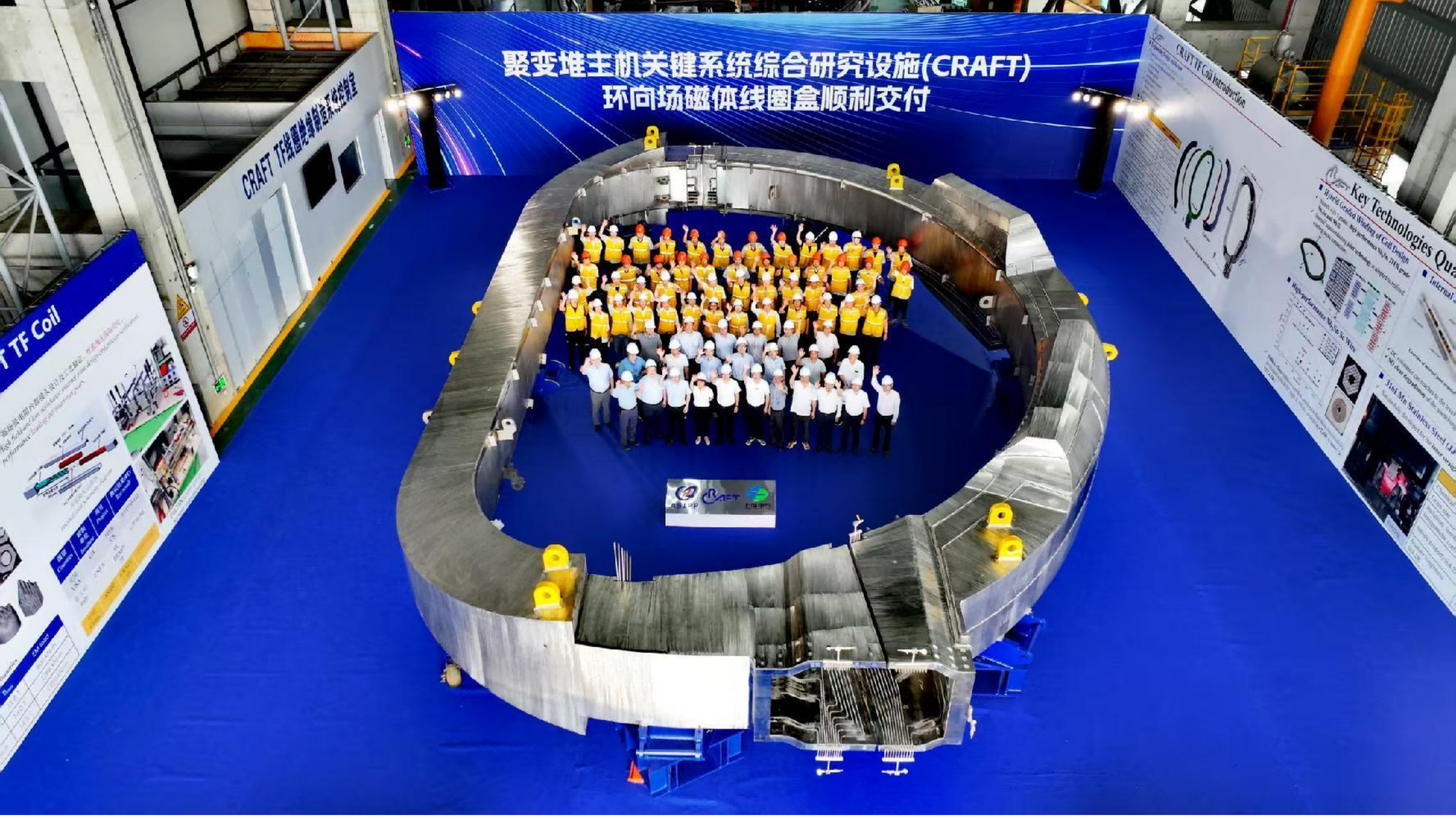
Horizontal way


Full size welding mockup of straight leg and curve leg

Gap filling mockup



The commissioning of the coil assembly station


聚变堆主机关键系统综合研究设施(CRAFT)
环向场磁体线圈盒顺利交付
CRAFT TF Coil Introduction

7. Cryogenic System

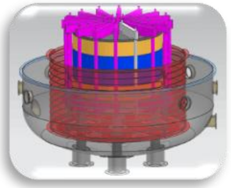
To develop cryogenic technology for DEMO and testing facility for CFETR SC magnets.

To build a research and test platform for future CFETR cryogenic system development.

Helium Refrigerators

- 6kW/4.5K refrigerator (containing 250W/1.8K refrigeration capacity)
- 3kW/4.5K refrigerator
- 1kW/3.8K refrigerator
- 200W/4.5K refrigerator

Total average cooling capacity over **7.2kW/4.5K**



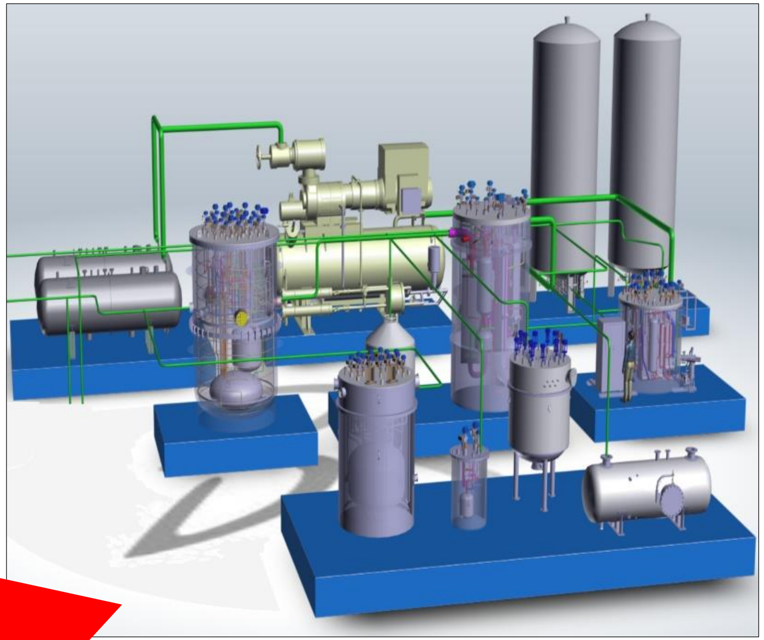
SC Magnet testing facility

SC Conductor testing facility

SC Material testing facility

Cryogenic Public Service Platform

Cryogenic Key Technology Research Platform



CRAFT Cryogenic System

- Super fluid Helium Production and Cooling Technology
- Helium Turbine Design, Manufacturing and Testing Technology
- Cryogenic Heat Exchanger Design, Manufacturing and Testing Technology
- Safety, Reliable and Intelligent Operation Technology for Cryogenic System

7. Cryogenic System

□ 200W/4.5K Refrigerator

- Assembly and commissioning has completed in October 2021.

□ 1kW/3.8K Refrigerator

- Assembly and commissioning has completed in May 2023.

□ 3kW/4.5K Refrigerator

- Commissioning is finished

□ 6kW/4.5K Refrigerator

- Assembly is in progress.

□ Helium compressors

- Compression capacity is over 1680 g/s@20 bar.

□ Oil removal system

- Ensure that the oil in the gas helium is below 10 ppb.

□ Helium recovery system

- Compression capacity is 210 Nm^3/hr with discharge pressure of 150 bar.

□ LN_2 & Helium Storage System

- Storage capacities of GHe and LN_2 are 21000 Nm^3 and 100 m^3 respectively .

8. Power supply testing facility

➢ Objective

- To solve the key issues of current superconducting coil power supply ;
- To develop the advanced (next generation) SC coil power supply ;
- To support the research and test of large current super-conductive magnet systems .

➢ Parameters

Feeding Coils:

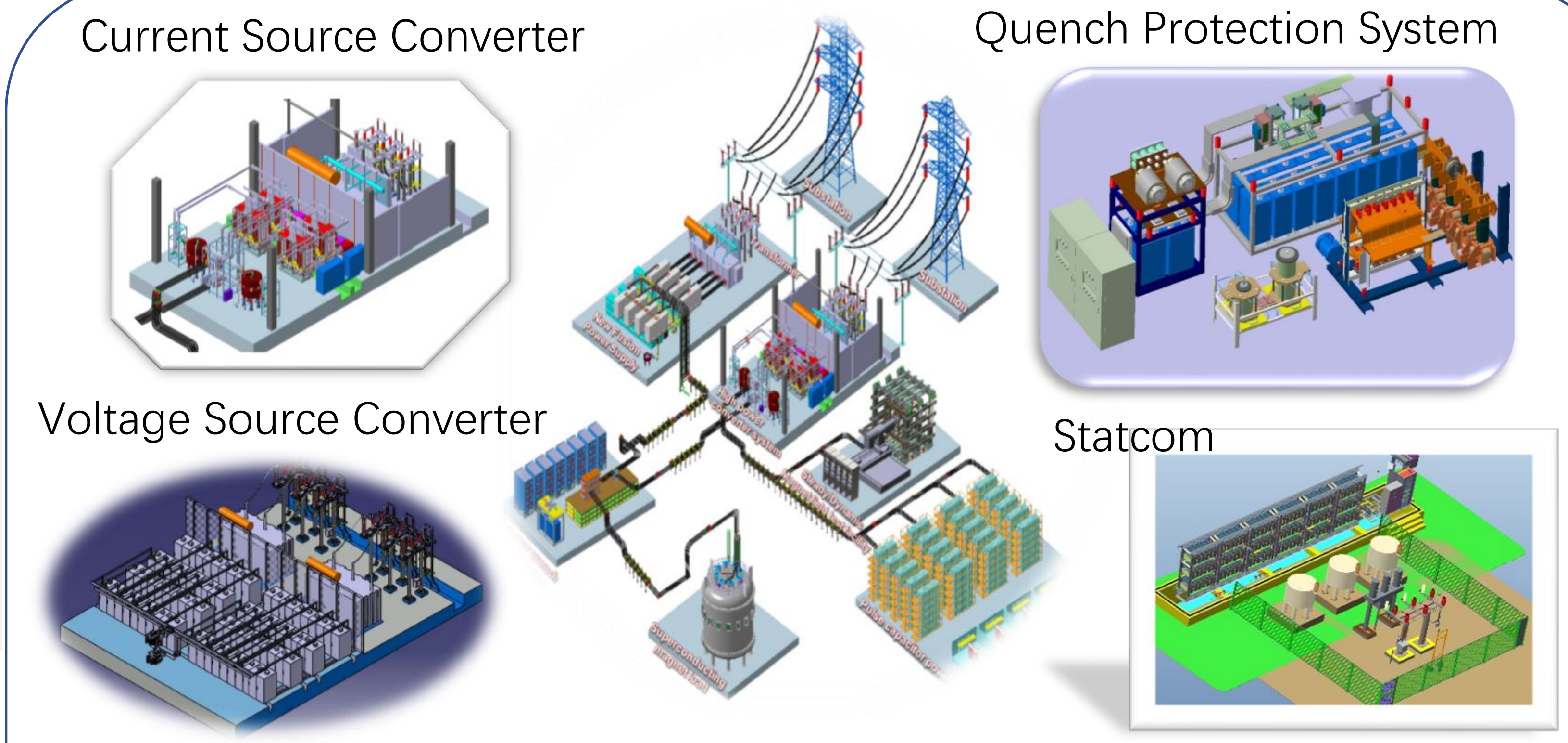
Current Source Converter:100 kA, 250 V

Voltage Source Converter: 60 kA, 3000 V

In case of quench:

Dissipated Power: 1GJ

Breaking time: <0.5 s



8. Power supply testing platform

The platform consists of TF power supply and 25 kA test facility; Prototype at 50 kA tested

1.TF power supply

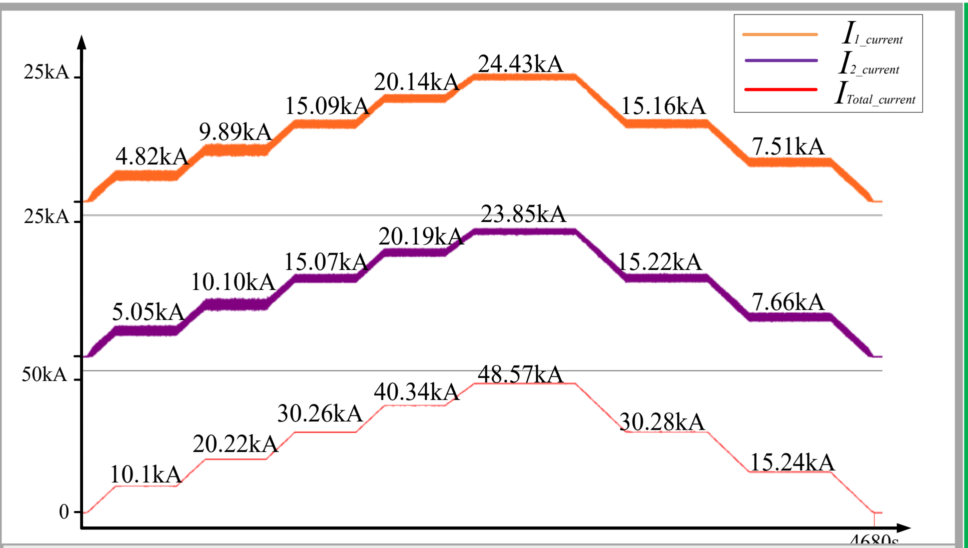
Key Parameters of TF power supply

Parameter	Unit	Value
Current	kA (DC)	100
Voltage	V (DC)	±250
Current ripple	%	<0.1
Power dissipation	GJ	4

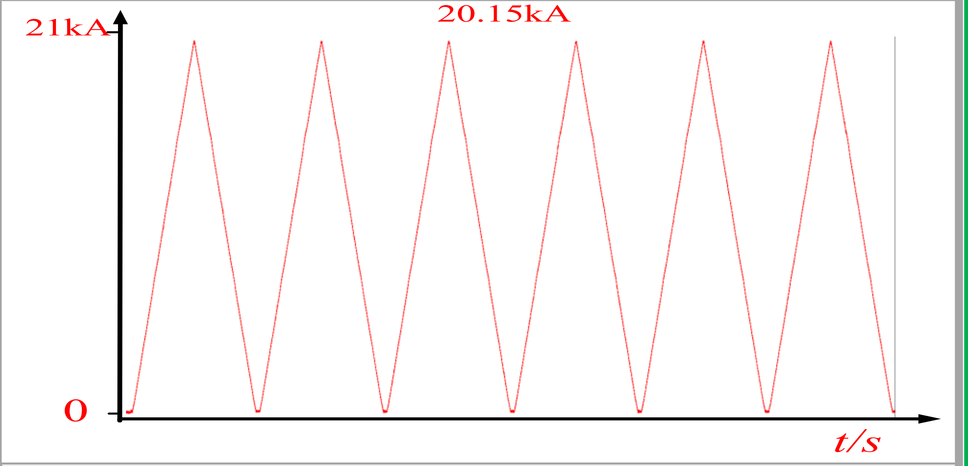
2. The 20kA test facility

Key Parameters of 20kA test facility

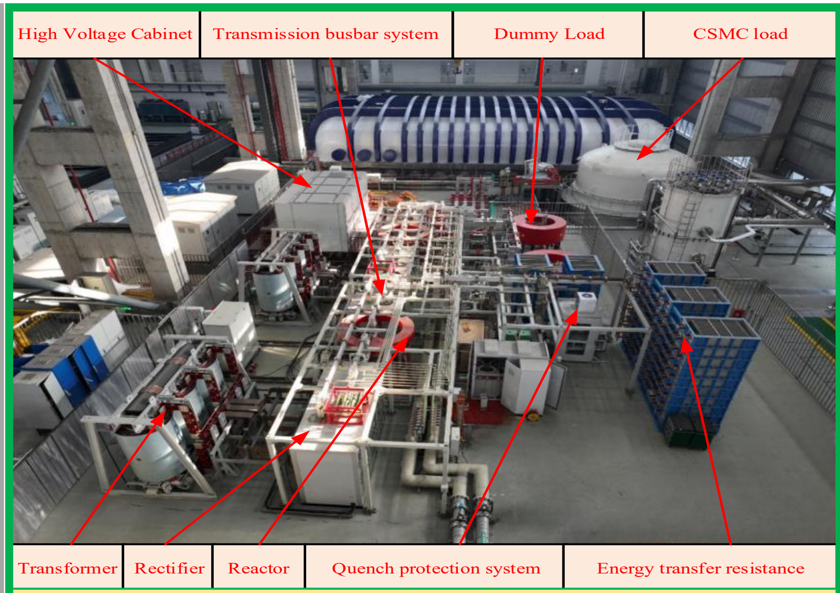
Parameter	Unit	Value
Current	kA (DC)	20
Voltage	V (DC)	±14
Current ripple	%	<0.1
Power density	GJ	103.17 kW/m^3



48kA steady-state output test @0.36H load



20 kA triangular wave experiment



50 k TF power supply prototype test

20kA test facility

The largest quench protection system accomplished

■ 100kA/10kV quench protection system successfully developed and verified by tests

