ISFNT-15

Progress on Blanket Technology Development in China

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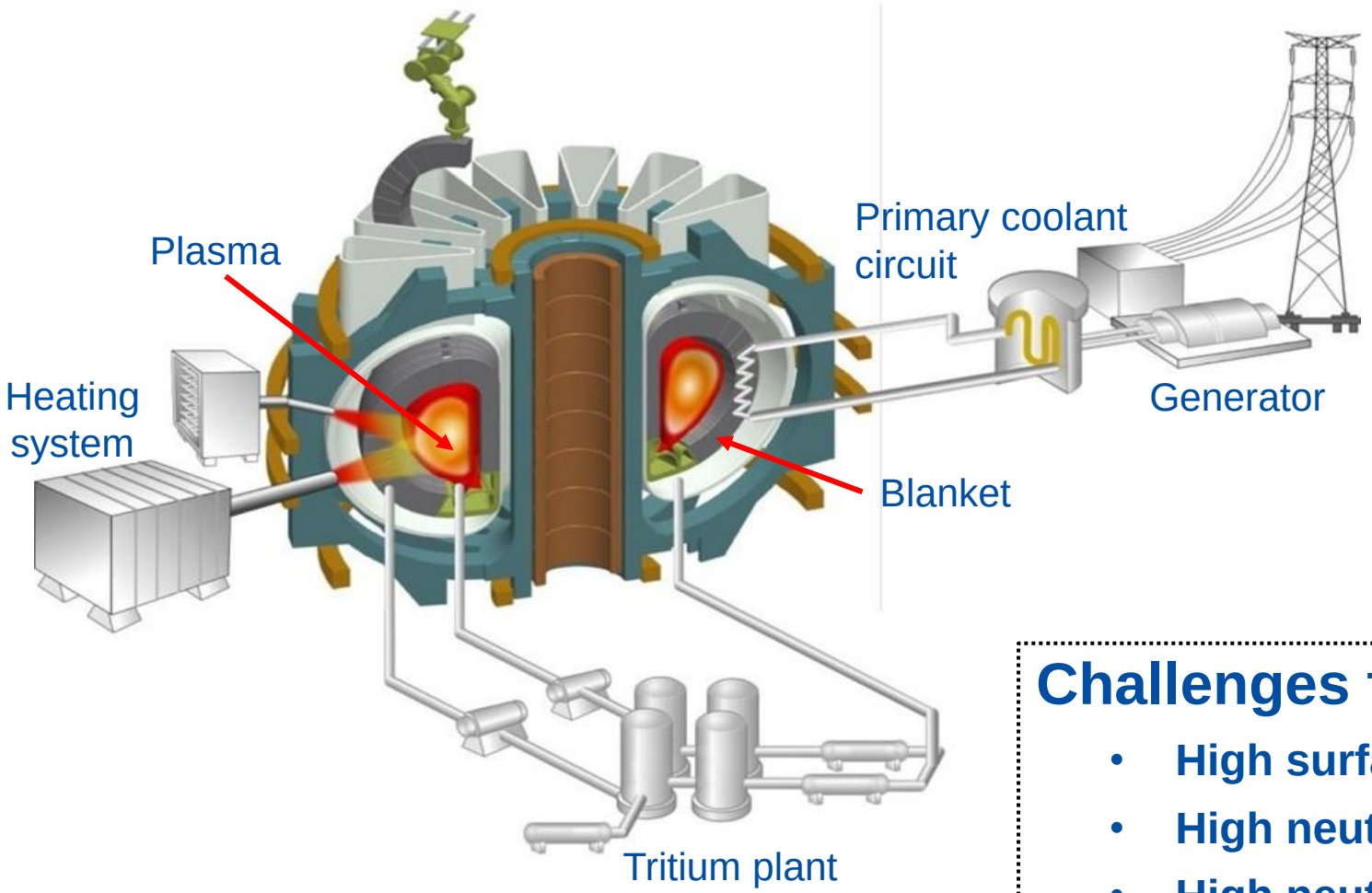
CONTENTS

1 Introduction of Tritium Breeding Blanket for Fusion Reactor

Fusion reactor and blanket



1000MW Fusion power

Burning: ~6.4g Tritium/hour
Fueling: several hundreds grams Tritium/hour

- **Tritium self-sufficiency**
- **Heat removal**
- **Radiation shielding**

Tritium Breeding Blanket

Challenges from work conditions

- **High surface heat flux: 1~2 MW/m^2 on FW**
- **High neutron wall loading: ~2.0 MW/m^2**
- **High neutron irradiation: 10~20 dpa/year in FW**
- **High magnetic field: ~7 Tesla**
- **Safety reliability**

Material Selection in Blanket

- **FW Armor: Protect blanket against high heat flux**
  - W, Be, CFC, etc.
- **Tritium Breeder: React with fusion neutron and generate tritium**
  - Li-based ceramic, Li/PbLi, FLiBe, etc.
- **Neutron Multiplier: React with fusion neutron and multiply neutrons**
  - Be/Be alloy, PbLi alloy, etc.
- **Structural Material: Keep structural integrity of Blanket under the loads of operation**
  - RAFM steel, V alloy, SiC_f/SiC, W alloy, etc.
- **Coolant: Bring heat out of blanket and transfer heat power to electrical generation loop**
  - Helium, Water, Supercritical CO_2, Liquid Li/PbLi, FLiBe, etc.
- **Shielding Material: Protect VV and superconducting coils against irradiation**
  - Steel, Water, C, etc.

