

Status and Prospects of Fusion Energy Development at SWIP

China Fusion Energy Co., Ltd.

Southwestern Institute of Physics

Xuru DUAN

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CONTENTS

01 Introduction

02 Tokamak Programs

03 Fusion Energy Technology R&D

04 Prospects of Fusion Research

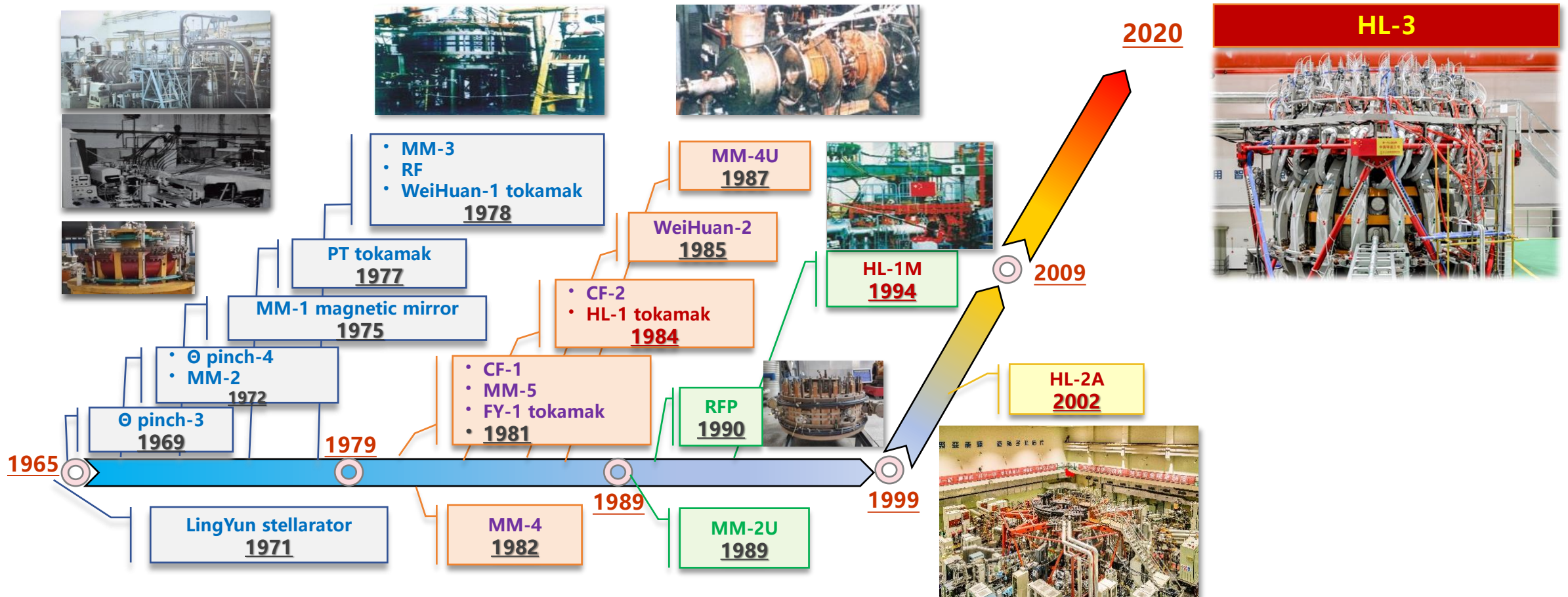
01

Introduction

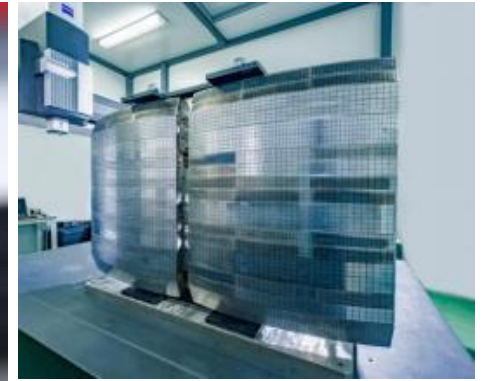
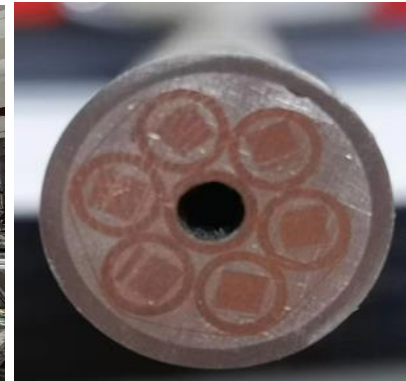
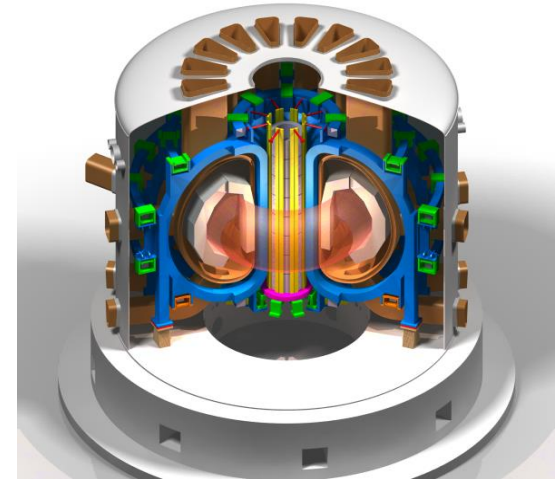
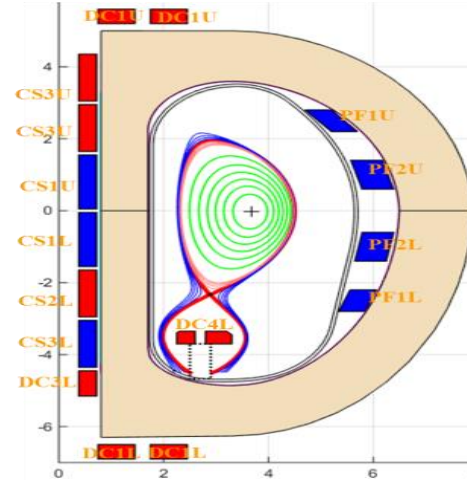
Affiliated with China National Nuclear Co. (CNNC)

Earliest institute for fusion energy research in China, founded in 1965 with staff > 2000

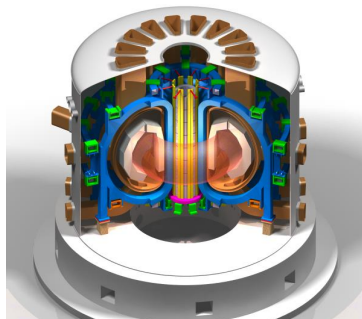
SWIP has developed **more than 20 fusion research devices** of various magnetic configurations



- Tokamak programs—experiment, theory and simulation
- Fusion reactor technology R&D
 - ITER-related technologies
 - Integrated design
 - Blanket & divertor
 - Materials
 - Heating
 - Tritium fuel cycle
 - Fusion nuclear safety
 - ...



