Development Status of ITER HCCB TBS and CFETR HCCB TBB

Xiaoyu WANG
On behalf of China HCCB TBB Team

Outline

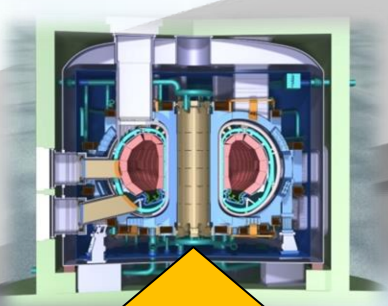
- China MCF Roadmap & TBB Development Strategy
- CN HCCB TBS Design for ITER
- CFETR HCCB TBB System Design
- TBB R&D activities
- Summary

China MCF Development Roadmap

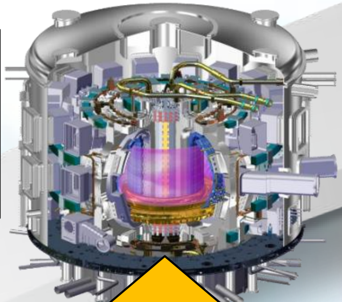
China Magnetic Confinement Fusion Development Roadmap ⇨ **TBB Development Strategy**

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

Experimental Facility

HL-2M EAST J-TEXT

ITER TBM
Validate technology feasibility of T production and heat removal

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)**
  - Advanced concept for future

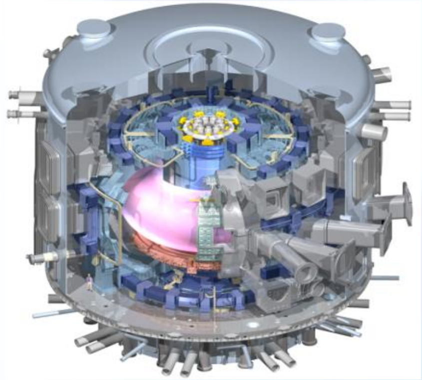
CN HCCB TBS Design

(For ITER TBM)

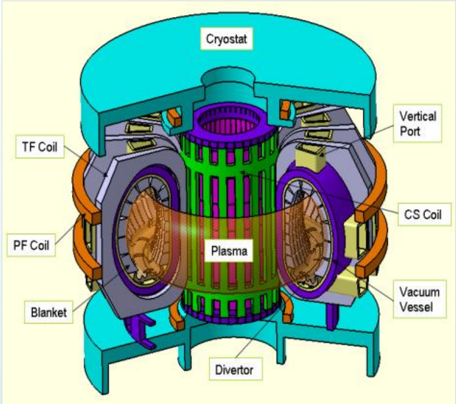
CN TBM program: *Helium Cooled Ceramic Breeder Test Blanket System (HCCB TBS)*
Leaded by CN DA
Supporting Institutes:
1). Southwestern Institute of Physics (SWIP)
2). China Academy of Engineering Physics (CAEP)
3). Institute of Nuclear Energy Safety Technology(INEST)

CN HCCB TBS for ITER

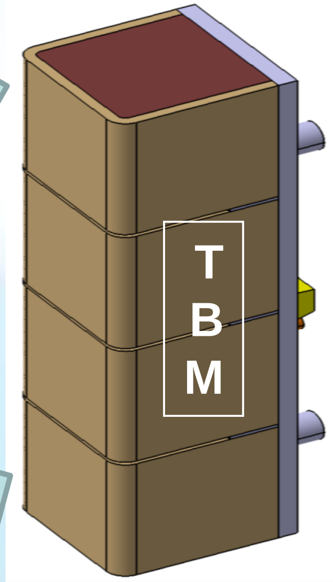
The objectives of CN HCCB TBS is to test the feasibility of tritium breeding blanket technology in the tokamak operation conditions provided by ITER.



ITER



HCCB DEMO



HCCB TBM

General Objectives

- Tritium technology
- Integral performance
- Power removal
- Diagnostics and control
- Safety
- Maintenance
- PIE

CN HCCB TBS schematic layout

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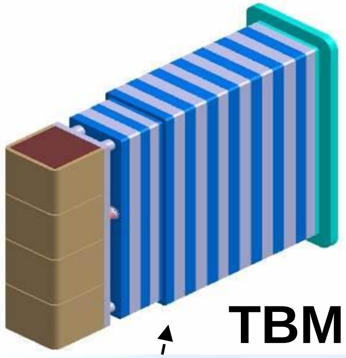
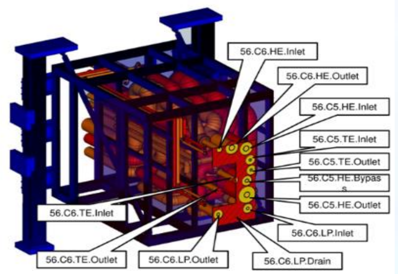
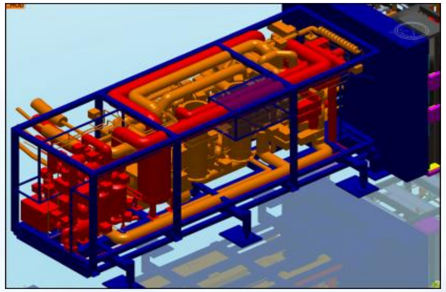


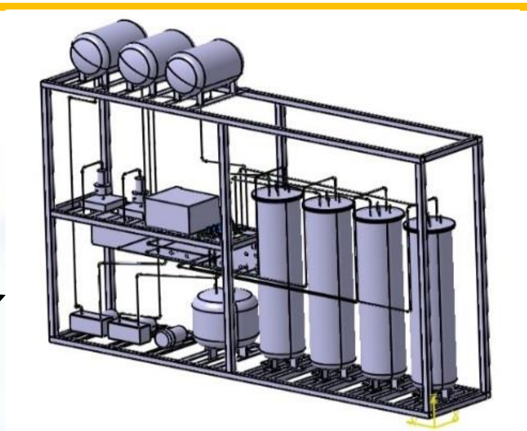
TBM set



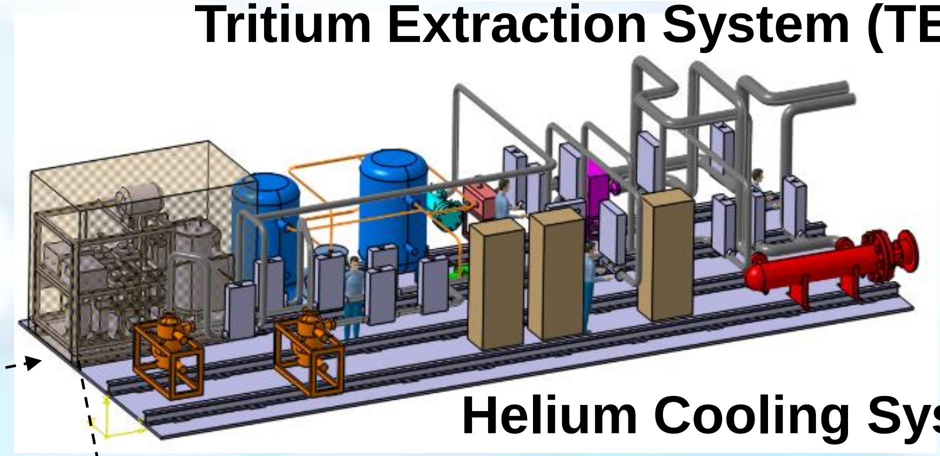
Pipe Forest (PF)



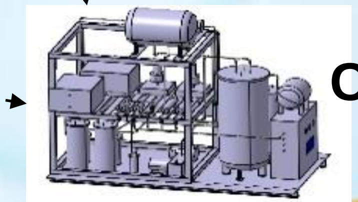
Ancillary Equipment Unit



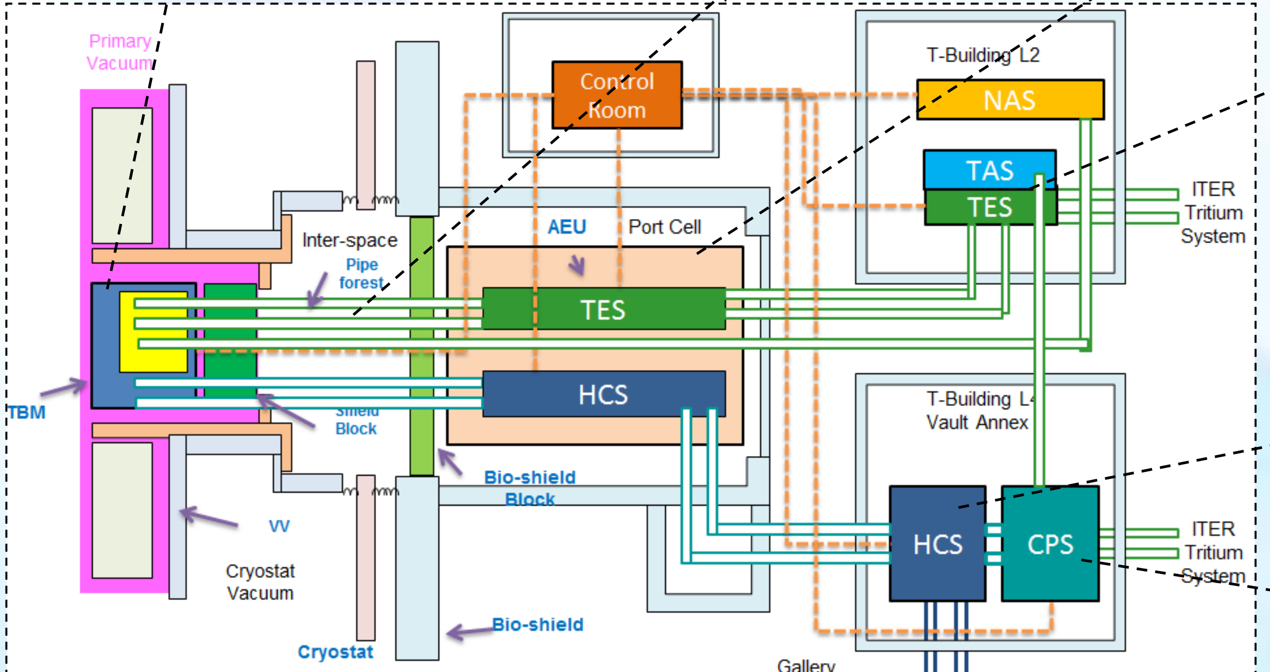
Tritium Extraction System (TES)