Different Blanket Concepts

Concept	Abbre.	FW coolant	BZ coolant	Tritium breeder	Neutron multiplier	Structural material	Countries	To be test in ITER
Helium-cooled solid breeder	HCSB HCCB HCPB	He	He	Li_4SiO_4 Li_2TiO_3 Li_2O	Be $Be_{12}Ti$	RAFM (ODS)	CN, EU, IN, JA, KO, RF, US	√
Water-cooled solid breeder	WCCB	H_2O	H_2O				CN, JA, KO	√
Gas-cooled liquid PbLi	HCLL COOL	He/S-CO_2	He/S-CO_2	PbLi	PbLi		CN, EU, IN, RF, US	
Water-cooled liquid PbLi	WCLL	H_2O	H_2O				CN, EU	√
Dual coolant liquid PbLi	DCLL	He/H_2O	PbLi				CN, EU, JA, US	
Self-cooled molten salt		FLiBe	FLiBe	FLiBe	FLiBe		JA, US	
Dual coolant molten salt		He/H_2O	FLiBe	FLiBe	FLiBe		US	
Self-cooled liquid Li-V		Li	Li	Li	-	V alloy	JA, RF, US	
Dual coolant liquid Li-V		He/H_2O	Li	Li	-	V alloy	US	

2 China MCF Development Strategy and Blanket Development Plan

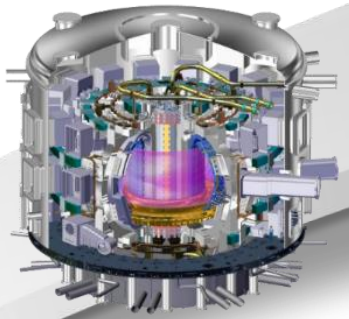
China MCF Development Strategy

Experimental Facility

HL-2M EAST J-TEXT

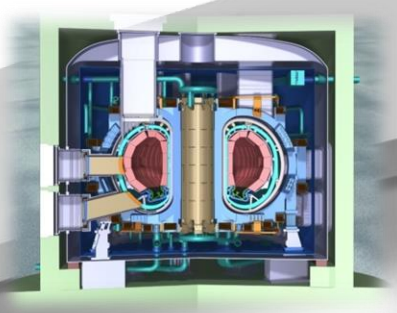
- Steady state advanced operation
- Advanced divertor, high power H&CD, diagnostics

ITER



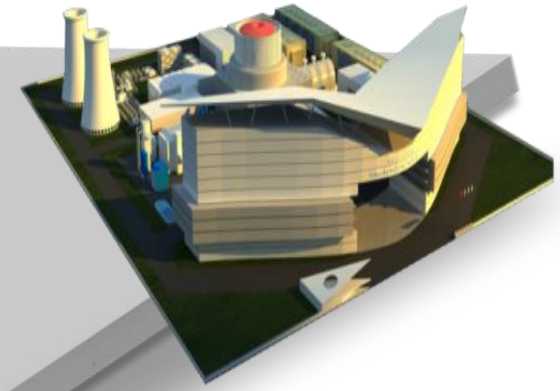
- Steady state burning plasma
- Hybrid burning plasma

CFETR/DEMO



- Fusion technology engineering validation
- Demonstration of fusion technology

PFPP



- Electricity generation into grid
- Safety, reliable, efficient

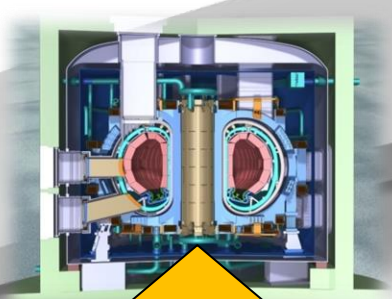
China MCF Development Strategy

China Magnetic Confinement Fusion Development

TBB Development Plan

PFPP

CFETR/DEMO



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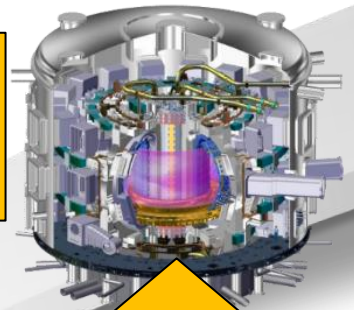


TBB Technology
Design, material, fabrication process, safety, etc.

PFPP TBB
Tritium self-sufficiency and electricity generation

CFETR/DEMO TBB
Verify engineering feasibility of Tritium breeding and electricity generation

ITER TBM
Validate technology feasibility of Tritium production and heat removal

Experimental Facility

HL-2M EAST J-TEXT

TBB Concepts and Application

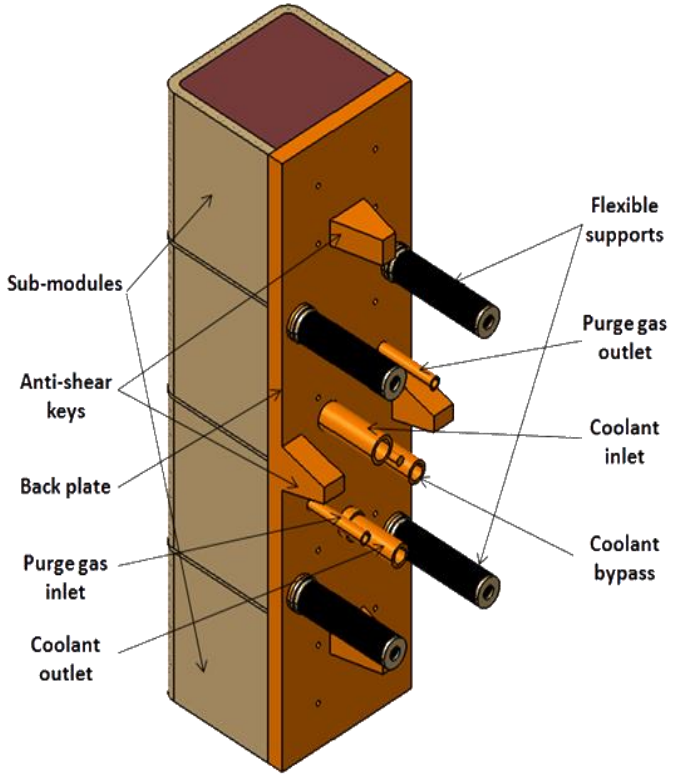
- **HCCB TBB Concept (Helium Cooled Ceramic Breeder)**
  - ITER HCCB TBM
  - CFETR HCCB TBB
- **WCCB TBB Concept (Water Cooled Ceramic Breeder)**
  - CFETR WCCB TBB
- **HCLL TBB Concept (Helium Cooled Lithium Lead)**
  - CFETR DFLL TBB
- **CCLL TBB Concept (Supercritical CO2 Cooled Lithium Lead)**
  - CFETR COOL TBB
- **Other TBB Concept**