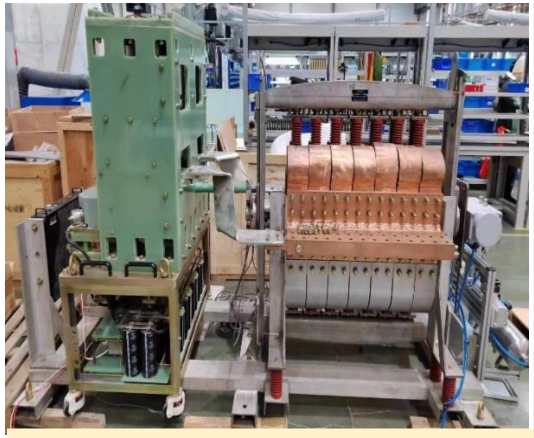
1. Key parameters:

- DC Current: 100 kA DC
- DC voltage: 10 kV
- Power dissipation: 4 GJ
- Pyrobreaker breaking time:0.2 ms

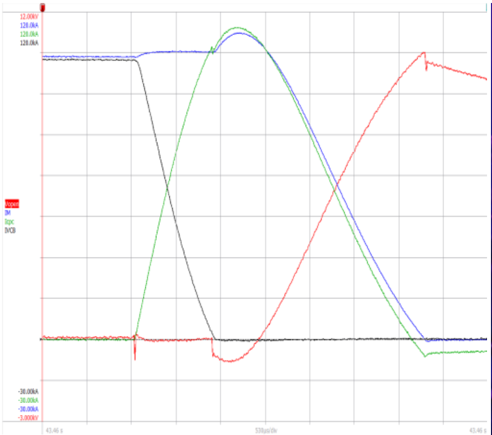
CRAFT quench protection system

2. Type tests passed:

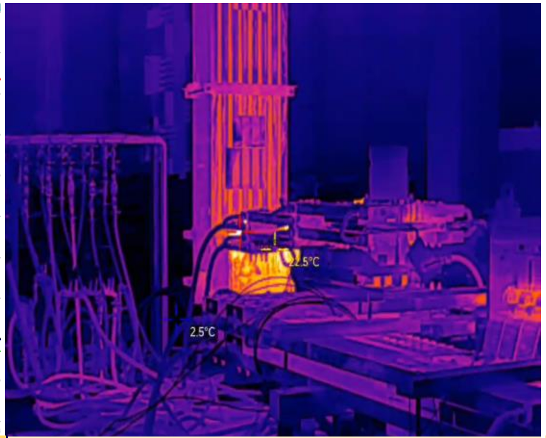
	Test items
Main breakers	100 kA/10 kV disruption
	Temperature rise test
	200 times no-load
	Breaking stability test
Pyro-breakers	100 kA/10 kV disruption
	Temperature rise test
	3 months in water test on powder
	Life test



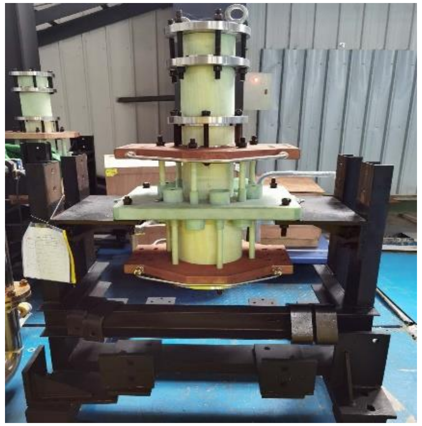
Main breakers



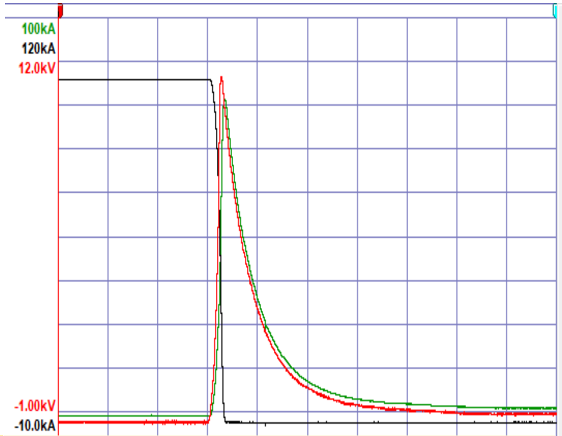
Current at breaking



Temperature rise test



Pyro-breaker



Current at breaking

9. Large linear plasma testing facility

Objectives: To address key R&D issues of plasma-facing materials and components for CFETR in appropriate physical regimes, size and time scales of plasma-material interactions.

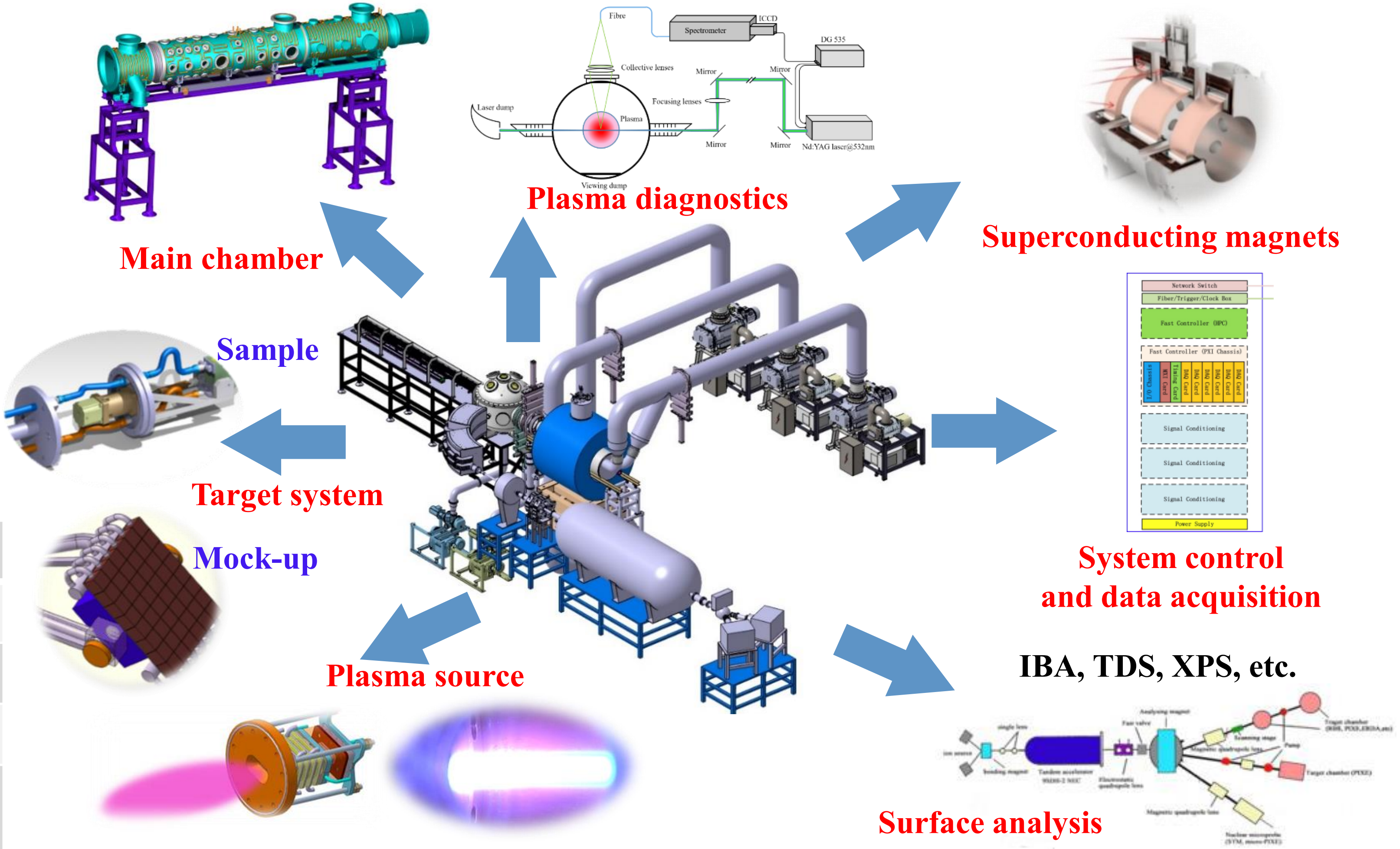
➢ Capabilities

- Delivering DEMO divertor-relevant plasma streams of high heat and particle fluxes for material/mock-up testing

- In-situ/in-vacuous analysis for material surfaces

➢ Machine parameters

Shot length	~1000 s - hours
Magnetic field	~3 T
Particle flux	10^{24} -10^{25} $m^{-2}s^{-1}$
Plasma dimension	30-100 mm
Max. Sample/mock-up size	250×250 mm



SWORD: Superconducting linear device for PWI study

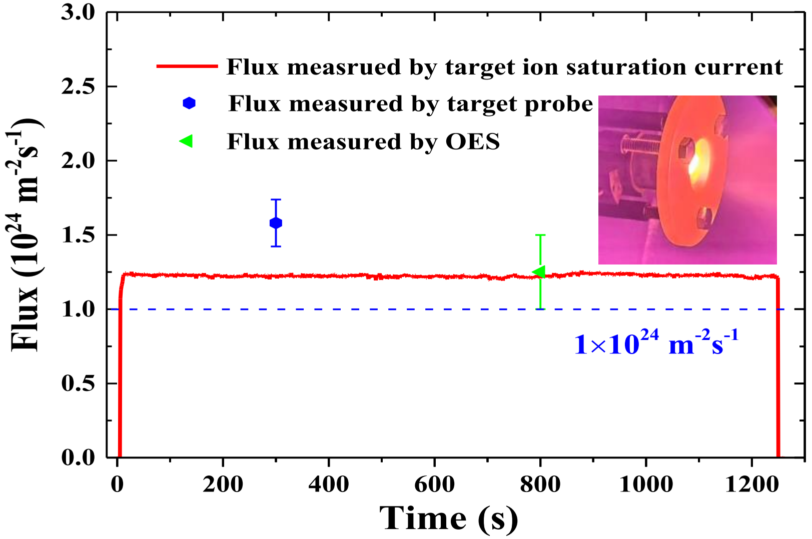
SWORD (Superconducting plasma Wall interactiOn lineaR Device)

Capabilities

- Delivering reactor-relevant particle flux to materials
- Large sample/mock-up exposure
- In-situ analysis on material surfaces

Shot length	~1000 s - hours
Magnetic field	~3 T
Particle flux	10^{24} -10^{25} $m^{-2}s^{-1}$
Plasma dimension	30-100 mm
Max. sample size	250×250 mm

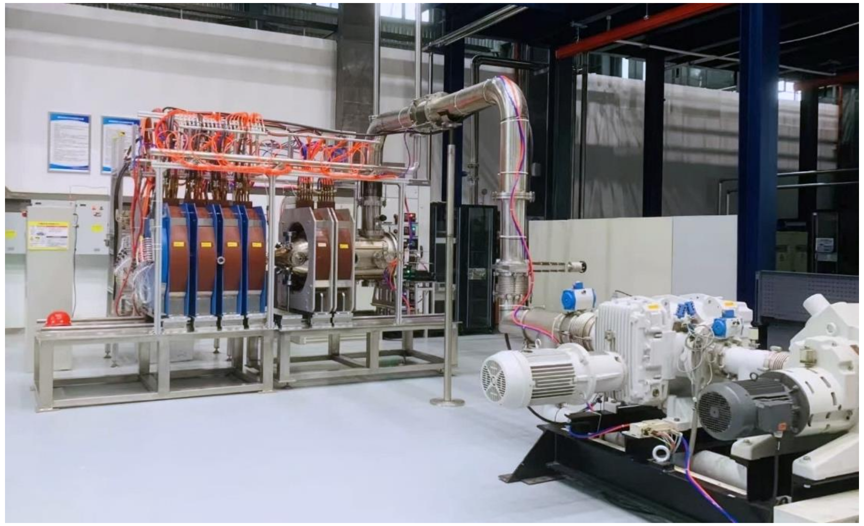
SWORD facility

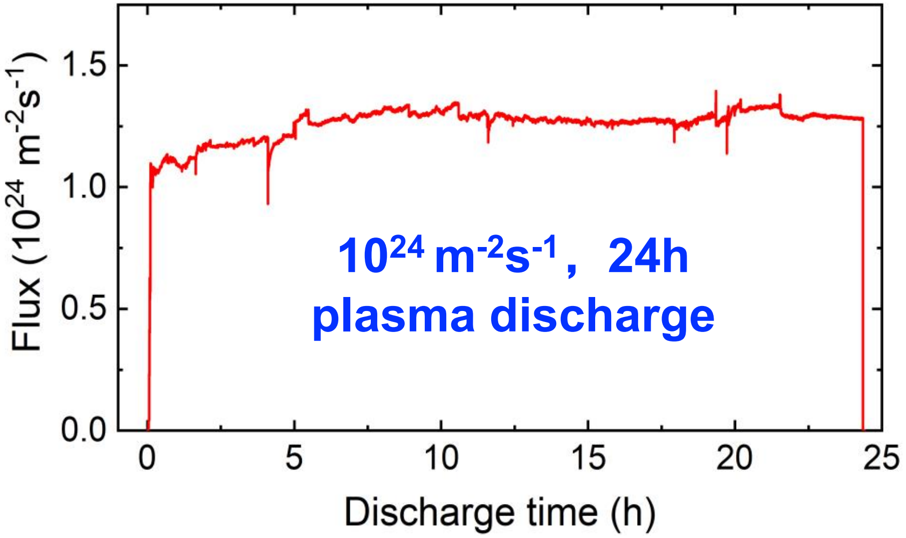


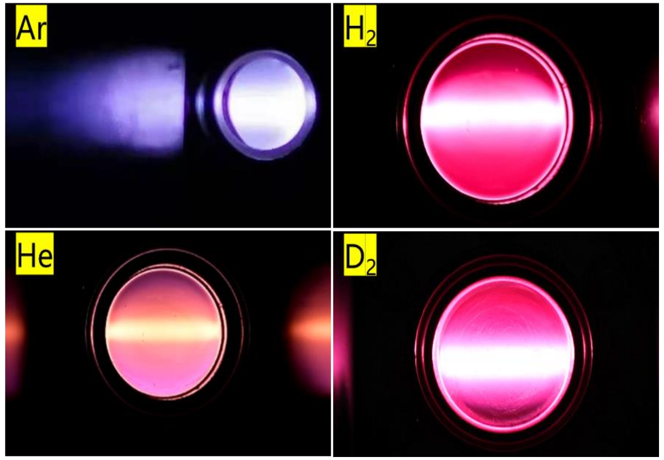
A typical 10^{24} $m^{-2}s^{-1}$ discharge

SPARROW: a prototype machine for plasma source testing

SPARROW (Steady-state Plasma Apparatus foR Research Of Wall materials)





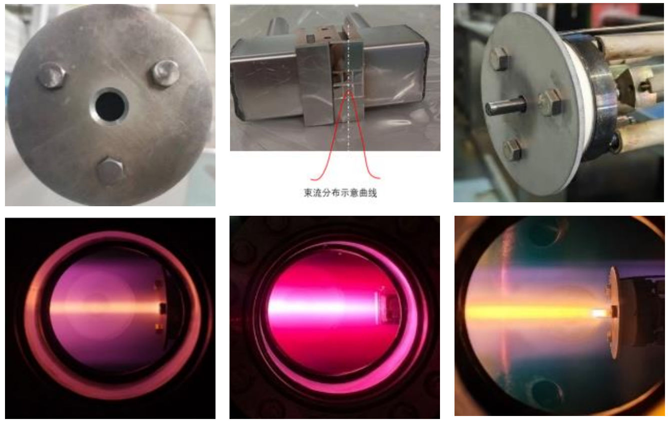


Ar/He/H_2/D_2 discharges

- 10^{24} $m^{-2}s^{-1}$, 24-hour long-pulse plasma has been achieved.
- The SPARROW facility is already open to users.

