Current Design and R&D Progress of CN HCCB TBS

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On behalf of CN TBM team

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

Outline

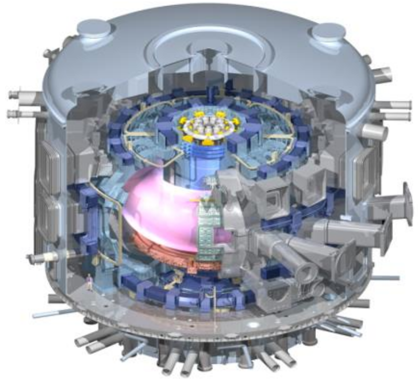
- Introduction
- System Overview
- Design Optimization
- R&D Progress
- Safety
- Summary

Introduction

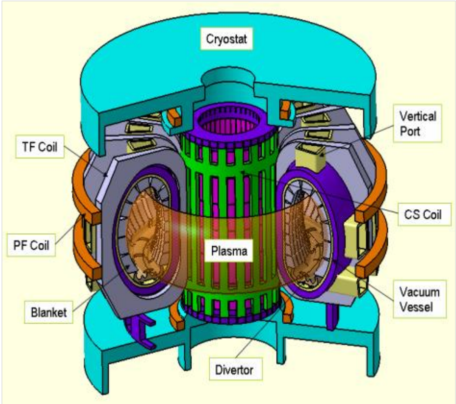
- The ITER facility could offer a unique opportunity to demonstrate the feasibility to test tritium breeding blanket technology in a tokamak reactor and to test Tritium producing components.
- Verification of tritium breeding technology by Test Blanket Module (TBM) program is one of the engineering goals for ITER.
- CN TBM Program was established by CN DA in 2009 and the Helium Cooled Ceramic Breeder (HCCB) TBM concept was selected.
- CN TBM Program is the first step toward the future breeding blanket for CFETR and DEMO.

General Objectives of CN HCCB-TBM Program

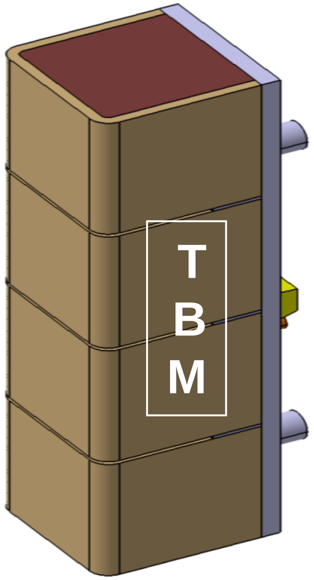
The objectives of CN HCCB TBS is to test the tritium breeding blanket technology in the tokamak operation conditions provided by ITER.



ITER



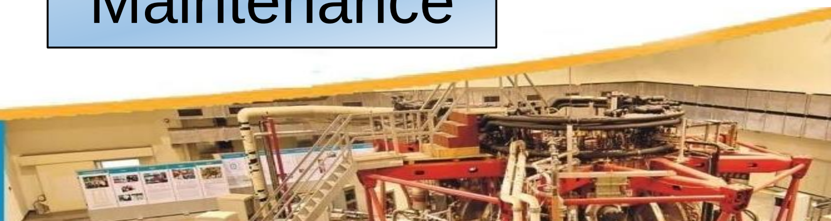
HCCB DEMO



HCCB TBM

General Objectives

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



TBM Concepts and Port-Sharing

TBM Port allocation

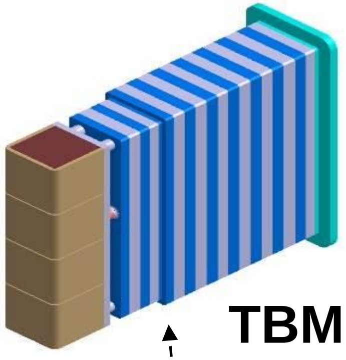
Port No. and PM	TBM Concept	TBM Concept
#2 (PM : CN)	HCCB (TL : CN)	LLCB (TL : IN)
#16 (PM : EU)	HCLL (TL : EU)	HCPB (TL : EU)
#18 (PM : JA)	WCCB (TL : JA)	HCCR (TL: KO)

PM : Port Master, TL : TBM Leader

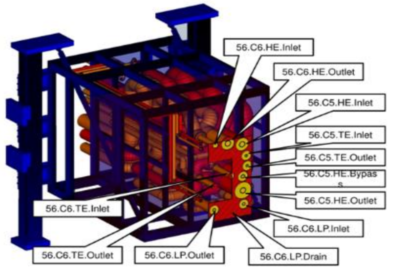
The signature of CN HCCB TBMA

- The HCCB-TBS TBM Arrangement (TBMA) was signed on Feb. 13th 2014 by ITER Organization and CN DA. This is a fundamental step forward for the Chinese TBM Program.
- The CDR has been hold in July 2014 and approved in September 2015 by ITER. Now HCCB-TBS is at the preliminary design phase.