Helium Cooling System (HCS)



Coolant Purification System (CPS)

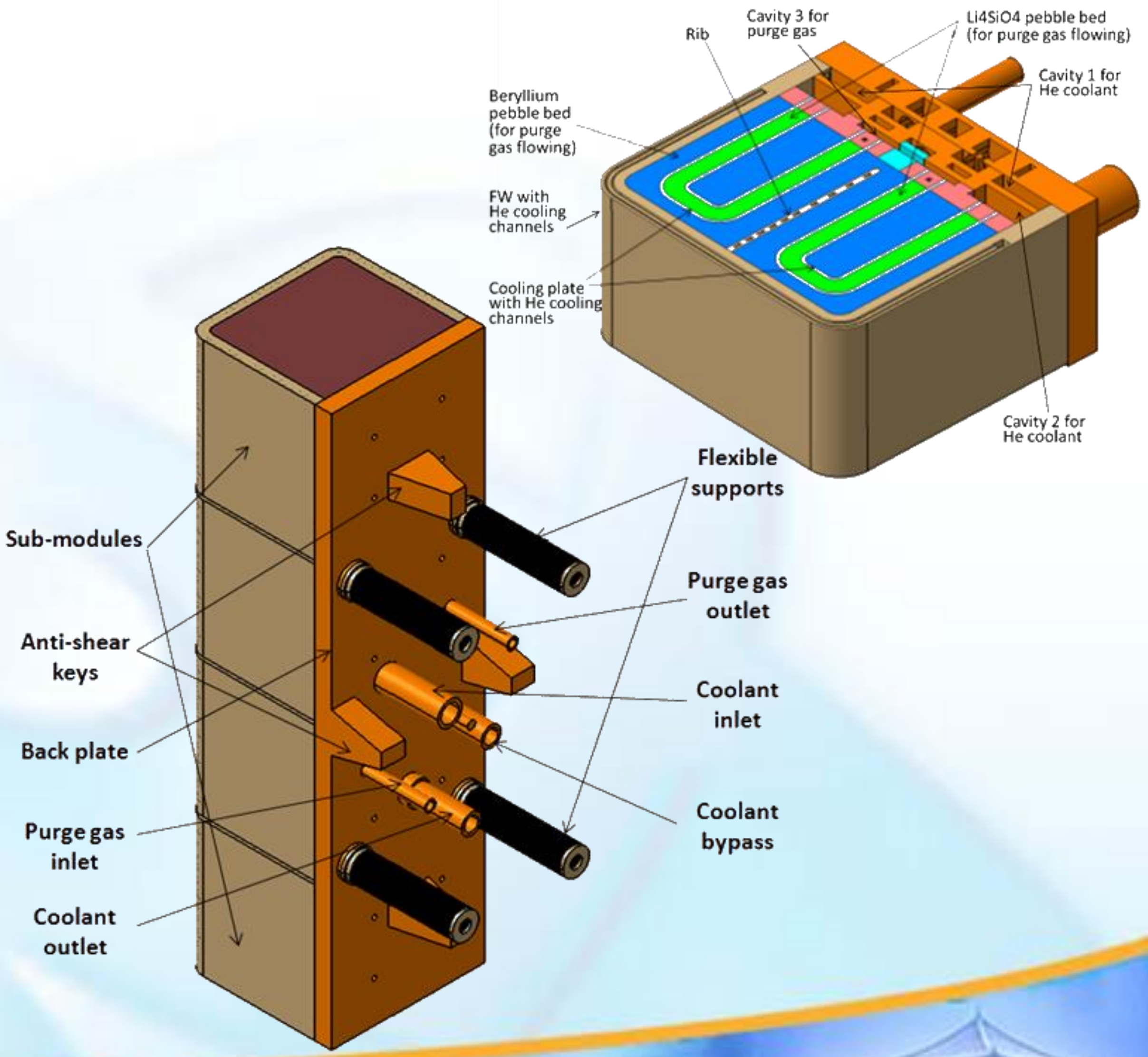


HCCB TBS Schematic

CN HCCB TBS for ITER – TBM module

Main design parameters

Parameters	Values
Neutron wall load	0.78 MW/m^2
Surface heat flux	0.3 MW/m^2
Structural material	CLAM/CLF-1 ~1.2ton (<550ºC)
Tritium Breeder	Li_4SiO_4 pebble bed (<900ºC)
Neutron Multiplier	Beryllium pebble bed (<650ºC)
Coolant	Helium (8MPa) 1.04 kg/s (300ºC/500ºC)
Purge gas	Helium (0.3MPa) with 0.1% H_2
TPR	61mg/FPD



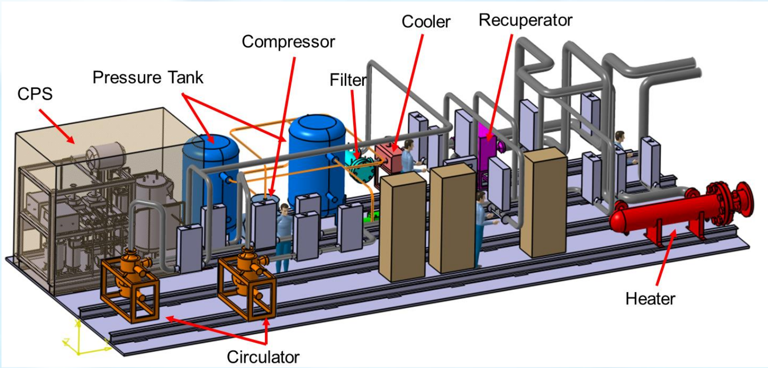
CN HCCB TBS for ITER - Ancillary Systems

Main design parameters

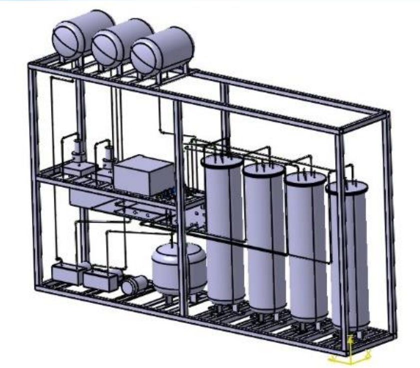
Parameters	Values (HCS)
Main structural material Supporting structure material	SS316L SS304
Primary coolant circuit - Pressure - Total flow rate - Pressure drop - Inlet/outlet temperature	Helium 8 MPa 1.04 kg/s ~0.5 MPa 500ºC/300ºC
Interface with CCWS - Pressure - Total low rate - Inlet/outlet temperature	Water 0.8 MPa 21.3 kg/s 31ºC/43ºC
Tritium related system	**Values (TES, CPS)**
- Purge gas - T purification efficiency - Impurity removal efficiency - T extraction efficiency	He with 0.1% H_2 ≥ 95% ≥ 90% ≥ 90%

The design of all ancillary systems have been optimized considering the system performance, safety and interface requirements:

- Configuration update based on equipment investigation, PFD and PID diagrams
- System performance assessment, structural analysis, accident analysis



HCS Design



TES Design

CN HCCB TBS for ITER - Ancillary Systems

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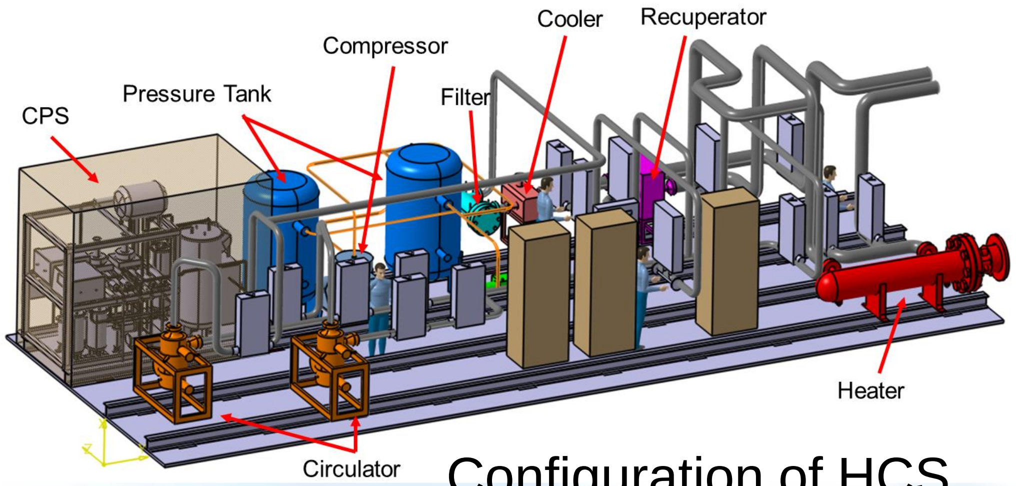
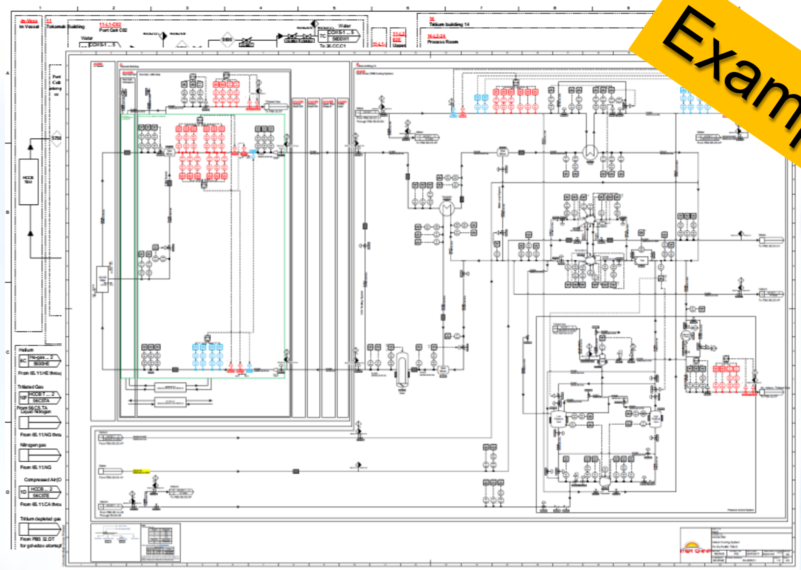