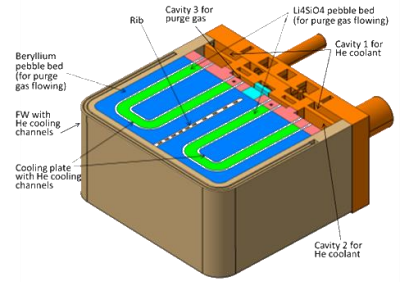
ITER HCCB TBM

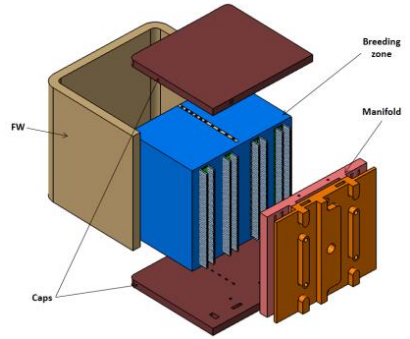
- **Basic design features:**
  - 4 sub-modules+1 back plate
  - U-shape breeding zone
- **Main parameters:**

Parameter	Design values
Neutron wall load	0.78 MW/m^2
Surface heat load	0.3 MW/m^2
Structural material	CLF-1/CLAM (~1.1 t, <550 ºC)
Tritium breeder	Li_4SiO_4 pebble bed (<900 ºC)
Neutron Multiplier	Be pebble bed (<650 ºC)
Coolant	He (8 MPa, 1.04 kg/s) FW (300 ºC/390 ºC) BU (390 ºC/500 ºC)
Purge gas	He+0.1%H_2 (0.3 MPa, 0.3 g/s, 20 ºC/400 ºC)

@SWIP







CFETR HCCB TBB

- **Basic design features:**
  - “Banana” segment design compatible with RH
  - Several blanket modules in each segment
  - Blanket module consist breeding zone and shielding zone
  - Blanket modules connected at shielding zone or by back plate to form segment
  - Tritium breeder and neutron multiplier in alternation ranking
- **Material selection:**
  - FW armor: W / W alloy
  - Structural: ODS FS
  - Tritium Breeder: Li_4SiO_4 / Li_2TiO_3
  - Neutron Multiplier: Be / Be alloy
- **Design parameters:**
  - Coolant: He@12MPa
  - Purge gas: He(0.1%H_2)@0.3MPa

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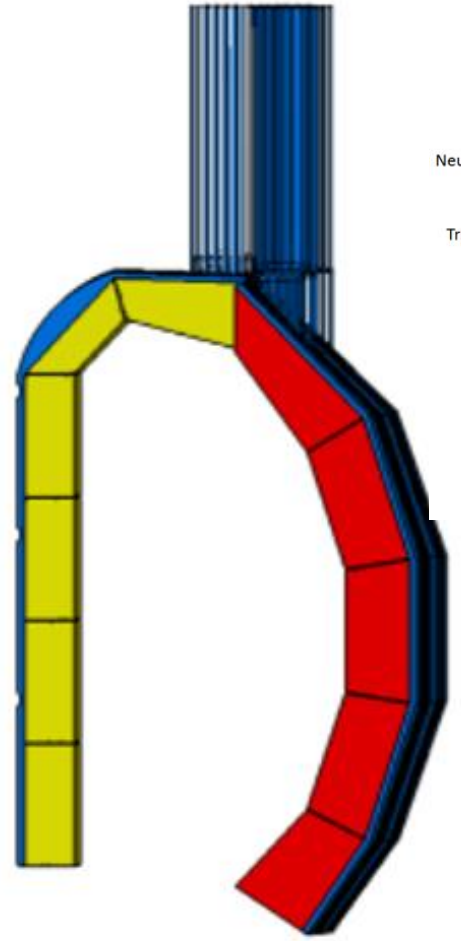
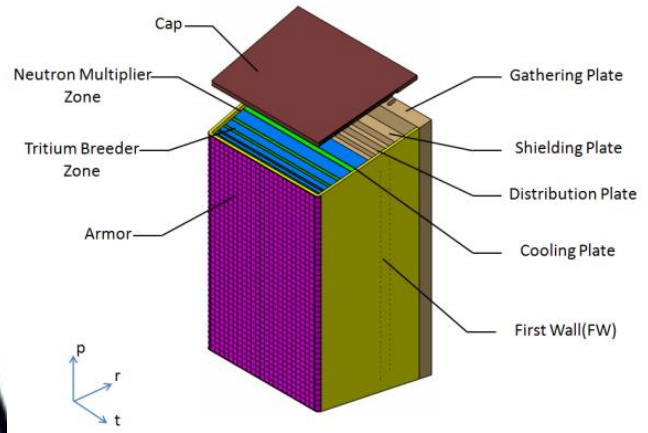
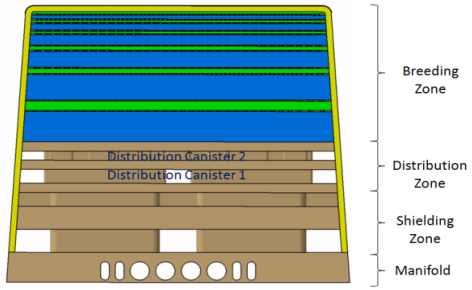


