

CN Facilities Anticipated for DEMO Preparation

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On behalf of Chinese Tritium breeding Blanket team

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Contributions from SWIP, ASIPP, CAEP, CIAE, INEST, UCAS, etc.

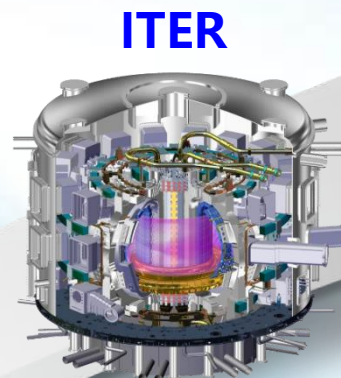


- **China MCF & TBB Development Strategy**
- **Facility development and plan to support next-step device and DEMO blanket**
 - Breeder, multiplier and structural material
 - Blanket fabrication
 - Cooling technology
 - Blanket test (high heat flux)
 - Fuel cycle
 - Remote handling



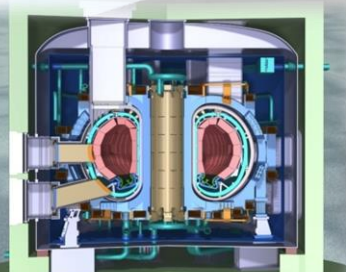
China MCF Development

China Magnetic Confinement Fusion Development



ITER

- Fusion technology engineering validation
- Demonstration of fusion technology



CFETR

- Steady state burning plasma
- Hybrid burning plasma



PFPP

- electricity generation into grid
- Safety, reliable, efficient

Experimental Facility



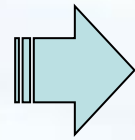
HL-2M EAST J-TEXT

- Steady state advanced operation
- Advanced divertor, high power H&CD, diagnostics



China MCF Development

China Magnetic Confinement Fusion Development

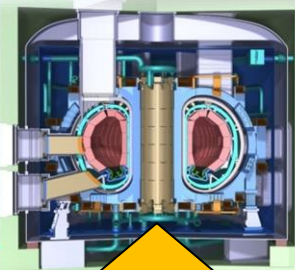


TBB Development Strategy

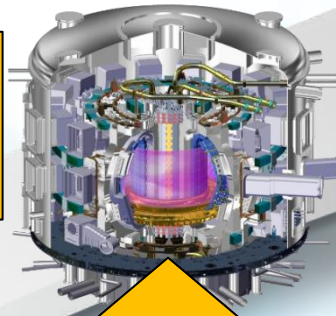
PFPP



CFETR



ITER



TBB Technology
Design, material, fabrication process, safety, etc.

PFPP TBB
T self-sufficiency and electricity generation

CFETR TBB
Verify engineering feasibility of T breeding and electricity generation

ITER TBM
Validate technology feasibility of T production and heat removal

Experimental Facility



HL-2M EAST J-TEXT

TBB Concepts and Application

- **HCCB TBB Concept (Helium Cooled Ceramic Breeder)**
 - ITER TBM
 - CFETR HCCB TBB
- **WCCB TBB Concept (Water Cooled Ceramic Breeder)**
 - CFETR WCCB TBB
- **HCLL TBB Concept (Helium Cooled Lithium Lead)**
- **SCLL TBB Concept (Supercritical CO₂ cooled Lithium Lead)**
 - Advanced concept for future



Facility development and plan to support next-step device and DEMO blanket

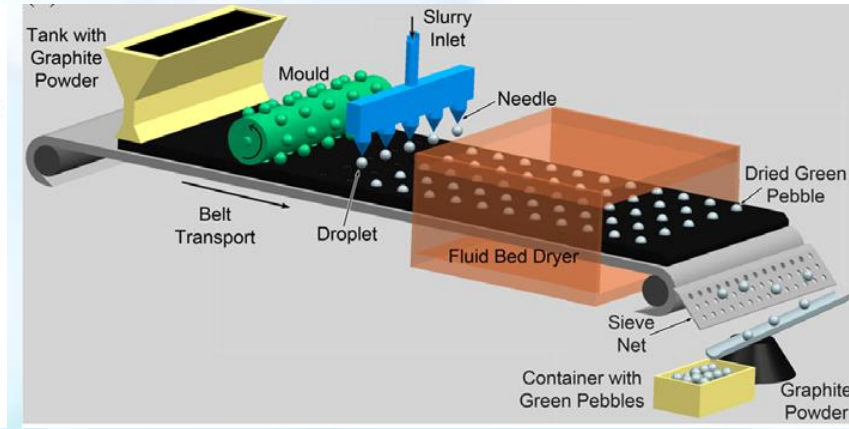
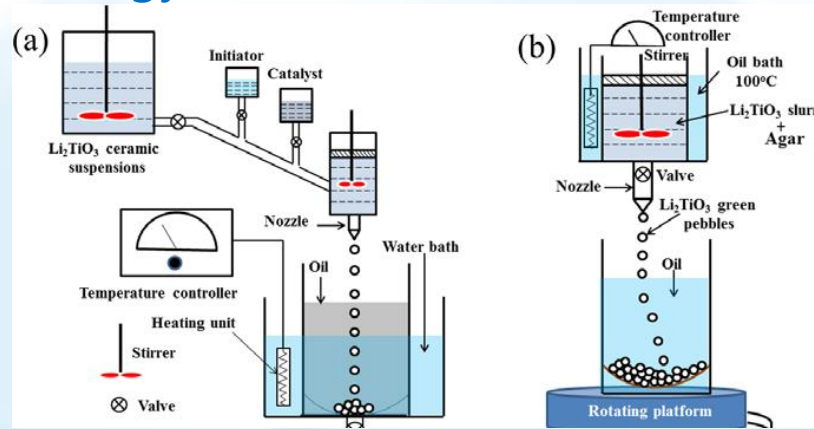
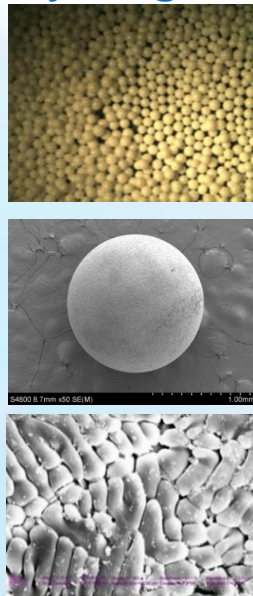


Tritium Breeder Technology

- **Mostly focus on lithium ceramic breeder**
 - Melt spray method tritium breeder manufacturing equipment, small-scale: 200 kg/year.
 - Other wet processes facility: laboratory-scale.
 - Many universities and institutes are developing new advanced tritium breeder materials.
 - **Plan:**
 - Low-cost large-scale fabrication facility (ton level);
 - Lithium-6 recycling technology and advanced tritium breeder.