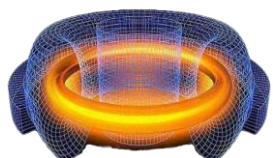
Fusion Engineering Design Center



Integrated design of fusion reactors

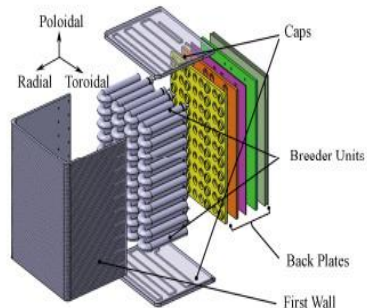


High temperature superconducting (HTS) magnets R&D



Digital tokamak

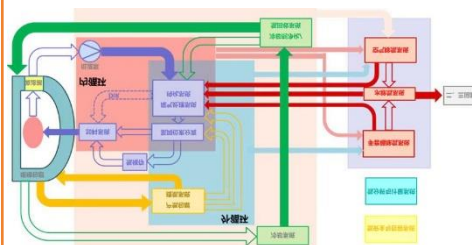
Fusion Technology R&D Center



First Wall R&D



Power supplies for special applications

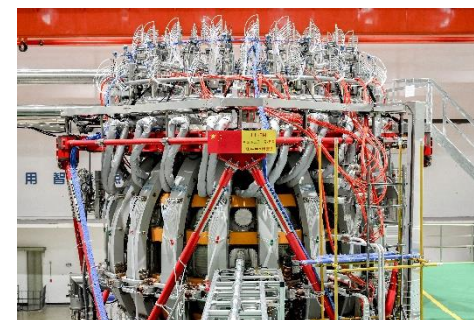


Fuel cycling system



Heating and Current Drive R&D

Fusion Scientific Experiment Center



Large-scale Scientific Experiments

02

Tokamak Programs

Tokamaks Developed at SWIP



HL-1 (1984)

Radius 1.02 / 0.20 m

First Large-scale Scientific Facility of
magnetic confinement fusion in China



HL-2A (2002)

Plasma current 0.45 MA
Radius 1.65 / 0.4m

Diverted tokamak in China



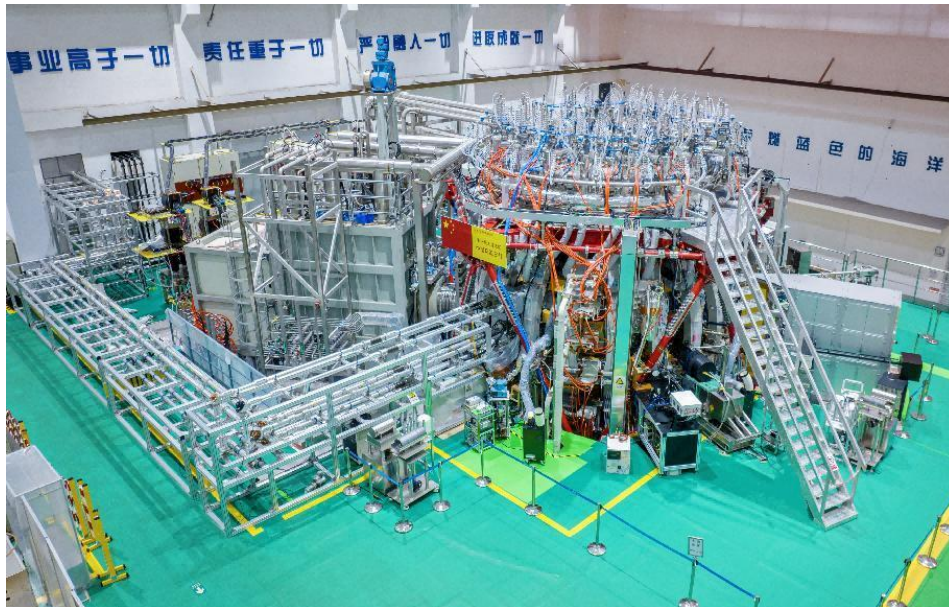
HL-3 (2020)

Plasma current 3 MA
Radius 1.78 / 0.65 m

Largest tokamak in China
High-performance operation
Advanced divertor

Addressing critical physics and technology issues for ITER & fusion reactors

- **ITER-related scenarios.** Explore **high-performance regimes towards fusion reactors.** $\beta_N > 3$
- **Advanced divertor configuration concept** and physics. Test and validate **high heat flux PFCs**
- **ITER key plasma physics and technologies**, including EP / VDE / NTM / ELM control, disruption alerting & mitigation, etc.
- **Experiment to explore physics and technologies related to burning plasma**

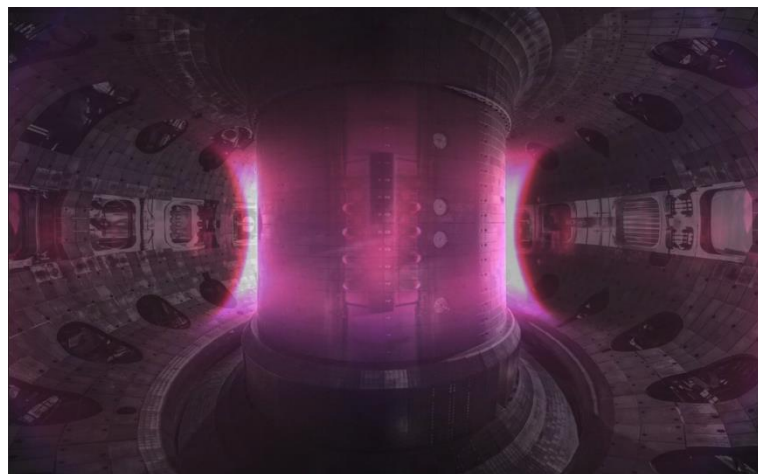


HL-3 Main Parameters

Major radius	$R = 1.78 \text{ m}$
Minor radius	$a = 0.65 \text{ m}$
Plasma current	$I_p = 3 \text{ MA}$
Toroidal field	$B_T = 3 \text{ T}$
Elongation	$\kappa = 1.8\text{-}2$
Heating power	NBI (20)+ECRH (11)+ LHCD (4)+ICRH (6)

Towards High Performance Plasma Operation

- ✓ High β_N Operation ($\beta_N > 3.5$)
- ✓ $T_i > 10\text{keV}$
- ✓ $T_e > 13\text{keV}$
- ✓ Triple product $> 6.7 \times 10^{19} \text{m}^{-3} \cdot \text{keV} \cdot \text{s}$
- ✓ 1.5MA H-mode Operation
- ✓ H-mode in Tripod Divertor Configuration
- ✓ High Density Operation ($\sim 1.2 \times n_{GW}$)