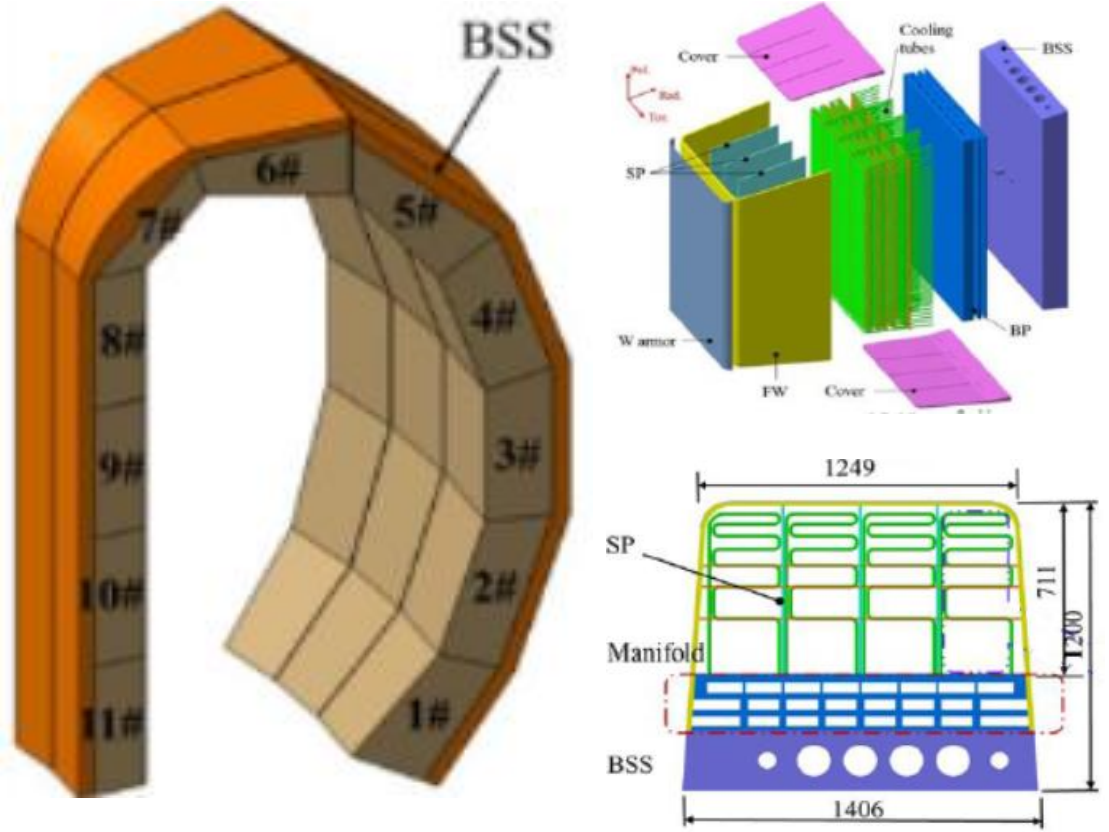




CFETR WCCB TBB

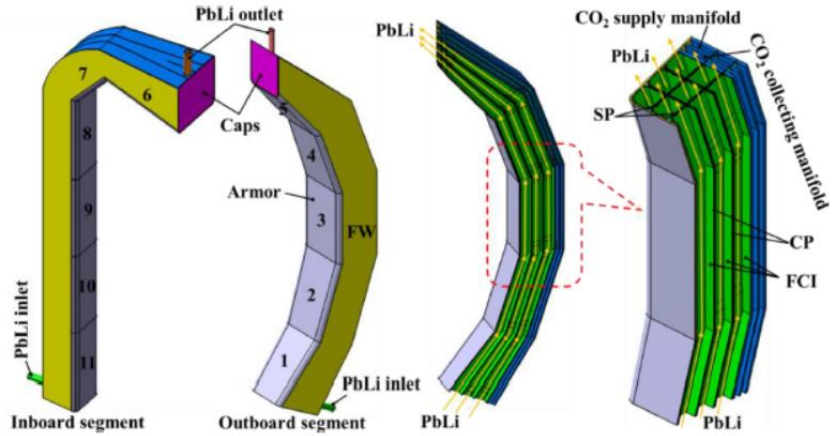
- **Basic design features:**
  - 2 inboard segments and 3 outboard segments in one sector
  - 6 blanket modules in each inboard segment
  - 5 blanket modules in each outboard segment
  - S-shape double-wall tubes (DWT) in breeding zone with mixture of Li_2TiO_3 and $Be_{12}Ti$ pebbles
  - Stiffening plates for enhancing structure
- **Material selection:**
  - FW armor: W
  - Structural material: RAFM-ODS steel
  - Tritium breeder: Li_2TiO_3
  - Neutron multiplier: $Be_{12}Ti$
- **Design parameters:**
  - Coolant: Water@15.5MPa，285/325℃
  - Purge gas: He(0.1%H_2)@0.2MPa

@ASIPP



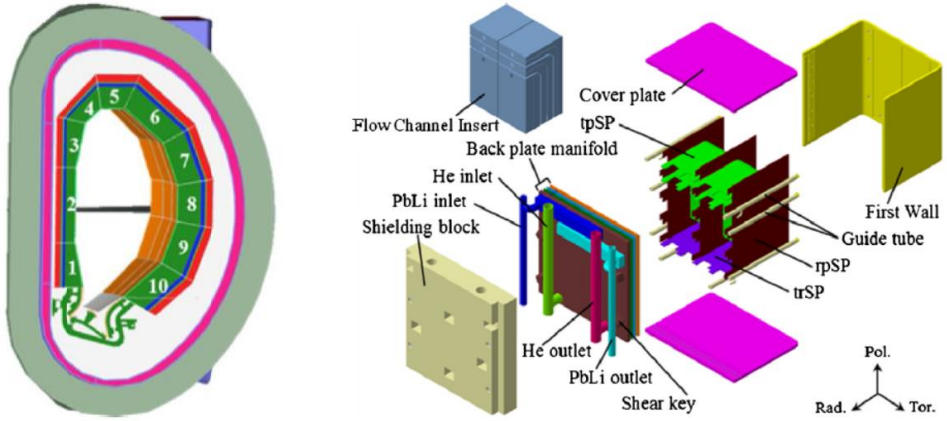
CFETR COOL/DFLL TBB

➢COOL blanket (@ASIPP, @SWIP):



- **Basic design features:**
  - BZ divided by CPs and SPs
  - PbLi flow along poloidal parallel channels
  - FCI to reduce the MHD-induced pressure drop and decrease the temperature of steel structures
- **Design parameters:**
  - Coolant: S-CO_2@8MPa
  - Tritium breeder: PbLi@1~2MPa,460/600~700℃

➢DFLL blanket (@INEST):



- **Basic design features:**
  - Blanket divided into two parts: tritium breeding module (replaceable) and shielding block (permanent)
  - BZ separated by SPs
  - FCI serve as thermal and electrical insulators
- **Design parameters:**
  - Coolant: He@8MPa, 300/450℃
  - Tritium breeder: PbLi@480/700℃ or 450℃

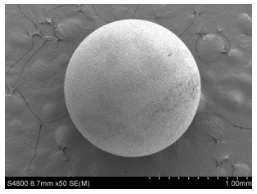
3 Blanket Materials and Fabrication R&D Progress

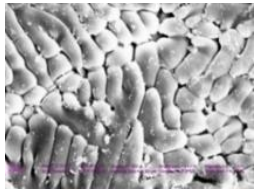
Tritium Breeder Development

- **Currently focus on lithium ceramic breeder**
  - Melt spray method manufacturing equipment: up to small-scale, 200 kg/year.
  - Other wet processes facility: up to laboratory-scale.
  - New advanced tritium breeder materials: under development by universities and institutes.

