Design and R&D Progress of Chinese HCCB TBS Programme

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IAEA International Atomic Energy Agency

26th IAEA Fusion Energy Conference, Kyoto, Japan

SWIP Southwestern Institute of Physics

Outline

- Introduction
- Objectives of CN HCCB TBS
- CN HCCB TBS Design Progress
- CN HCCB TBS R&D Progress
- Time Schedule
- Summary

Introduction

- ITER is an unique opportunity to test tritium breeding blanket mock-ups in integrated tokamak operating conditions;
- Helium-cooled ceramic breeder (HCCB) test blanket system is the selected concept for the Chinese ITER TBM program.
- The CN HCCB TBMA has been signed between ITER and CN DA in Feb. 2014. The conceptual design review has been hold in Jul 2014 and approved in Sep 2015.
- The schedule of CN HCCB TBS has been established in 2014 and updated recently in compliance with ITER schedule.
- The detail design and R&D of CN HCCB TBS for preliminary design phase is on-going under the supporting of CN DA.

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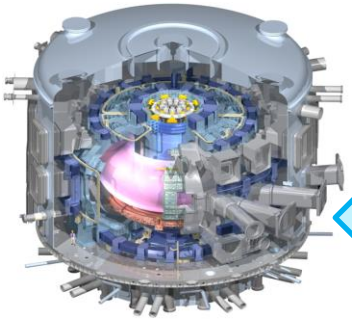
General HCCB-TBS Test Objectives



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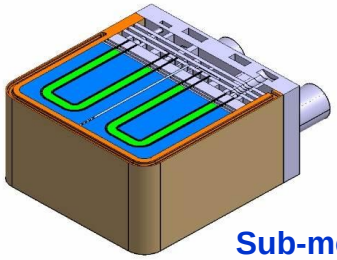
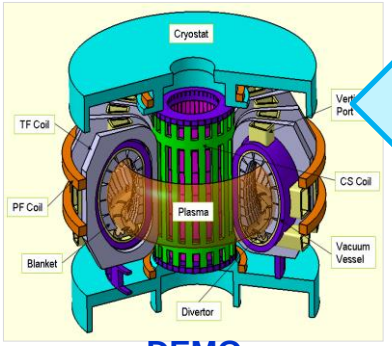
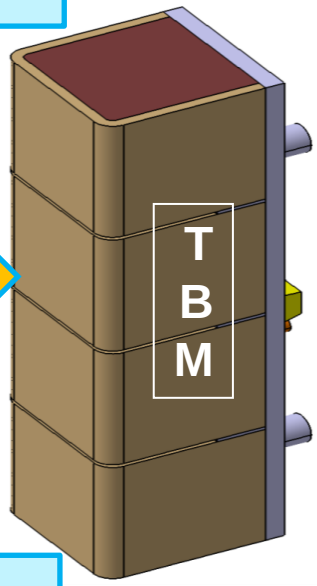


Sub-module



DEMO



General TBM Program Objectives

- Tritium breeding performance for DEMO –BB (blanket breeding)
- Integral performance of blanket systems
- Fusion neutron irradiation for materials
- Blanket power removal predictions
- Diagnostics for the monitoring of blanket systems
- Control system for the operation of blanket systems
- Provide operational data base for TBS
- Safe operation and maintenance of systems
- Power production and transfer of blanket system and components

Related R&D Activities for Supporting DEMO-BB

Basic Material Development

RAFM(CLF-1), Tritium permeation barrier
Beryllium pebble, Ceramic Breeder

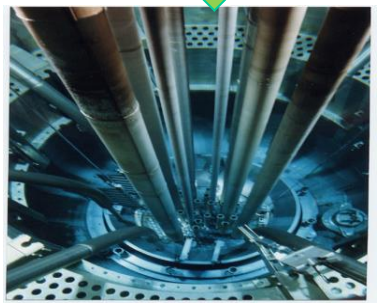
He test loop

Pebble-Bed Tests

Thermal behaviour, Flow
Mechanical behaviour

In/Out-of-pile Component Tests

High temperature /pressure He test loop construction



High flux test reactor

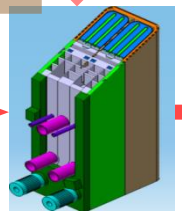
Sub-modules In-pile Tests

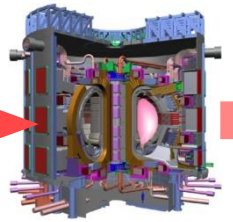
Neutron irradiations

TBS integration

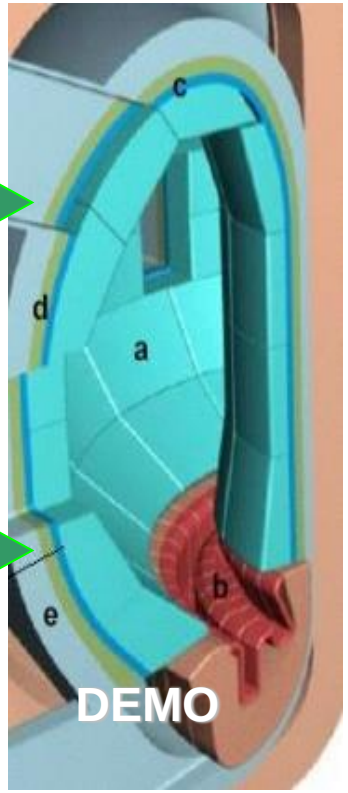
TBM Interface with ITER

TBM Design ,R&D, Mock-up Integration, Test on ITER





DEMO Blanket Design and Development



Testing Plan for the CN HCCB TBS

- The objectives of CN HCCB TBS is to test the tritium breeding blanket technology in the Tokamak operation conditions provided by ITER.
- At least four kinds of TBM modules will be tested during ITER different operating phases (H-H, D-D,D-T phases).