Melt spray method facility @SWIP

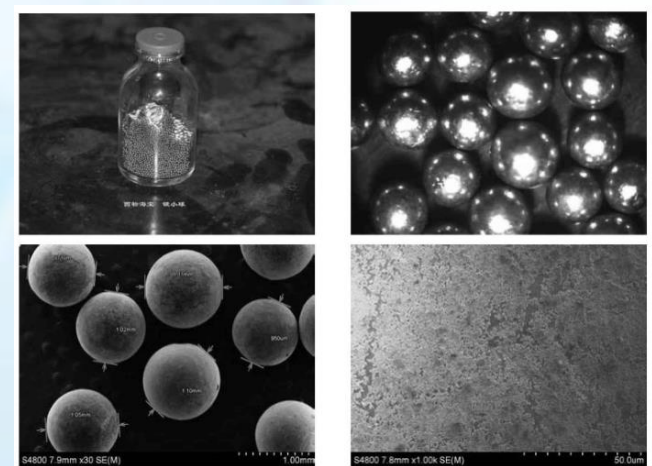


Wet method fabrication process and facilities of breeder pebbles
@CAEP,SCU,USTB,SWIP, etc.



Neutron Multiplier Technology

- **Focus on Be-based neutron multiplier (@SWIP & Haibao)**
 - Rotating electrode method beryllium pellet manufacturing equipment achieves small batch production: 10 kg/batch.
 - Advanced multiplier beryllide is under studied by universities and institutes.
 - **Plan:**
 - Low-cost large-scale fabrication facility of beryllium and beryllide pebbles (ton level);
 - Develop materials and solutions to recycle or replace beryllium.



Fabrication facility of Be pebbles based on rotating electrode method @SWIP & HaiBao

Beryllium pebbles fabricated by 10kg / batch process

Topography of beryllium @SWIP

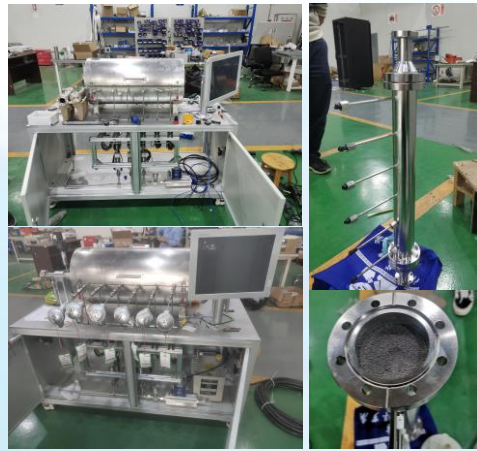


Pebble Bed Technology

- A series of pebble bed experiment facility has been constructed (@SWIP)
 - Covering thermophysical, thermal mechanical, multiphysics coupling, pressure drop, etc.
 - Plan:
 - comprehensive performance of pebble bed in a multi-field environment;
 - T production and comprehensive performance under neutron irradiation.



Multiphysics coupling pebble bed performance test platform



Pebble bed gas pressure drop



Thermal mechanical with compress load



Thermophysical property testing facility



Structural Material

● RAFM steel and advanced structural materials

- The industrial fabrication process has been established for RAFM steel (CLF-1 and CLAM). The material database has been established, including welding database.
- **Advanced materials** (ODS, TMT, CNA, vanadium alloy) development at laboratory scale.