Configuration of HCS

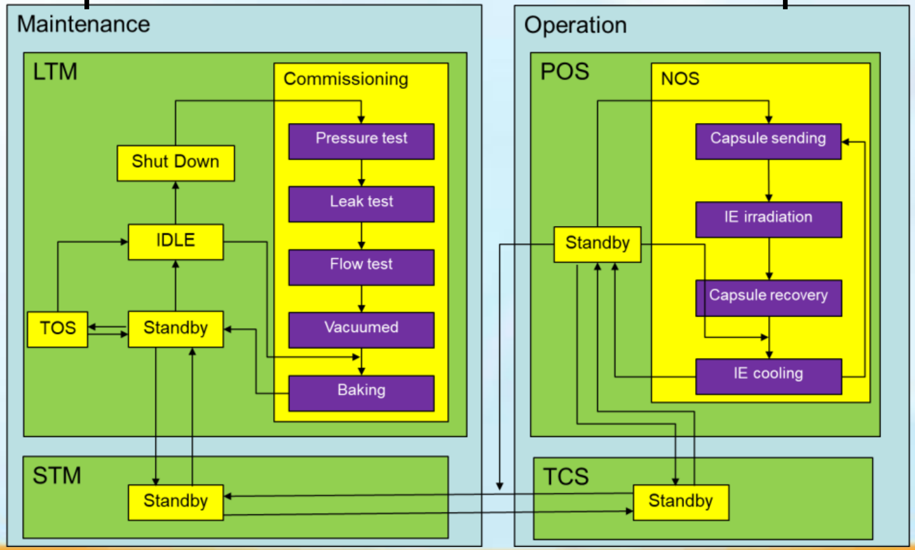


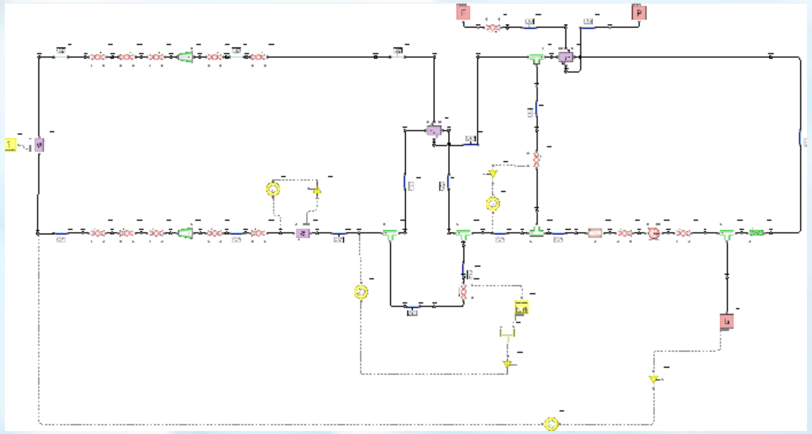
PFD and PID

Example for all ancillary systems

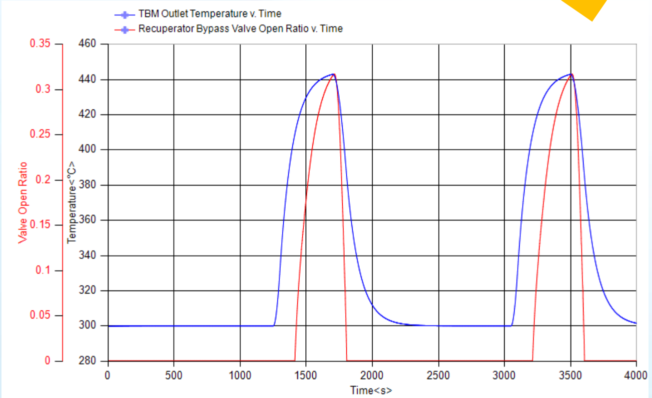
TBM Outlet Tempera... Plasma Pulse

Operation states and transition path





Performance analysis model for HCS

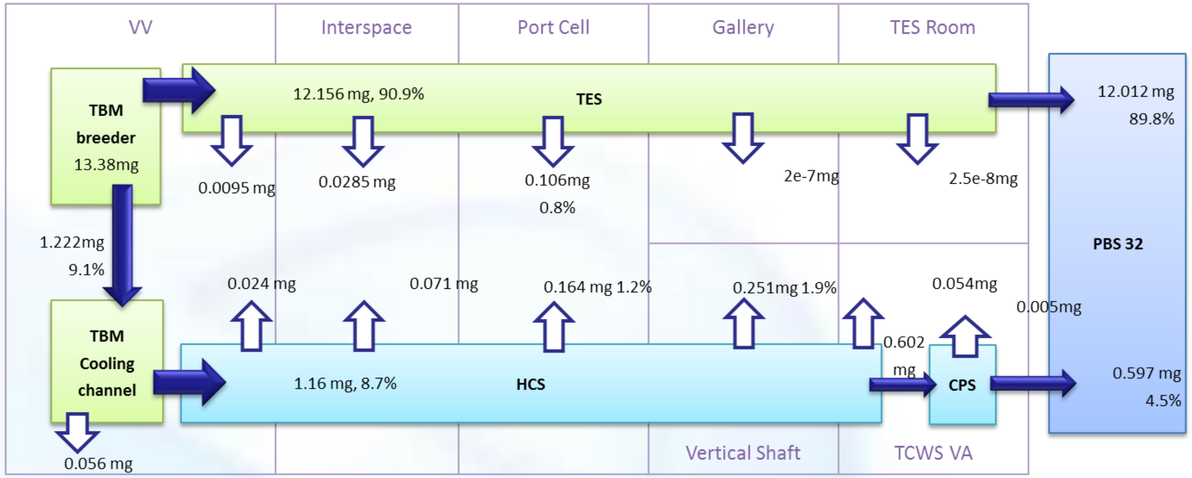


Bypass Valve Open Ratio vs. TBM Outlet Temperature

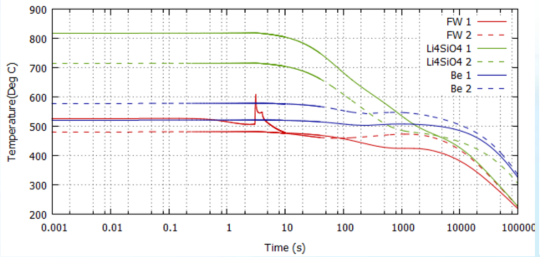
CN HCCB TBS for ITER - Safety

The safety work covers the whole design activities of all subsystems.

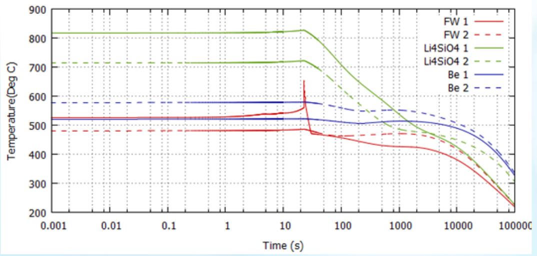
- Design description and safety function
- Nuclear analysis
- Tritium analysis
- Accident analysis
- Other analysis



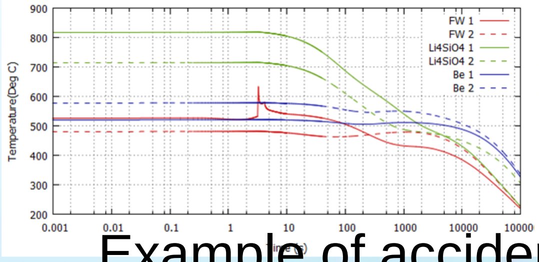
Example of tritium release results



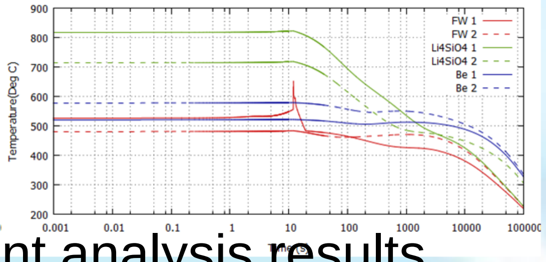
Temperature of CN HCCB TBM during large break area (LOCA in Port Cell)



Temperature of CN HCCB TBM during small break area (LOCA in Port Cell)