First
Plasma

1.1MA plasma

✓ 1MA H-mode Operation
✓ Advanced Divertor
(Snowflake & Tripod)
Operation

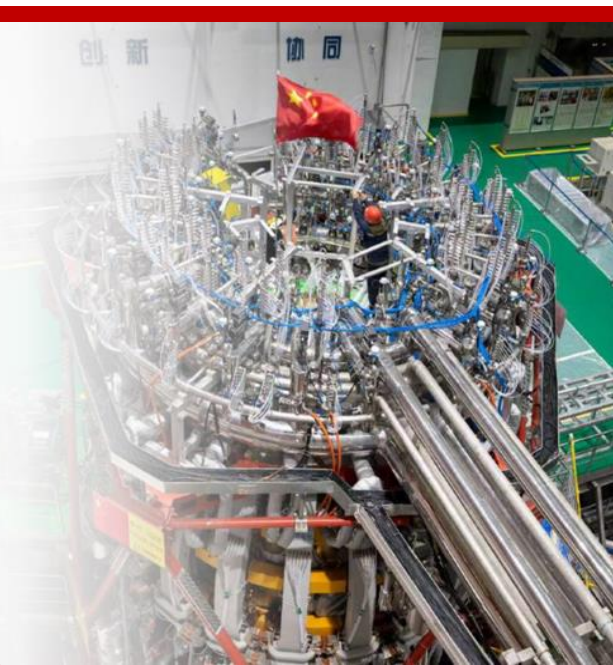
2020

2022

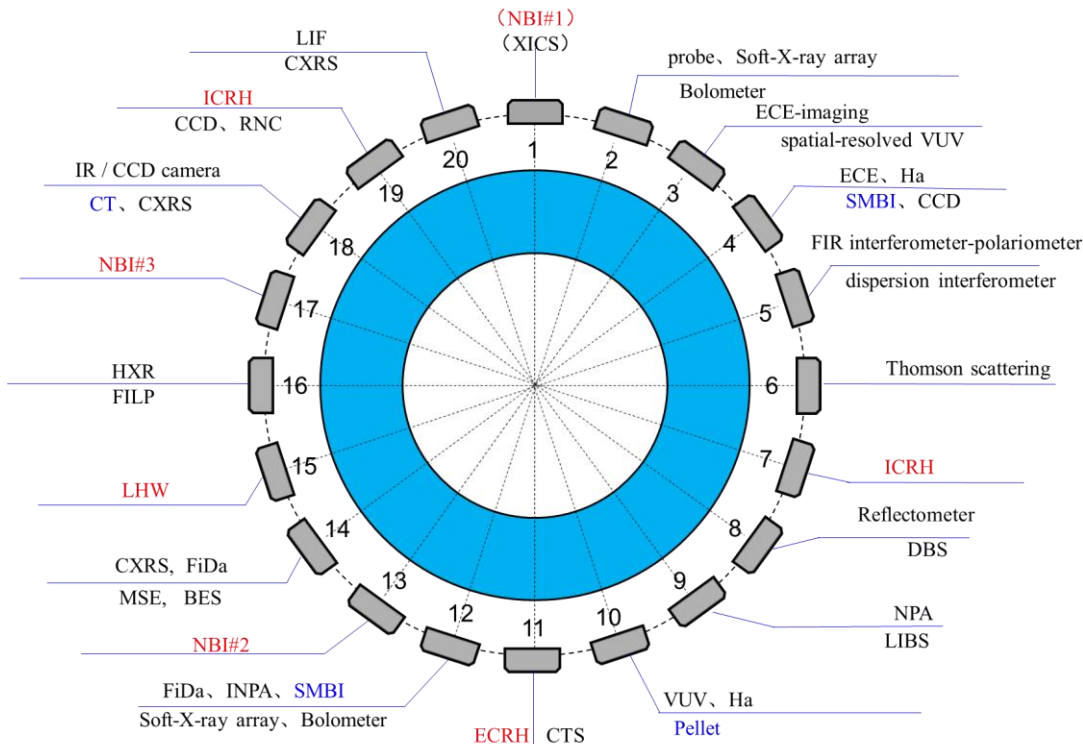
2023

2024

2025

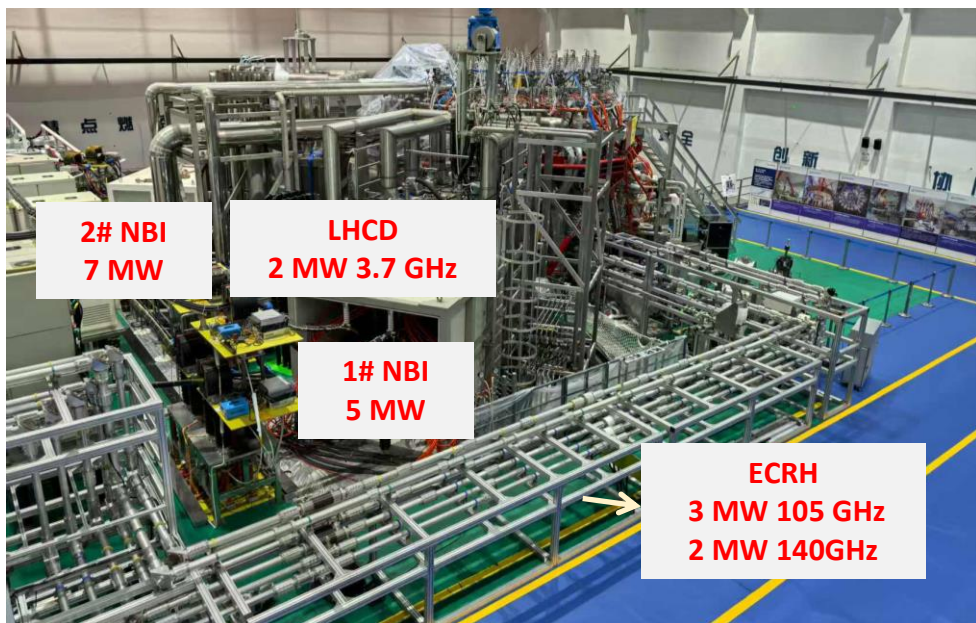


Diagnostic systems including electromagnetic / laser / spectrum / microwave / nuclear diagnostics



- Thomson scattering system enables Te/ne profile measurement
- FIR 12-channel density measurement and multi-channel polarization measurement
- CO2 interferometer achieved fully automatic operation
- CXRS measured the data of ion temperature at 100 million degrees
- Construction of spatially resolved EUV spectroscopic diagnostics completed
- Neutron time-of-flight spectrometer (TOF) developed
- High-frequency signal on Fast Ion Loss Detector (FILD) obtained

Auxiliary H & CD power increased to 19MW in 2025, will achieve 41MW in 2027
Support key operation scenarios & burning plasma physics study



NBI 20 MW

- 6 MW + 7MW + 7 MW
(120 keV/ 40A/ 5s)

ECRH&CD 11MW

- 4 MW 140/175 GHz
- 2 MW 140 GHz
- 5 MW at 105 GHz

ICRH 6MW

- 6MW 25-50 MHz

LHCD 4MW

- 4MW 3.7 GHz

2025

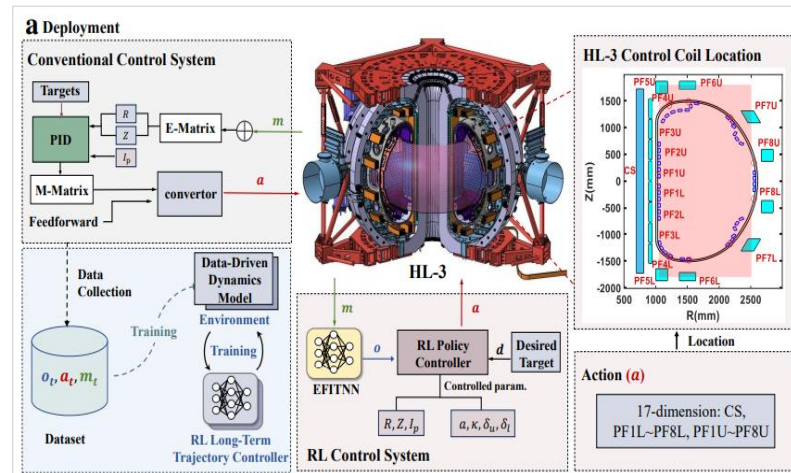
2027

Plasma Control & AI Application

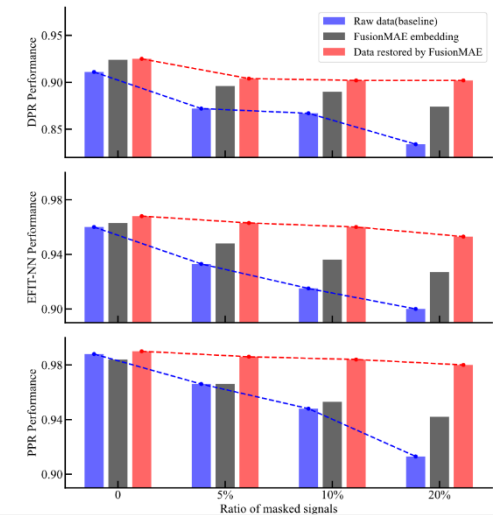
- **The Fusion Device Operating System (CODIS)**, integrating control, operation, data, and intelligence, successfully developed and validated on the HL-3
- **Two key AI capabilities demonstrated:** reinforced learning magnetic control and the large-scale pre-trained model FusionMAE