Operation Phase	Testing Description	TBM types
H-H	Safety, thermal load of surface, E-M load, disruption	EM-TBM
D-D	Neutron response data, Thermal behaviors	TN-TBM
D-T (Low duty)	Structure behaviours, Nuclear response for D-T neutron, Tritium production, Tritium procedure validation	TN-TBM
D-T (High duty)	Operational behaviours, Heat transfer, Tritium production and management. Overall reliability and operational performance	INT-TBM

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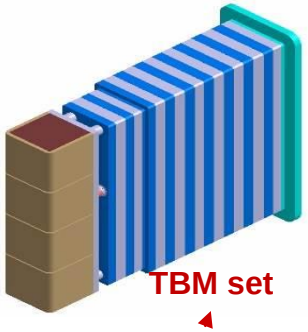
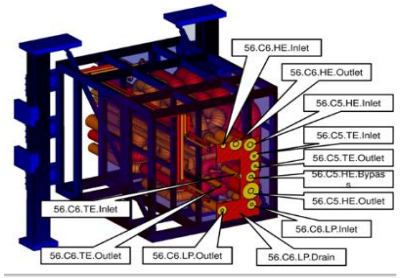
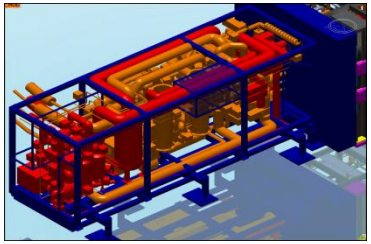
Subsystems and Configuration of HCCB TBS



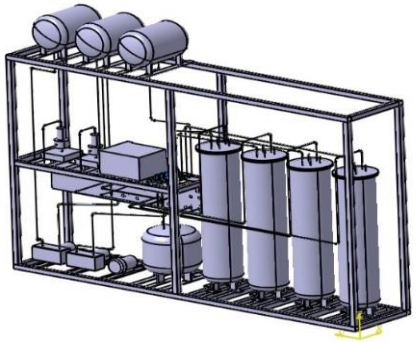
TBM set



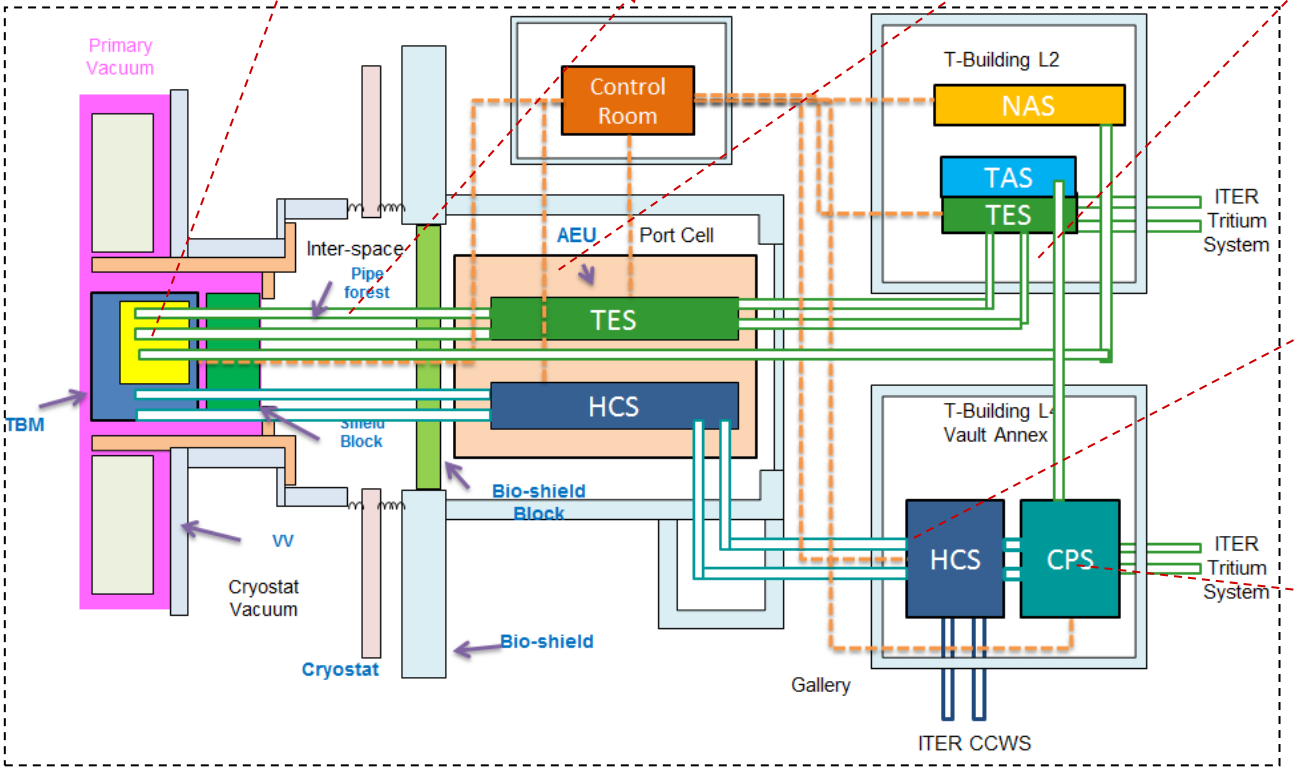
Pipe Forest (PF)

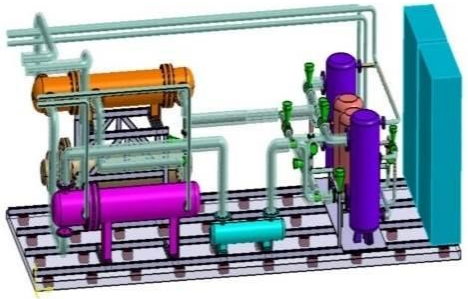


Ancillary Equipment Unit (AEU)

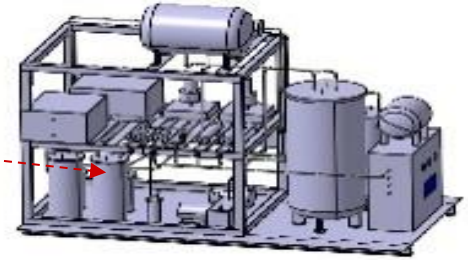


Tritium Extraction System (TES)





Helium Cooling System (HCS)



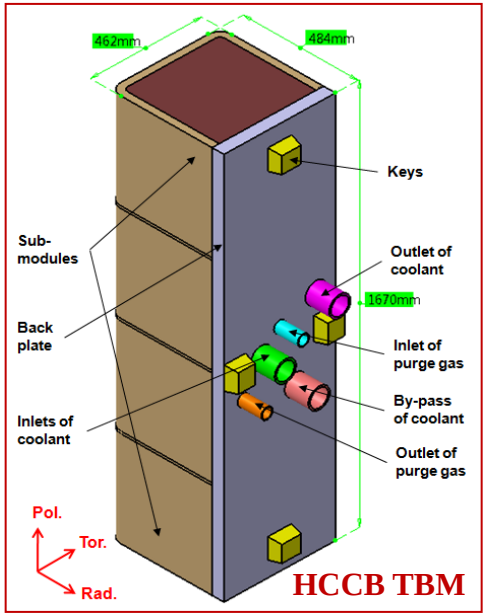
Coolant Purification System (CPS)

Updated TBM Module Design

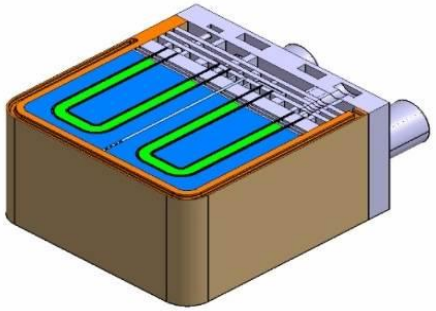
- In order to simplify the manufacturing processes, the design of HCCB TBM was updated based on the fabrication technology R&D and engineering analyses since 2015.