China Low-activation Ferrite steel (CLF-1)
Scale-up

With impurity control

10 kg 50 kg 350 kg 1 ton 5 ton × 3

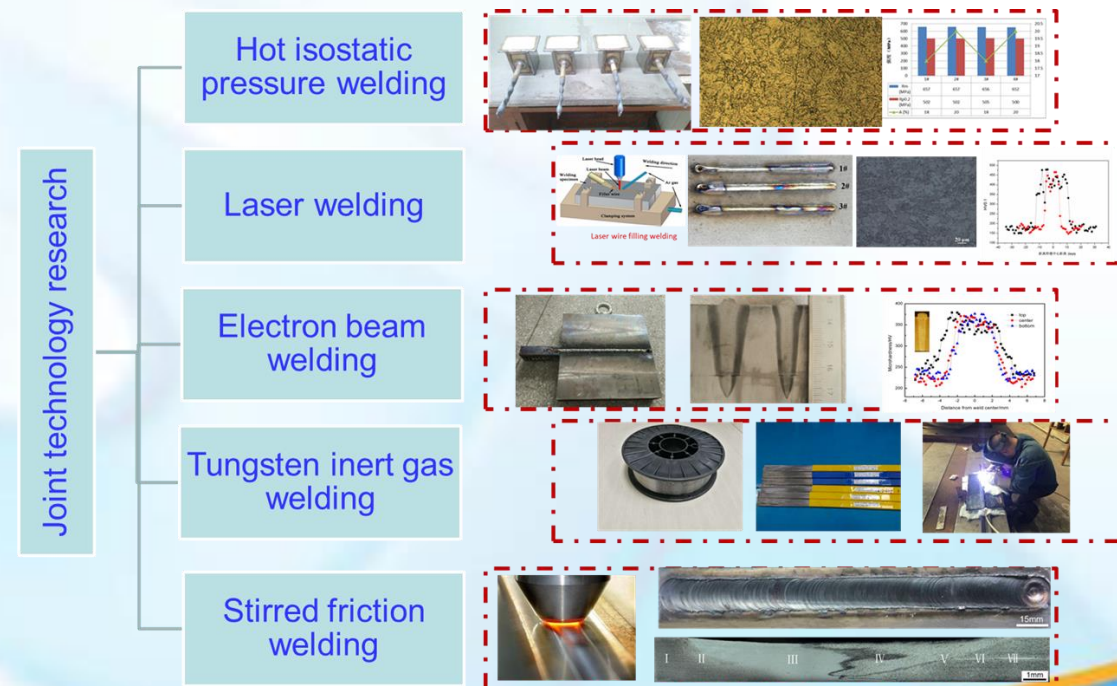
VIM+ ESR

Forging

Forge piece

10-55mm plate

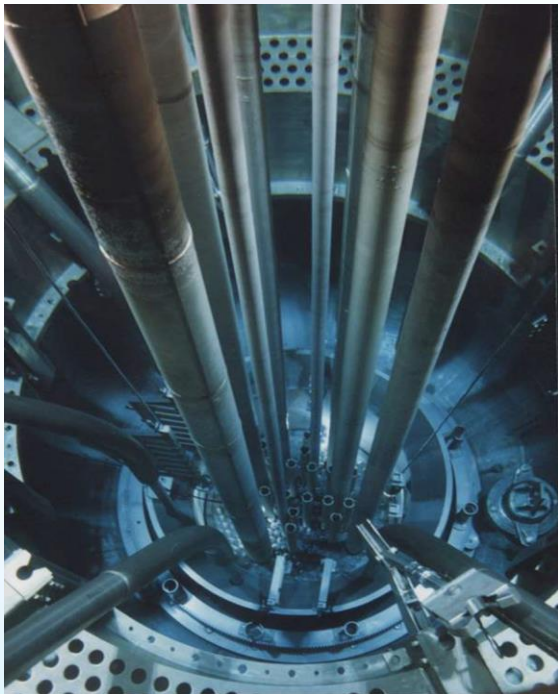
RAFM steel development (@SWIP)



RAFM steel welding technology development (@SWIP)

Irradiation of Material

- Focus on irradiation experiment and its PIE
 - Fission reactors have been used for irradiation experiment of functional materials and structural materials.



HFETR
(@NPIC)

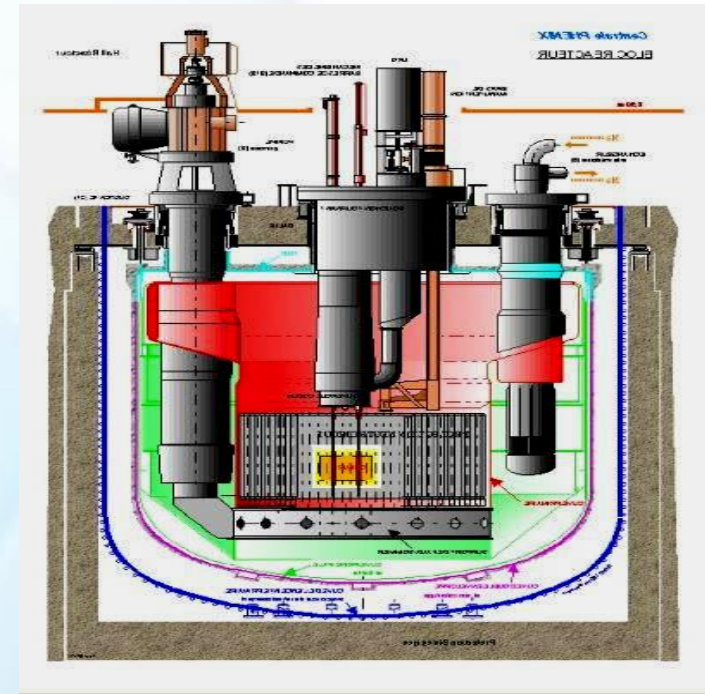


CMRR
(@CAEP)



Operation Hall

CARR
(@CIAE)



CEFR
(@CIAE)



Irradiation of Material

- **Focus on irradiation experiment and its PIE**
 - Several **accelerator driven D-T neutron sources** have been used for both functional and structural material study.



D-T neutron sources ($\sim 10^{11}\text{s}^{-1}$)
(@CAEP)



D-T neutron sources ($\sim 10^{12}\text{s}^{-1}$)
(@INEST)

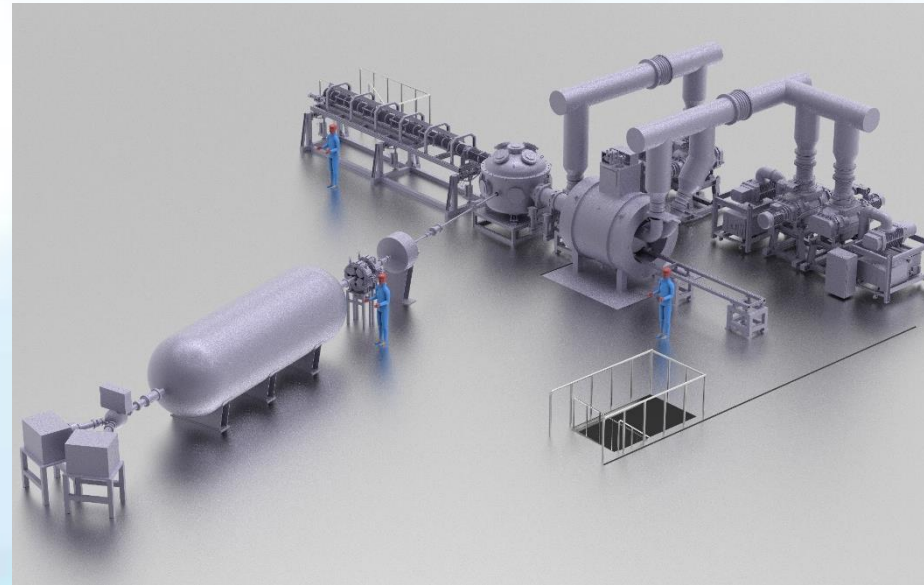


● Material PWI Research Platform (@SWIP&ASIPP)