Key parameters

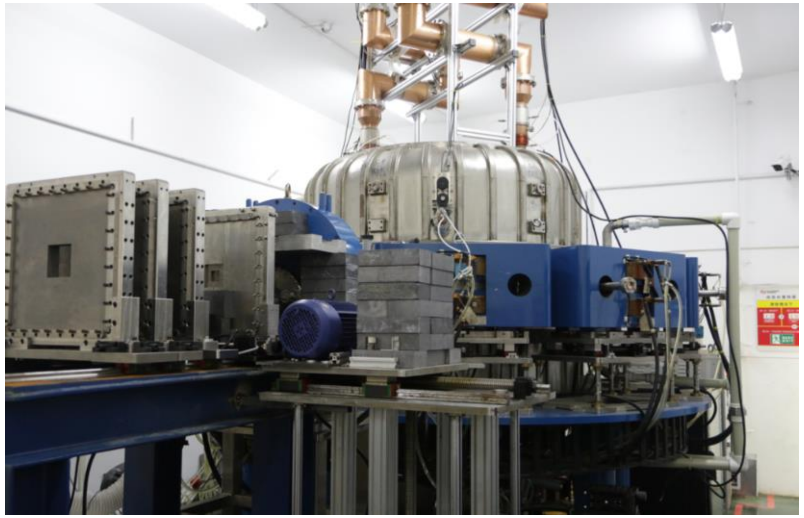
Shot length	~1000 s - 24 hours
Magnetic field	~0.9 T
Particle flux	10^{23} -10^{24} $m^{-2}s^{-1}$

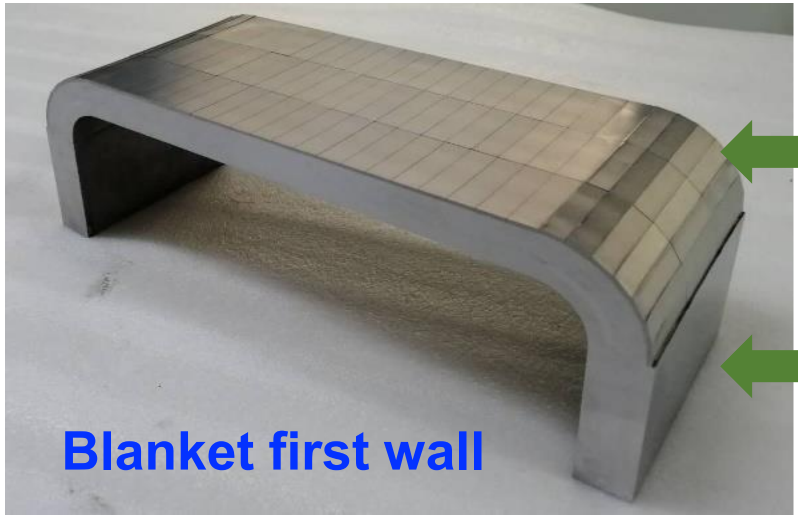


Various users' samples

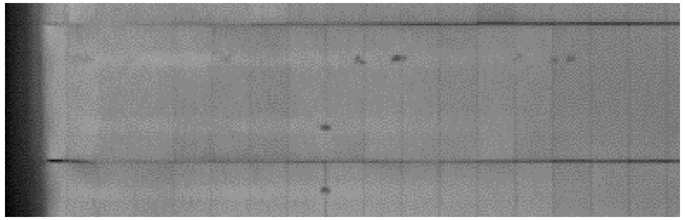
Accelerator CTs for fusion component inspection

Developing state-of-the-art high-energy CT systems with the highest resolution, enabling quality inspection of meter-scale components.

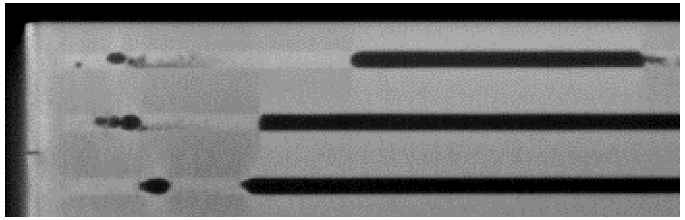




Blanket first wall



Defects between W and RAFM



Failures in the cooling channels

Parameters of the high-energy CT systems		
Energy	9 MeV	1.5 MeV
Spatial resolution	≤ 30 μm	≤ 25 μm
Load capacity	2 t	150 kg
Sample size	Φ1200×H2000 mm (can be doubled)	Φ300×H1200 mm (can be doubled)

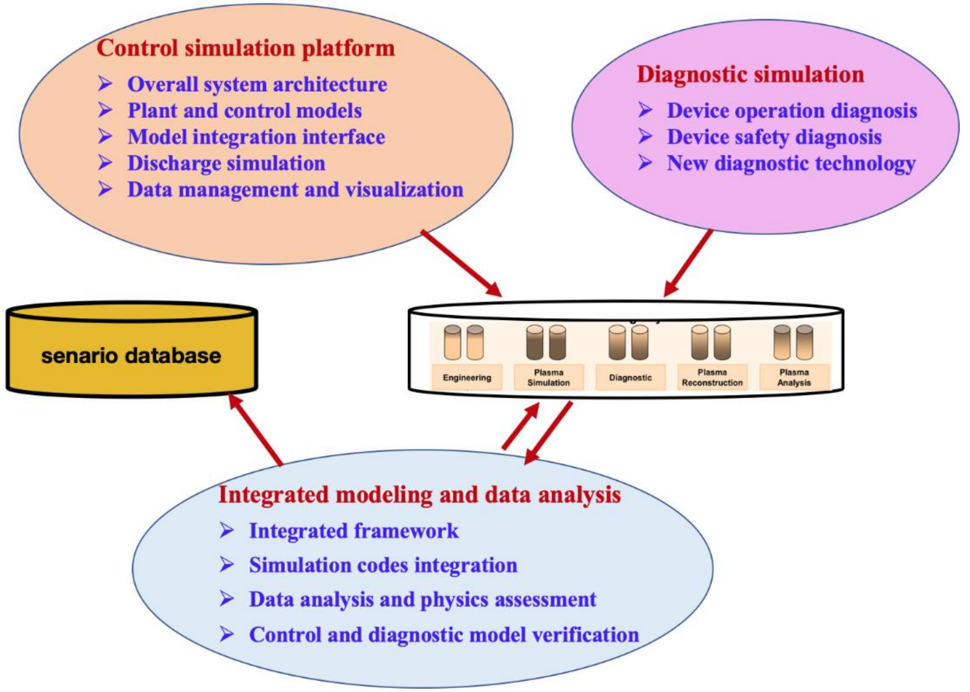
10. Mater Control facility

➢ **Scientific objectives：Establishing numerical tokamak for CFETR plasma control system and discharge scenarios assessment.**

development of platform framework

- **PCSVP**, Plasma control simulation platform
- **FuYun**, Integrated modeling and analysis platform
- **SDP**, Synthetic diagnostics platform

- ***Lingshu PCS*** provides routine control services for EAST, **>9000 shots** with success rate **99.4%**.
- **>24 hours** continuous running with **real time data archiving and access.**



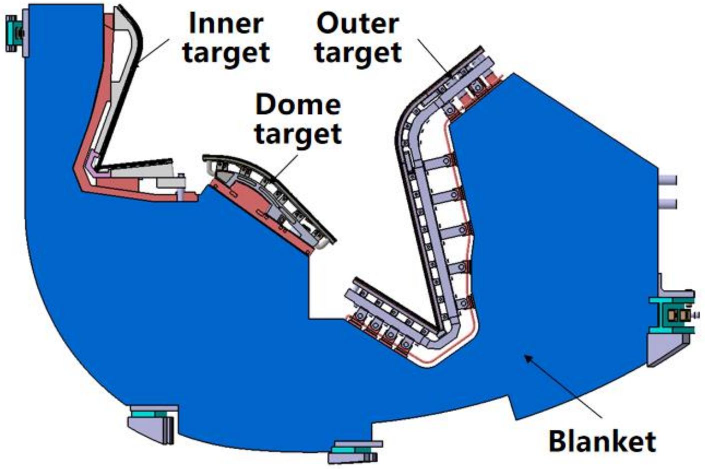
Numerical Tokamak

- Control simulation
- Design and verification of discharge scenarios
- Event analysis and handling
- Discharge assessment
- Diagnostic technical development

11. Water-cooled Divertor Development

To develop advanced technology for design, manufacture, preparing and operation of DEMO divertor

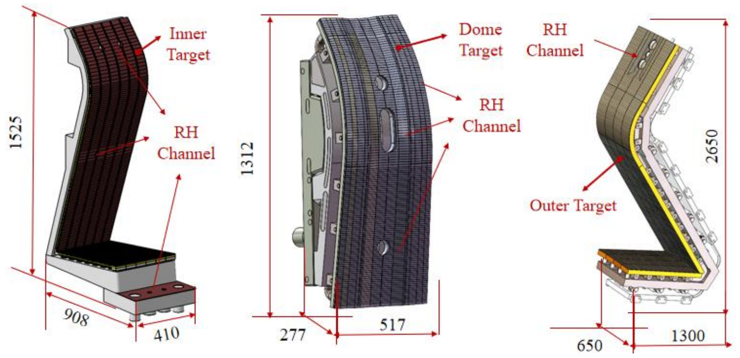
To develop advanced materials, components, tools, testing facility and prototype DEMO divertor.

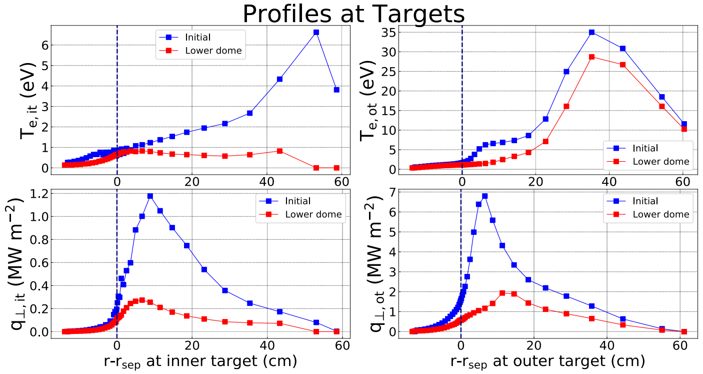


CFETR hybrid divertor-blanket concept

Items		CFETR Divertor
DM Number		80
Weight of one DM (ton)	Inner target	0.7
	Dome Target	0.65
	Outer Target	1.5
Target materials	PFC & Heat sink	K-doped W/ODS-Cu/Cu/RAFM
	Water T(°C)/P_{in}(MPa)	140/5

Flat tile units were finally chosen as basic units due to lower surface temperature in **extreme SS 20 MW/m²**



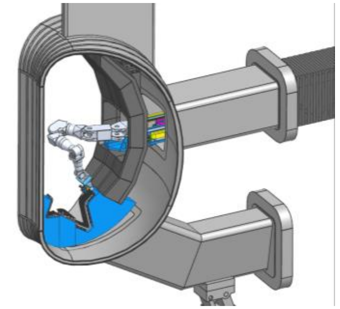


The physical results of new divertor geometry are acceptable

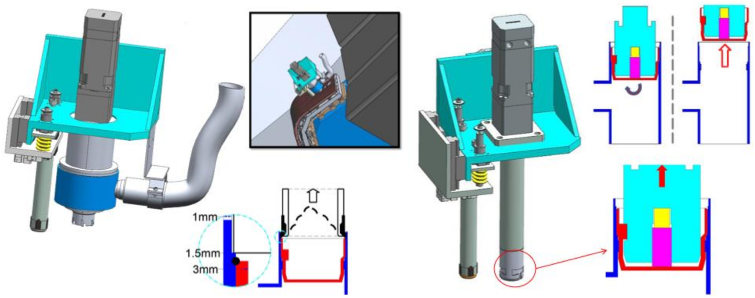
- Heat flux towards the targets is decreased and the pump efficiency can comparable.
- **Increase of TBR is about 4%**

Hybrid Design, RH capable, HH tolerant, QA for DEMO

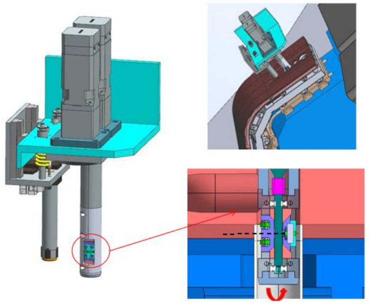
RH Maintenance Procedure



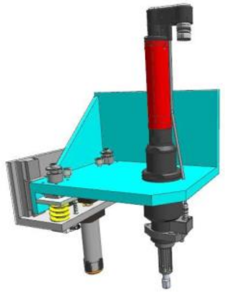
MPD carries actuator to scheduled location



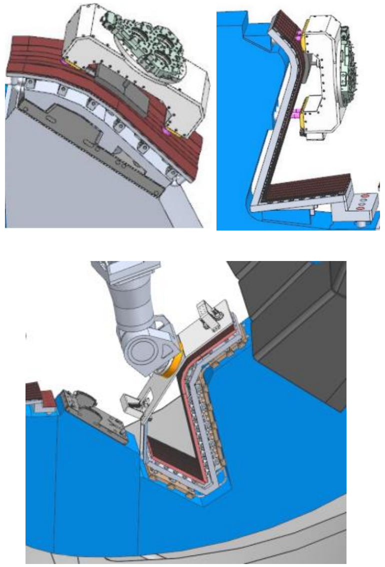
Pipe cap cutting and removal



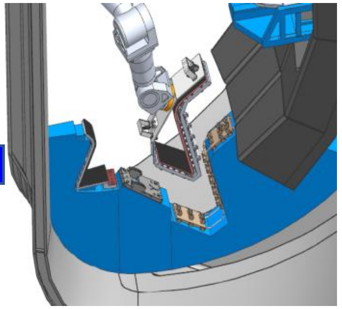
Pipe internal cutting



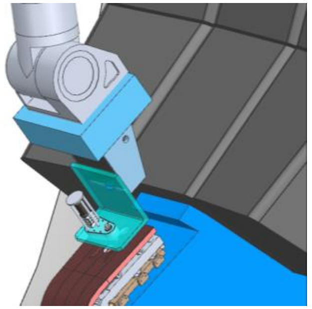
Fastener disassembly



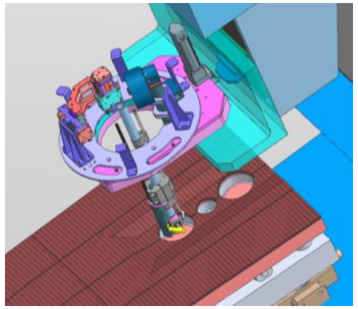
Target gripping and removal



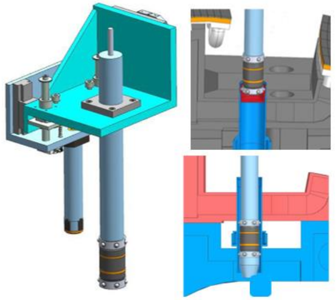
Replacement of new target



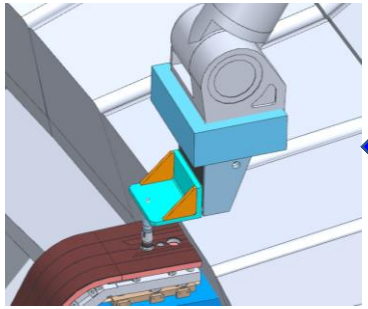
Fastener mounting



Pipe internal welding

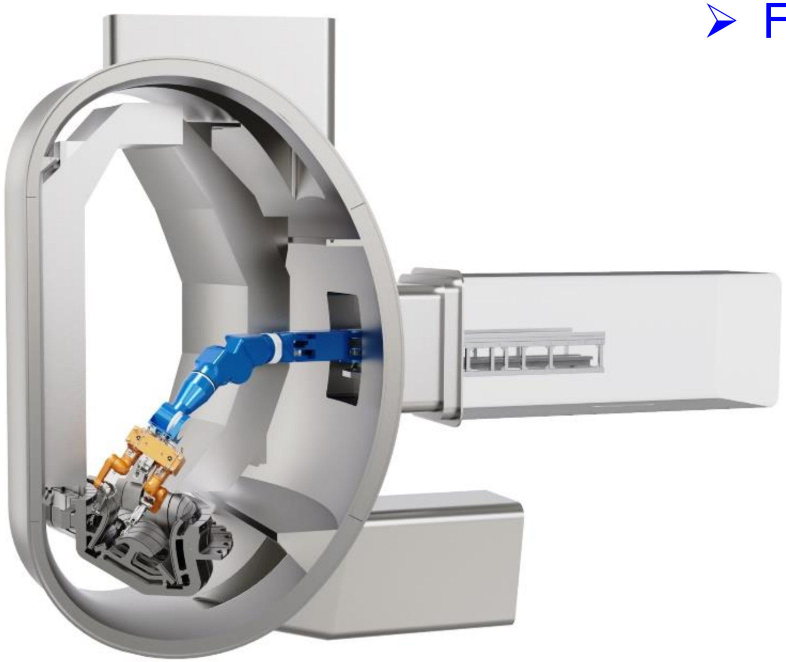


Weld flaw NDT detection



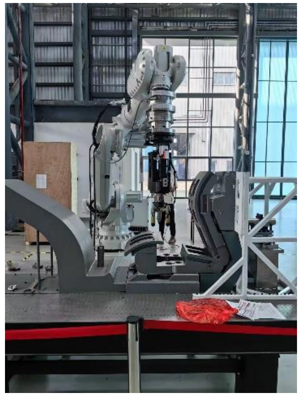
Pipe cap welding and leak detection

Key RH Tools Lab Verification



Successfully developed pipe internal cutting/welding tools, dismantling tool and gripping tool, demonstrating the replacement of the target.