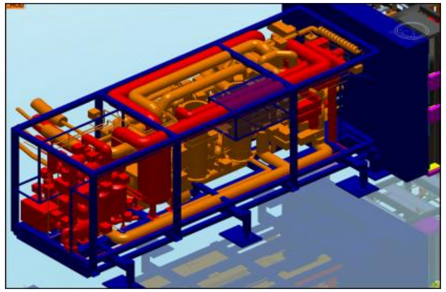
Subsystems and Configuration of HCCB TBS



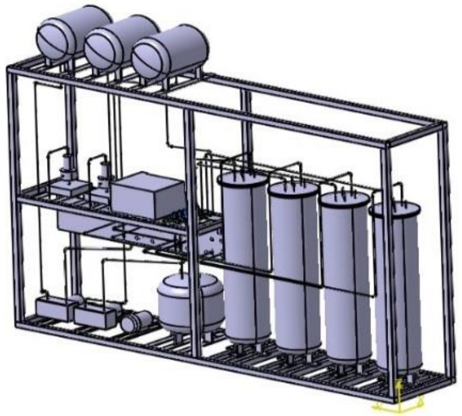
TBM set



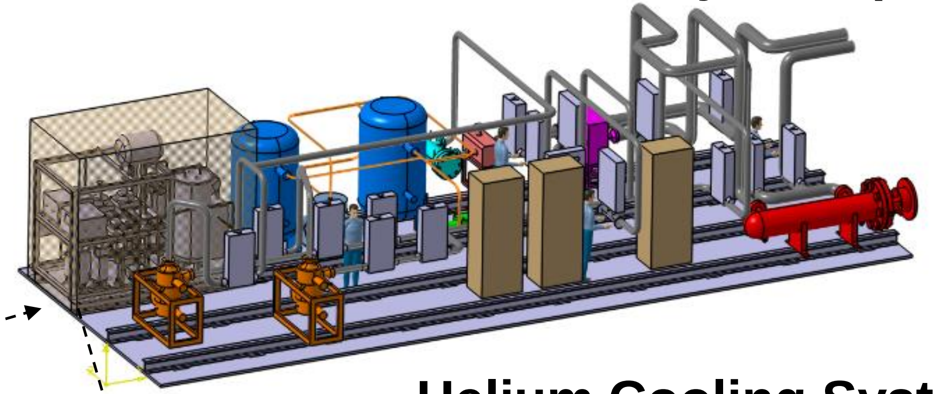
Pipe Forest (PF)