- Deliver reactor-relevant particle flux to materials
- Capability of in-situ analysis on material surfaces



LEAD (@SWIP)



Shot length	>1000 s
Particle flux	>1x10 ²⁴ m ⁻² s ⁻¹
Magnetic field	>3 T

Main chamber

Superconducting magnets

Plasma source

Target system

Plasma diagnostics

Surface analysis

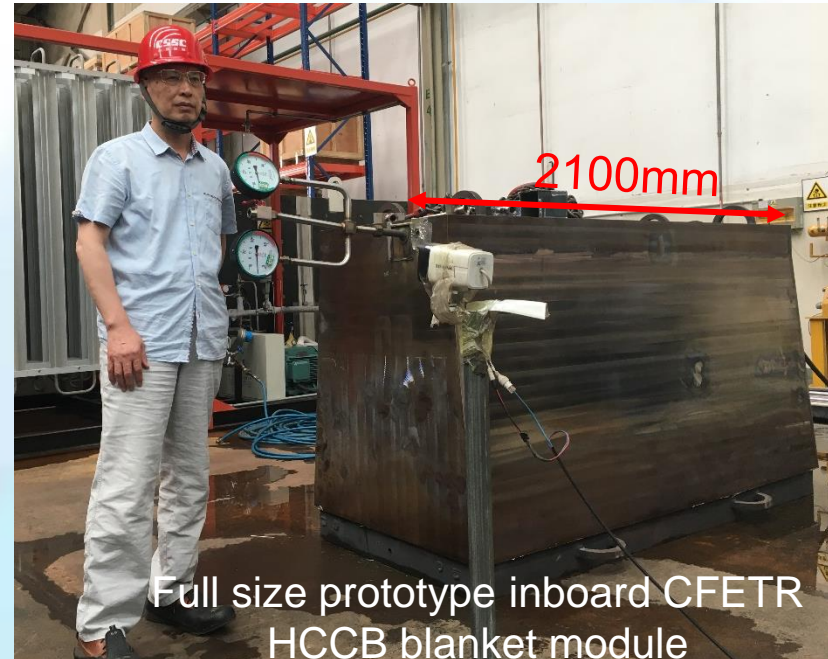
Data acquisition

Blanket Fabrication

- **Blanket fabrication technology has been developed with industries supported by China TBM program and domestic project.**
 - Semi-prototype HCCB TBM module (@SWIP)
 - Full size prototype inboard HCCB blanket module for CFETR (@SWIP)
 - Large size outboard WCCB blanket module for CFETR (@ASIPP)



Semi-prototype
HCCB TBM module



Full size prototype inboard CFETR
HCCB blanket module



Large size outboard CFETR
WCCB blanket module

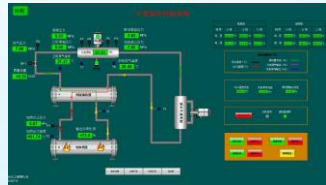
Cooling Technology

● Helium cooling (@SWIP)

- Helium cooling experiment loop HeCEL-1 was constructed for the thermohydraulic testing of component for blanket.
- HeCEL-1 was connected with 60kW high heat flux facility and ITER Mini-CODAC.



HHFT facility EMS-60



Control system
& ITER Mini-CODAC



HeCEL-1
(0.1kg/s, 8MPa, 400°C)



Hydraulic testing



High heat flux testing

Cooling Technology

● Helium cooling (@SWIP)

- New helium cooling experiment loop HeCEL-3 was constructed for the thermohydraulic testing of prototype blanket of CFETR and accident experiments.
- HeCEL-3 is planned to connect with 400/800kW high heat flux facility.



HeCEL-3
(2.5kg/s, 12MPa, 550°C)



EMS-400 High Heat Flux Testing facility

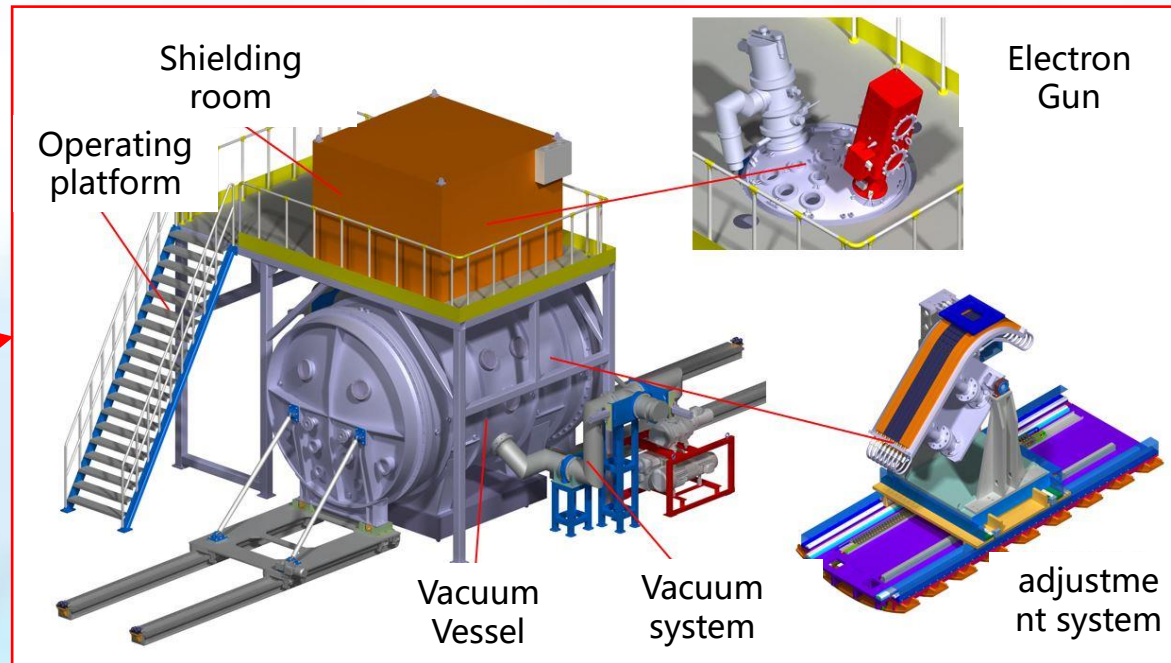
Cooling Technology

● Thermal Hydraulic Test Platform for WCCB BLK (@ASIPP)