- Fastener dis-/assembly

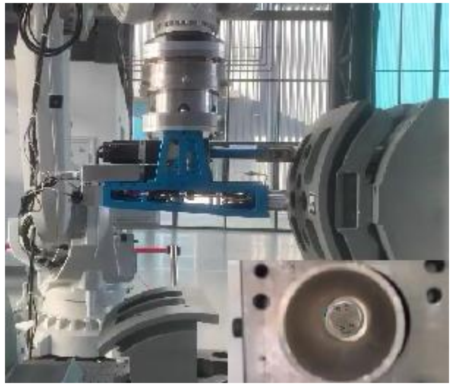


Realization of M30 bolt operation

- Target gripping

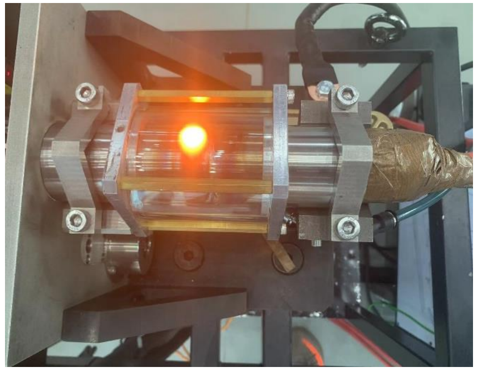
Target gripping and removal procedure implementation

- Pipe internal cutting



Debris-free cutting of 3 mm-thick 316L pipes(50, 60mm)

- Pipe internal welding



Achieved automatic TIG welding of 316L pipes without filler wire

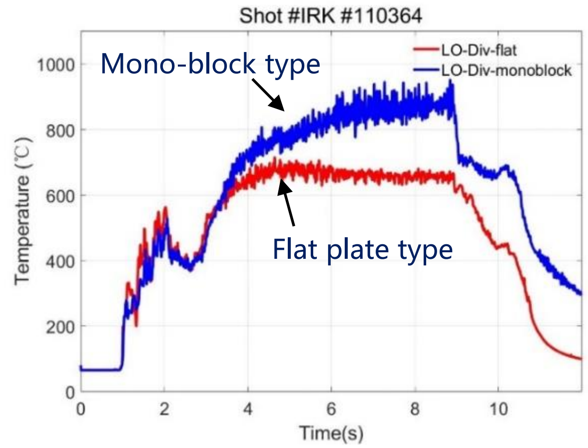
12. CRAFT-High Heat Flux Testing Facility

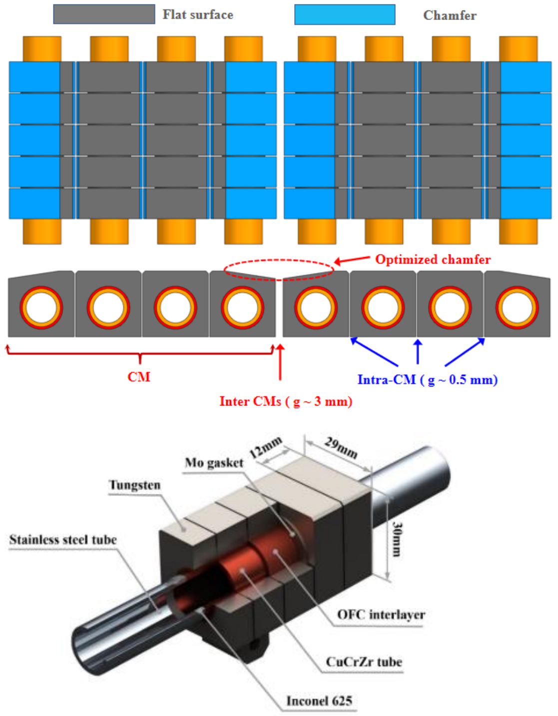
Consists of electron-beam generator, vacuum vessel system, and cooling water system.
To provide testing environment of high heat flux loading and thermal hydraulic performance for water-cooled divertor and blanket component.

Main parameters	
EBG-I	60kW@150kV，10 kHz，1mm，0.1s-1h
EBG-II	800kW@60kV，10 kHz，50mm，1s-1h
Vacuum Vessel	φ3m×4m，＜5×10^{-3} Pa@30min
IR-Camera	T: 0-3000℃, 1024×1024 pixels
CCD-Camera	4 M pixels @4510 f/s; 0.3 M pixels @19840 f/s
DIC-strain	Strain: 0.005%~2000% @500mm*500mm
Coolant	20m³/h@25℃，2-15 MPa

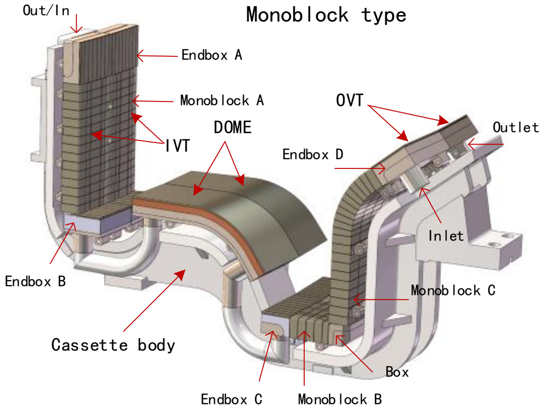
EAST Lower divertor Validation

Technical specification & parameters			
	Mono-block type	Flat plate type	Notes
Quantity of Modules	42	6	Total：48
Heat flux capability	10MW/m^2	20MW/m^2	Steady state
Cooling water	Max flow velocity：8m/s，Inlet：20℃		Total：650 ton/h
Work pressure	3MPa，Test：3.8MPa		



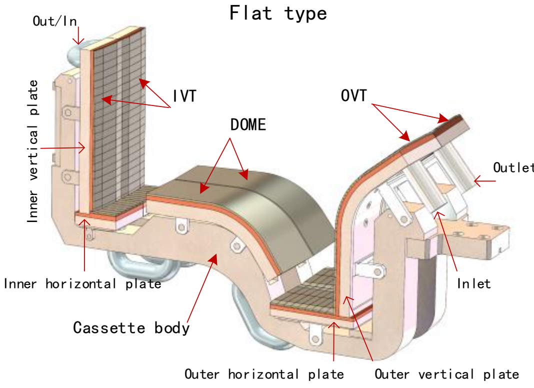


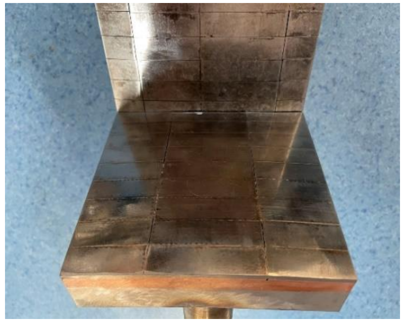
Mono-block type
ITER-Like design
Steady state:20MW/m^2

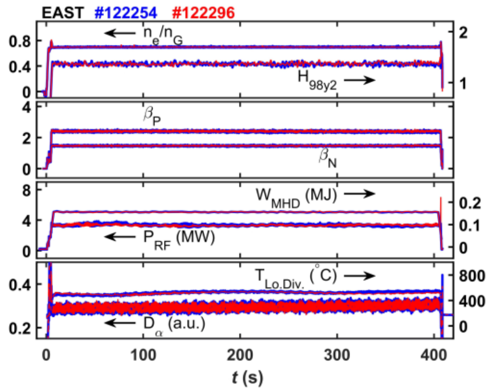


Flat plate type
Hyper-vapotron design
Steady state:20MW/m^2

Based on the parameterized design method, the optimal fin geometry size was obtained with the goal of reducing the maximum temperature.

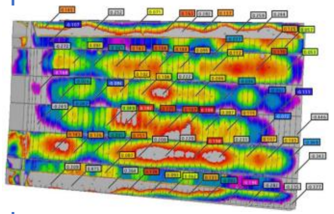






Prototype construction& final testing

Target quqatification



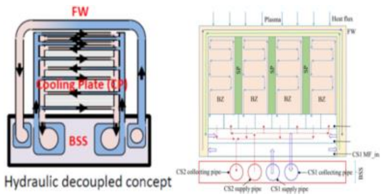
Full size targets passed 1000 cycle full power (20MW/m2) testing.
Assembling was finished and meeting all requirements

13.blanket-I :Water cooled ceramic breeder

Design strategy

Hydraulic decoupled concept for blanket heat removal

- Two independent cooling systems (CSs): CS1 for FW and CS2 for BZs.
- Easy to adjust mass flow for CS1 and CS2 independently during multiple power operation (0.5/1/1.5GW)

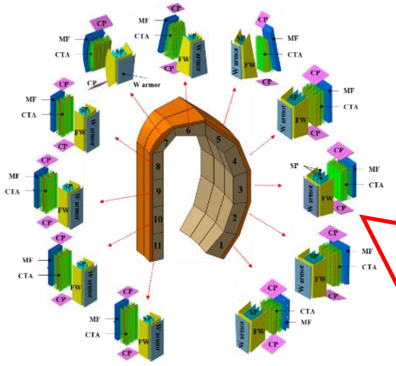


Hydraulic decoupled concept

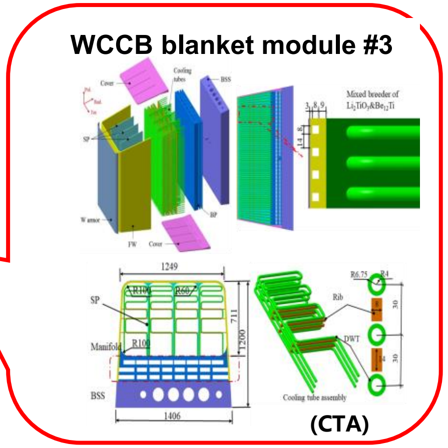
Material selection

	material	parameters
Coolant	Pressurized water	15.5 MPa, 285℃/325℃
Structure	RAFM/ODS steel	Allowable temp. ≤550/650 ℃
FW armor	Tungsten	Allowable temp. ≤1300 ℃
Breeder and multiplier	Li_2TiO_3 & $Be_{12}Ti$ mixed bed	Allowable temp. ≤900 ℃ and >400℃ (tritium release)
Purge gas	He+0.1%H_2	0.1-0.3MPa， 0.1-10 cm/s

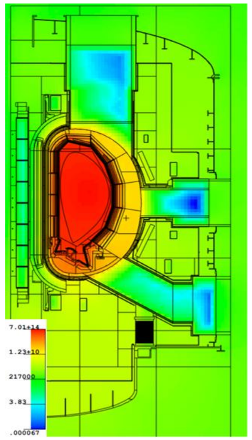
Structure features for normal blanket modules



WCCB blanket module #3



Neutron flux distribution



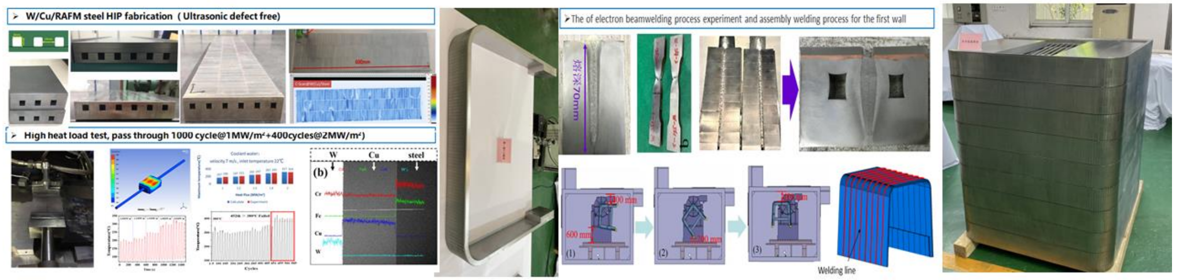
- Stiffening plates (SPs) divide the steel blanket box into several sub-zones to enhance the structure.
- The FW is a U-shaped plate bended in the radial-toroidal direction and cooled by water.
- Cooling tube assemblies (CTAs) are embedded in BZs filled with mixed pebble beds for heat removal.
- The ribs are bonded with SW/SP to enhance the blanket box structure.

Global TBR is 1.17, 33% efficiency

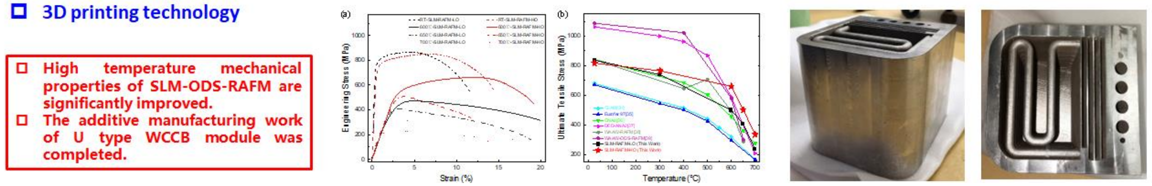
R&D activities

Fabrication technology

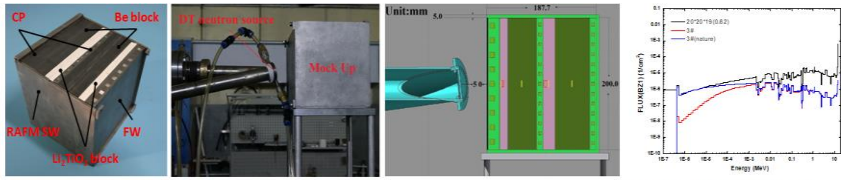
- HIP+EBW technology



- 3D printing technology



Neutronics experiment



WCCB Mockup (20×20×19 cm) (scaled module #3 of WCCB V2013)

Experiment setup

Monte Carlo model and neutron flux comparison between WCCB blanket module #3 and the scaled mockup

- TPR measurement by online lithium glass detector and offline liquid scintillator
- Calculated/Experimental results of TPR are consistent

Supercritical CO_2 cooled Lithium-lead (COOL) blanket

Design strategy

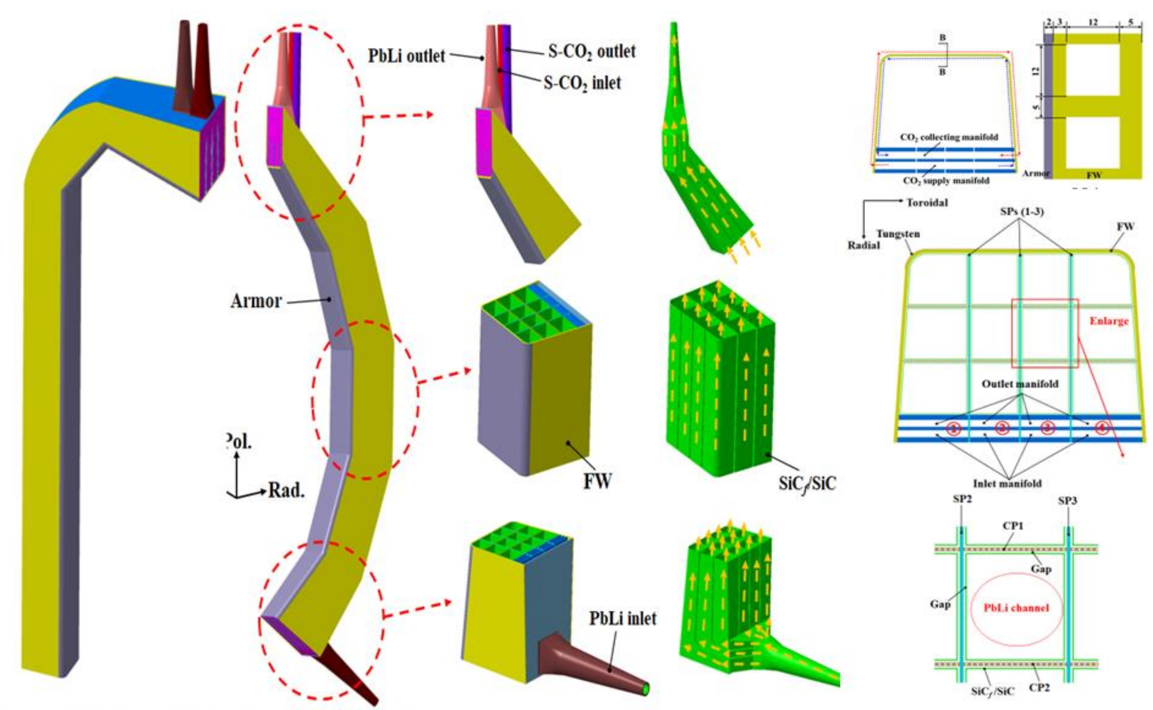
- **Coolant conditions:** (1) S-CO_2 for structures: 8 MPa, ~350/400 °C over DBTT for RAFM; (2) PbLi for BZs: ~0.01-0.1m/s, 460 °C /600-700 °C.
- **Temperature limits:** within material allowable temperature range (@1.5 GW, 0.5MW/m^2 on FWs)
- **Low MHD effect and weak corrosion:** (1) PbLi-RAFM interface: < 480 °C for avoiding strong corrosion; (2) SiC FCIs: thermal and electric insulating to decrease RAFM temp. and reduce MHD effect.
- **High thermal efficiency:** (1) outlet temp. of PbLi: 600-700°C; (2) efficient PCS: S-CO_2 recompressing Brayton cycle.