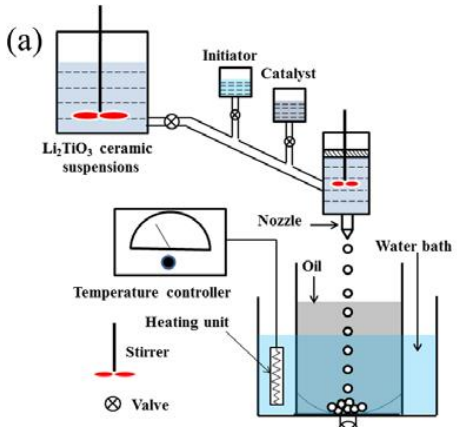
Plan

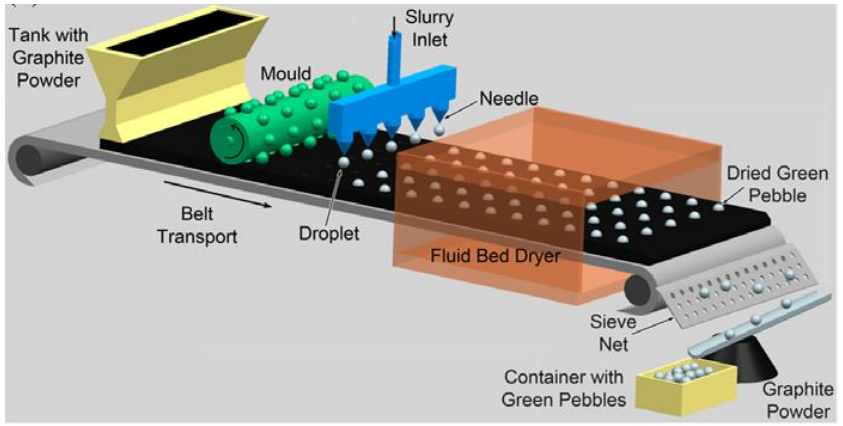
- Low-cost large-scale fabrication facility (ton level);
- Lithium-6 recycling technology and advanced tritium breeder.





Melt spray method facility @SWIP





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

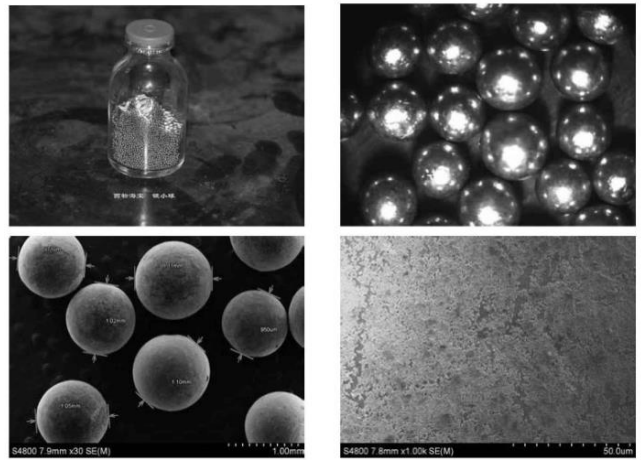
Neutron Multiplier Development

- **Currently focus on Be-based neutron multiplier (@SWIP & Haibao)**
  - Rotating electrode method beryllium pellet manufacturing equipment: achieve small batch production, 10 kg/batch.
  - Advanced multiplier beryllide: 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 REM



Topography of beryllium @SWIP

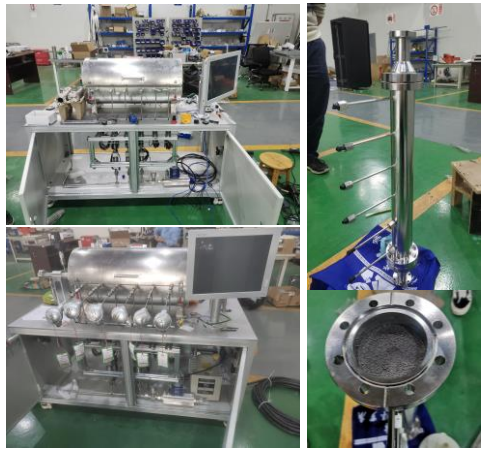
Pebble Bed Technology Development

- **A series of pebble bed experiment facility has been constructed (@SWIP)**
  - Covering thermo-physical, thermal mechanical, multi-physics 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 testing

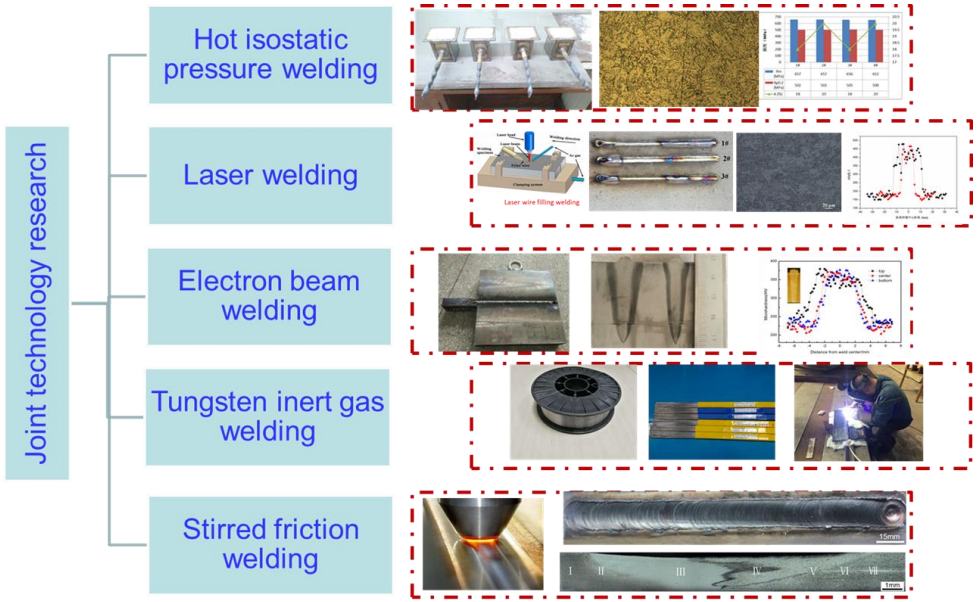
Thermal mechanical testing with compress load

Thermophysical property testing facility

Structural Material Development

- **RAFM steel and advanced structural materials:**
  - RAFM steel (CLF-1 and CLAM): Industrial fabrication process and material database have been established, including welding database.
  - Advanced materials (ODS, TMT, CNA, vanadium alloy): under development at laboratory scale.