- High heat load test (WCCB blanket prototype, divertor target)
- Capability of WCCB blanket thermal fluid experiment



High temperature and high pressure water loop



High heat flux test facility

Water loop

Pressure	15.5MPa
Temperature	285/325°C
Mass flow rate	≥14Kg/s

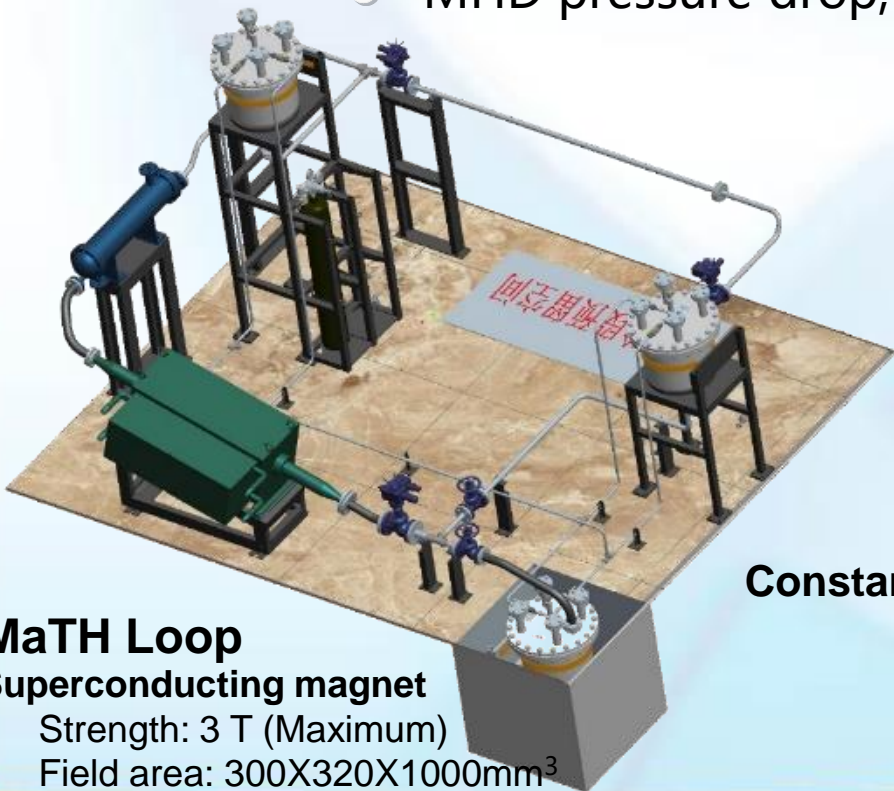
Vacuum Vessel Dimensions

Diameter: 3m
Length: 4m

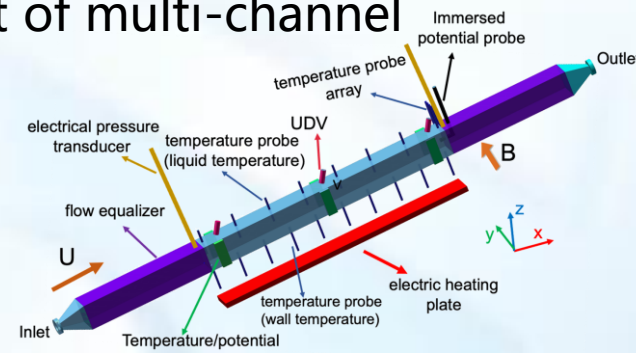
Cooling Technology

● Liquid metal (@UCAS)

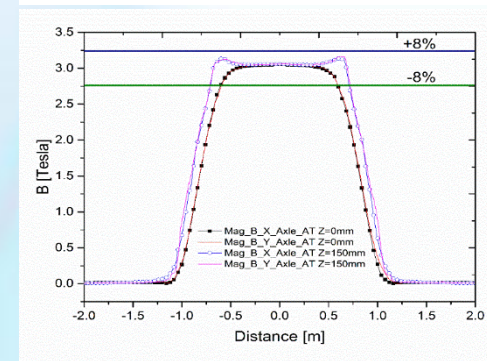
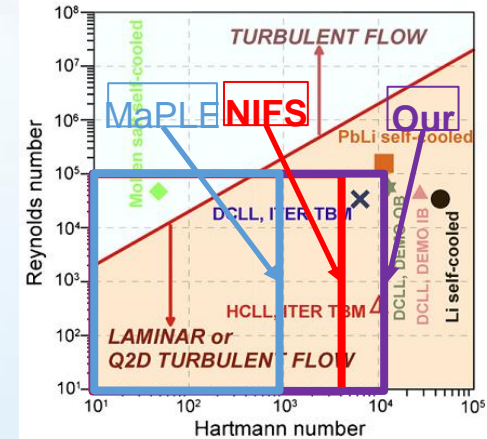
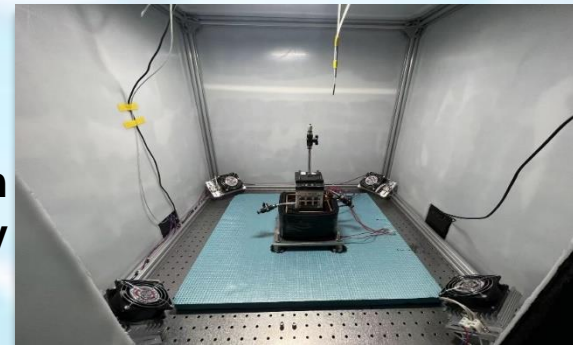
- MaTH (Magneto-Thermo-Hydrodynamic) loop
 - Flow and heat transfer, Magneto-convective fluctuations
 - MHD pressure drop, Couple MHD effect of multi-channel