CODIS validation in HL-3 experiment



Diagnostic model, FusionMAE, took over control of magnetic configuration

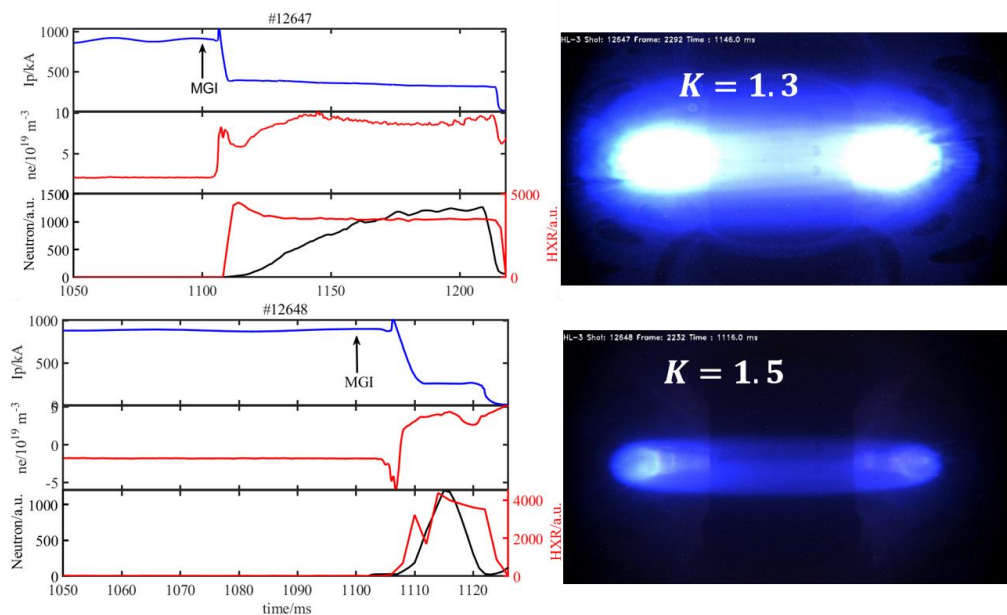


FusionMAE maintains downstream task performance with missing diagnostics

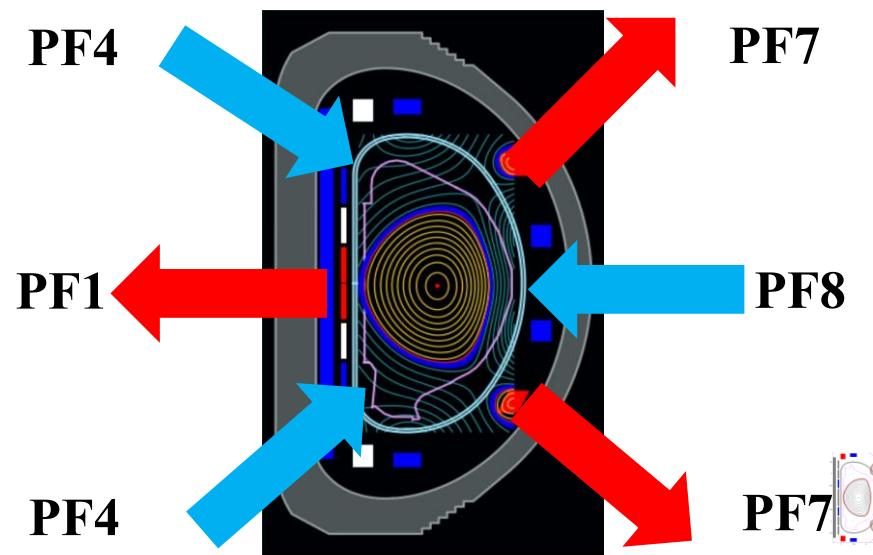
HL-3 International Cooperation

- In 2023, HL-3 opened as ITER satellite device to support ITER physics research and operation
- Recent joint experiments were done with Japan, Korea, France, Portugal, US, etc.

Focus on high β scenario / advanced divertor physics / ETB & ITB / disruption physics...



Research and Control of Disruptions and Edge Localized Modes (ELMs) (ITER Joint Experiment)



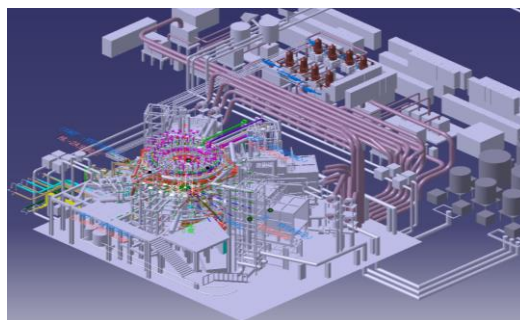
Negative Triangularity Configuration (U.S. Joint Experiment)