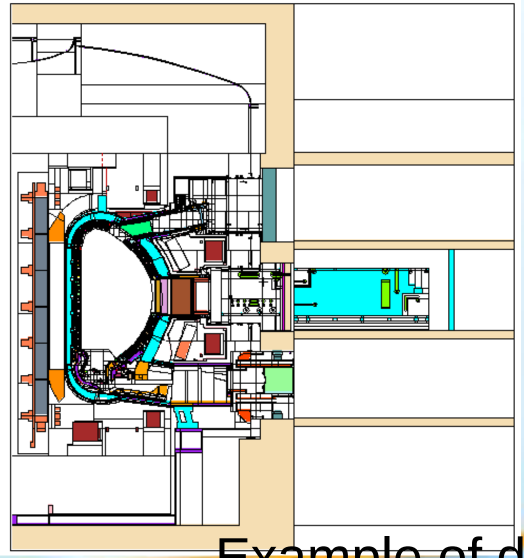


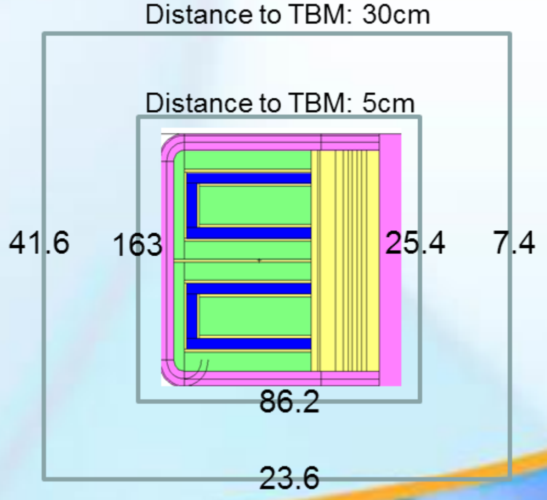
Temperature of CN HCCB TBM during large break area (LOCA in TCWS Vault)



Temperature of CN HCCB TBM during small break area (LOCA in TCWS Vault)

Example of accident analysis results





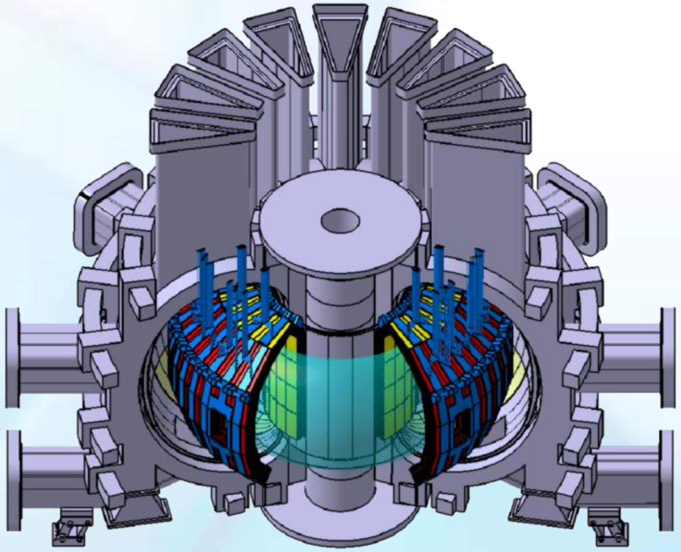
SDDR results for HCCB TBM (1d, Sv/h)

Example of dose rate results

In collaboration with **Dr. Brad Merrill, Idaho National Laboratory (INL), USA.**

CFETR HCCB TBB System Design

(For CFETR)



CFETR program: *Chinese Fusion Engineering Testing Reactor (CFETR)*
Supported by MOST of China
Main Supporting Institutions :
1). University of Science and Technology of China（USTC）
2). Southwestern Institute of Physics (SWIP)
3). Institute of Plasma Physics，Chinese Academy of Sciences（ASIPP）
4). China Academy of Engineering Physics (CAEP)
5). China Nuclear Power Engineering Co.,LTD. (CNPE)

CFETR Mission

Obtained Burning Plasma for fusion power

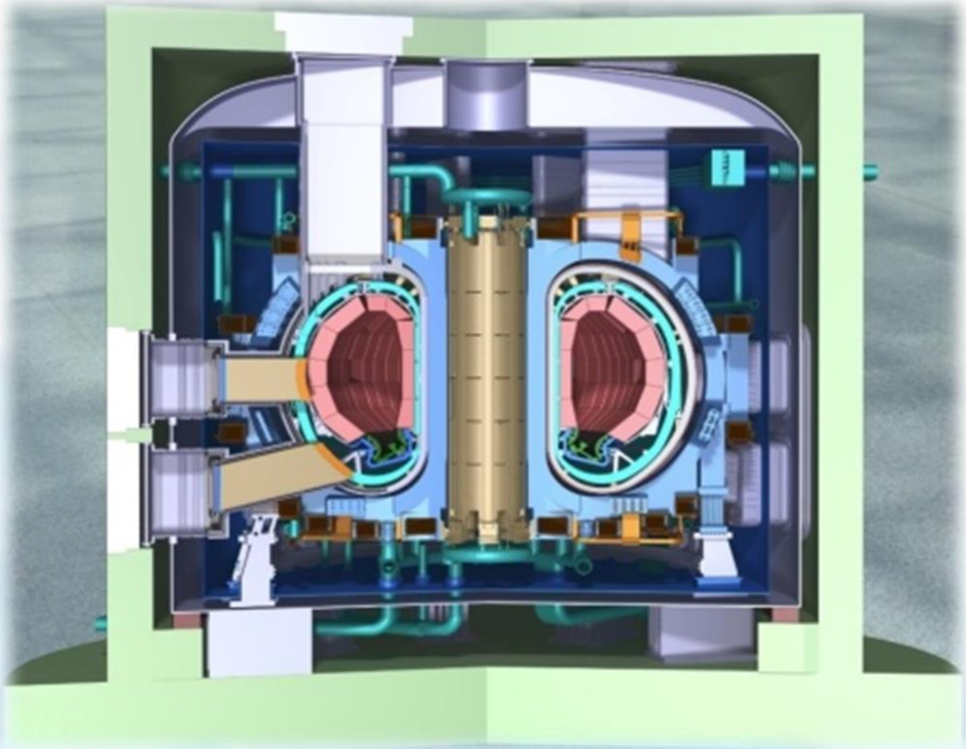
1. P=200-2000MW
2. Q=1-10，SSO， hours
3. Q=20-30 hours-SSO
4. High energetic α heating

Steady-state operation for fusion energy

1. Hybrid（OH+BS+CD)
2. SSO（Ext H&CD +Higher f_b)
3. PSI on the first wall
4. Heat & particle exhaust on Div.

Breeding Tritium for T self-sufficiency

1. T-breeding by blanket
2. T-plant: extract & reprocessing
3. Materials & components
4. Reliable and quick RH
5. Licensing & safety



CFETR

Design Objectives of CFETR HCCB TBBS

Neutron shielding

- Together with other CCSs to provide radiation protection

Heating removal

- High T, High P, Helium Cooling Loop
- Heat exchange with secondary Loop

Structural integrity, compatibility and reliability

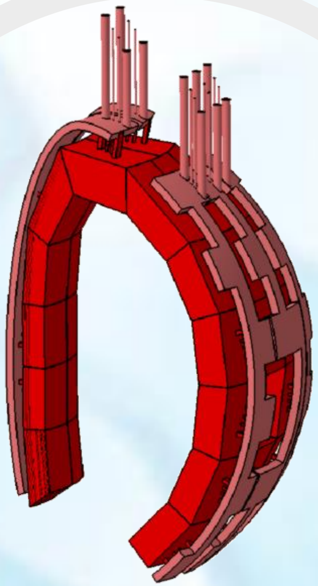
- Withstand Load of Fusion environment
- Compatible with TOKAMAK and Remote Handling

Tritium breeding

- TBR≥1.1
- As Large As Reasonably Achievable

Safety

- For normal and accidental condition
  - •Confinement radioactive inventory;
  - •Protect operator and equipment