Advantage

- **High thermal efficiency**: high PbLi outlet temp. and more suitable for efficient power conversion
- **Acceptable construction cost:** (1) cheaper neutron multiplier of Pb; (2) abundant CO2 in natural world
- **Controllable MHD effect and metal corrosion:** using electrical and thermal insulating Flow Channel Inserts (FCIs)
- **Enhanced heat removal capacity of S-CO2**: larger density than helium (over 10 times @8MPa, 400°C)

Structure features

Global TBR is 1.18, 45% efficiency

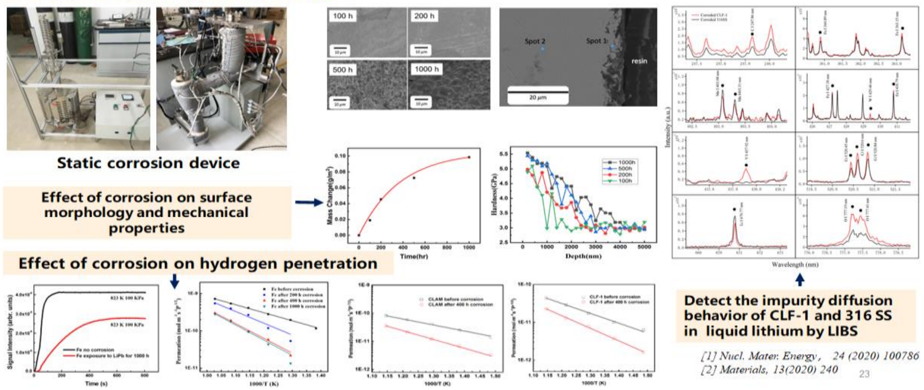


Inboard BLK Segment   Outboard BLK Segment

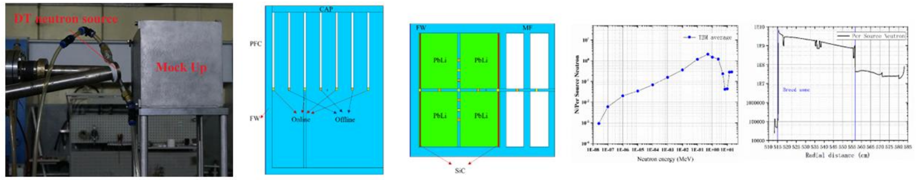
- Single-Module Segment
- U shaped FW coated with Tungsten armor, containing 127 channels, cross section of 12mm*12mm
- S-CO2 manifold configured in the back
- SPs and CPs divide breeding unit into several PbLi breeder zones
- PbLi flows through parallel channels from segment bottom to top
- FCIs to mitigate the MHD effect and corrosion
- 5mm gap between FCI and steel wall

R&D activities

Corrosion compatibility of liquid metals



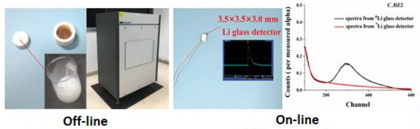
Neutronics experiment for COOL mock-up (out-of-pile)



Experiment design   Mock-up design   mockup neutronics performance

Parameters of DT neutron generator

Mode	DC	Pulse
Beam Spot	<10mm	<6mm
D^+ Intensity	0~1.5 mA	0~40 μA
Neutron Intensity	0~ 3E11 /s	0~1.0E10 /s



Off-line TPR measurement   On-line TPR measurement

- Mock design
- Experiment under DT neutron field
- TPR measurement by online and offline technology

14. China PbLi MHD Blanket expERIment facility

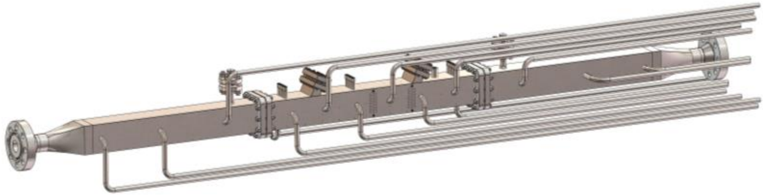
Main Functions	
	• To characterize MHD/mixed convection of PbLi under high magnetic field • To coupling heat transfer performance with S-CO_2 in blankets • To validate of design codes, methods and models for MHD/mixed convection

CLIMBER

superconduct magnet

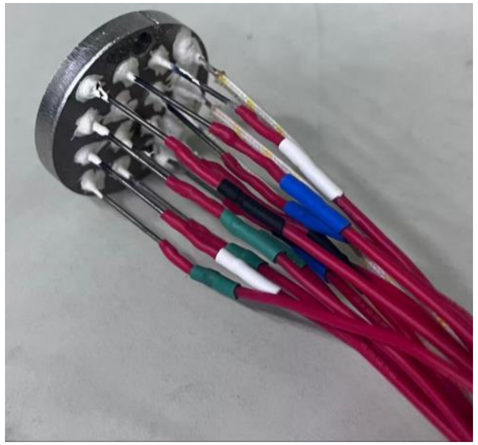
◆ Main parameters

Max. Temperature (℃)	Max. Flow rate (Kg/s)	Max. Magnetic filed (T)
700	32	3



MHD/mixed convection test section

Ultrasonic Doppler Velocity (UDV)



Electro Probe Velocity (EPV)

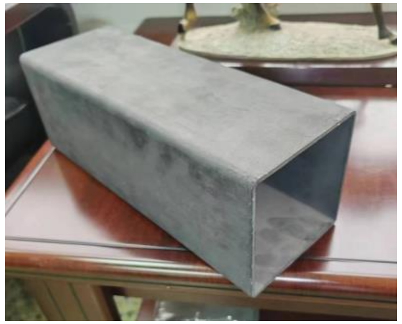
14. Supercritical CO_2 loop testing facility

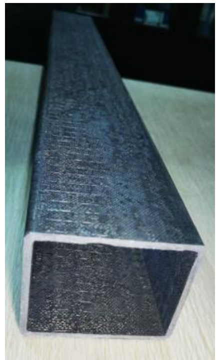
Main Functions	
	• To characterize flow and heat transfer performance of FW • To Test coupling heat transfer performance with PbLi in blankets • To validate of design codes, methods and models for thermal hydraulics

Supercritical CO_2 loop for thermal hydraulic testing

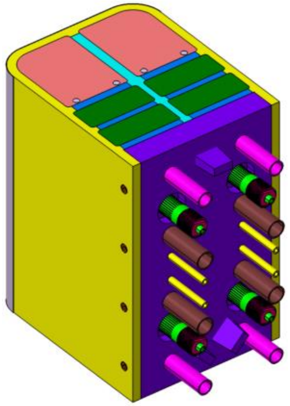
◆ Main parameters

T (℃)	P (MPa)	Mass flow rate (kg/s)
300-500	8-9	0.2-6

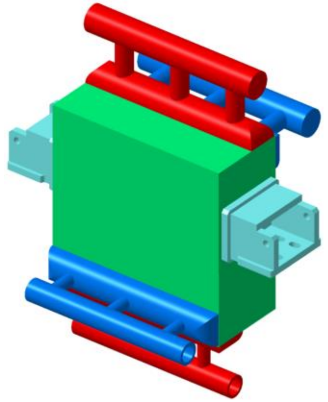




CIC insertors



TBM/BLK module testing (coupled with PbLi loop)

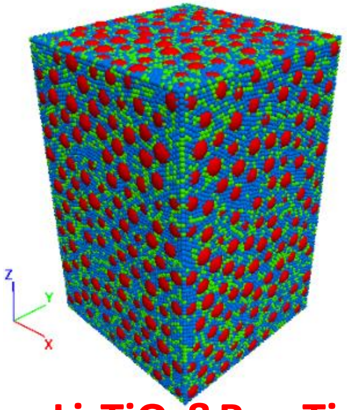


Heat exchanger testing

14. Pebble bed test facilities for WCCB

① Thermal hydraulic facility

- Flow and heat transfer characterization
- 0.1~2 MPa He, RT~500 ℃, 0~80 Nm^3/h



Li_2TiO_3&$Be_{12}Ti$ mixed pebble bed for tritium breeding

② Thermo-mechanical facility

- Thermo-mechanical characterization
- RT~800℃, 0.1~0.3 MPa helium, 0~10 MPa load

③ Mixing and sieving facility

- Breeder loading/ unloading testing
- Flow rate ≥ 360 kg/h, Mixing uniformity ≥ 0.9

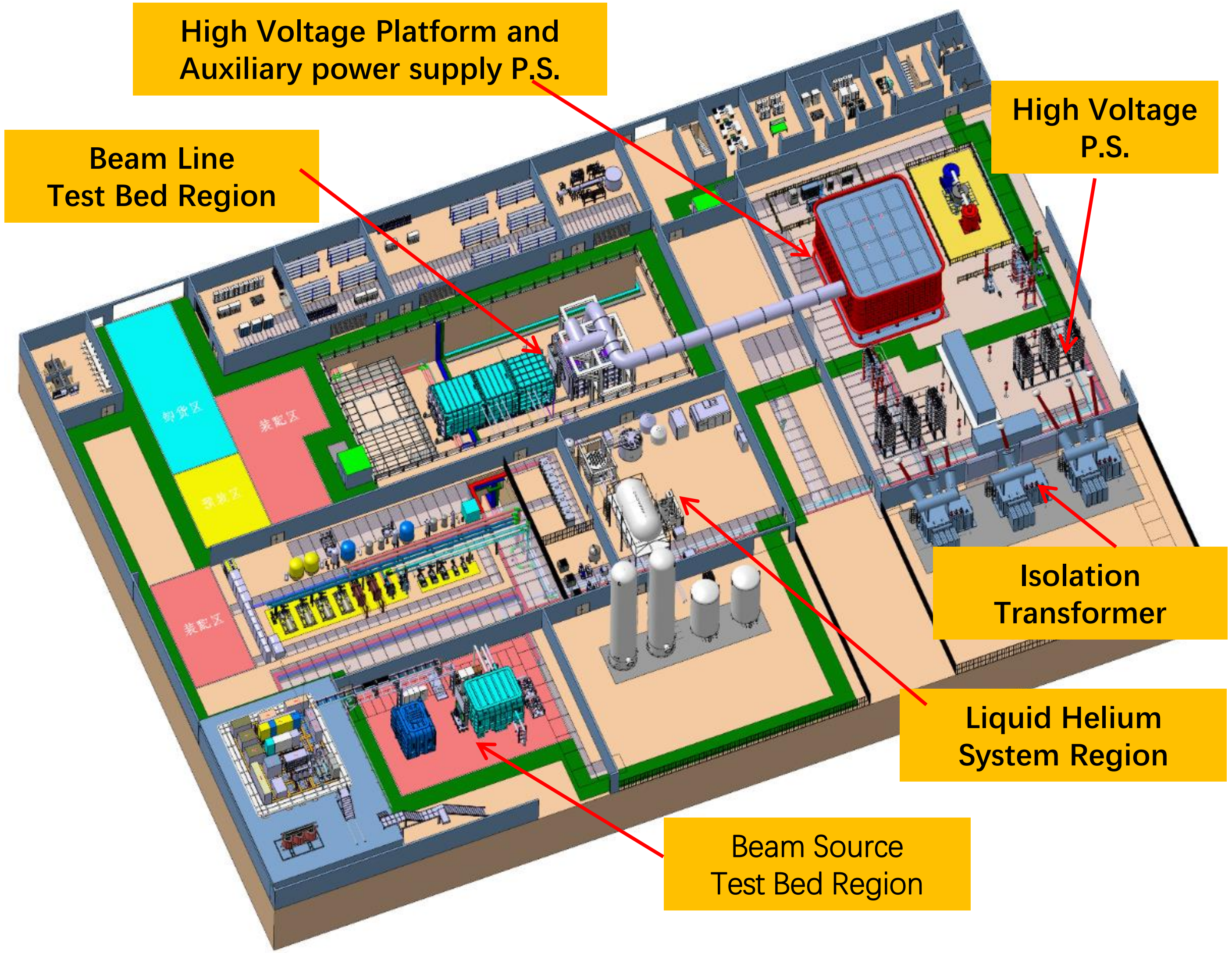
④ Computer Tomography (CT)

- Packing structure testing/crack analysis
- Sample < 200×200×200 mm^3, Max. resolution < 20 μm

⑤ Vibration testing facility

- Packing structure stability testing
- He flow, 0~5 MPa load, 0~10 g, 1~100 Hz

15. NNBI System of CRAFT Project



Comprehensive Research Facility for Neutral Beam Injection System Based on Negative Ion Source

- **Establish a comprehensive research facility for neutral beam injection system based on negative ion source.**
- **Developing negative ion source technology for NNBI and cultivating a professional talent team.**

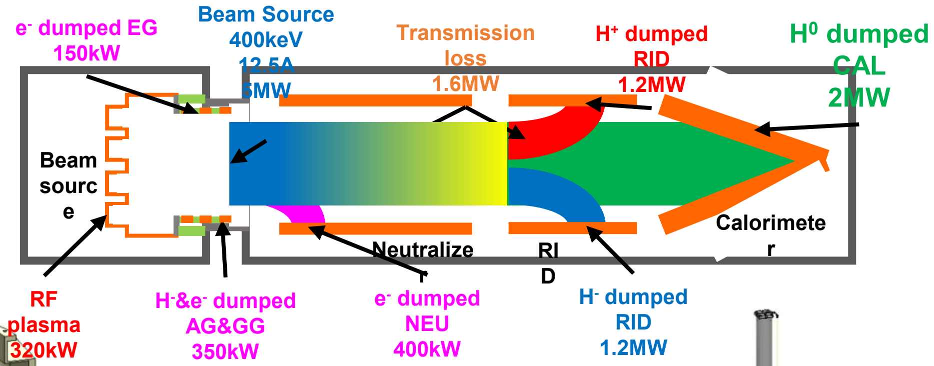
Parameters	Target Aim
Beam Species	D^0, H^0
Beam Energy	200-400keV
Neutral Beam Power	2MW
Beam Duration Time	100s

15. NNBI system

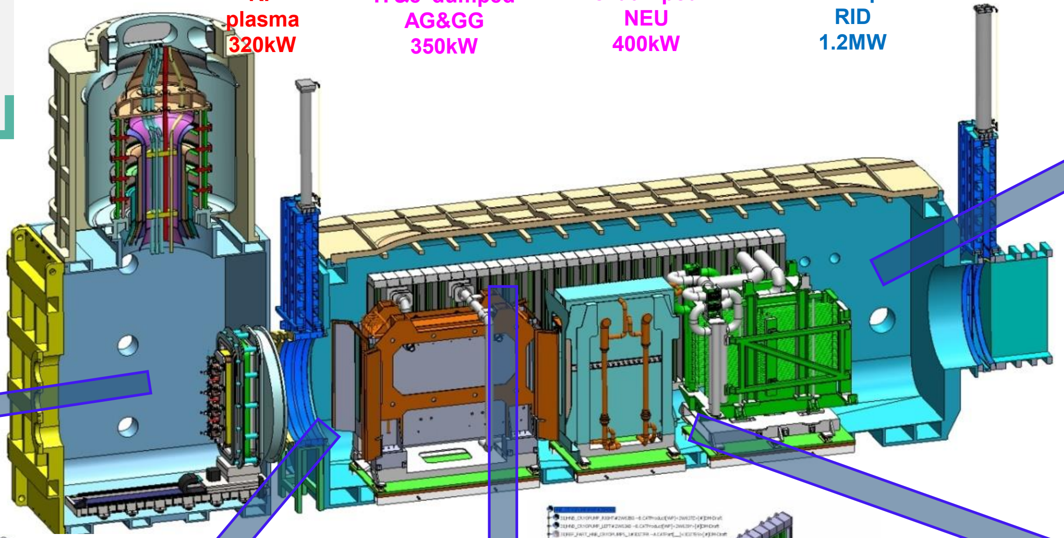
➢ Key technology

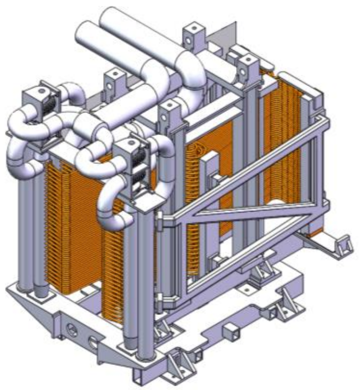
- Negative ions generation
- Negative beam acceleration
- HVPS and transmission
- High speed cryopump