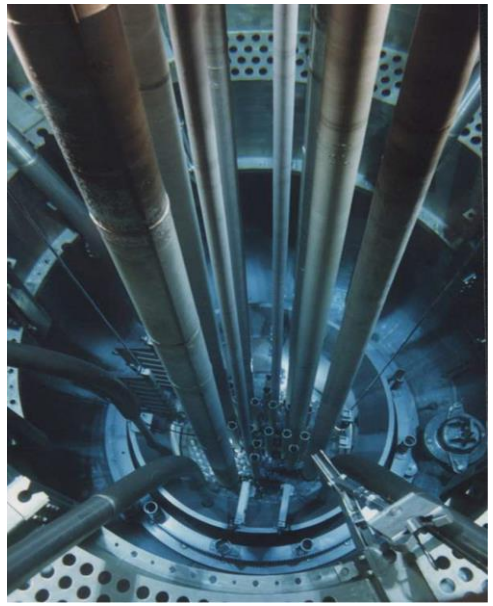
RAFM steel development (@SWIP, @INEST)



RAFM steel welding technology development (@SWIP , @INEST)

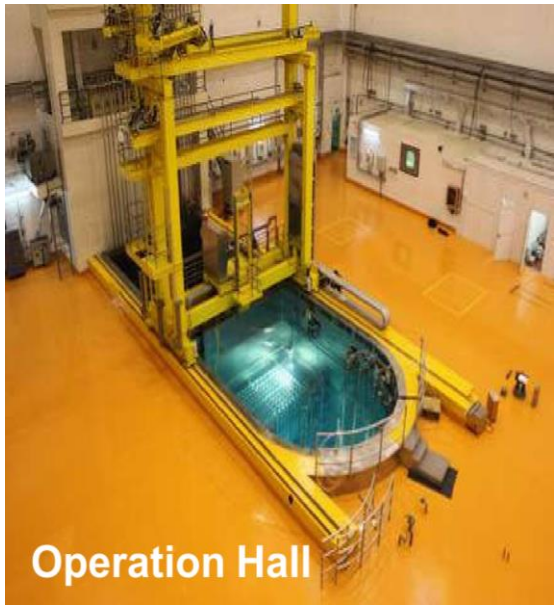
Irradiation of Material

- **Focus on irradiation performance study**
  - Fission reactors have been used for irradiation of functional materials and structural materials.
  - PIE will carried out for mechanical properties and tritium related performance

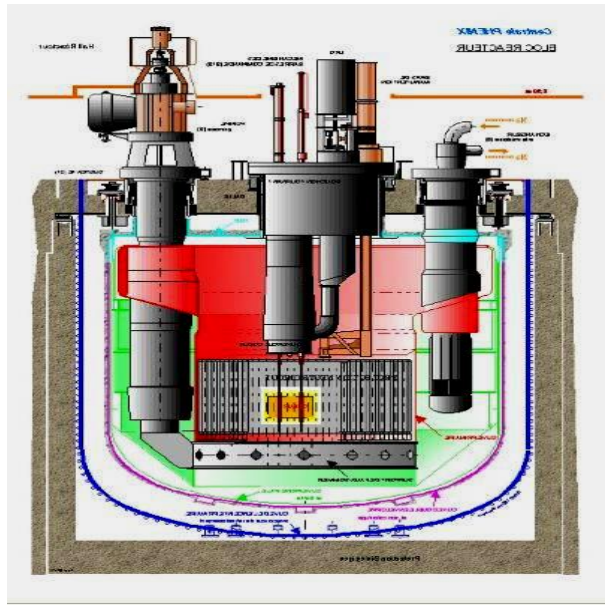


HFETR
(@NPIC)

CMRR
(@CAEP)



CARR
(@CIAE)



CEFR
(@CIAE)

Irradiation of Material

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

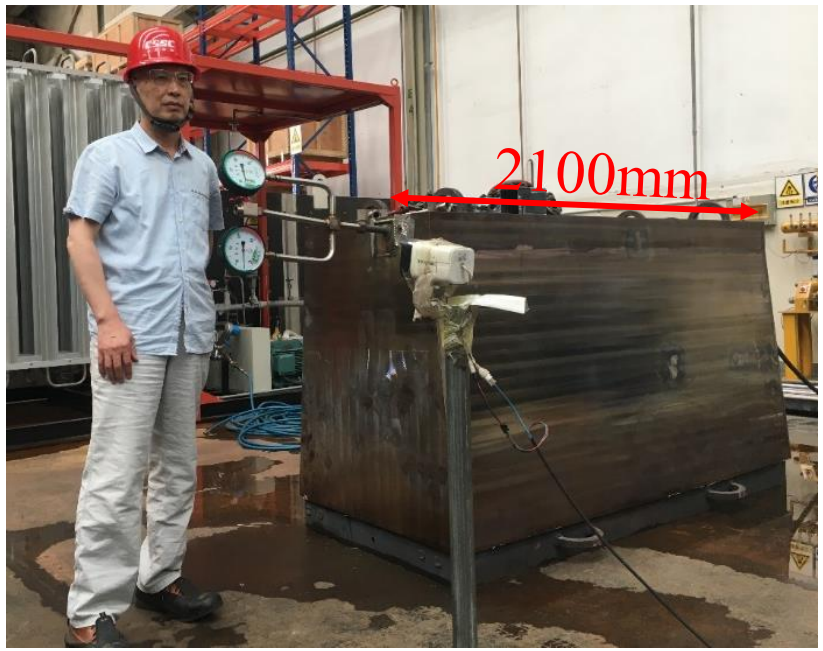
D-T neutron sources (~$10^{11}s^{-1}$)
(@CAEP)