Main design parameters

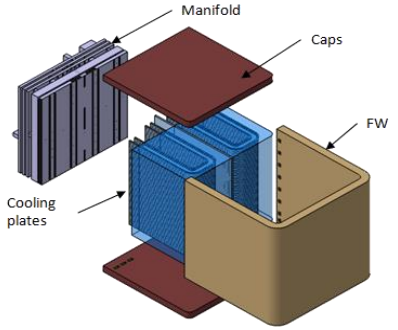
Parameters	Values
Neutron wall load	0.78 MW/m^2
Surface heat flux	0.3 MW/m^2
Structural material	CLAM/CLF-1 ~1.3ton (<550ºC)
Tritium Breeder	Li_4SiO_4 pebble bed (<900ºC)
Neutron Multiplier	Beryllium pebble bed (<650ºC)
Coolant	Helium (8MPa) 1.04 kg/s (Normal) FW(300ºC/370ºC) Breeding zone (370ºC/500ºC)
Purge gas	Helium with H_2
TPR	0.061g/FPD



Updated design with 1X4 Sub-Modules



Sub-Modules

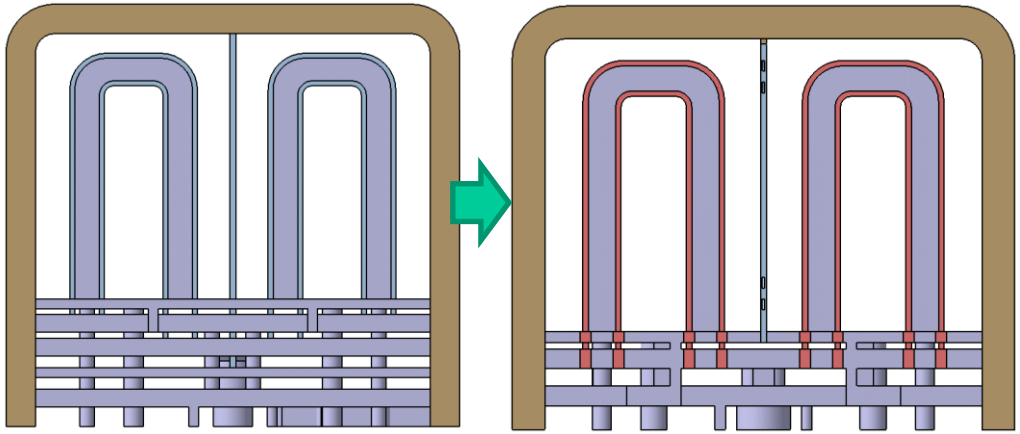


3D explosion figure

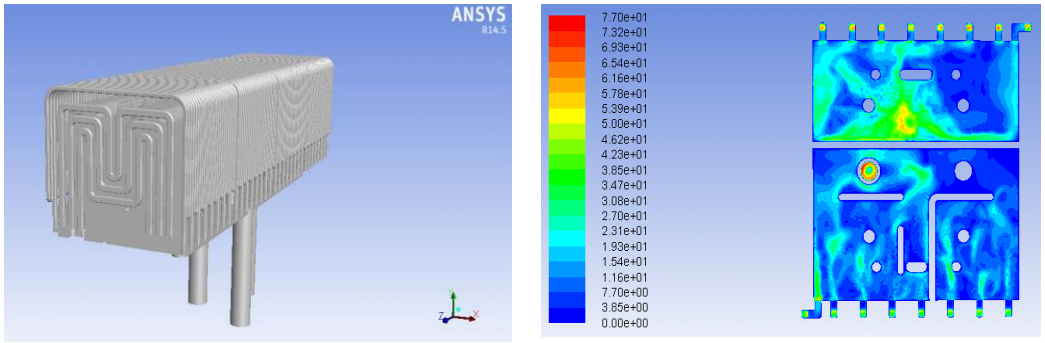
- Four sub-modules concept
  - Manufacturability
  - PIE/ transportation
- U shape breeding zone
  - Reduce the mass of structural material

Updated TBM Module Design

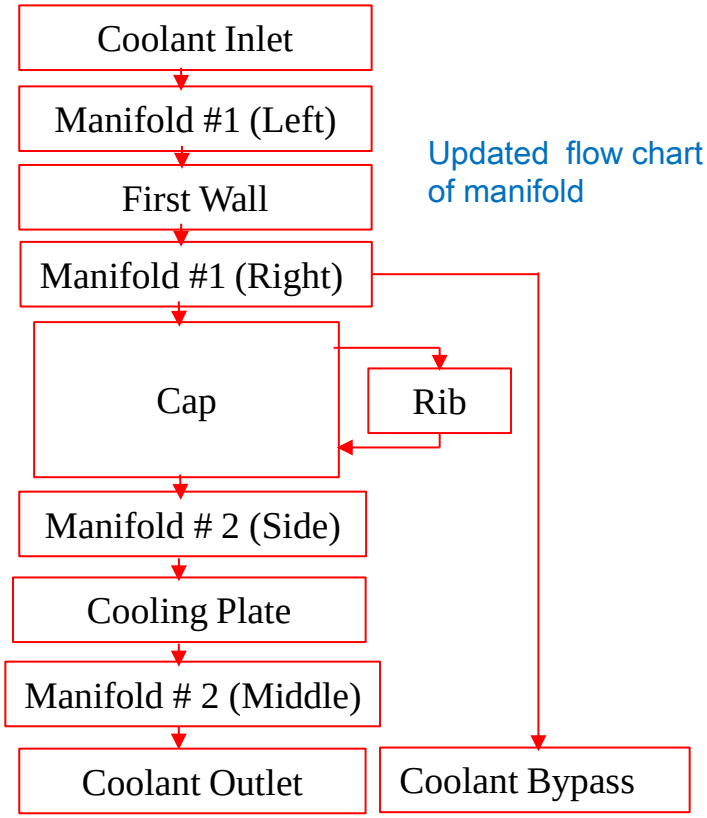
- **Optimization for manifold:**
  - Back plate and supporting structure
  - Filling of pebble bed
  - Flow scheme