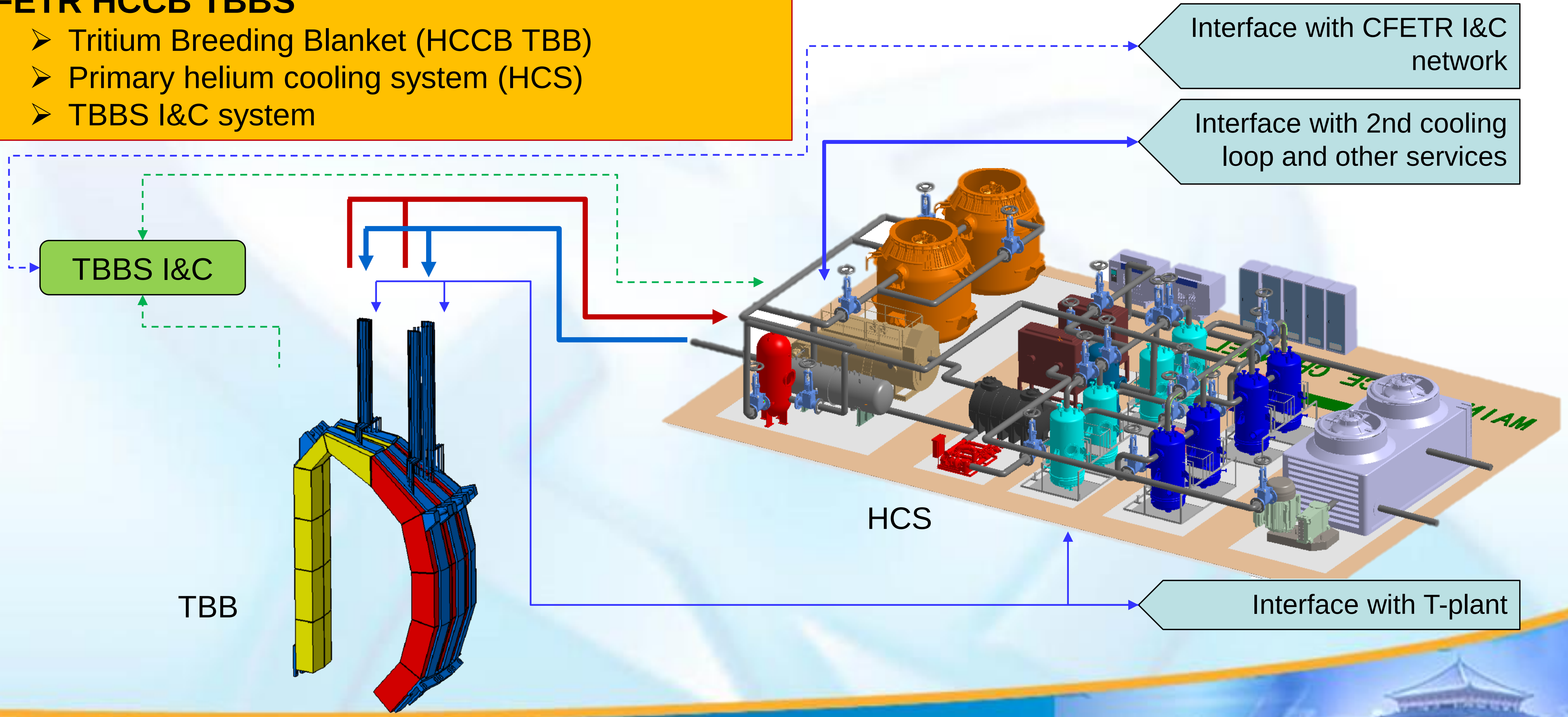


CFETR HCCB TBB

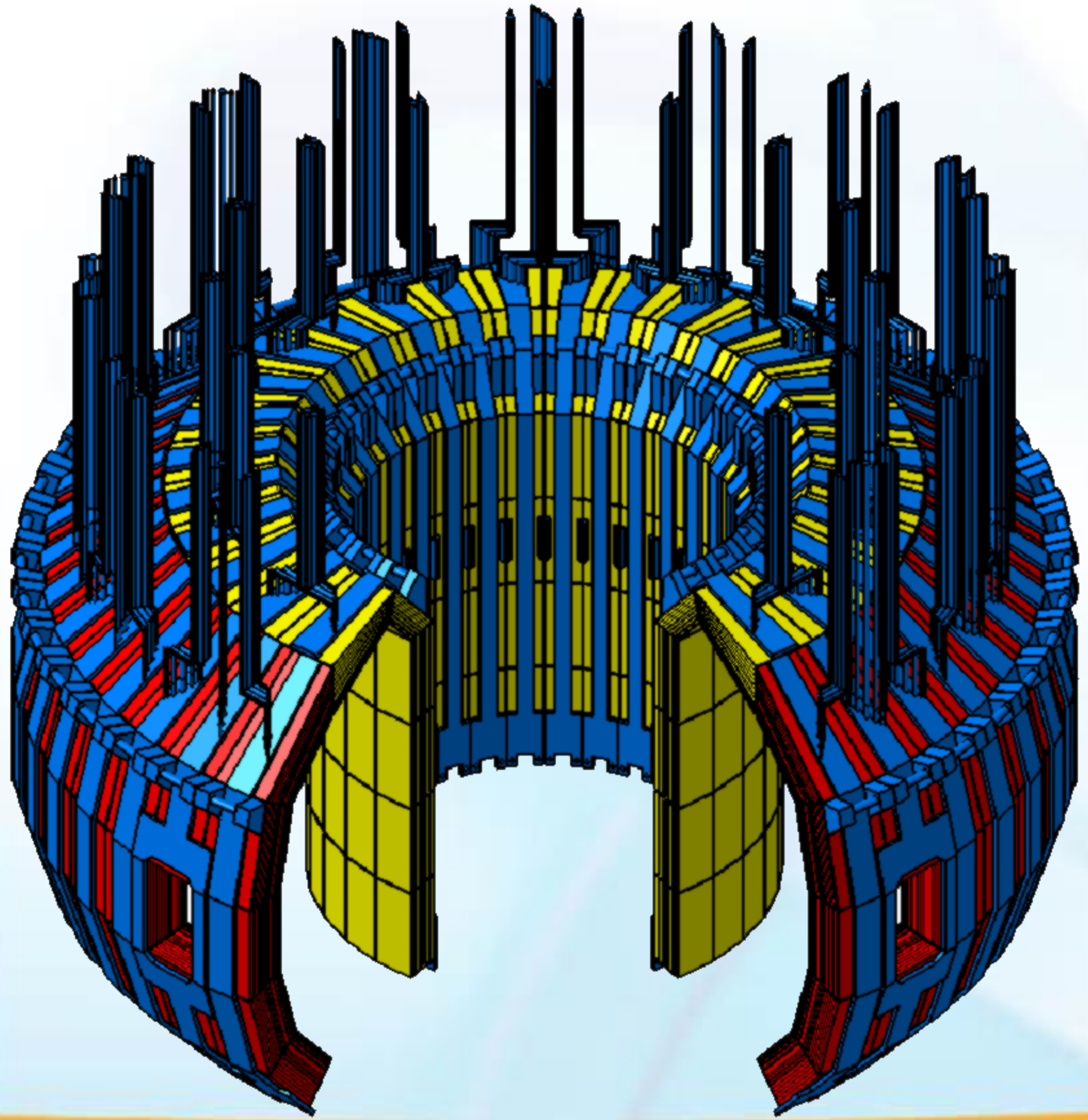
CFETR HCCB TBB system

CFETR HCCB TBBS

- Tritium Breeding Blanket (HCCB TBB)
- Primary helium cooling system (HCS)
- TBBS I&C system



CFETR HCCB TBB design features



Basic design features

- “Banana” segment design compatible with RH
- Several blanket modules in each segment
- Total
    - 16 sectors
    - 80 segments
    - 432 blanket modules
    - ~5000 tons

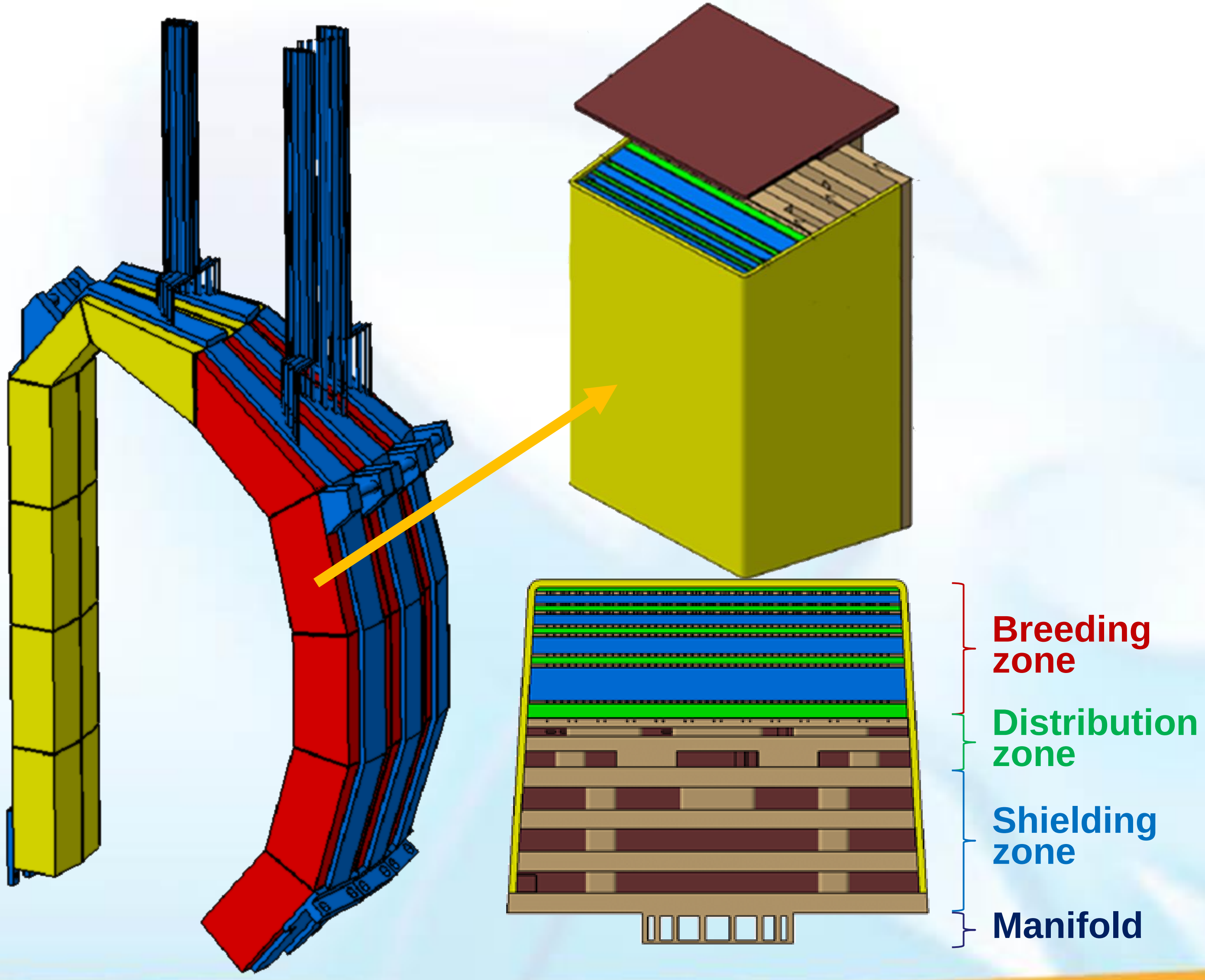
Material selection

- FW armor: W / W alloy
- Structural: ODS + RAFM steel
- Breeder: Li_4SiO_4 / Li_2TiO_3
- Multiplier: Beryllium / Beryllium alloy