- 400keV, 2-4MW, 1000s

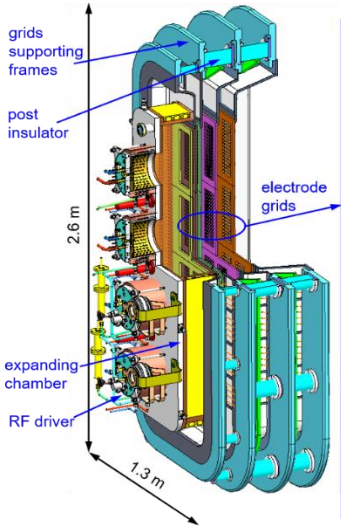


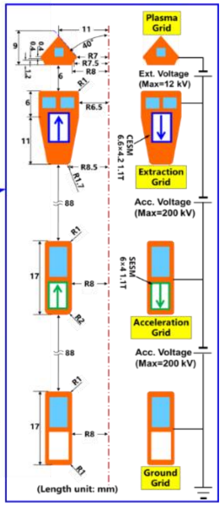
CRAFT NNBI components



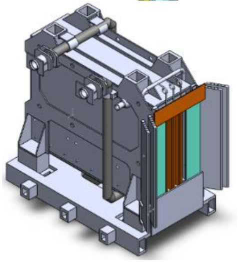


Calorimeter

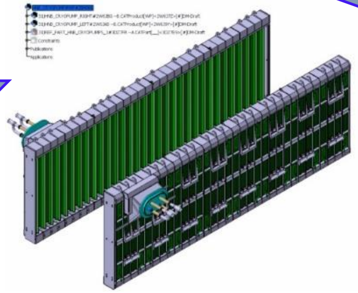




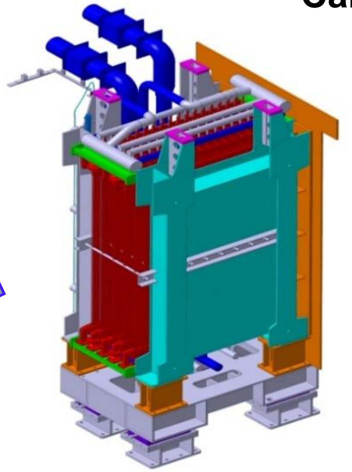
Giant negative beam source



Neutralizer

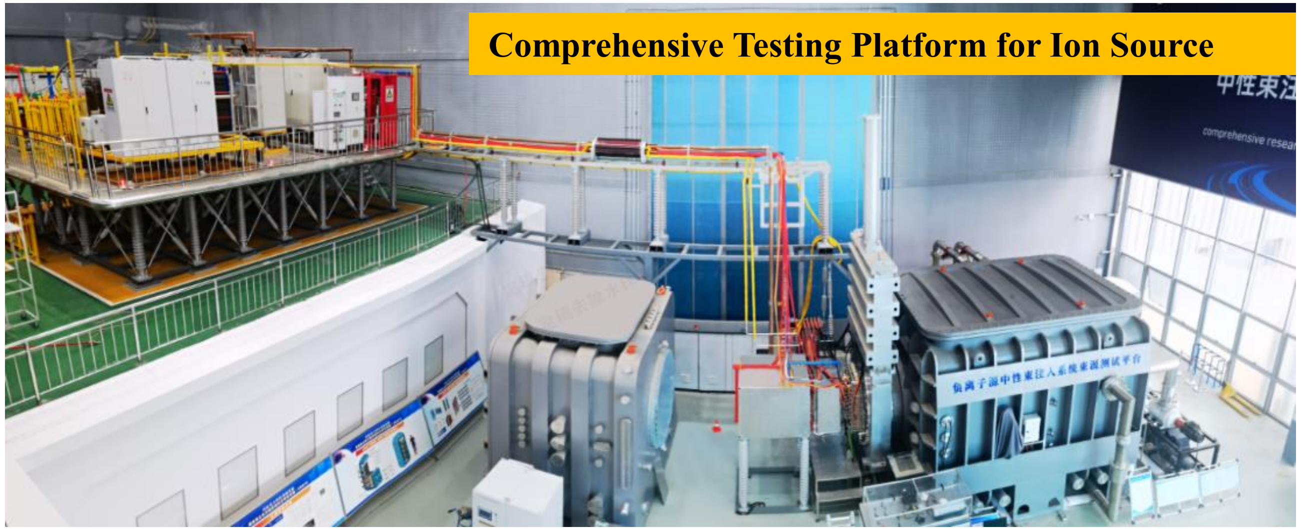


Cryopump panels



Electrostatic residual ion dump

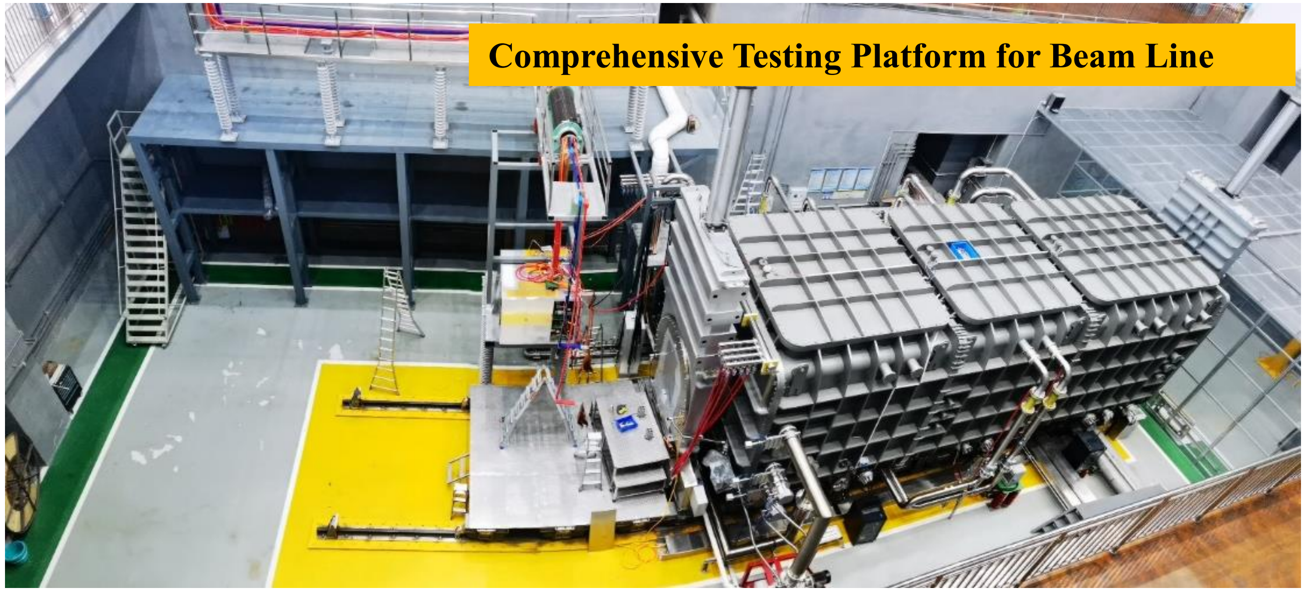
System Construction Status


Comprehensive Testing Platform for Ion Source


Liquid Helium System@1kW


Control room


High Voltage Platform @400kVDC


Comprehensive Testing Platform for Beam Line

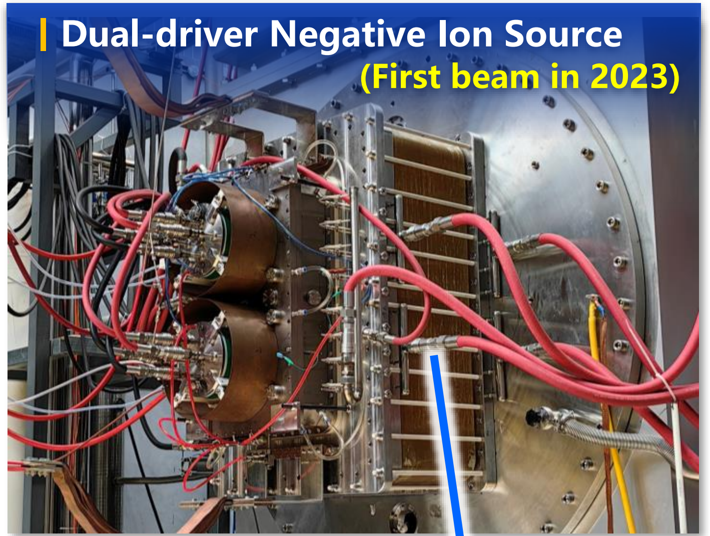

Water-Cooling System


High Voltage P.S. @200kVDC

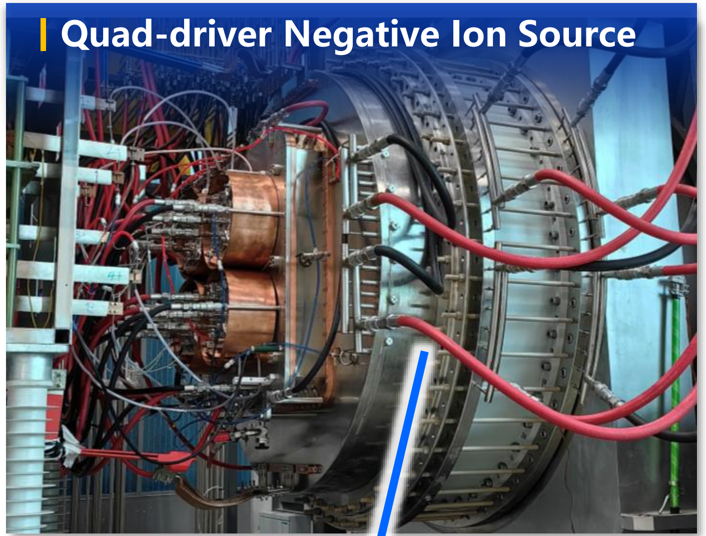
CRAFT NNBI system- Present state

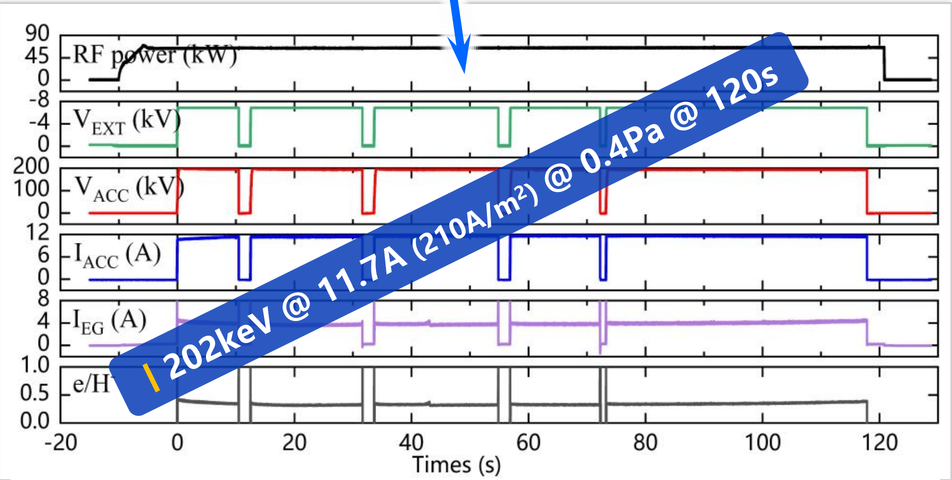
Recent Progress (3rd Experimental Campaign of CRAFT NNBI)

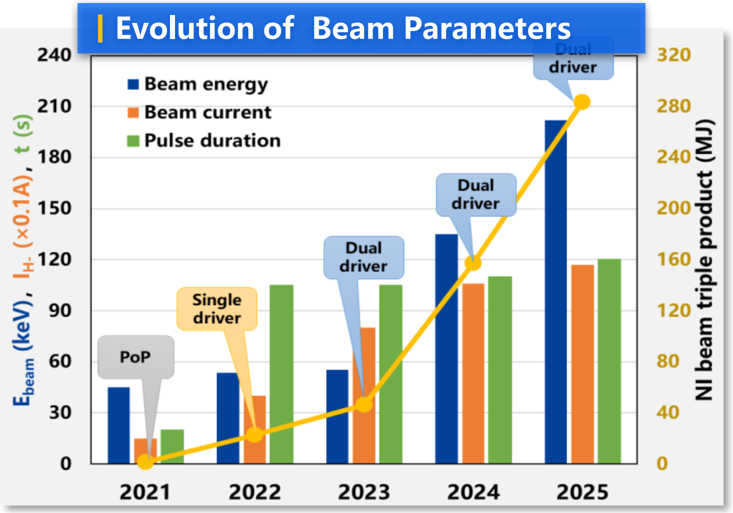
- Repeatable **202 keV, 2.3 MW, 120s** H- beam accelerations, via dual-driver RF negative ion source

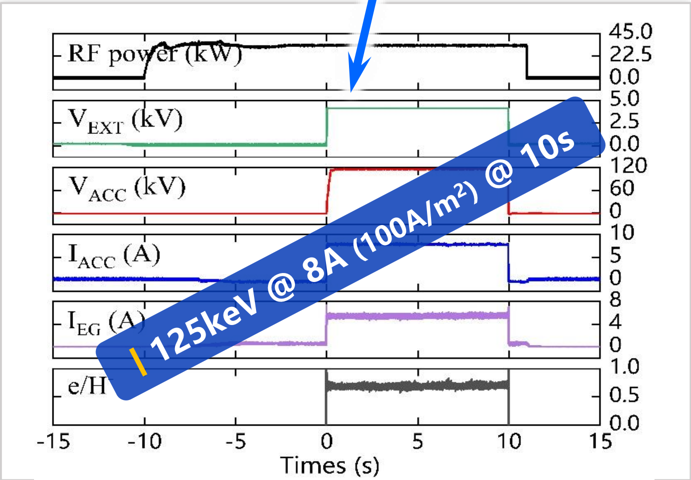


Design parameters	Dual-driver negative ion source	Quad-driver negative ion source
RF driver	2×80 kW, 1 MHz	4×80 kW, 1 MHz
Source size	85×45 cm²	110×90 cm²
Ext. voltage	<12 kV	<12 kV
Acc. voltage	1×200 kV	2×200 kV
Beam current	15 A (250 A/m²)	25 A (200 A/m²)
Pulse duration	>100 s	>100 s





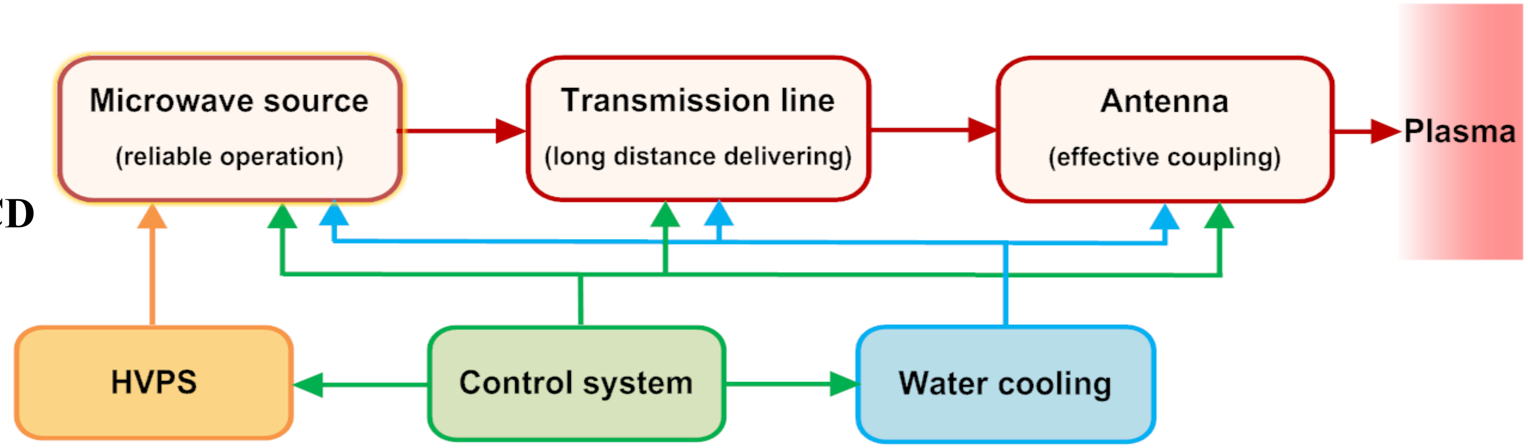




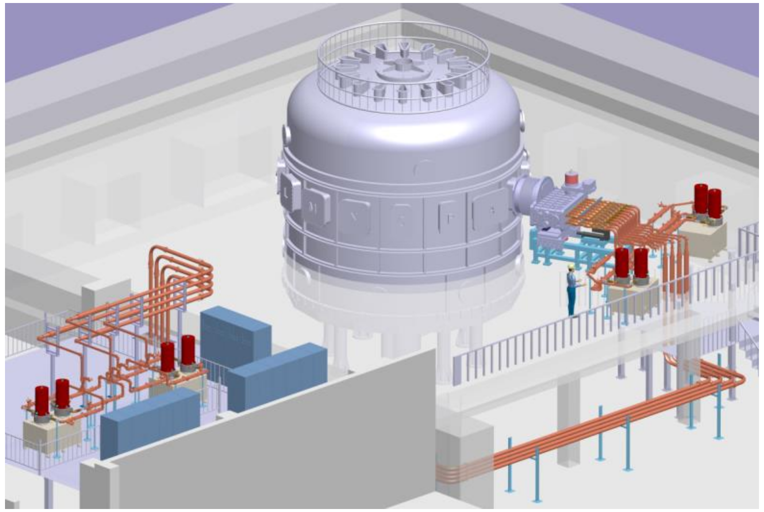
16. LHCD system

➢ Objectives

- Explore the feasibility of CFETR LHCD system.
- Developing all technologies needed for CW LHCD system.
- Building all components of LHCD.
- Integrated testing of 4MW system.
- Explore RH compatibility testing of antenna with blanket.



Schematic diagram



System layout

➢ Key technology

- ➢ Developing CW 4.6GHz 500kW **klystron**
- ➢ The design and manufacturing of the near field coupling **antenna**.
- ➢ 500kW microwave components, oversized circular waveguide power transmission technology.
- ➢ The intelligent operation and control, to improve operating efficiency and to enhance reliability.

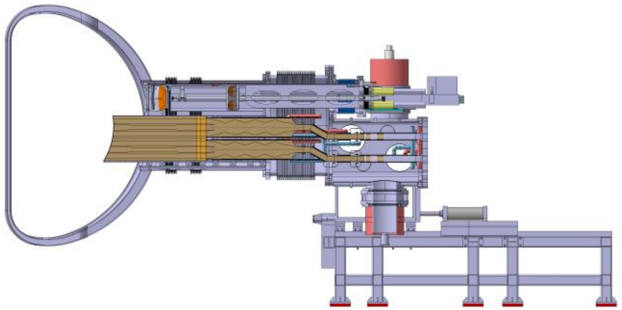
LHCD System-Progress

- 4.6GHz 500kW CW test bench has been designed and built. Two types of klystrons have passed 500kW/1000s high power test, double window klystrons have been put into mass production.