Update Design of HCCB TBM Sub-module Manifold



Update flow scheme and its flow distribution



Updated flow chart of manifold

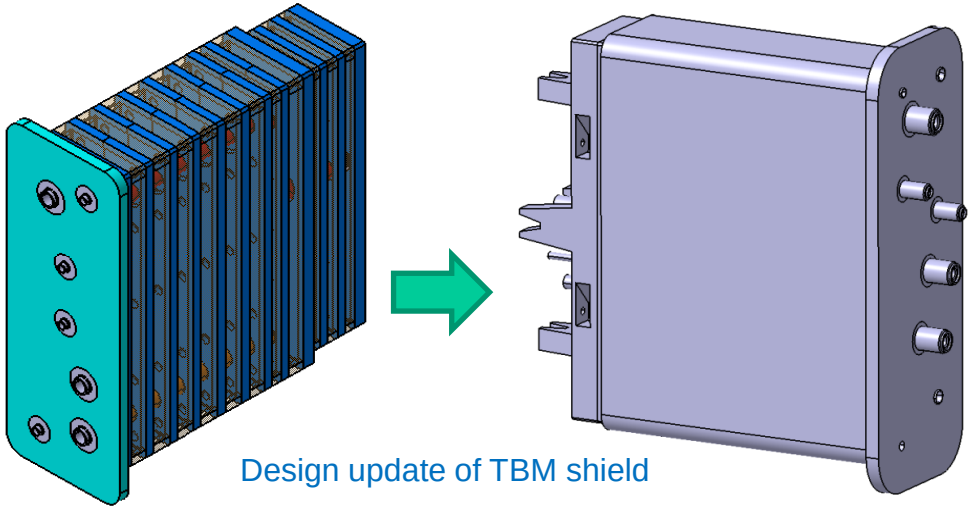
- **Optimization results:**
  - Simpler fabrication procedure
  - Food flow distribution in cooling channels and pebble beds
  - Keeping TPR

Updated TBM Shield Design

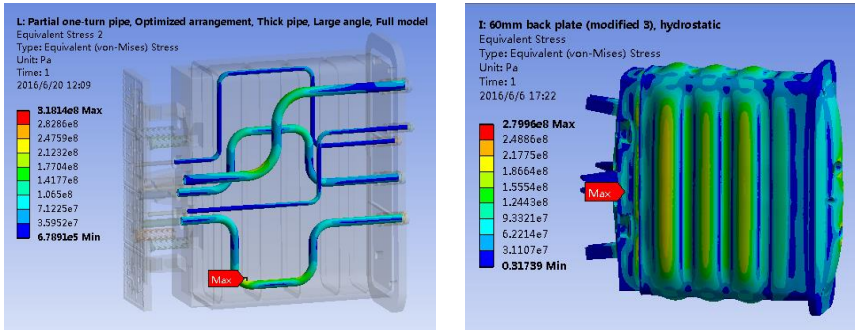
- Based on fabrication technology R&D and engineering analyses, HCCB TBM shield design was further updated:
  - Reduce the total length to increase the interspace with TBM with similar shielding capability
  - Optimize pipe configuration, thickness of shell, supporting structure to simplify the manufacturing processes

Main design parameters

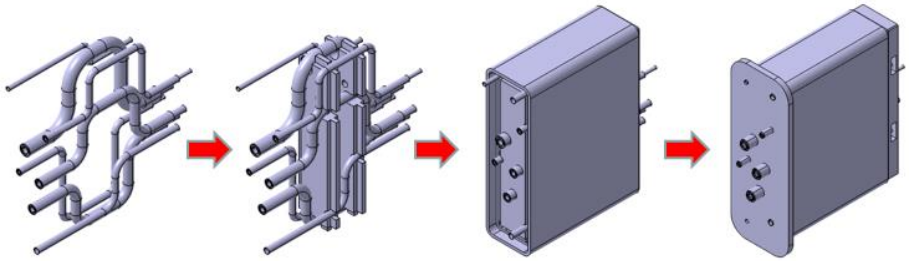
Parameters	Values
Structural material	SS316LN-IG
Coolant	Water (4MPa) 0.1 kg/s 70ºC/125ºC
Dead weight	~5 tons
Water volume	0.98 m3
Water fraction	~40%
Nuclear heating	20.3 kW



Design update of TBM shield



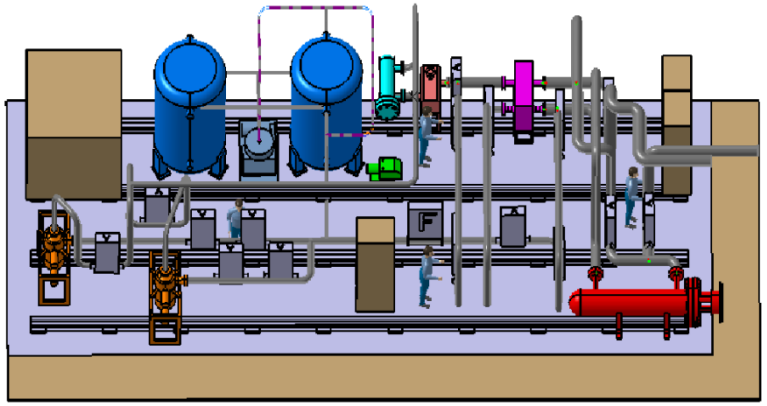
Stress distribution under operation and pressure test conditions