Design parameters

- Coolant: Helium@12MPa
- Purge gas: Helium(0.1%H_2)@0.3MPa

CFETR HCCB TBB blanket module



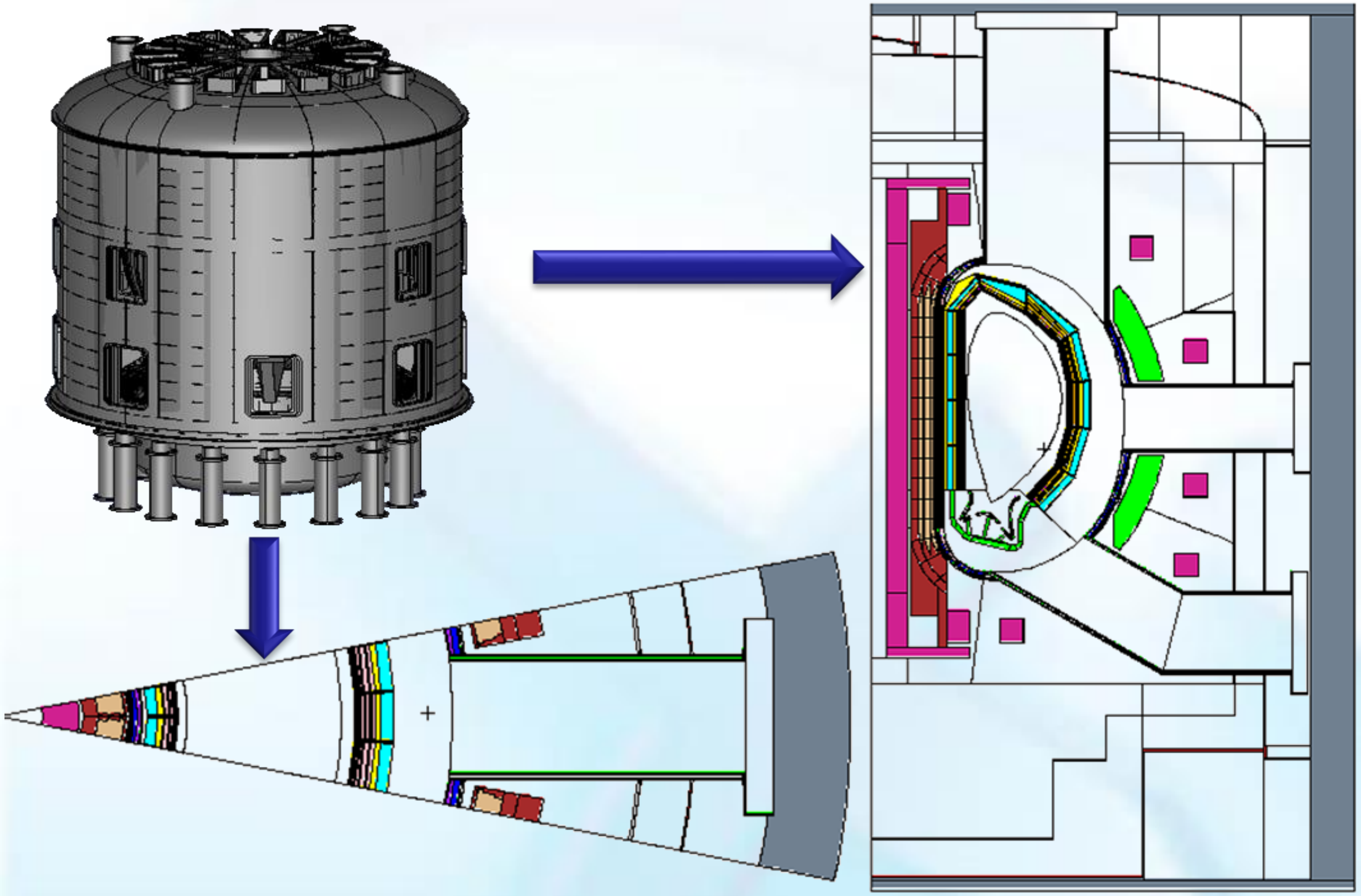
Blanket module

- Integrated design for breeding and shielding functions
- Four zones
  - Breeding zone
    - Breeder pebble bed / porosint
    - Multiplier pebble bed / porosint
  - Distribution zone
  - Shielding zone
  - Manifold

- Cooling channel for breeding zone
- Cooling channel for shielding zone
- Purge channel for breeding zone

Design code: RCC-MR

Neutronics model and nuclear performance



Nuclear analysis model

Nuclear heating (1.5GW Fusion power)

	Nuclear heating (MW)
Inboard BLK	460
Outboard BLK	960
Total	1420

NBI ports impact to TBR

Number of NBI port (3m×2m)	TBR
No NBI port	1.16
Two NBI ports	1.13
Three NBI ports	1.11

CFETR HCCB TBBS - Safety

LOFA accident analysis ：

➢Event sequence ：

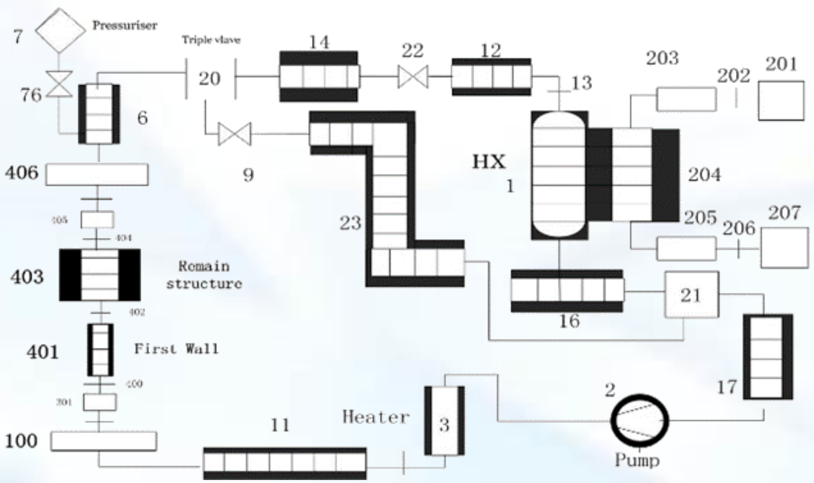
t=1800s , pump trip in HCS

t=1802s, terminate the plasma burn

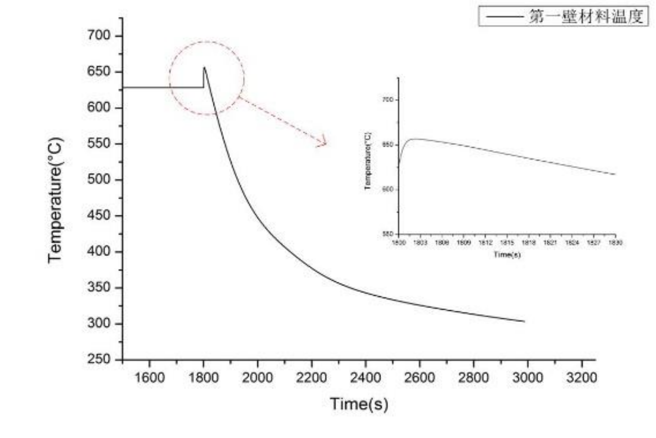
➢Results ：

Max. temperature FW: 656℃.

Natural circulation flow rate: 8kg/s.



LOFA modeling



LOFA analysis result

In-vessel LOCA accident analysis ：

➢Event sequence ：

t=0s, break in FW, plasma breaks down

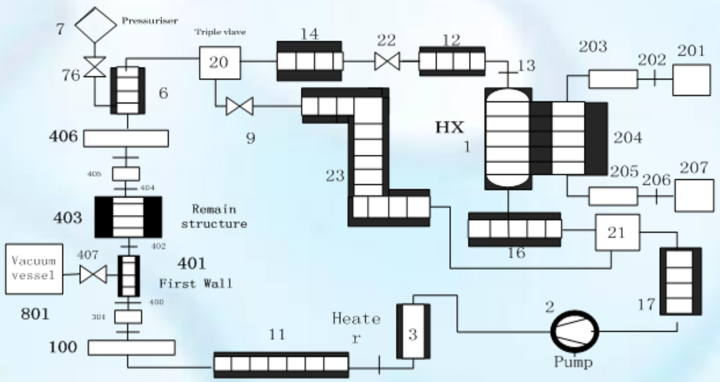
t=6s, HCS is isolated

➢Results ：

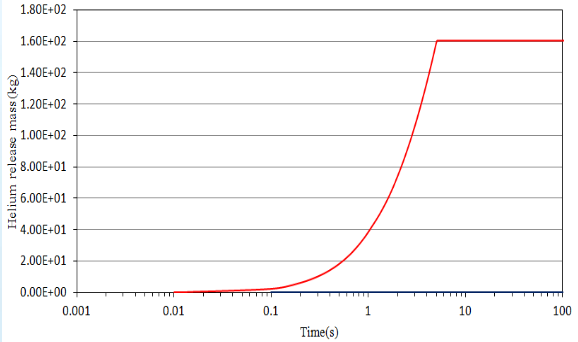
Max. temperature FW: 648℃.

Max. pressure VV: 88KPa.

Max. helium leakage VV: 160kg.