Constant temperature system and convection cavity



Mixed convection test section

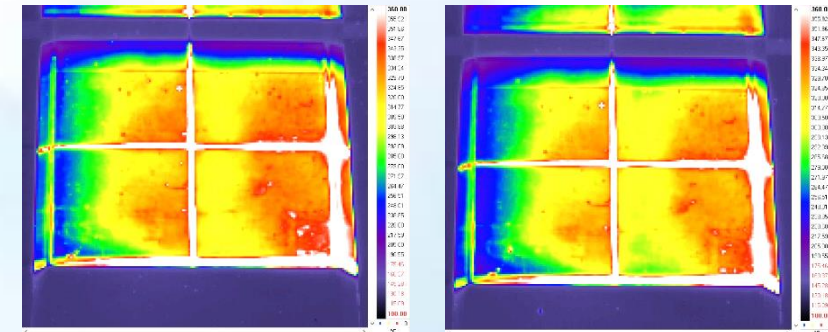
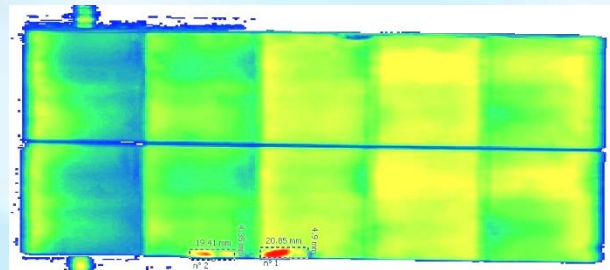
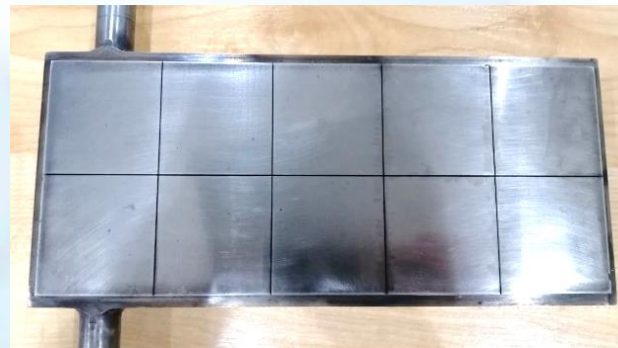


Blanket Test

- **Mostly based on cooling loop for thermohydraulic testing**
 - Also connect with high heat flux testing facility (@SWIP)
- **The multiphysics coupling testing platform is under consideration.**
 - to cover thermal load, pressure, high heat flux, mechanical load (EM load)



EMS-400 High Heat Flux Testing facility (@SWIP)



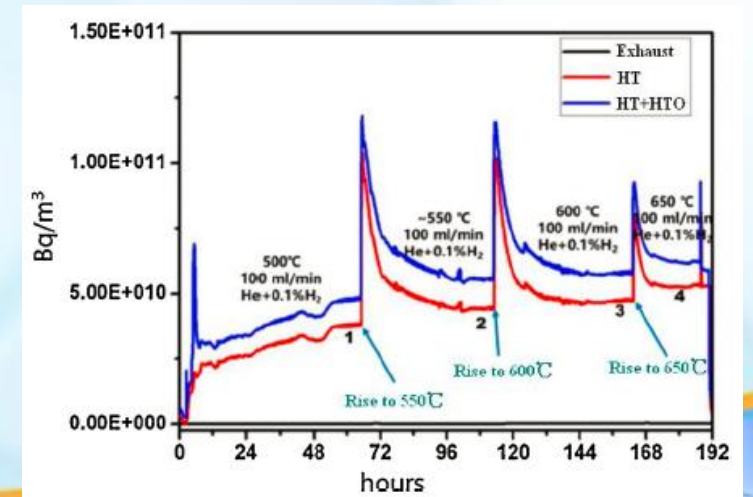
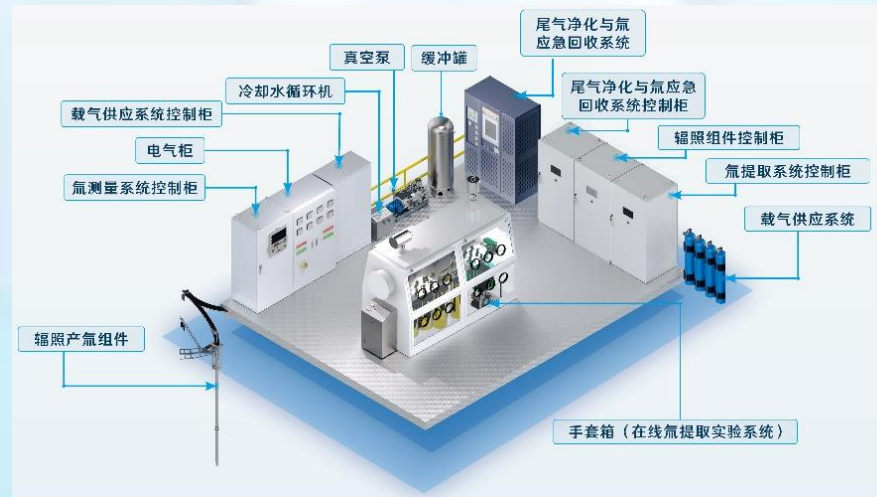
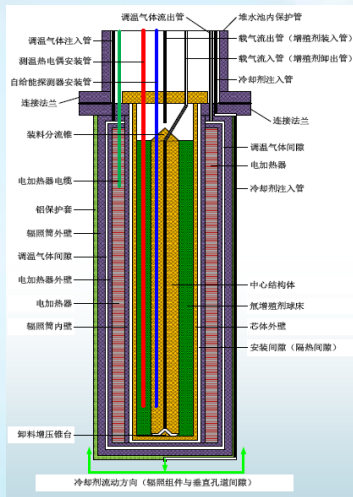
W armor / RAFM(CLF-1) FW sample and its high heat flux testing