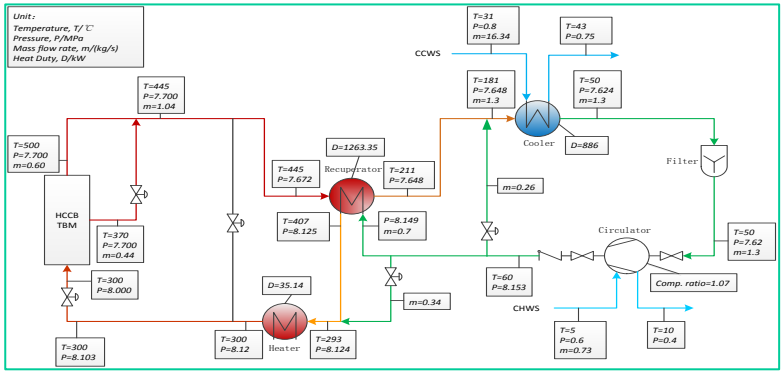
Basic assembly scheme

Updated HCS Design

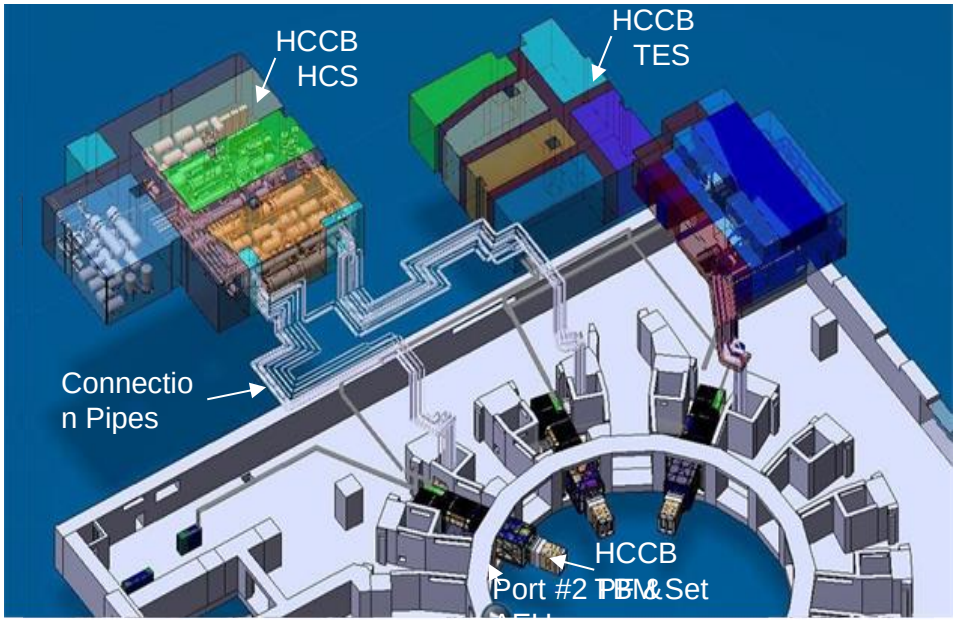
- The configuration of HCS was updated considering the actual equipment size and maintenance requirements.
- The statuses and status shifting have been development and the steady state simulation has been performed to verify the design.
- One small helium testing loop has been constructed and started the testing.



New configuration of HCS



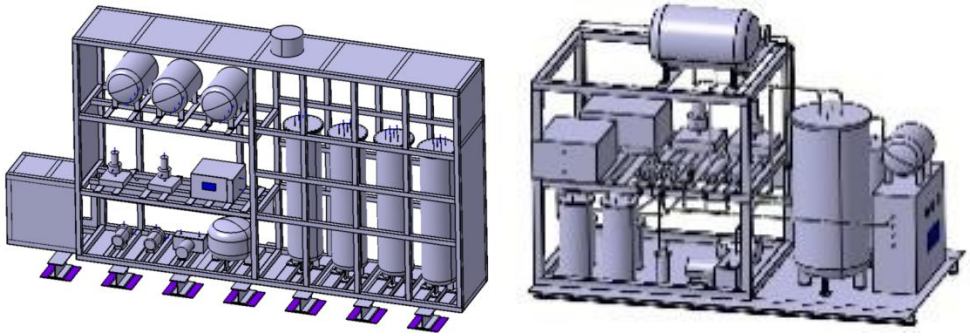
The flow chart of HCS



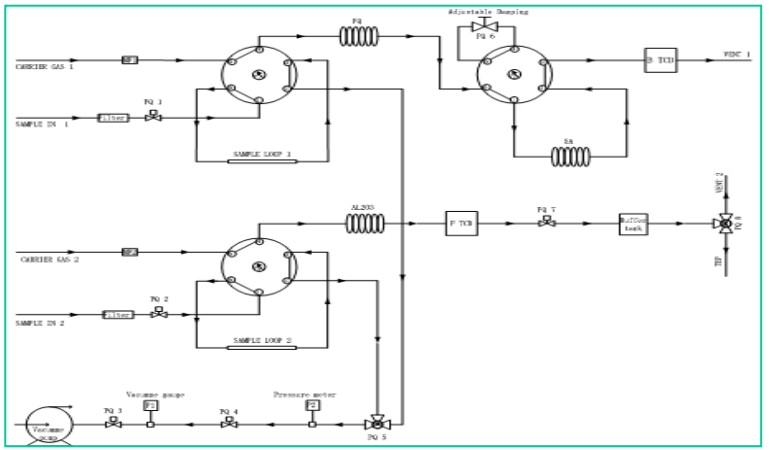
Layout configuration of HCCB TBS

Updated TES/CPS Design

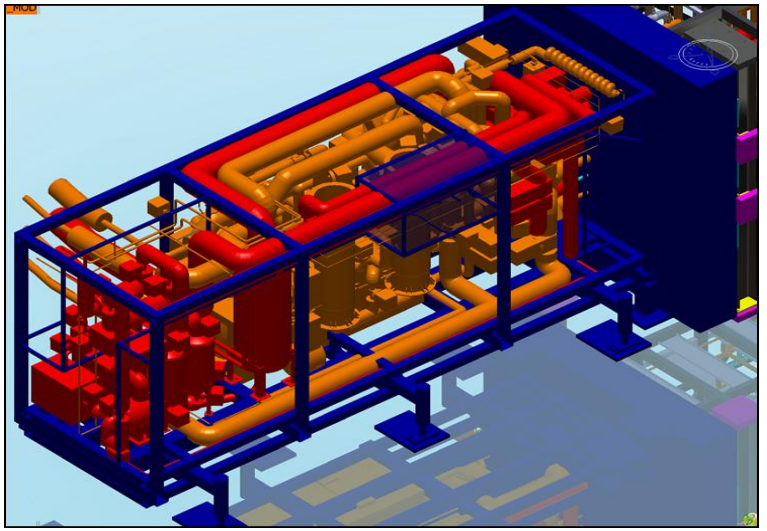
- **TES&CPS**
  - Updated related component parameters for the TES and CPS systems.
  - The operation states and shifting plan have been defined.



TES and CPS design



The flow char of CPS



Integration of Sub-system in AEU

TES, TAS and CPS operation status

TBM →	HCCB							
Systems ↓	Operation states							
	Plasma Operations	Baking	Short Term Standby	Test and Conditioning	Short Term Maintenance	Tritium outgassing	Long Term Maintenance	Commissioning
TES	Plasma operation, Hot standby	Hot waiting	Hot waiting	Hot waiting	Cold waiting, Vacuumed, Regeneration	Hot waiting	Absent, Off, Safe	Commissioning
CPS	Plasma operation, Hot standby	Baking	Hot waiting	Hot waiting, Baking	Cold waiting, Vacuumed, Regeneration	Baking	Absent, Off, Safe	Commissioning
TAS	Plasma operation, Hot standby, accountancy	Hot waiting	Hot waiting	Hot waiting	Cold waiting, Vacuumed, Hot waiting	Hot waiting	Absent, Off, Safe	Commissioning

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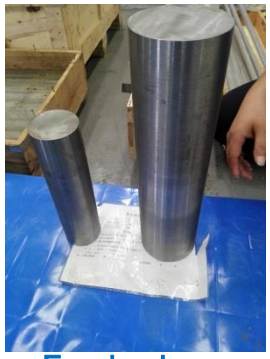
RAFM steel CLF-1 - Fabrication