In-vessel LOCA modeling



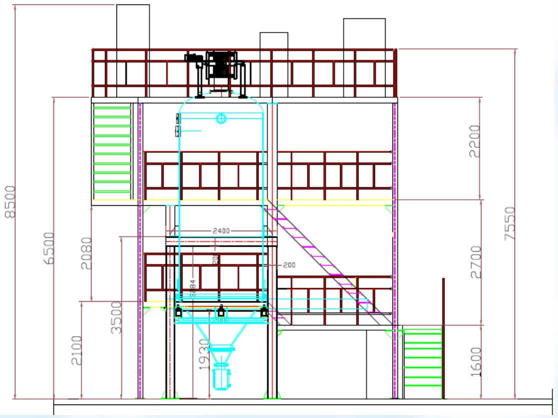
In-vessel LOCA analysis result

TBB R&D activities

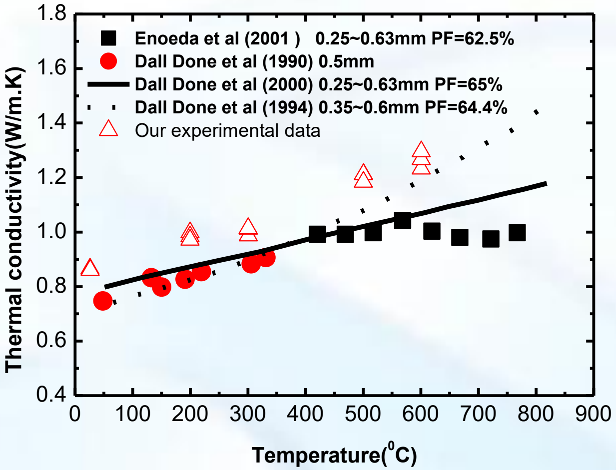
Functional materials and pebble bed technology

Based on the CN HCCB TBM program, the fabrication technology of Li_4SiO_4 and beryllium pebble have been developed, the database is under establishment.

Li_4SiO_4 pebbles

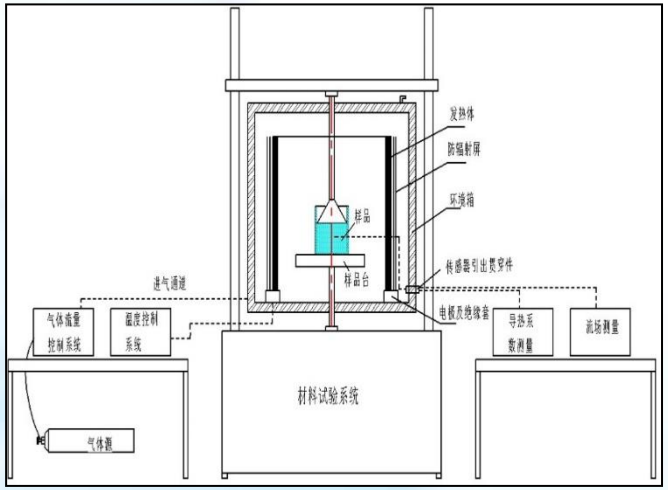


Li_4SiO_4 fabrication facility (under construction)

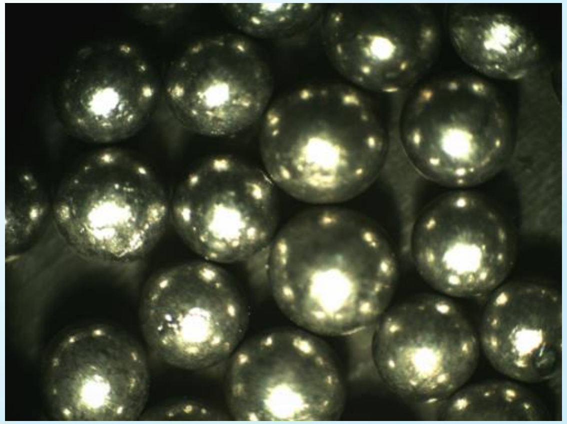


Compositions of Be Pebbles

Be	98.7
BeO	0.9
Fe	0.070
Al	0.0252
Si	0.0097
Mg	0.0139
Cr	0.0099
Cu	0.0018
Mn	0.0124
Ni	0.0092
Pb	0.00017



Multi-physics field pebble bed testing facility (under design)

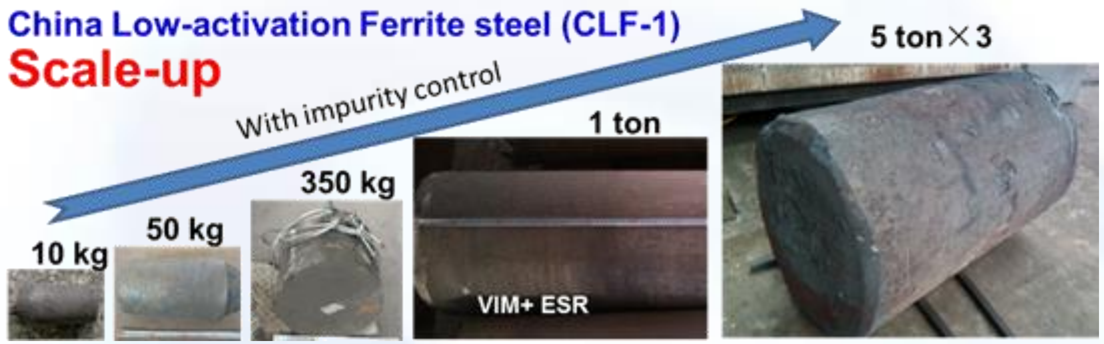


Beryllium pebbles

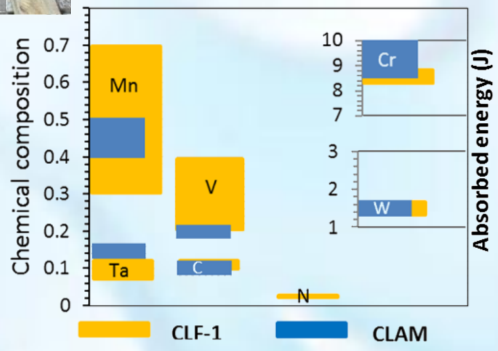
Beryllium fabrication facility

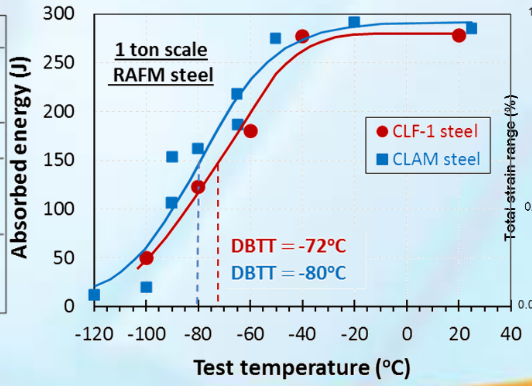
In collaboration with **Dr. Alice Ying, UCLA, USA.**

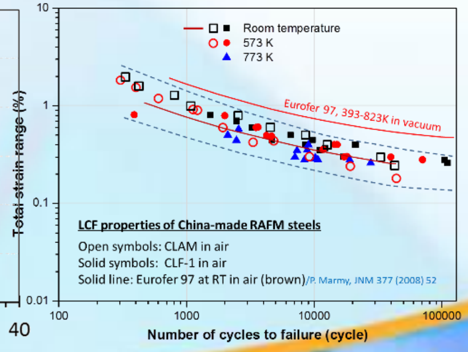
Structural material development



- **RAFM steel**
  - Two kinds of RAFM steel: CLF-1&CLAM
  - Fabrication procedure for >5 tons ingot
  - 3.2 certificate based on RCC-MR
  - Material database
  - Irradiation experiment
  - Environment compatibility experiment
- **ODS steel**
  - Ton-scale casting
  - High performance:



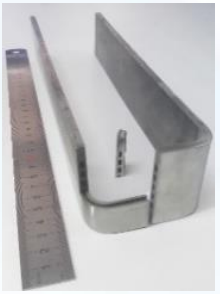




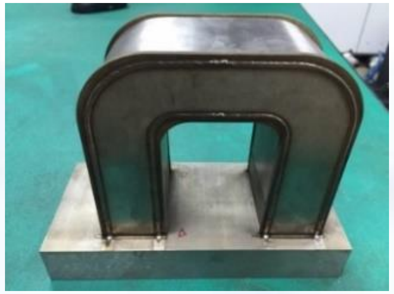
Fabrication processes

Fabrication processes development for HCCB TBM, whose experience can by use for CFETR TBB