4.6GHz 500kW klystron with double output windows

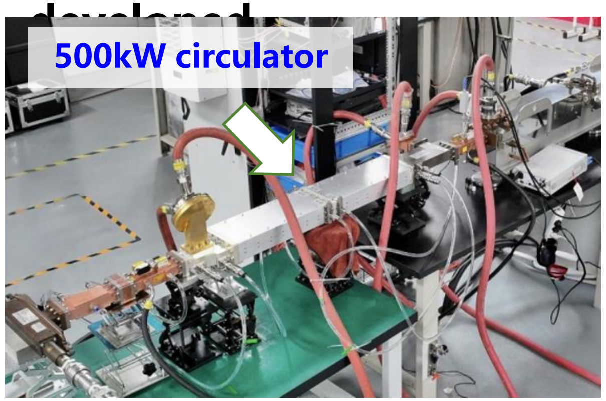
4.6GHz 500kW klystron with single output window

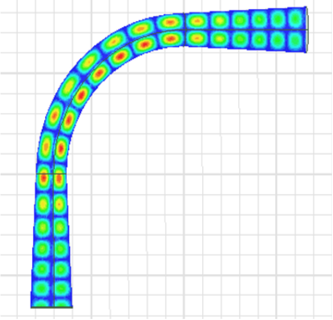
- Passive and active multi-junction will be chosen; all nuclear parameters can meet the design limits; maintenance strategy has been determined; hot isostatic pressing welding is used for water-cooling plates.



4MW PAM antenna will be tested on EAST

- Using mode converters and circular waveguides to realize long distance low loss power transmission; 500kW microwave devices, such as circulator, have been developed.





Bend EM simulation

17. ICRF System

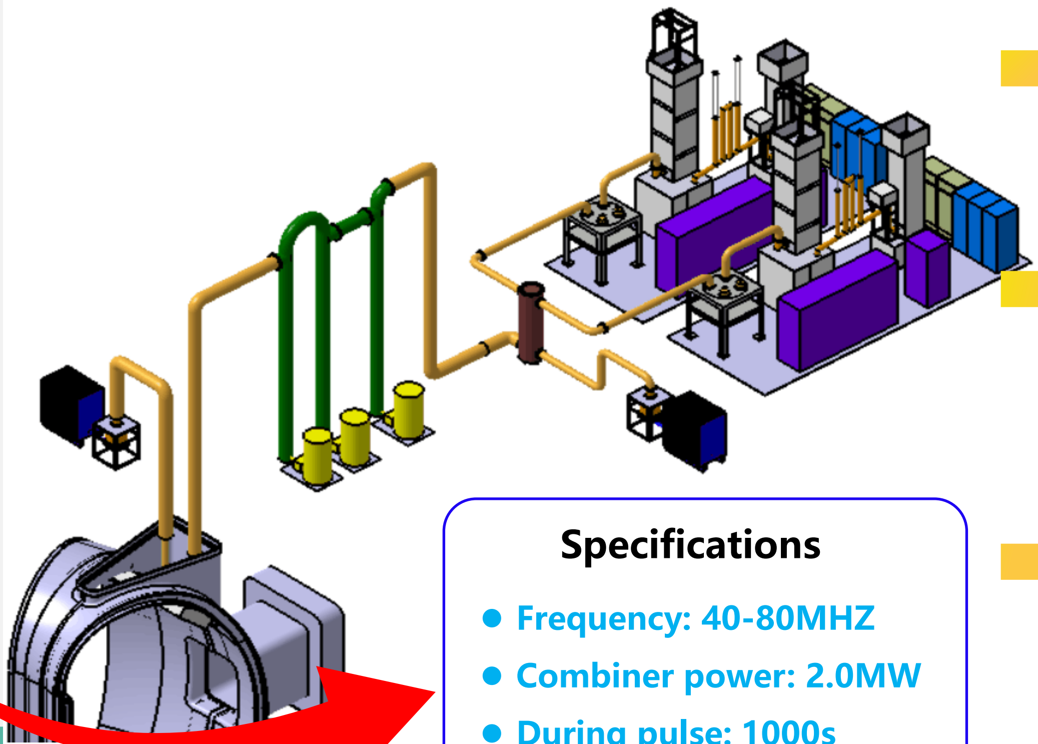
Objectives

- To provide a testing facility with 2MW RF power for finding a solution to use ICRF in CFETR
- Solving technical challenges and developing required technologies.
- Manufacture, testing and validating of the key components, proto-type system for the CFETR.

CRAFT ICRF System

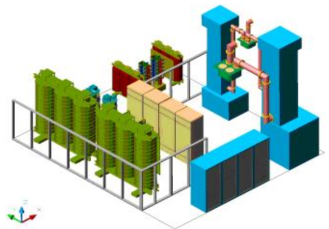
- **RF generator and power supply**
  - 2×1.0MW,40-80MHZ,CW
  - HVPS with PSM and IGBT
- **3dB hybrid couplers**
  - 2×1.0MW combination to 2MW
- **12 inch，50Ω, coaxial transmission line**
- **Matching system**
- **Distribution antenna**
  - ITER-like antenna

2MW generator ⟷ **Prototype Antenna**

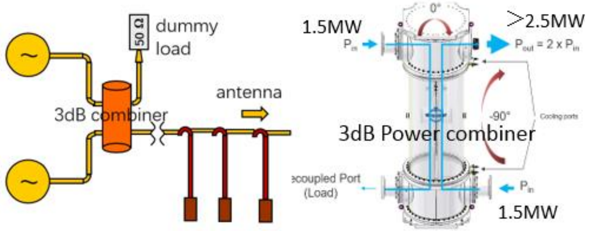


Specifications

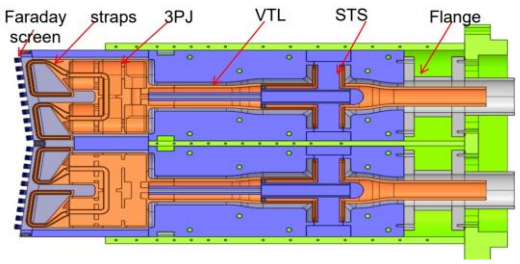
- Frequency: 40-80MHZ
- Combiner power: 2.0MW
- During pulse: 1000s



RF generators and power supply



3dB hybrid combiner



ITER-like Antenna

Key technologies

1.5MW
DB967

100kW
DB968

feeder though 1.5MW

power combiner

Antenna module 3D printing(56 pieces φ5mm TPMS cooling channels)

System integration & commissioning

MHz	G1 kW	G2 kW	Ref kW	Total kW	time(s)
40	1193.7	1190.0	7.6	2364.7	1010
45	1193.9	1189.6	8.0	2367.0	1010
50	1292.4	1284.5	11.8	2548.8	1010
55	1165.1	1160.8	5.8	2297.5	1010
60	1164.9	1139.0	13.2	2293.2	1010
65	1186.2	1153.6	11.4	2312.2	1010
70	1164.0	1169.4	5.9	2295.3	1010
75	1161.9	1155.6	6.2	2277.2	1010
80	1159.3	1162.5	6.1	2279.7	1010

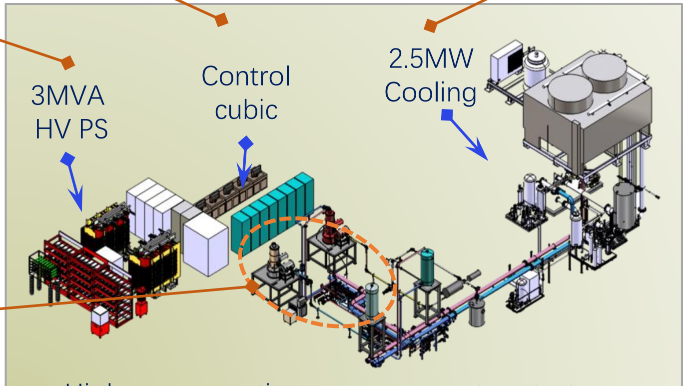
18. ECRH facility

- **Aims:** to address the technical issues as well as to pursue technical solutions for critical components of the future advanced CFETR ECRH system.
- R&D efforts focus on the design and performances assessment of key components, (conditioning of gyrotrons, trans and launcher.

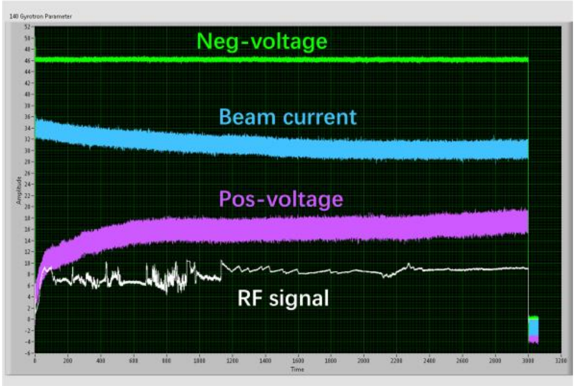
Specifications		
1	Frequency	170 GHz
2	Output power	2 MW
3	Pulse length	>60 s

◆ Development and installation of high power CW gyrotron test bench

170GHz
0.4s, 0.56MW
30s, 0.36MW



High power continuous wave gyrotron test bench

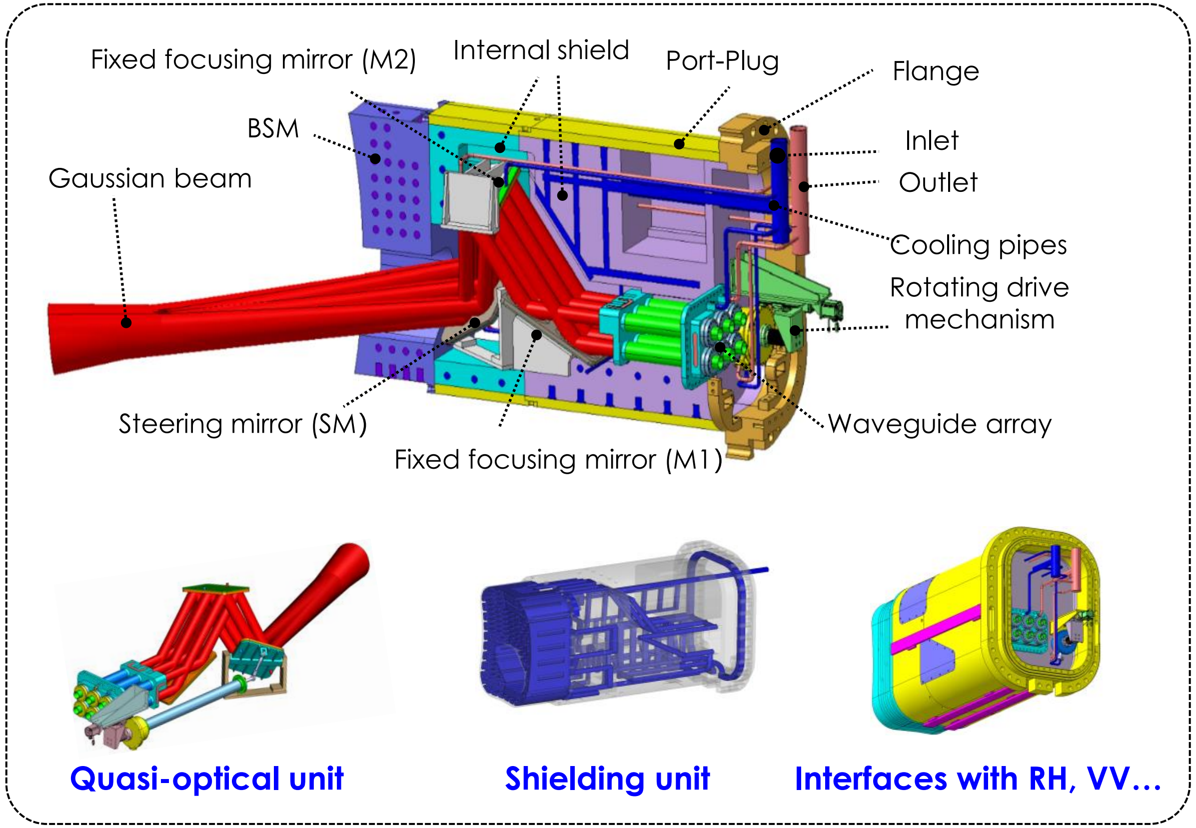


Test performance validated – 900kW, 3000s pulse duration

18. ECRH facility

- **2MW 170GHz EC system has been constructed and commissioning is finished. All components passed qualification except home made gyrotron.**

- **Mock-up design of multi-convergence launcher is ongoing**



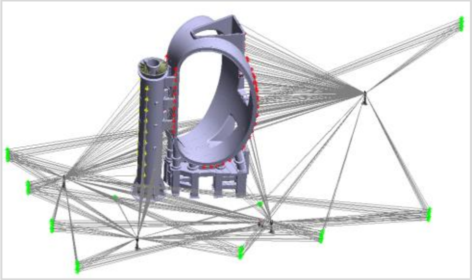
19. VV and installing testing facility

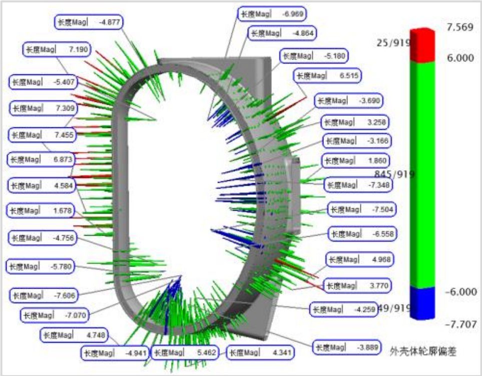
➤ Objectives

- ➤ Provide a full-scale simulated environment for VV manufacture, auto-welding, assembling and testing of parts and system: Testing bench for VV, blanket, divertor, RH, diagnosis and poet plug for auxiliary heating.
- ➤ Perform research and testing for: RH Assembly and Disassembly, in-site dimension detection and quality control,

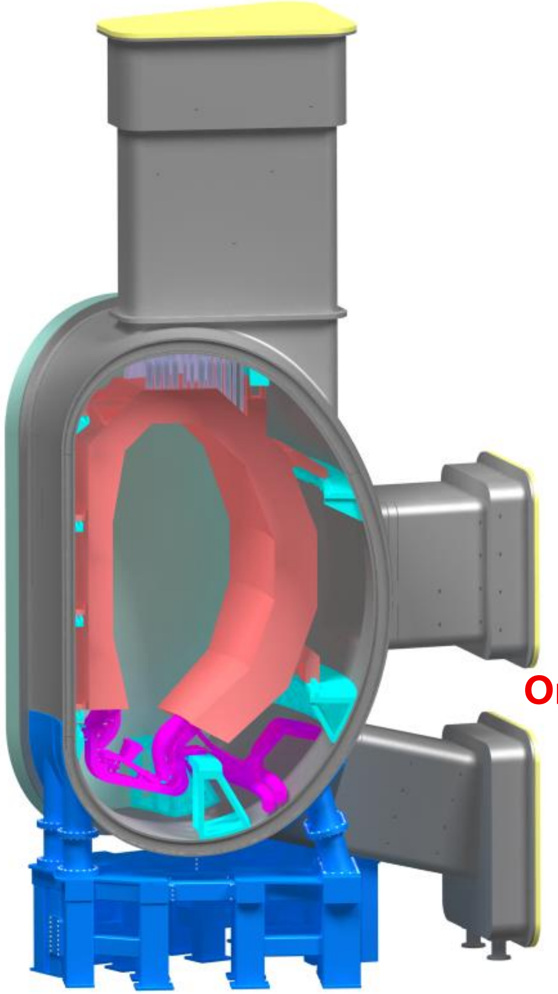
➤ Key technologies

- ✓ Automatic welding system for VV body and in-vessel pipework
- ✓ In-site NDT for weld
- ✓ In-site high-precision measurement
- ✓ blanket installation





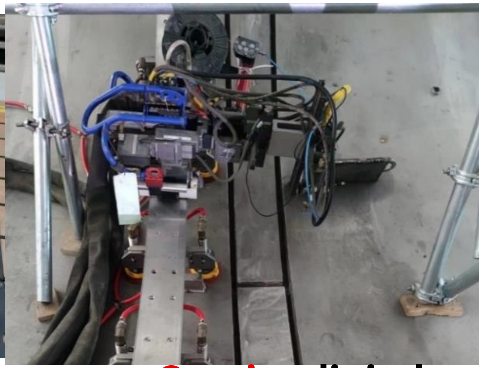
Contour deviation of 1/8 VV sector: ≤±8mm