5 ton CLF-1 ingot (ESR)

Forging of the ingot

Heat treatment

Thickness from 10 to 55mm

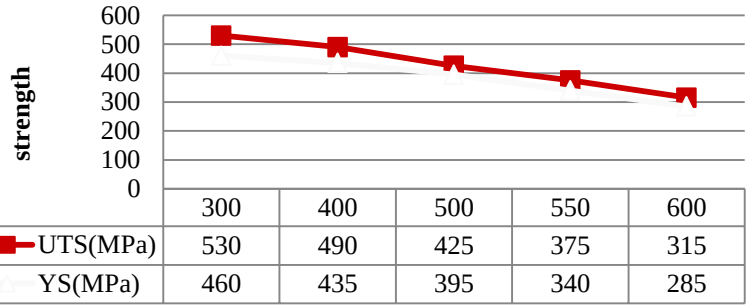


Forging bars

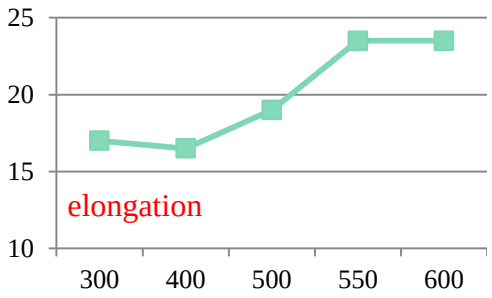
Tensile test

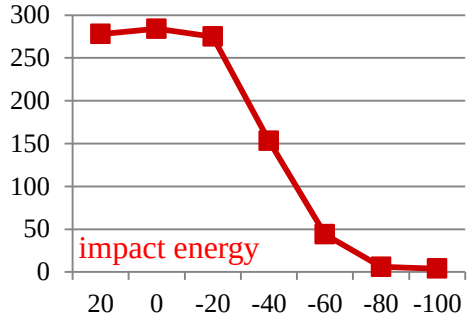
(sample and test)

high temperature tensile strength



	300	400	500	550	600
UTS(MPa)	530	490	425	375	315
YS(MPa)	460	435	395	340	285





- The current TBM design and R&D is based on the CLF-1 developed by SWIP.
- Based on the fabrication technology of 1 ton ingot, 5 ton ingot of CLF-1 has been manufactured and preliminarily tested.
- After the testing, the fabrication procedure will be finalized and the qualification procedure is under discussion with ANB.

RAFM steel CLF-1 - Irradiation

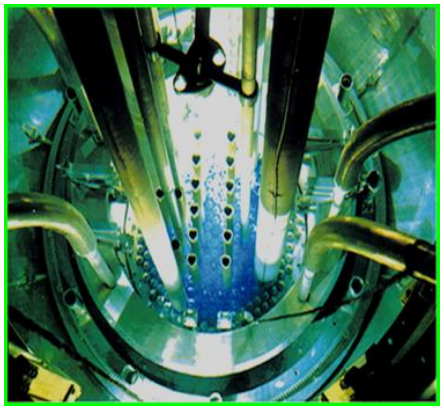
- An irradiation campaign was ongoing by SWIP in the High Flux Engineering Test Reactor (HFETR)in China. The data for the 1 dpa irradiation have been obtained.

Comparison on the Tensile properties

		Yield strength，MPa	Tensile strength，MPa	Elongation，%	Reduction of area，%
R. T.	Before irra.	685	766	20	72
		688	757	19	72
		703	778	20	70
	After irra.	768	815	17	71
		772	828	19	69
		708	796	20	68
300℃	Before irra.	610	626	15	73
		583	609	14	73
	After irra.	633	660	14	69
		617	643	14	71
		664	681	13	70

- The YS and UTS increased after irradiation.

Power: 125MW
Maximum Flux:
6.2×10^{14}n/cm^2.s



High flux engineering test reactor

Comparison on the Impact properties

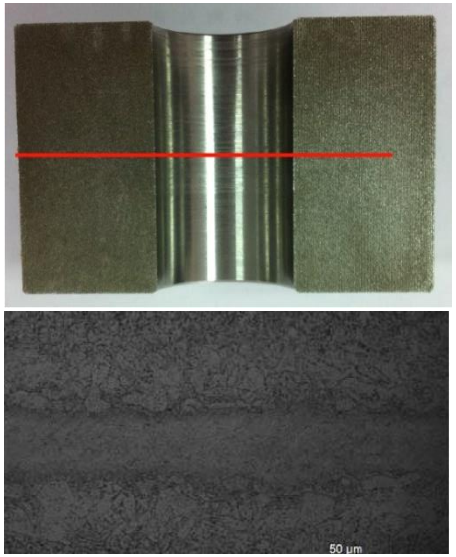
		Energy，J	，mm
R. T.	Before irra	182	1.56
		196	1.78
		167	1.54
	After irra	157	1.47
		192	1.68
		196	1.75

- The impact properties have no obviously changed.

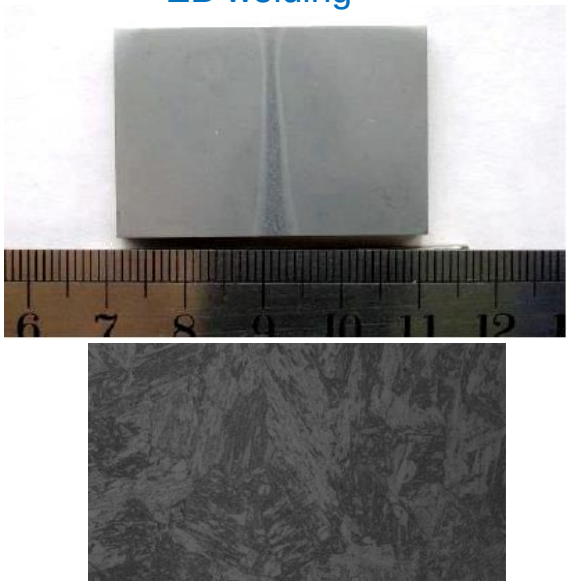
RAFM steel CLF-1 - Weldability

- The main potential welding methods for HCCB TBM have been tested. Based on these results, the preliminary fabrication method for HCCB-TBM has been proposed and will be verified.