HL-3 upgrade is ongoing

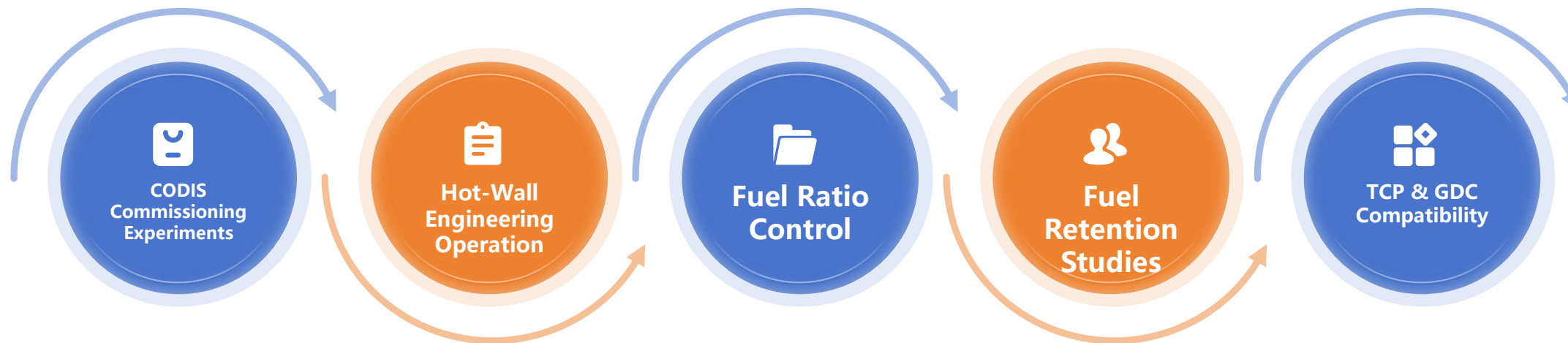
Campus refurbishment



Machine upgrade



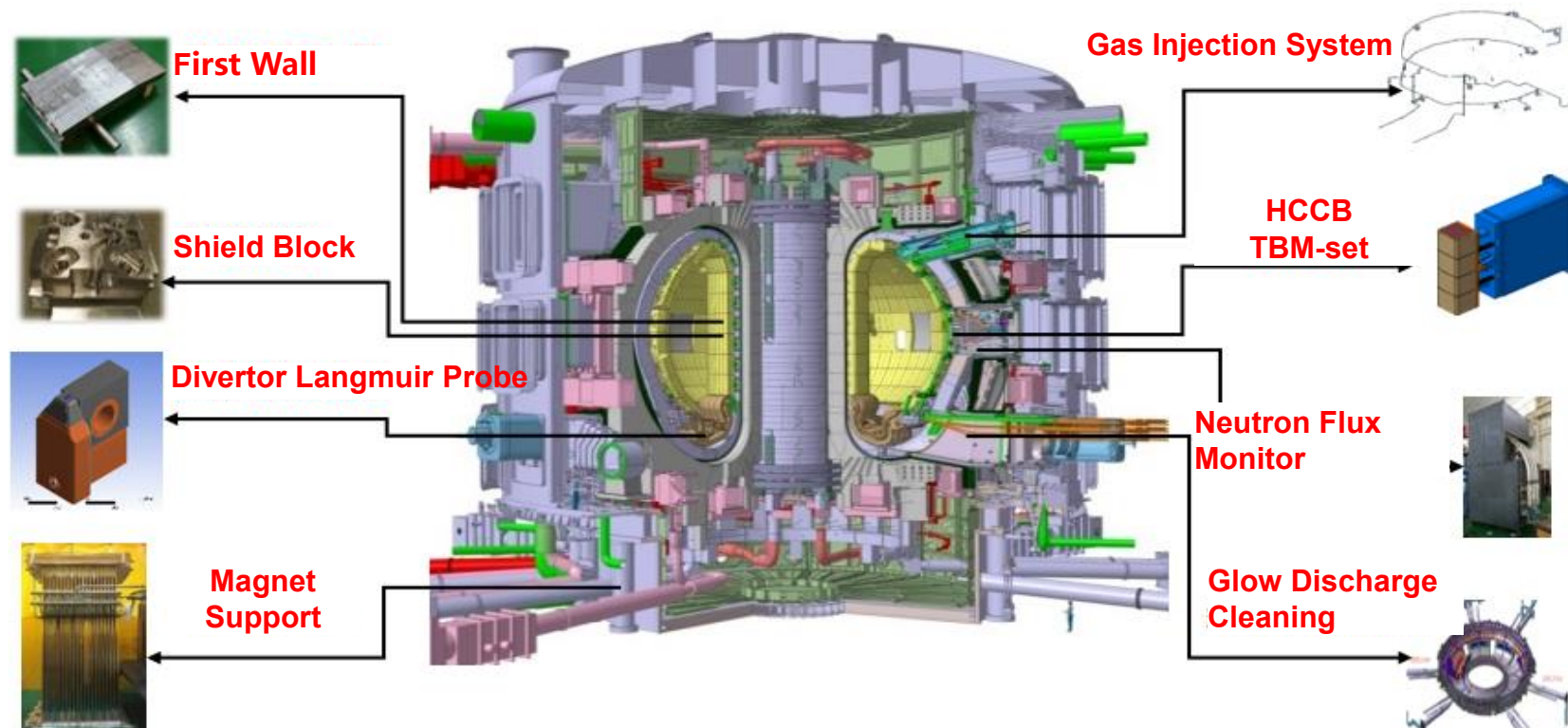
New control center



03

Fusion Energy Technology R&D

SWIP is responsible for 9 R&D Tasks of ITER Key Components,
including TBM / First Wall / Shielding Block / GIS & GDC / Magnet Support /
Neutron Flux Monitor / Divertor Langmuir Probe...



Enhanced Heat Flux (EHF) First Wall (FW)

Undertake research and qualification program of ITER FW

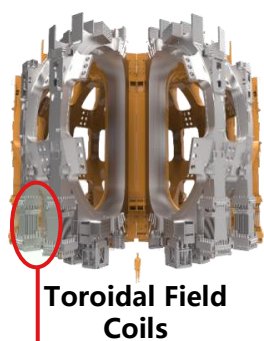
- ITER-certified high heat flux test system
- Leading laser welding & NDT for thin-wall stainless steel (spatter-free)
- Advanced HIP bonding tech for heterogeneous materials
- Large-scale Hot Helium Leak Testing system satisfied ITER specs (The first fusion ISO international standard)



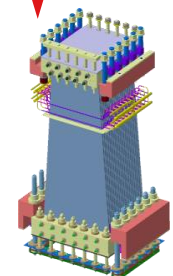
Prototype of EHF FW (tungsten armour) completed in 2025, ready for mass production

Magnet Support (MS)

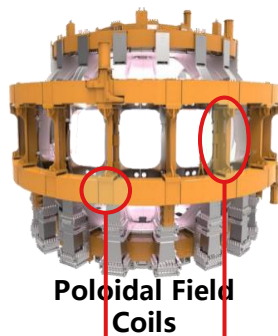
- SWIP undertakes the manufacturing task of ITER Magnet Supports, including 18 sets of Gravity Supports (GS), 108 sets of Poloidal Field Coil Supports (PFCS), and 6 sets of Correction Field Coil Supports (CCS)
- They are ITER's key structural safety component, withstanding over 20,000 tons of complex loads from superconducting magnets