FW sample

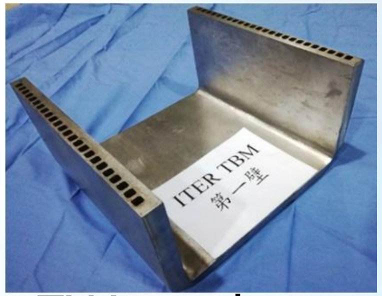


CP sample



Breeding unit sample

Prototype mockup of double-layer pipe for shield

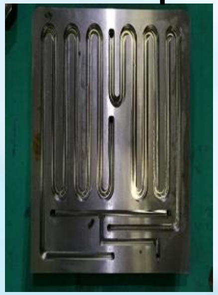


FW mockup

Cooling plate (CP) mockup

Submodule mockup welding

Back plate mockup

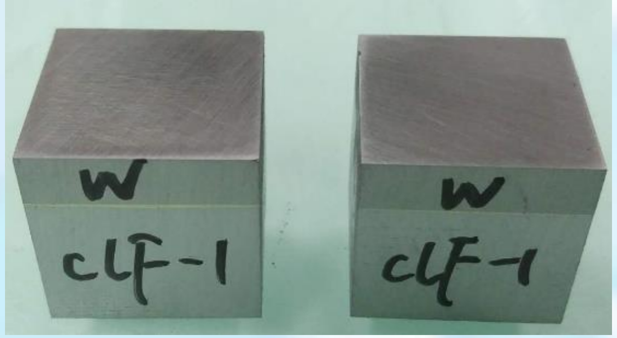


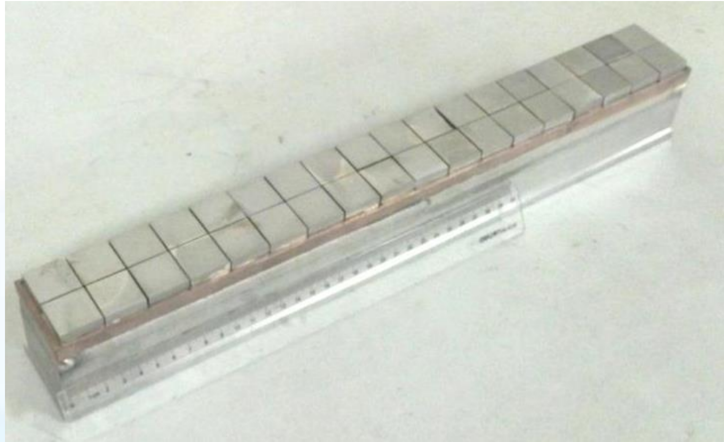
Cover plate mockup

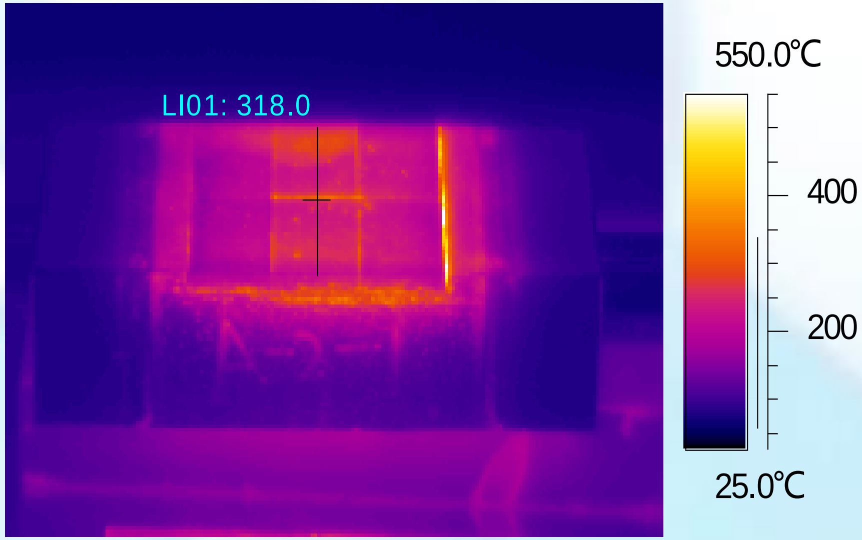
Fabrication processes – CFETR TBB

Deep drilling hole

W armor



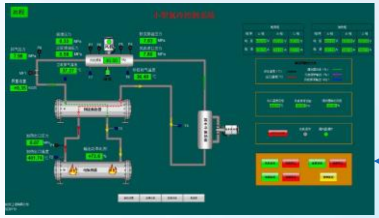




Helium cooling technology

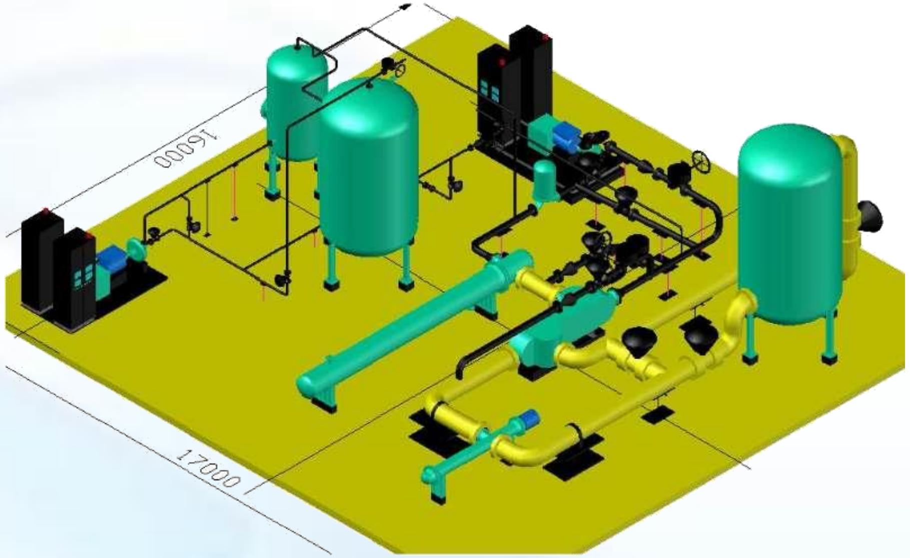
HHFT facility EMS-60

He



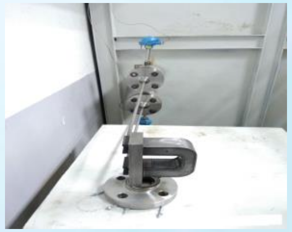
Control system and ITER Mini-CODAC

HeCEL-1 (0.1kg/s, 8MPa, 400℃)



HeCEL-3 (under design) (>2kg/s, 12MPa, >500℃)

Hydraulic testing

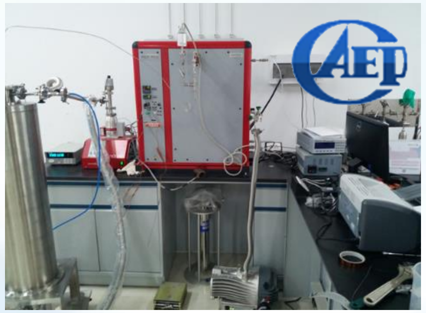


High heat flux testing

Tritium related technology

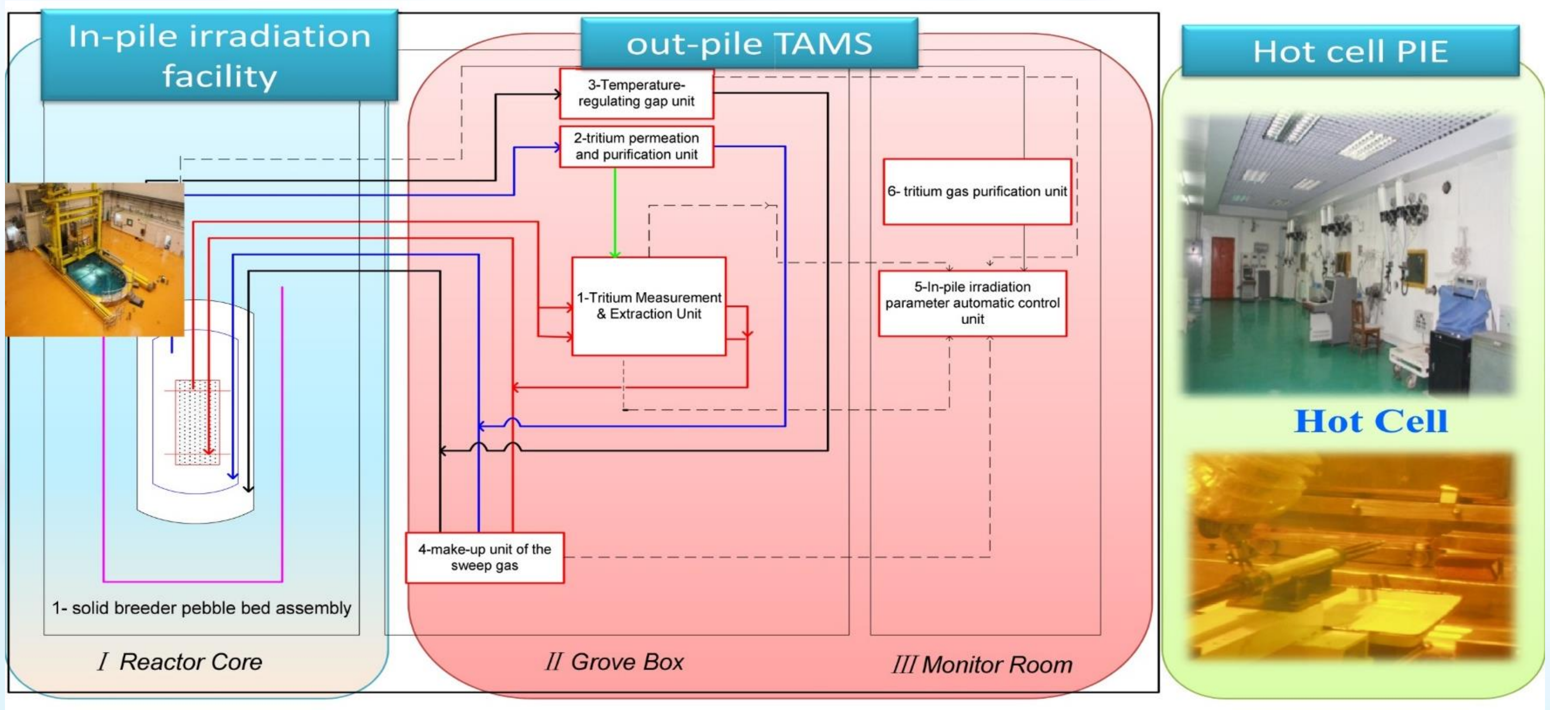
- Several testing facilities/loops have been constructed by CAEP to verify the tritium technology.
- In-pile irradiation of lithium ceramic and tritium extraction experiment in both CIAE and CAEP.

CPS testing facility



Material testing facility

TES testing facility



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

Summary

- The development of HCCB TBB is **one of the most important part** of China fusion development roadmap toward DEMO.
- In order to support the design validation, a lot of **design and R&D activities** have been implemented. It will be an key step for the technology development of HCCB TBB and also it is providing the indispensable experience.
- The development of CFETR HCCB TBB is one of the most important activities of CFETR, which is learning from the CN HCCB TBS and ITER. Its preliminary design has been started based on the latest CFETR design. But some technology challenges have been identified and will be developed in the future.

Collaboration

Institutes

核工业西南物理研究院
中核集团 CNNC Southwestern Institute of Physics

IMR

IMP

中国原子能科学研究院
中核集团 CHINA INSTITUTE OF ATOMIC ENERGY

Universities

Industries

HANGTIANXINLI

中国核电工程有限公司
中核集团 CHINA NUCLEAR POWER ENGINEERING CO., LTD.

XTC

Thank you very much for your attention!