>1000 cycles for $1\text{MW}/\text{m}^2$



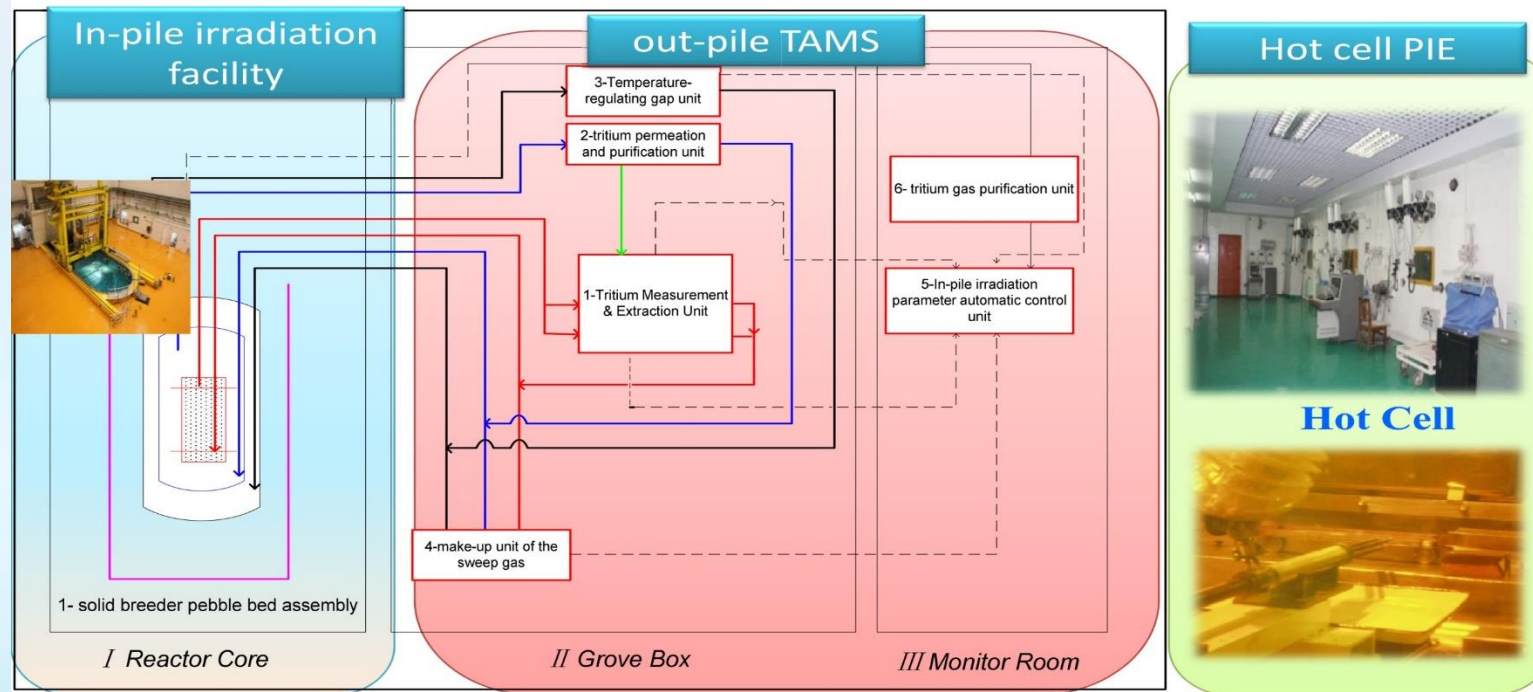
● In-pile experimental loop (@CAEP)

- A new in-pile experimental loop has been established in CMRR reactor for ceramic tritium breeder irradiation with capability of online reloading of irradiated samples.
- The irradiation temperature: 300 ~ 750 °C (± 10 °C).
- A series of irradiation experiments have been carried out for $\text{Li}_4\text{SiO}_4(7.5\% \text{ } ^6\text{Li})$, $\text{Li}_4\text{SiO}_4 (93\% \text{ } ^6\text{Li})$ and $\text{Li}_2\text{TiO}_3 (7.5\% \text{ } ^6\text{Li})$ pellets.
- The facility realizes the dual function verification of tritium extraction from carrier gas and coolant in 2022.



● In-pile experimental loop (@CIAE)