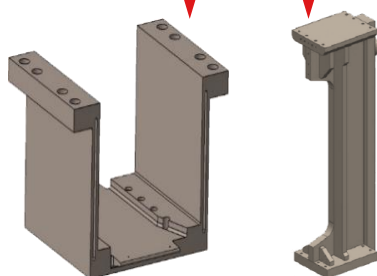
Toroidal Field Coils



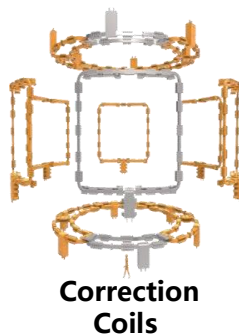
GS



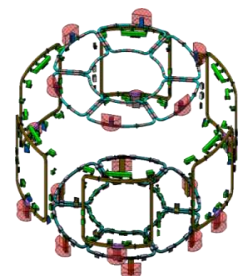
Poloidal Field Coils



PFCS, U-shaped BOX,
PFCS 3/4 Suspension Beam



Correction Coils



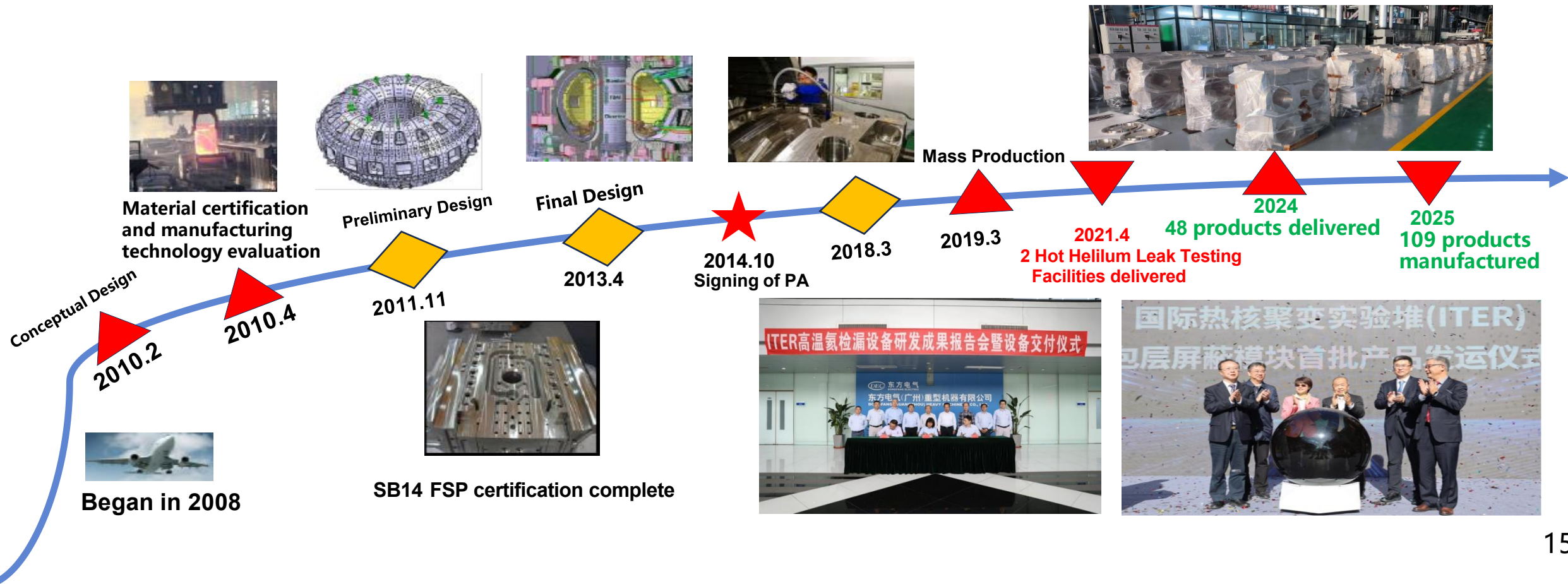
CCS



Shielding Block (SB)

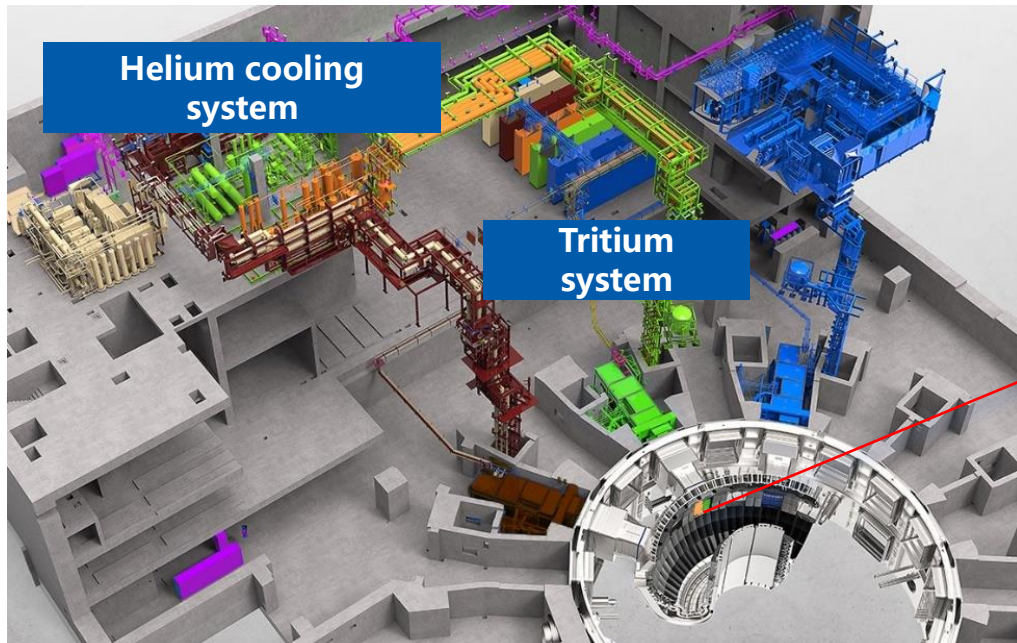
Resolved key technical problems such as high-precision deep hole drilling & welding deformation control of ITER-level 316L(N) stainless steel forgings

The first batch of 48 shielding modules manufactured, inspected and delivered

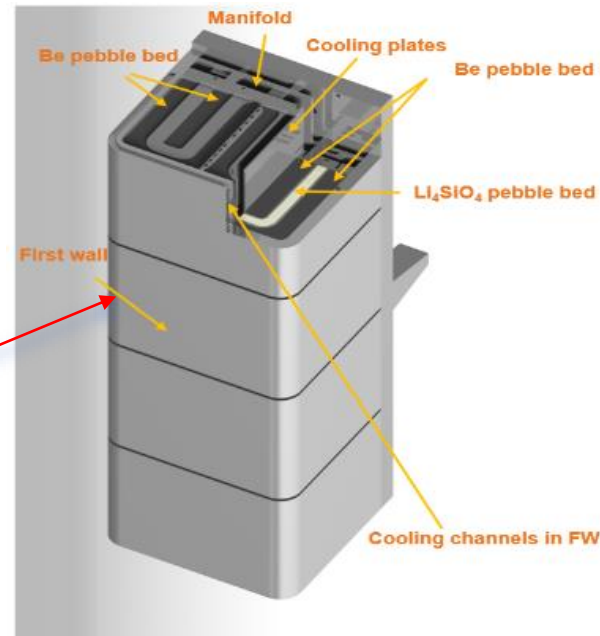


CN HCCB TBS (TBM Program)

- One of the three major engineering goals of ITER is to test and verify the tritium breeding and energy extraction technologies of fusion reactors
- Completed the first TBS conceptual & preliminary design
- Developed the first semi-prototype module



Test Blanket System



Test blanket module



**Semi-Prototype
HCCB TBM Module**

SWIP is one of the China Nuclear Power Engineering (CNPE) consortium members undertaking the ITER Assembly Contracts

■ 2019: ITER Tokamak Assembly Contract-1 (TAC1)

Physical work has been completed as planned, with the current progress at 93.5%. It is expected to be fully concluded by the end of October

■ 2024: Vacuum Module Sector Assembly (SMSA)

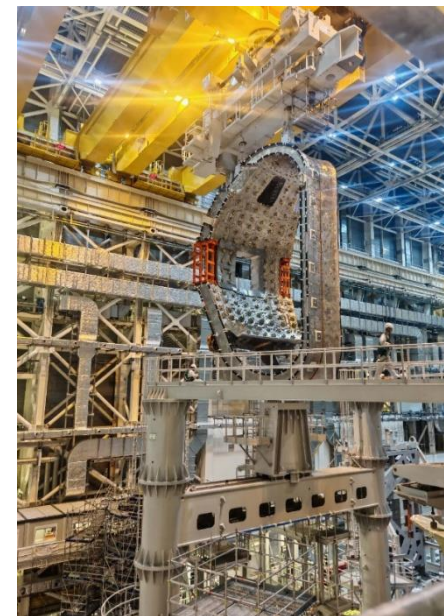
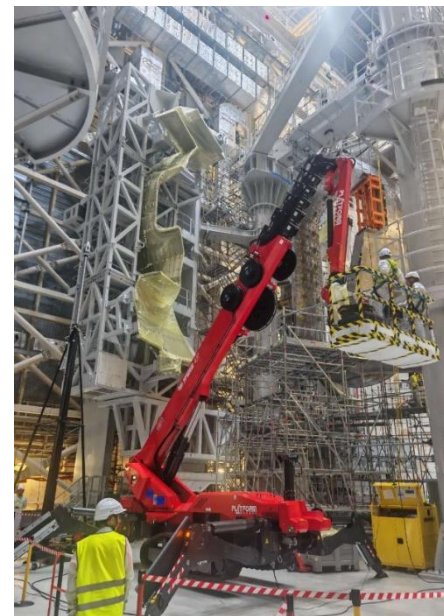
VVS6# and VVS7# have been transferred into pit. The work for VVS5# has been 73.7% completed, and VVS8# is 33% complete