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

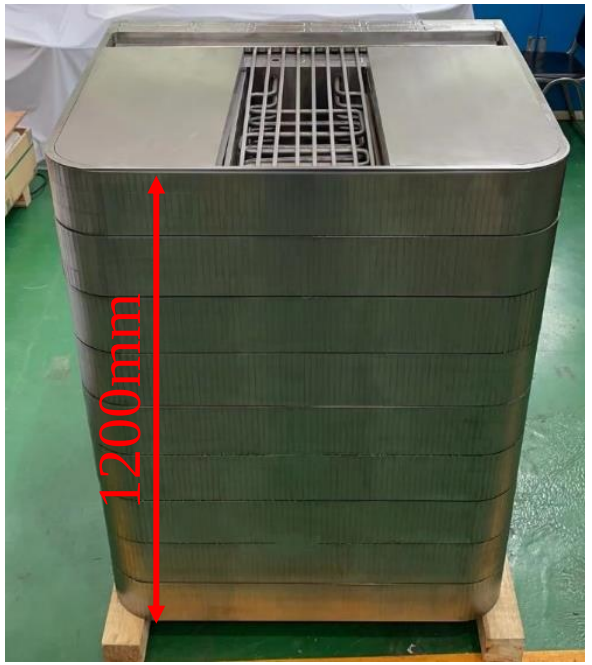
Blanket Fabrication Technology Development

- **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



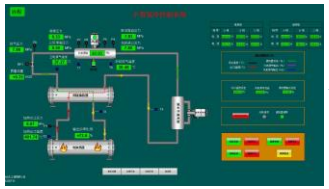
Large size outboard CFETR WCCB blanket module

4 Blanket Test Platform Development Progress

Blanket Test Platforms

- **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.

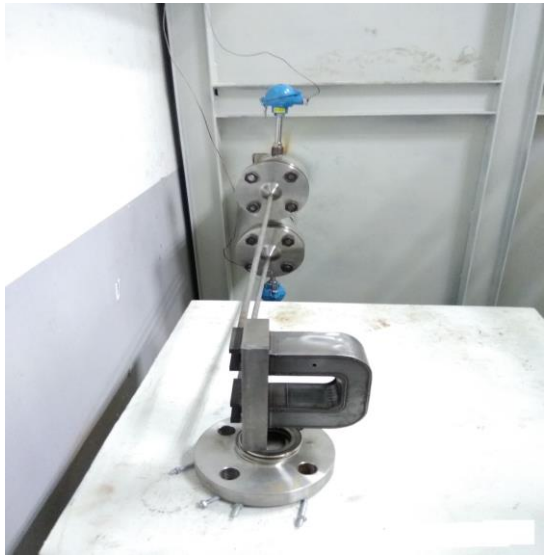
HHFT facility EMS-60



Control system
& ITER Mini-CODAC

He

HeCEL-1
(0.1kg/s, 8MPa, 400℃)



Hydraulic testing

High heat flux testing

Blanket Test Platforms

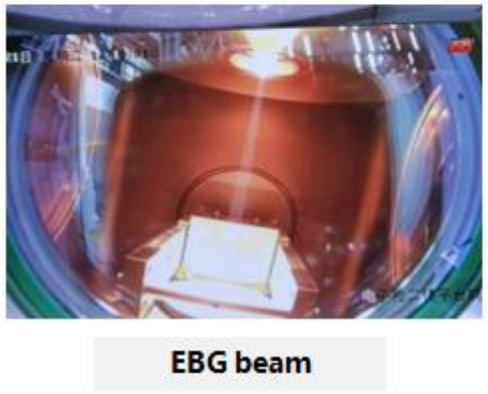
- **Helium cooling (@SWIP)**
  - New helium cooling experiment loop HeCEL-3 was constructed for the thermohydraulic testing of prototype blanket of CFETR and accident experiments.
  - HeCEL-3 is planned to connect with 400/800kW high heat flux facility.

HeCEL-3 (2.5kg/s, 12MPa, 550℃)

EMS-400 High Heat Flux Testing facility

Blanket Test Platforms

- **Water cooling (@ASIPP)**
  - Thermal Hydraulic Test Platform for WCCB BLK and DIV
    - High heat load test (WCCB blanket prototype, divertor target)
    - WCCB blanket thermal fluid experiment



High heat flux test facility

High temperature and high pressure water loop

Water loop

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

Vacuum Vessel Dimensions

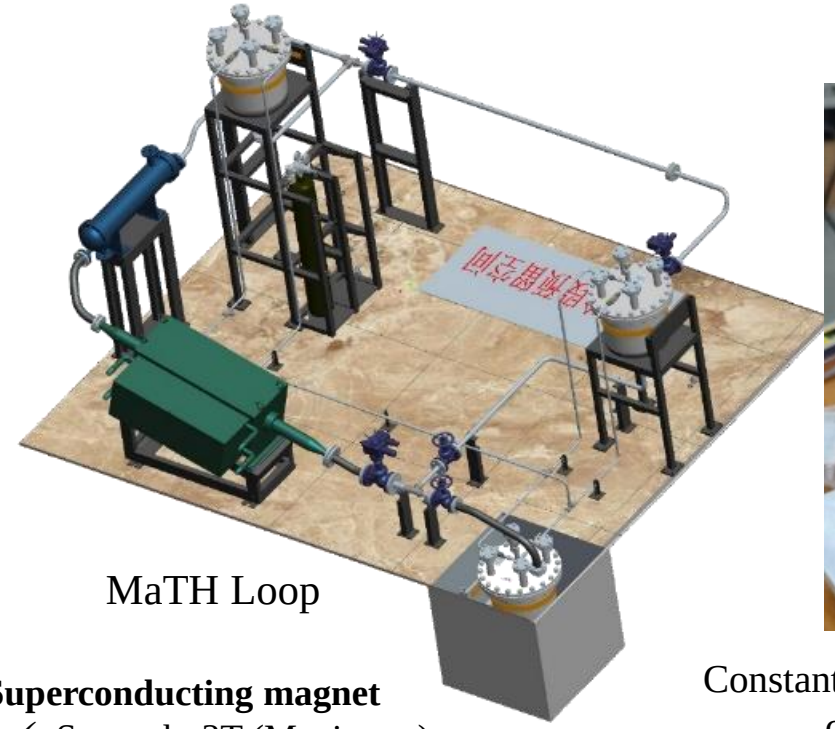
Diameter: 3m

Length: 4m

EBG
800kW，60kV
60kW，150kV

Blanket Test Platforms

- **Liquid metal cooling (@UCAS)**
  - MaTH (Magneto-Thermo-Hydrodynamic) loop
    - Flow and heat transfer, Magneto-convective fluctuations
    - MHD pressure drop, Couple MHD effect of multi-channel