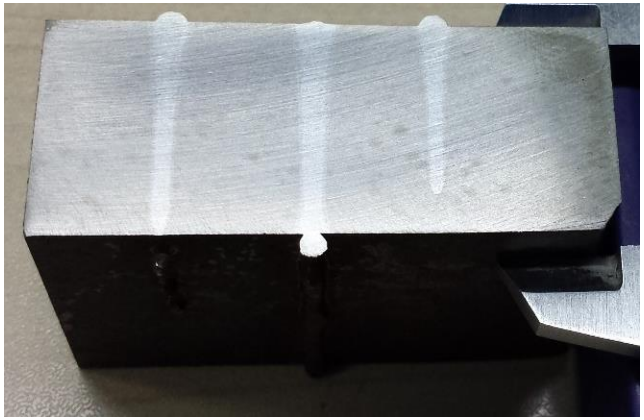
Hot pressing diffusion welding



EB welding



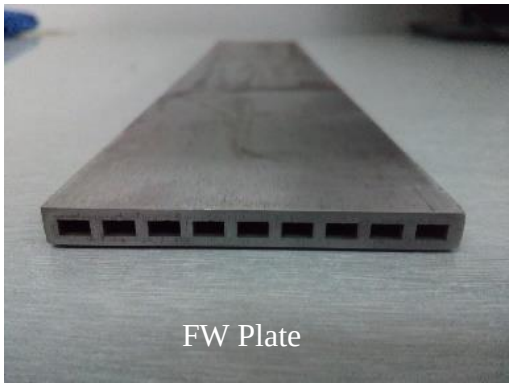
HIP welding



Laser welding

	RT tensile property		Impact test
	UTS (MPa）	TE (%)	Absorbed energy (J)
Hot press welding	690	26	22
EB welding	635	24	240
HIP welding	656	28	120
Laser welding	647	25	265

TBM Fabrication Technology

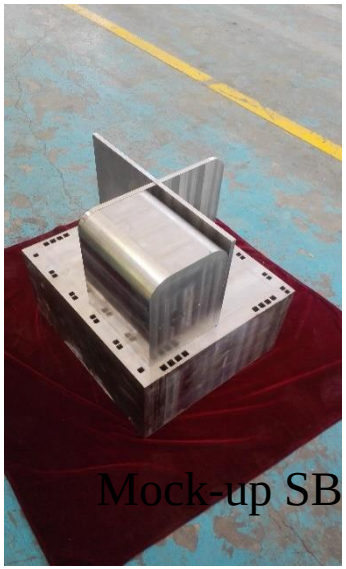

FW Plate


U-sharped FW


Manifold plate


Module mock-up

Welding and fabrication of component and module of HCCB TBM

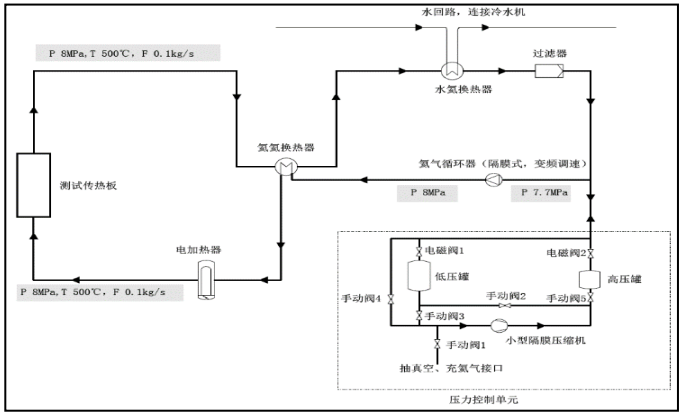

Mock-up SB

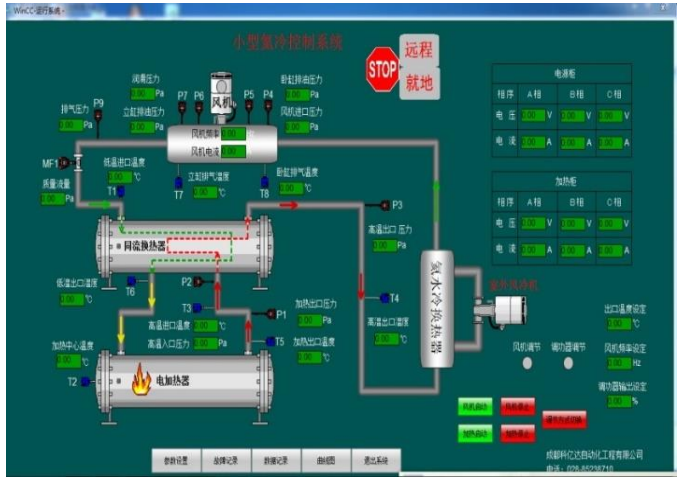

Leak test

Small scale TBM mock-up

- Based on the TBM-set design, the fabrication technology is under studied and testing, such as the vacuum diffusion, HIP, EB, Laser, etc. also including some new technology, such as laser printing.
- The welding method between CLF-1 and SS316L(N)-IG has also been studied.
- After the testing of these above method, the fabrication process of TBM has been proposed. Some components have been fabricated.
- The large size mockup will be fabricated and tested later.

Helium Testing Loop





Parameters	Value
Pressure	8MPa
Flow mass	0.1kg/s
Testing temp.	300-500ºC

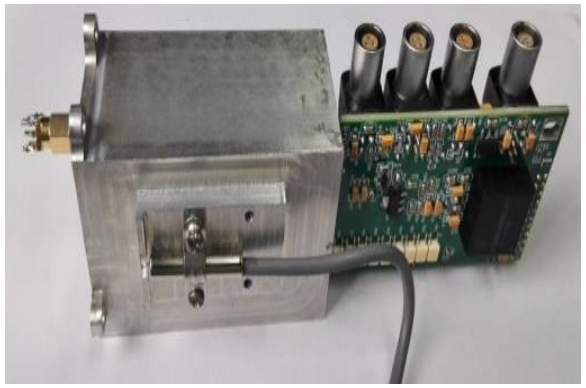
- The helium testing loop has been constructed including its I&C system and the initial testing has been performed. The following items have been considered for the next operation phase.
  - Pressure drop for the pebble bed
  - Flow distribution and pressure drop for the key components
  - High heat flux test for first wall with electrical beam heating

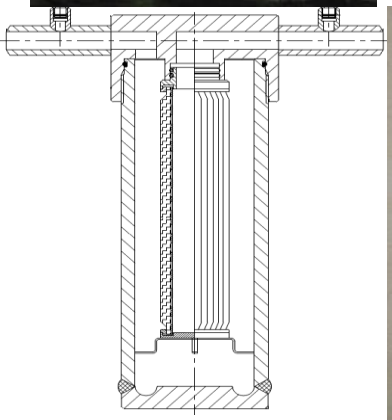
  The testing plan is under preparation.