■ 2024: Vacuum Vessel Sector Pit Assembly (SMPA)

Lifting of Vacuum Vessel Module 6 completed, overall project progress has reached 11.4%

■ 2025: Vacuum Vessel Sector Pit Welding preparation (WPP)

Newly signed contract. The installation package file list has been finalized, and relevant documents have been submitted to IO

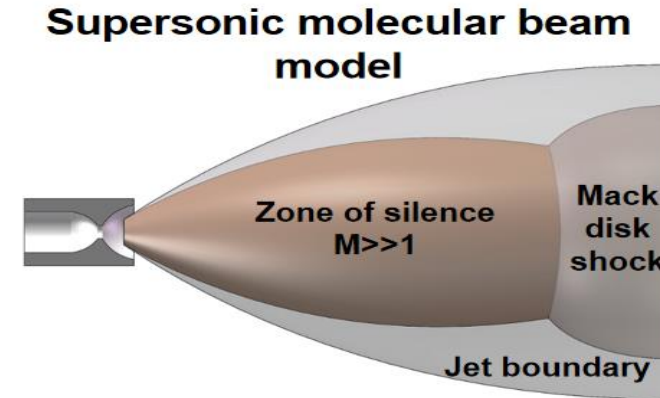


Tri-Band High-resolution Spectrometer



- Highly integrated, compact structure, capable of simultaneously measuring the temperature, rotational speed and concentration of carbon and helium ions

Supersonic Molecular Beam Injection



- IOS standard approved
- Injection speed > 10 Mach
- Applied in many tokamaks
- Widely used in plasma control and experiment research

Advanced Technologies R&D Platforms



Hot Helium Leak Testing System



**Liquid Metal
Integrated Research Platform**



**CNAS-approved Fusion Material
Testing Center**



**Helium Cooling
Experimental Loop**



**ITER-approved
High Heat Load Testing platform**



Neutron Activation System

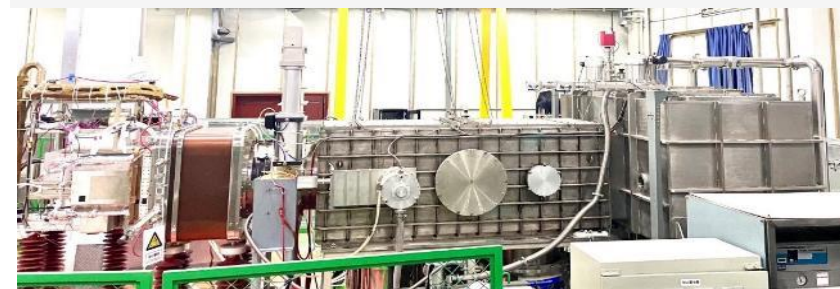
- High-power steady-state RF negative ion source (2MHz/RF) test platform achieving beam pulse > 200s, beam energy 200keV
- ECW of 105/140GHz, 1000s & LHW of 3.7GHz test platform



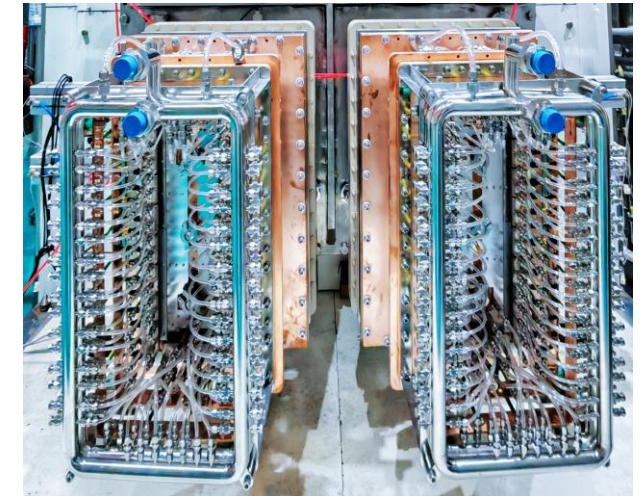
High-power steady-state ion source experimental platform



120keV Beamline Conditioning Platform



RF negative ion source with world-class high-power radio frequency coupling technology



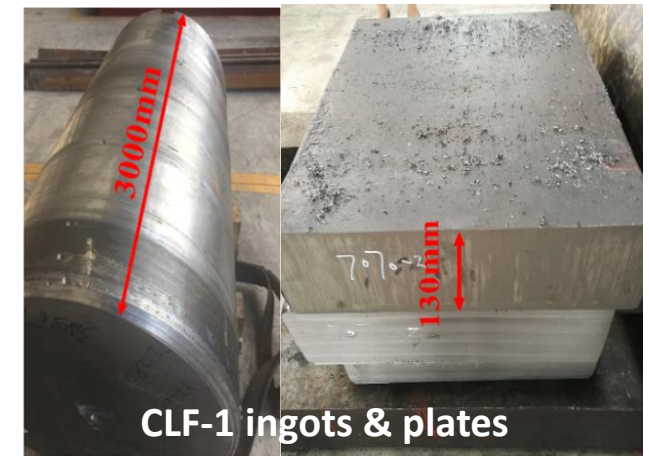
Ion Source of high-power neutral beam system

■ Plasma facing materials

- Advanced tungsten alloys prepared by industrial technology route
- W-Y₂O₃ and W-K with very good low-temperature ductility and high recrystallization temperature
- Divertor mockups with advanced W alloys show good thermal resistance capability

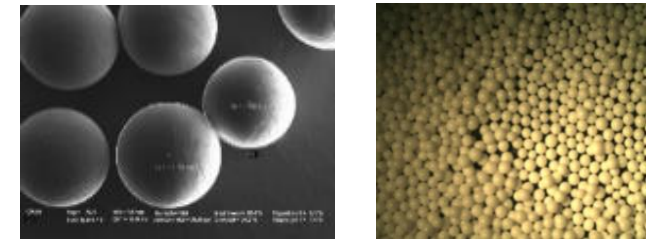
■ Reduced Activation Ferritic Martensitic (RAFM) steel - CLF-1

- Large ingots up to 5 tons
- CLF-1 steel engineering qualification is ongoing
- Establish a complete welding process database
- Establish a complete material database of CLF-1 steel



■ Functional Materials (beryllium pebble & Li₄SiO₄ pebble)

- Complete the production process for 10kg grade beryllium (Be) pellets of neutron multiplier
- Complete the development of tritium breeder Li₄SiO₄ pellet production process and its engineering qualification starts



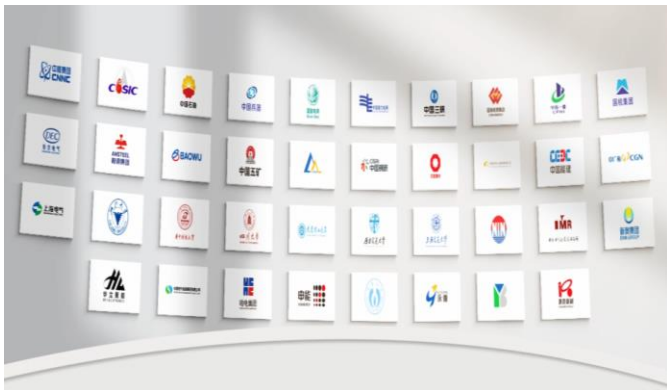
5kg Li₄SiO₄ pellets made by Rotating electrode method

04

Prospects of Fusion Research

1. After 60 years of research and development, SWIP has had a profound accumulation of technologies, talents and platform for nuclear fusion.
2. Great progress on nuclear fusion technology has been made via the implementation of ITER project. There is still **a large gap among ITER, DEMO and Fusion Power Plant (FPP), such as steady-state and self-sustained operation of burning plasma, materials resistant to high-energy neutron bombardment and high heat load, tritium self-sufficiency, thermal-electric conversion, etc.**
3. **To face these challenges,** under the guidance of the State-owned Assets Supervision and Administration Commission of the State Council of China, **the Controlled Nuclear Fusion Innovation Consortium was established** in Dec. 2023, and **China Fusion Energy Co., Ltd. (CFEC) was established** in 2025.