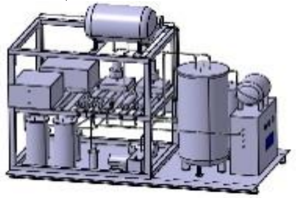
Ancillary Equipment Unit



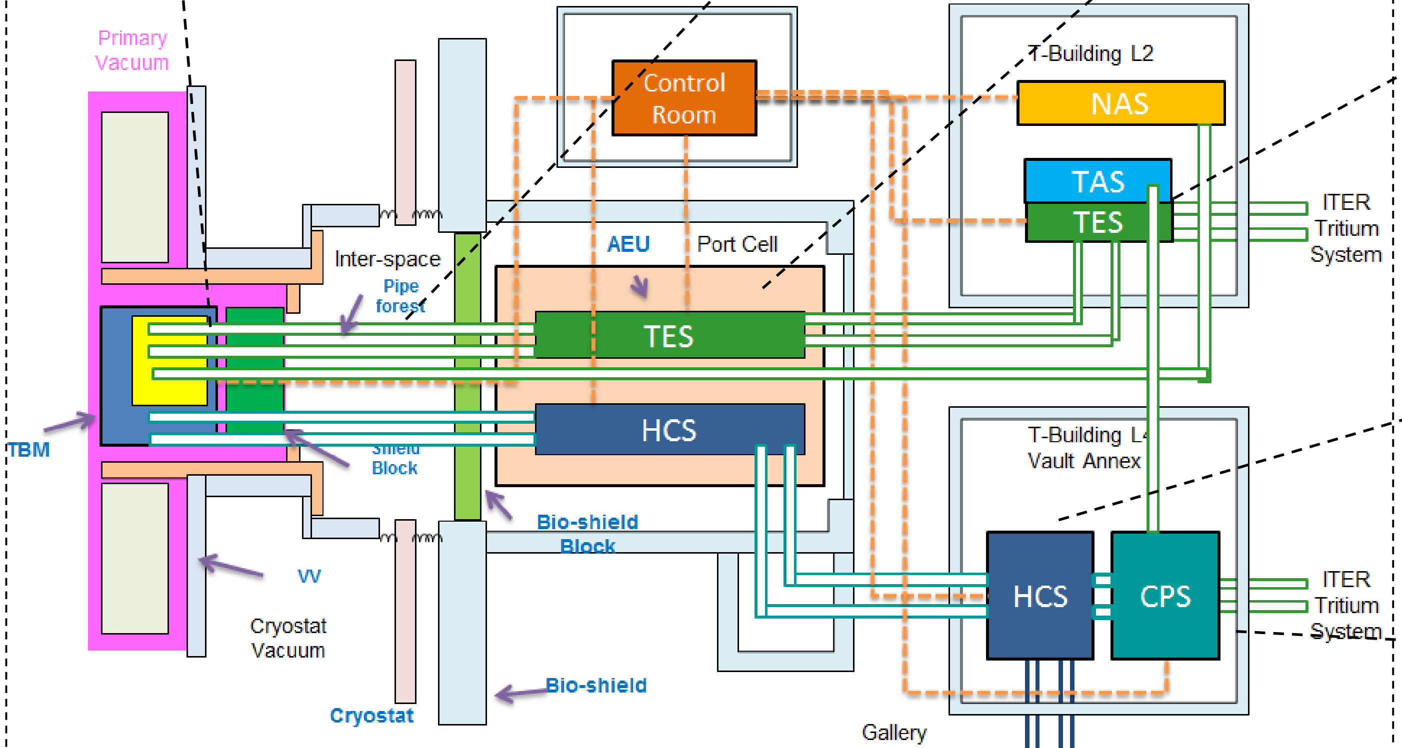
Tritium Extraction System (TES)



Helium Cooling System (HCS)



Coolant Purification System (CPS)