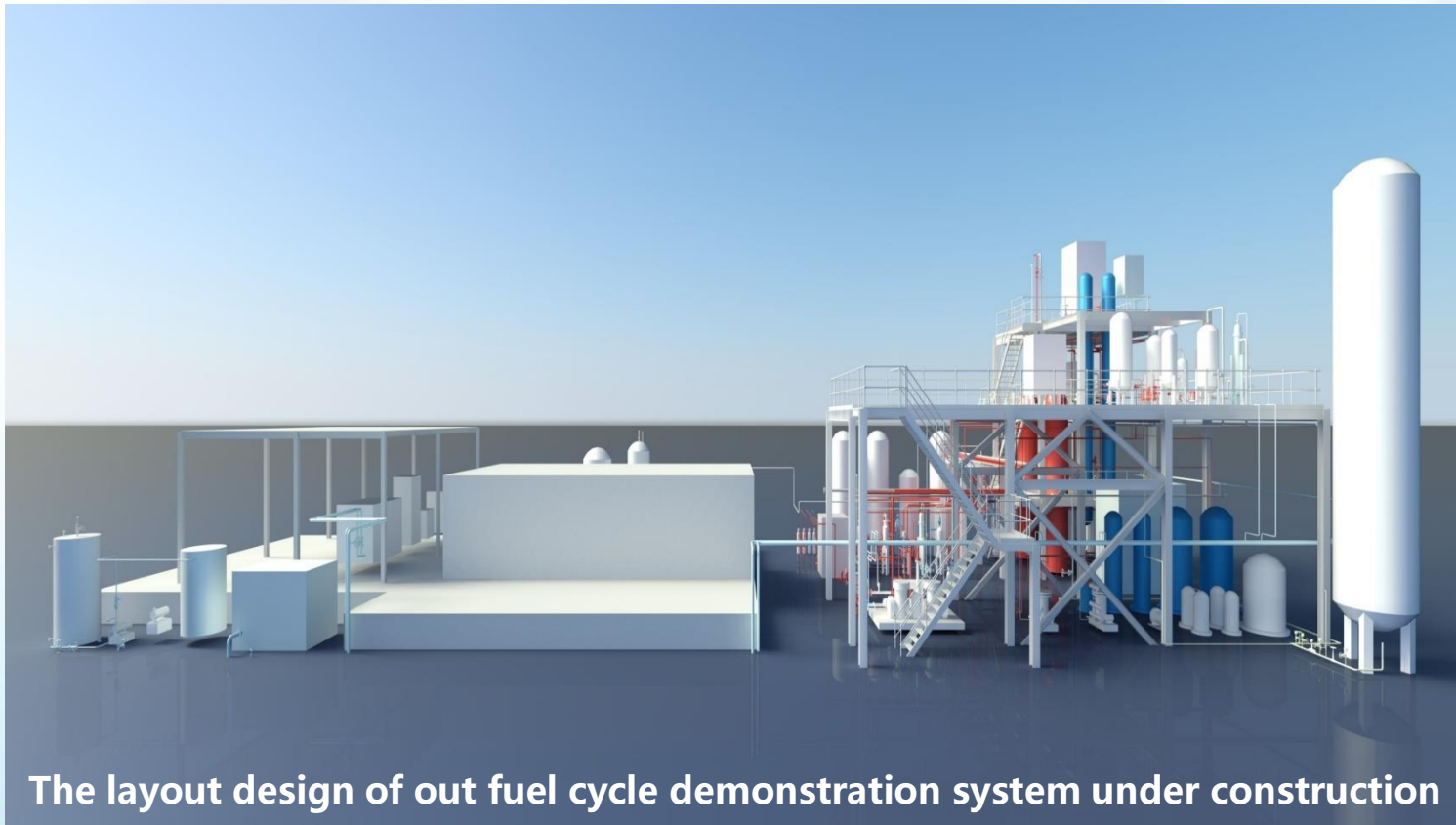
- Another in-pile irradiation of lithium ceramic and tritium extraction experiment loop was constructed in CARR reactor in CIAE.
- A series of irradiation experiments have been carried out for different lithium ceramic pellets from different universities and institutes.



In-pile irradiation of lithium ceramic and tritium extraction experiment in CIAE

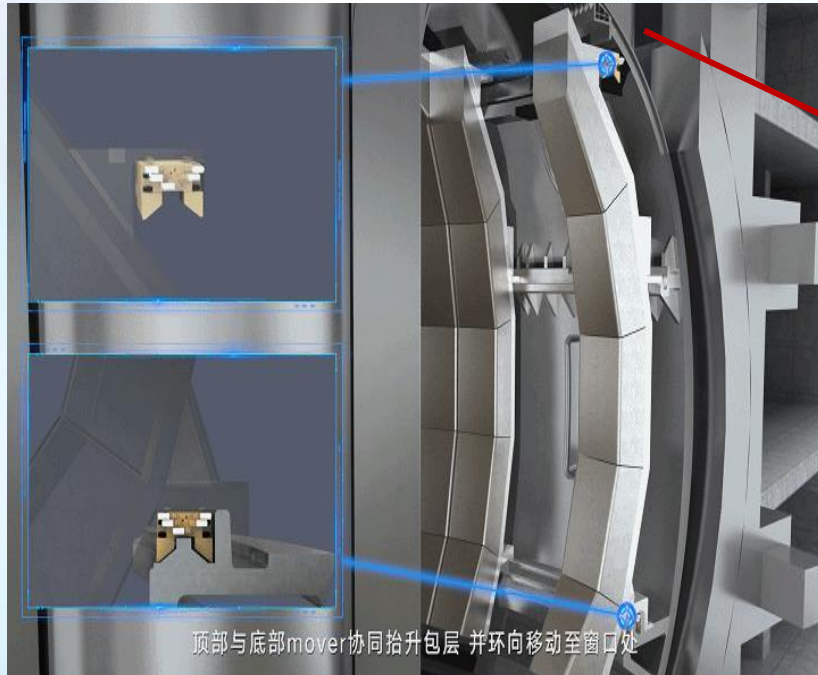
Fuel cycle

- **Outer fuel cycle system of tritium plant (@CAEP)**
 - 1:1 scale tritium plant **outer fuel cycle system** for the 200MW CFETR has been established.

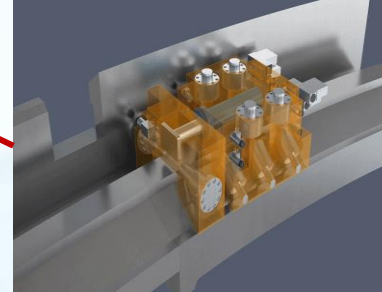


Blanket toroidal transfer system (@ASIPP)

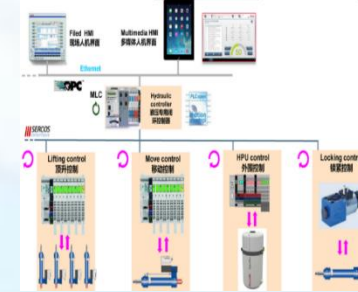
- Aiming at large load, high control accuracy and narrow operating space, the engineering design of the mover system was completed.
- Pre-research of highly integrated hydraulic system with functions of lifting, circular movement and posture adjustment of the blanket has been manufactured and functionally tested.



Blanket toroidal transfer device of Mover



R&D of Mover system



- **The technology development of tritium breeding blanket is one important part of China fusion development toward DEMO.**
- **Under support by domestic project and China TBM project organized by MOST, a lot of design and R&D activities have been implemented, also many testing facilities and platforms are constructed to support and verify the design, which will provide indispensable experience.**
- **Still a lot of challenges are on the way, the international collaborations offer effective way to bring our effort together to tackle these difficulties.**

**Thank you very much
for your attention!**