1. CNNC and SWIP established the Innovation Consortium for Controlled Nuclear Fusion in December 2023. Its membership has grown to 38, encompassing **various entities** such as large enterprise groups, universities, and research institutions, **covering the entire industrial chain, including: basic technology research, fusion engineering technology development, key material R&D, advanced manufacturing, and current nuclear power construction and operation.**
2. It will **fully leverage the advantages of the entire nuclear industry chain**, build an intensive key capability system and an open industrial collaboration network, **drive the innovation chain, promote industrial chain coordination and supply chain security in the field of controlled nuclear fusion, and accelerate the commercial fusion energy.**



Currently, the member units of the Consortium has grown to 38

- 22 central enterprises
- 2 local state-owned enterprises
- 7 universities, 2 research institutes
- 5 private enterprises

Based on 60-year development of SWIP
China Fusion Energy Co., Ltd. (CFEC) established



CFEC established in Shanghai in July 2025
Registered capital of 15 billion RMB

- Shareholders include China National Nuclear Corporation, China National Petroleum Corporation, the National Green Development Fund and Shanghai Future Fusion Energy Technology Co., Ltd, among others, forming a capital ecosystem covering the entire chain.
- **Promote the engineering and system integration of fusion reactors**
- **Accelerate breakthroughs in key technologies and enhance research and development capabilities**
- **Facilitate technology transition from laboratory to industrialization & engineering**

R&D layout with 3 Campuses



📍 Chengdu, Sichuan Province

■ Shuangliu District

Frontier scientific experiment (HL-3)

■ Tianfu New Area

Key engineering technology R&D for fusion reactor



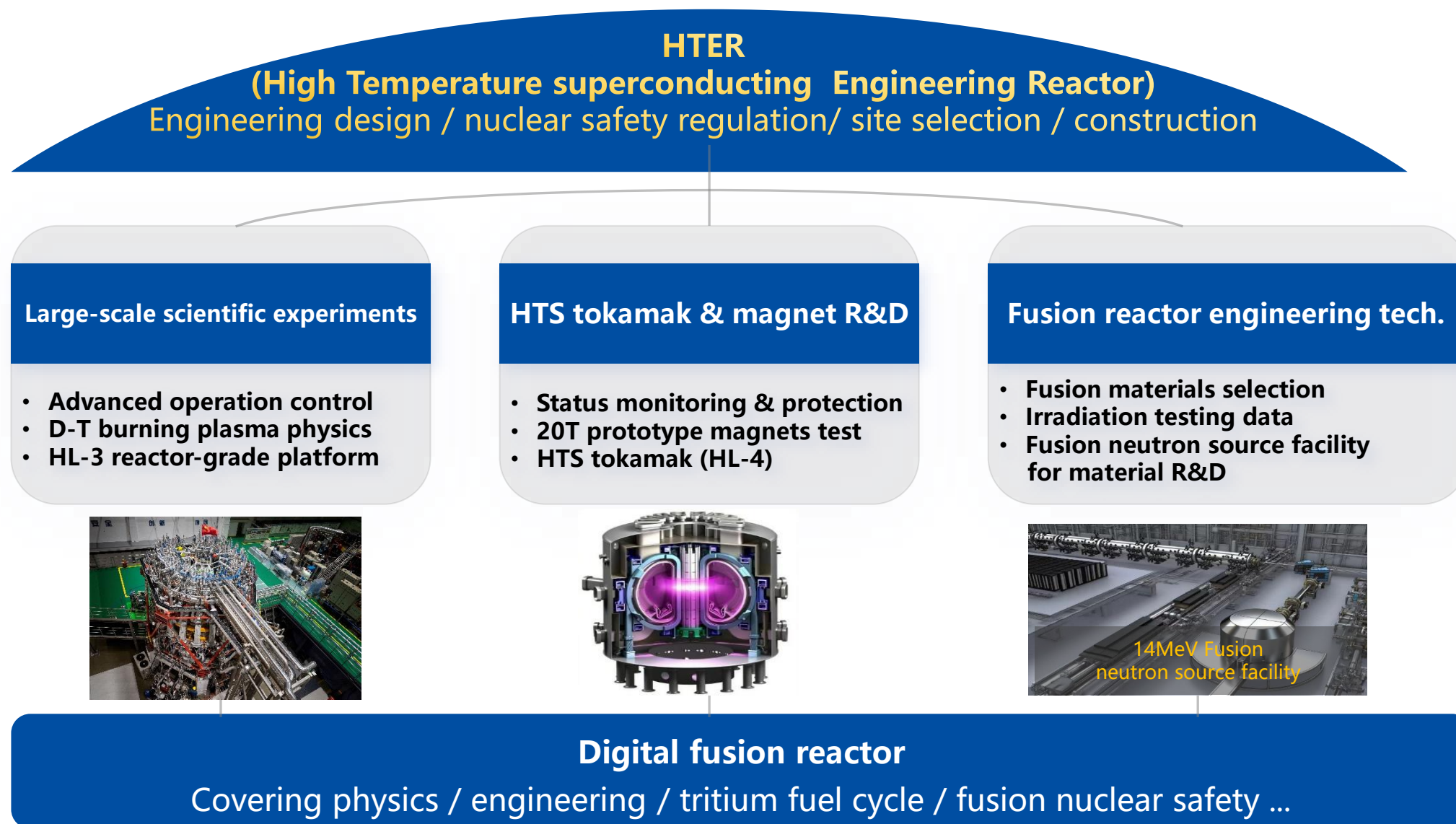
📍 Shanghai

■ Minhang District

- Fusion reactor design, high-temperature superconducting (HTS) magnet, digital tokamak
- High-field tokamak with HTS magnet



Prospect in the next 10 years—1 goal + 3 pillars



1. Progress of high plasma performance operation has been made, HL-3 achieved $\beta_N > 3.5$, $T_i > 10\text{keV}$, $T_e > 13\text{keV}$, $n_e T > 6.7 \times 10^{19} \text{m}^{-3} \cdot \text{keV} \cdot \text{s}$. Heating power of 19MW was reached and AI was applied in plasma magnetic control.
2. Fusion energy technologies have been developed to support ITER and future reactors.
 - Completed the prototype of EHF FW (tungsten armour), ready for mass production.
 - Achieved RF negative ion source beam pulse $> 200\text{s}$, beam energy 200keV.
 - Developed the first semi-prototype test blanket module.
 - Established component and material R&D platforms.
3. HTER is to be built in the next 10 years to fill the gap among ITER, DEMO and FPP.
4. CFEC and the Innovation Consortium promote industrial chain coordination and supply chain security in the field of controlled nuclear fusion, and accelerate the fusion energy commercialization.

Thanks for Your Attention!