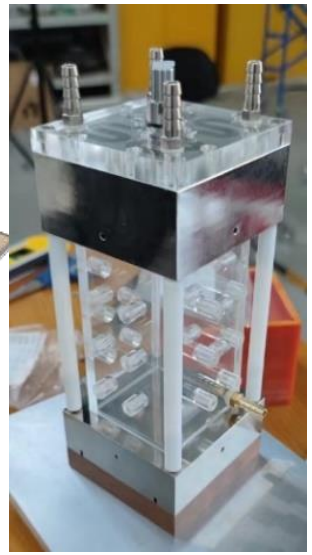


MaTH Loop

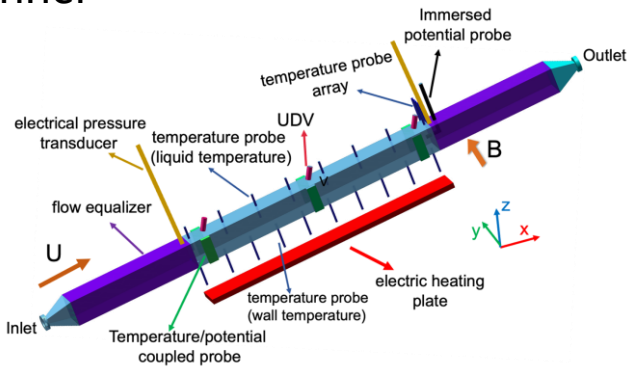
Superconducting magnet

✓ Strength: 3T (Maximum)

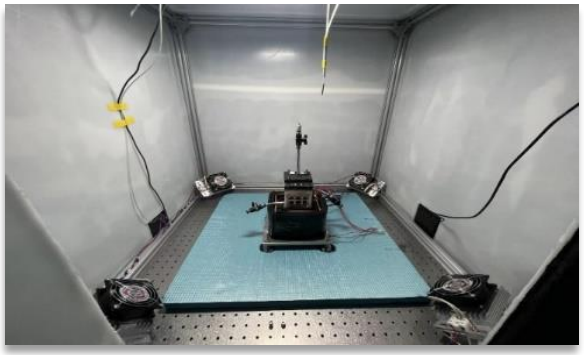
✓ Field area: 300X320X1000mm^3

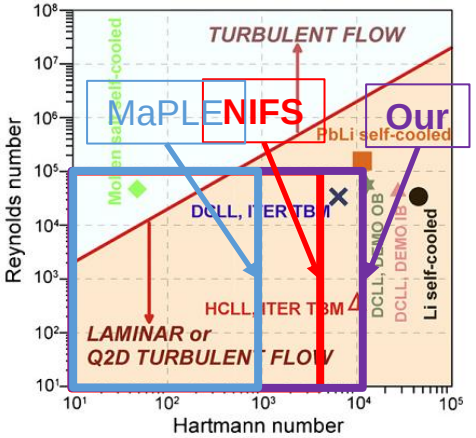


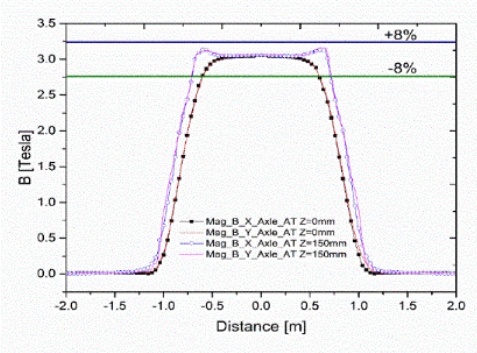
Constant temperature system and convection cavity



Mixed convection test section



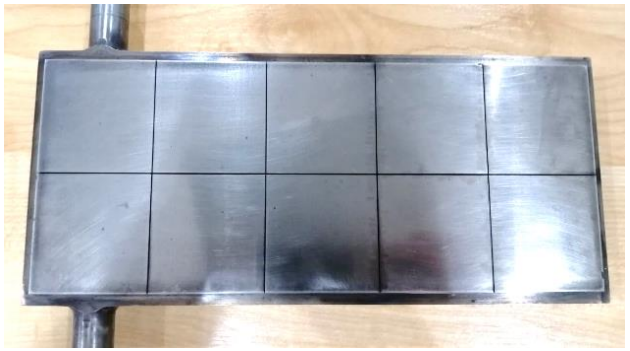


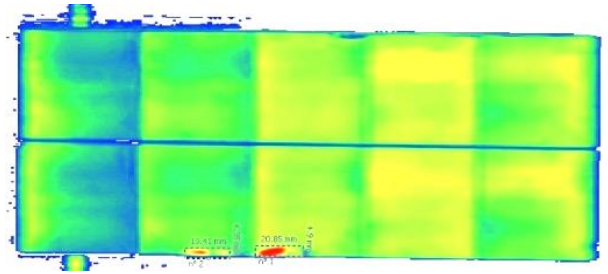


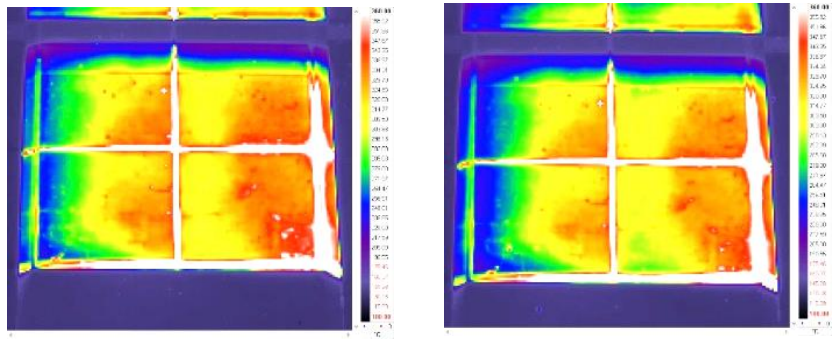
Blanket Test Platforms

- **Mostly based on cooling loop for thermohydraulic testing**
  - Also connect with high heat flux testing facility (@SWIP)
- **The multi-physics 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 1MW/m^2

5 Summary

Summary and outlook

- 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 related to the various blanket concepts 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 efforts together to tackle these difficulties.

Thanks for your attention!