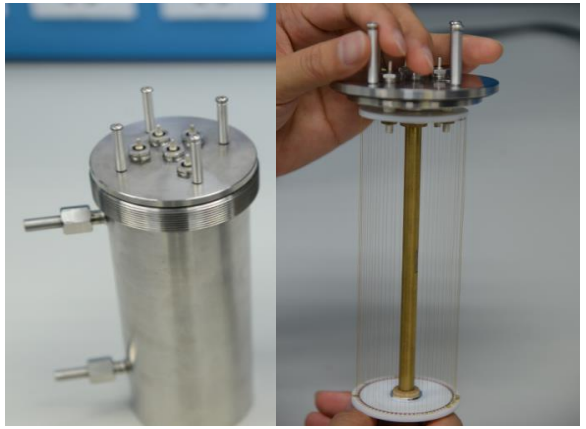
TES/TAS/CPS - Components R&D

- Based on the design and performance requirements, the prototypes of filter, cooler, heater, Ionization chamber and micro-GC have been fabricated and are now under test.
- The functional material testing platform has been constructed, and the materials for hydrogen oxidation and impurity removal have been tested.
- A CPS test loop has been constructed at CAEP.







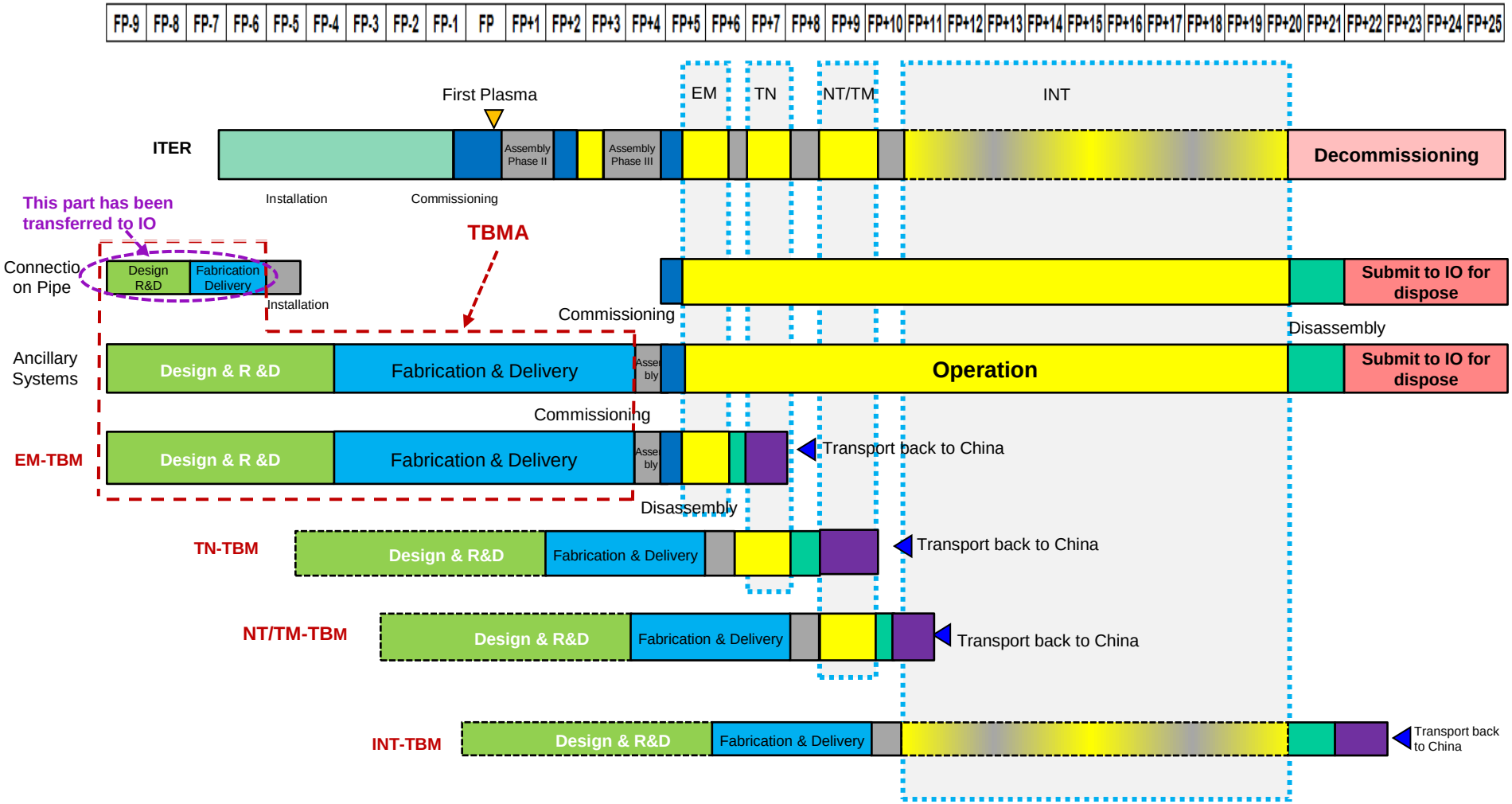



Outline

- Introduction
- Objectives of CN HCCB TBS
- CN HCCB TBS Design Progress
- CN HCCB TBS R&D Progress
- **Time Schedule**
- Summary

HCCB-TBS Overall Schedule

ITER Commissioning and Operations



CN HCCB TBS Milestones

- Current HCCB TBMA milestones (for EM TBM only) is based on the current ITER construction, operation plan.
- According to the TBS need date provided by ITER, the HCCB-TBS schedule was updated recently in compliance with ITER schedule.

Milestone	New Date
HCCB TBS PD Design Readiness Workshop	2019.3
HCCB TBS PDR	**2019.12**
HCCB TBS PDR approval	2020.6
HCCB TBS FD Design Readiness Workshop	2021.9
HCCB TBS FDR	**2022.6**
HCCB TBS FDR approval	2023.1
Amendment HCCB TBMA	2023.7
Contract signature for HCCB TBS	2024.1
Manufacturing process qualification	2024.9
End of Manufacturing(TBS and Ancillary systems)	2029.1
HCCB TBS delivery	**2029.6**
Pipe forests and Ancillary Equipment Units	**2029.6**
HCCB TBS acceptance tests start in ITER site	2029.7
Assembly start	AP III (2030)

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Summary

- The TBM program is an important part of China fusion development Strategy, for which HCCB concept has been selected as testing objective.
- The HCCB TBMA has been signed between ITER and CN DA. The CDR was approved in 2015. Now it has enter Preliminary Design (PD) phase.
- The design of HCCB TBS is developing in details according to the schedule. R&D on the development of structure material and function materials, fabrication of medium-sized TBM mock-up, construction of the testing loops, are ongoing.
- The R&D and test plan, delivery of CN HCCB TBS are scheduled according to the ITER schedule and progress.
- Chinese TBM programme will be implemented with the cooperation of domestic and international institutions and industries.

Thank you for your attention !