Online milling of field weld seam defects

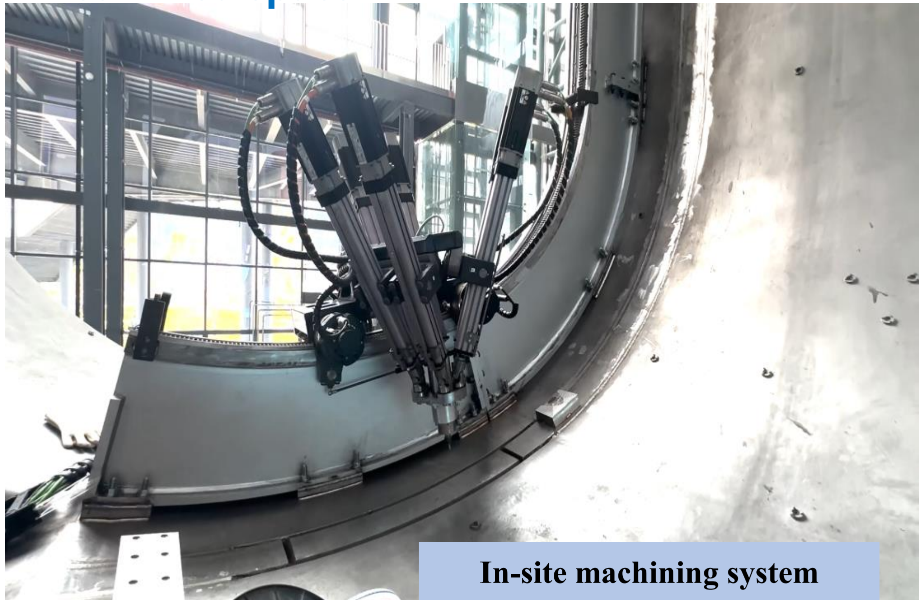
VV and installing testing facility

➢ Key Technologies

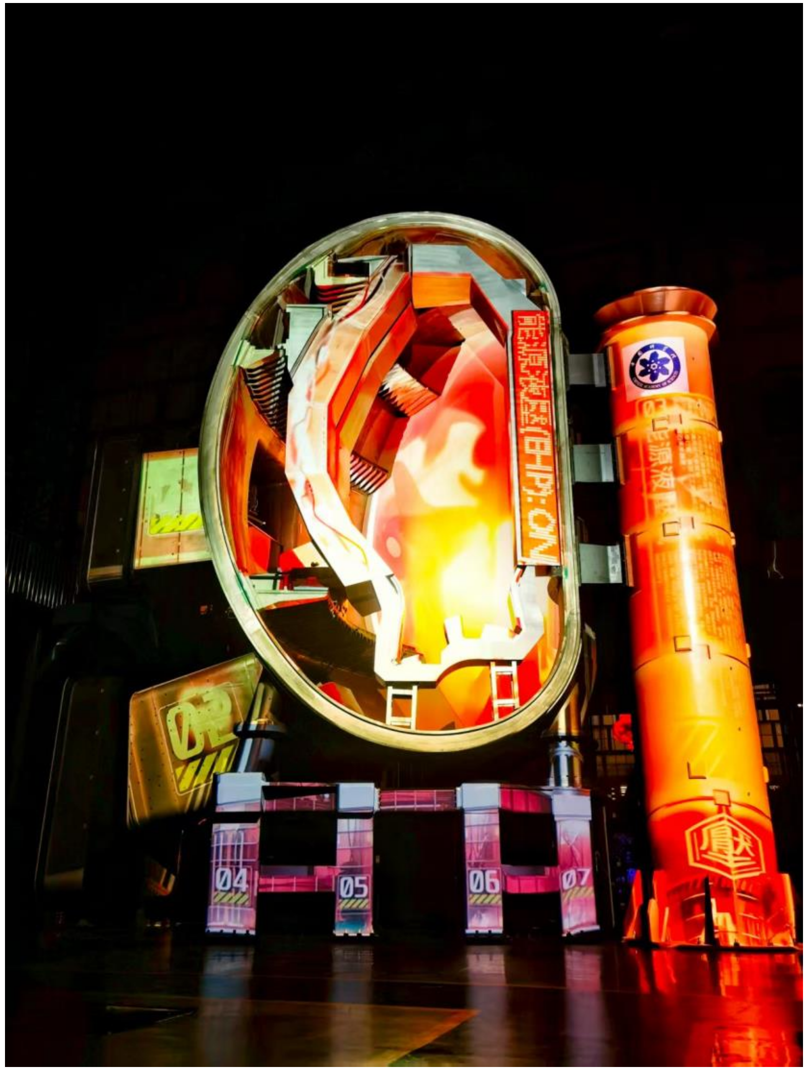


Automatic TIG welding of φ300×25 tubes in confined space

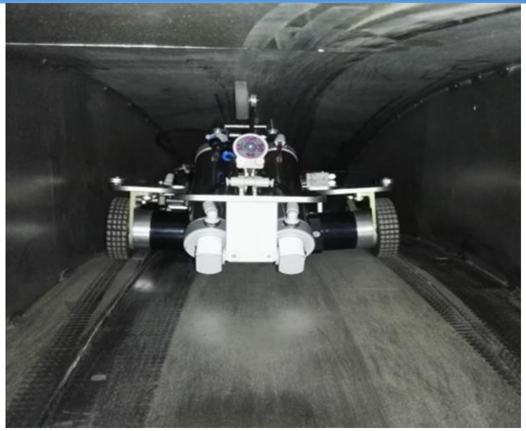
On-site digital radiography (DR) of VV field welds



In-site machining system



VV Facility



□ Online NDT

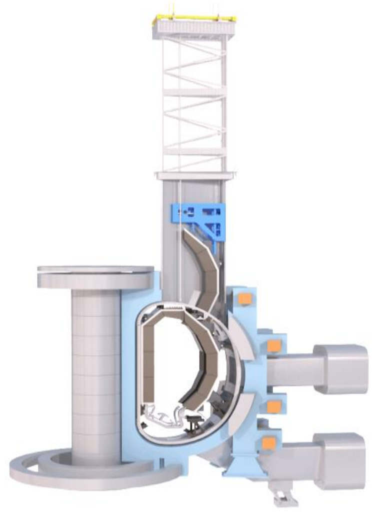
In-site automatic PAUT system

20. RH Testing Facility

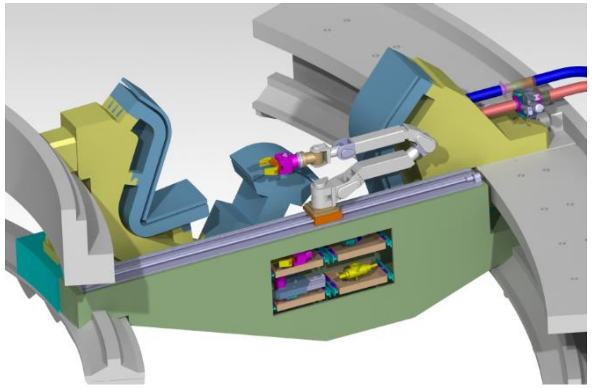
➢ **To develop DEMO RH technology and build testing facility**

- High reliability, heavy load maintenance mechanism
- Maintenance tools (cutting, welding, bolting …) and end-effectors (dual-arm, snake-arm …)
- Double door tansfer cask
- Remote control technology

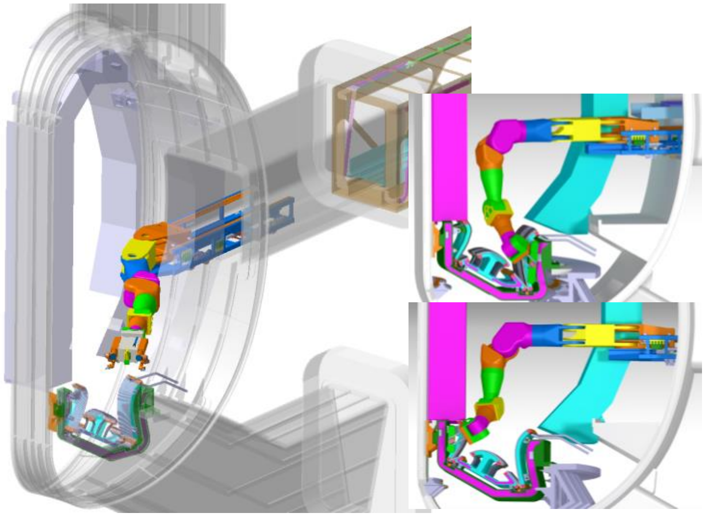
Flexible dual arm
Payload: 25 kg
Repeatability: ± 1 mm



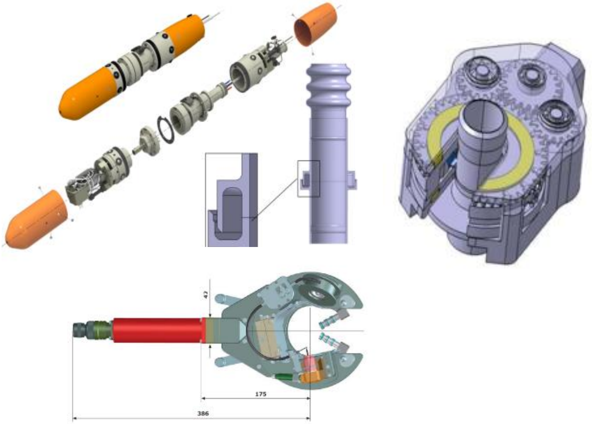
Divertor RH
Payload: 15 t
Position accuracy: ± 10 mm



Blanket RH
Payload: 60 t
Position accuracy: ± 20 mm



Heavy-duty manipulator
Payload: 2.5 t
Repeatability: ± 10 mm



RH Tools: cutting, welding, bolting

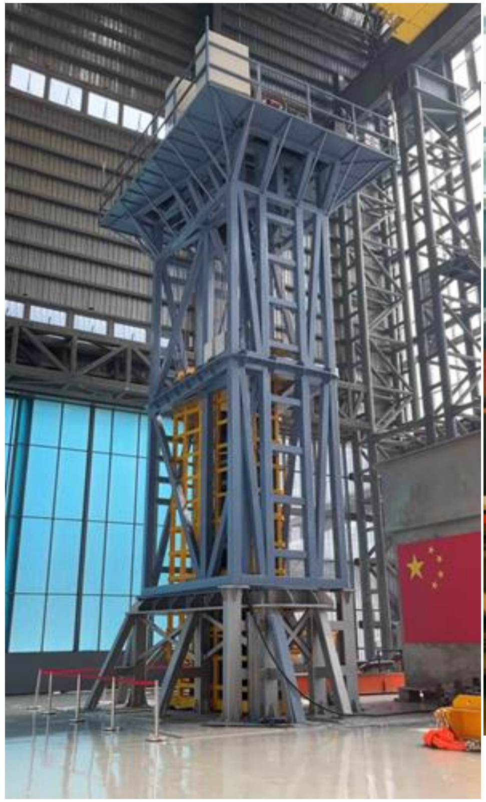
Research progress

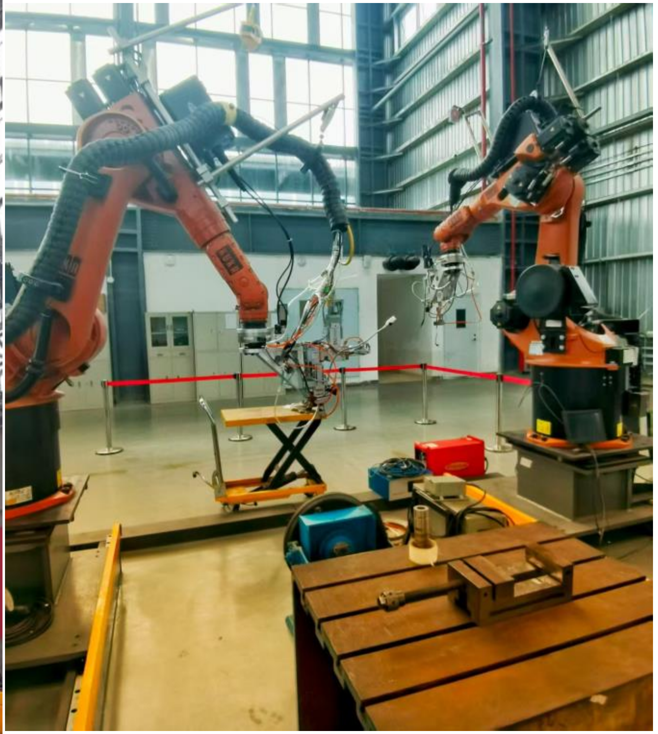
■ **Successfully developed a remote maintenance experimental platform for the FW and BB**

Research progress

■ Successfully developed a large-scale blanket module remote maintenance experimental platform

By employing a mover and a vertical lifting platform, the ±60-degree circumferential movement and high precision vertical lifting of large sized blanket modules have been realized.

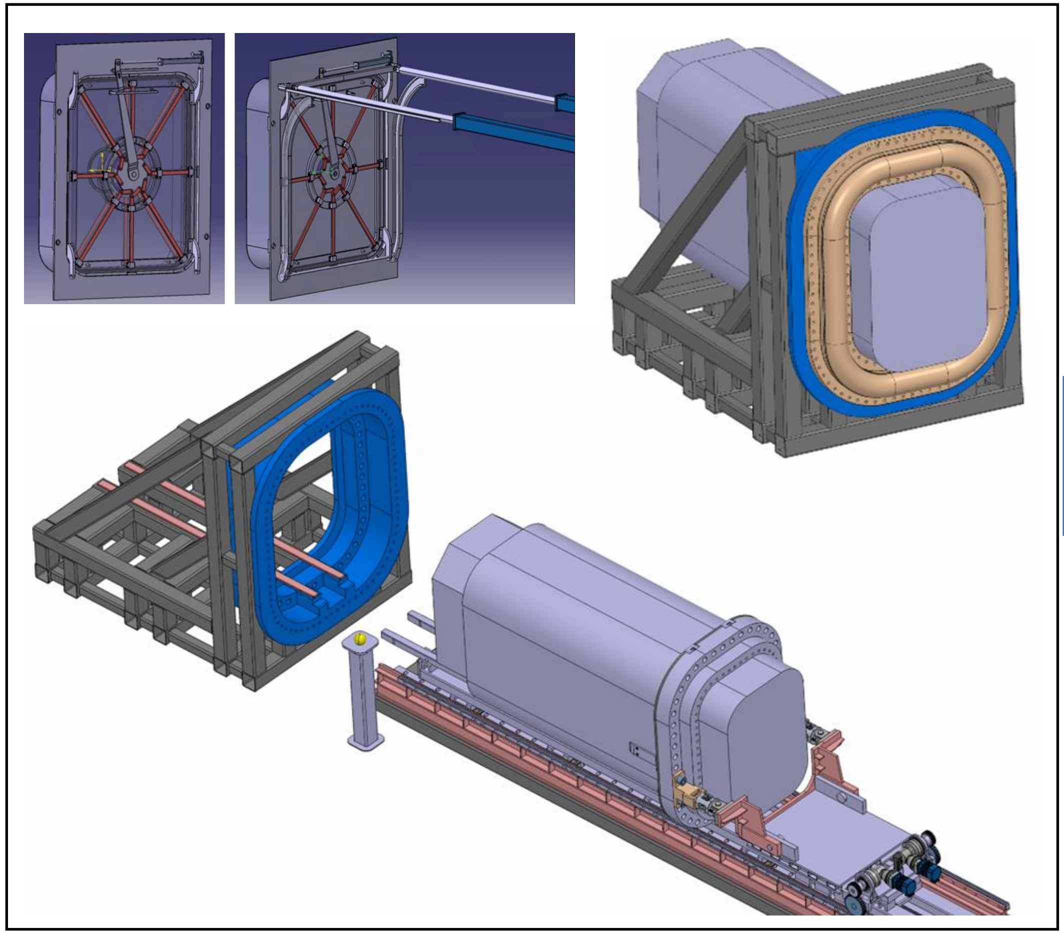




Research progress

■ Successfully developed a port plug remote maintenance experimental platform

Efficient replacement of 20 tons of port-plugs has been achieved, and the containment performance ($\leq 2.5 \times 10^{-3} h^{-1}$) of the double sealed door has been verified。



Campus and Buildings

B1-3	Office， guest house， art center
B4	meeting， stadium, resturant
B5-6	power station,Cooling water
B7	BEST magnets production
B8	Superconducting facilities
B9	Cryogenic system
B10	H&CD (IC, EC, NNBI, LHCD)
B11	Vacuum vessel +remote handling
B12-13	Divertor, blanket test facility
B14	Exhibition & visiting center

Campus of CRAFT

Summary

- CRAFT is a national big science facility aiming to develop key technologies and systems for CFETR.
- The construction of CRAFT started on Sept. 20, 2019 which should be finished within 5 year and 10 month with joint founds from central and local governments.
- CRAFT uses not only the technologies from ITER, but also those which need to be developed in future with significant challenges and efforts.
- CRAFT will provide a solid technical base for successful construction of CFETR in future. **Completeness is 92%.** It is within budget and whole system will be finished within 6 month.
- CRAFT has established solid bases for BEST and CFETR, It is fully open to world fusion community, joining integrating experiments are welcomed.


CRAFT
BEST
Burning plasma
Experimental
Superconducting
Tokamak
Research Plan
‘From vision to action:
BEST missions and
pathways to realisation’
ASIPP and EUROfusion
1st Edition
November 2025


Thanks！