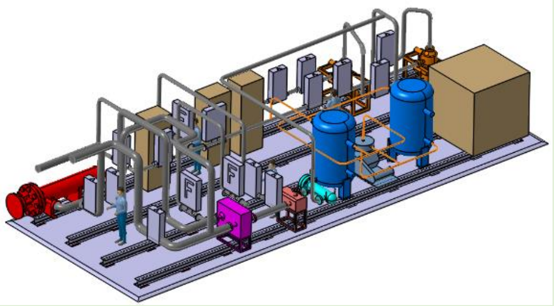


HCCB TBS Schematic

Subsystems and Configuration of HCCB TBS

Room: 14-L4-20

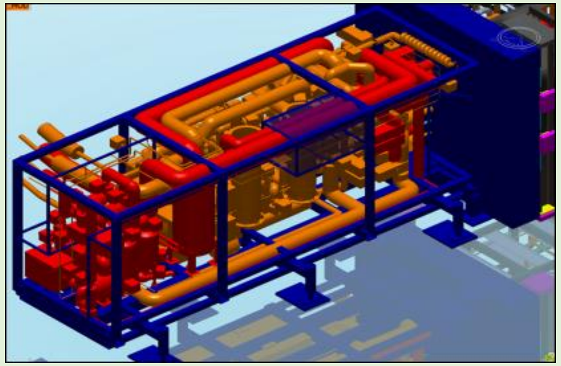
HCS & CPS

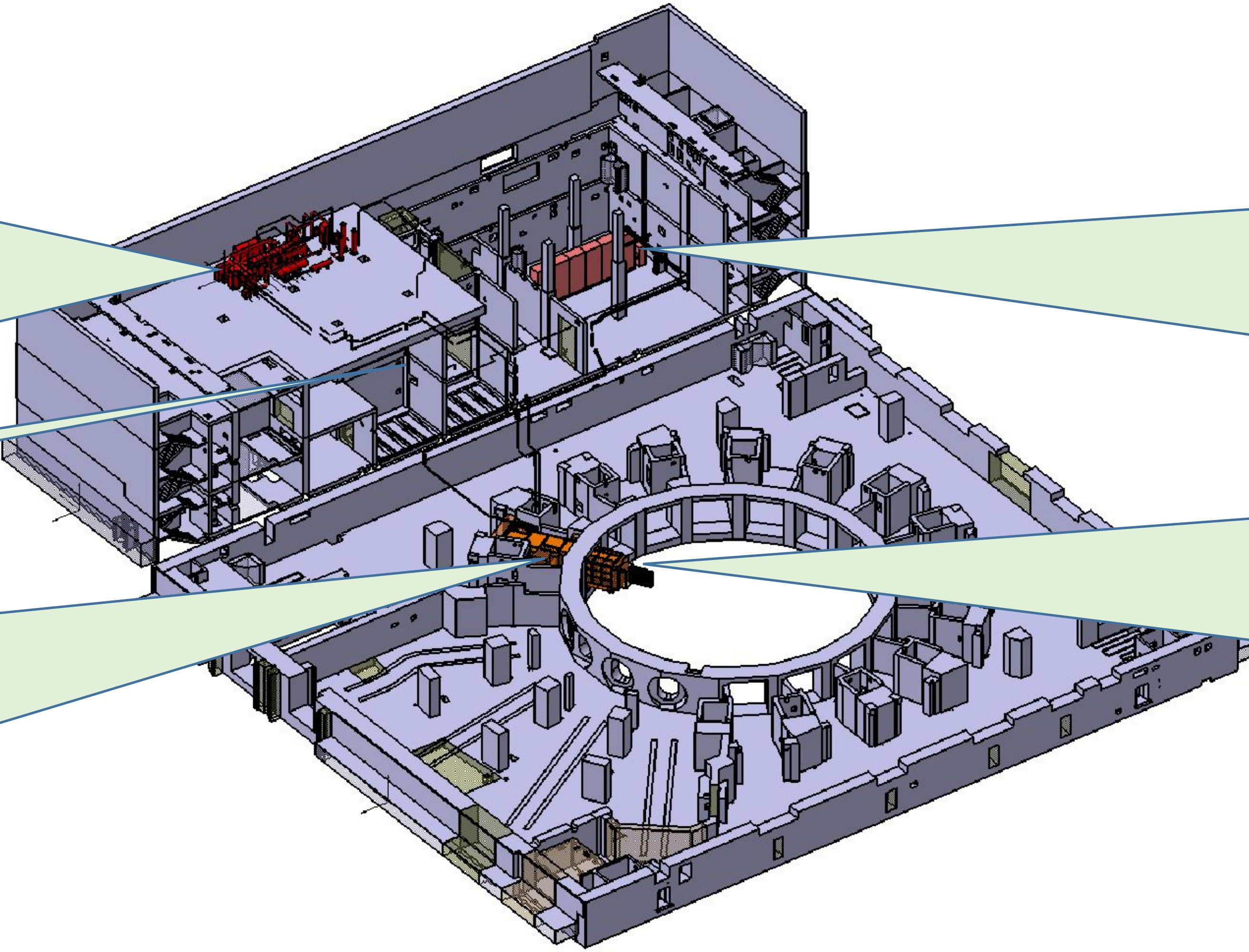


Connection Pipes

Room: 11-L1-C02

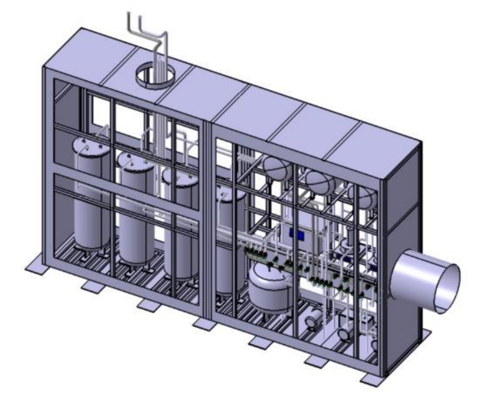
AEU & PF





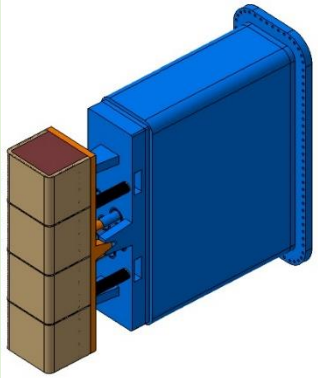
Room: 14-L2-24

TES & TAS & NAS



Tokamak Port #2

TBM-set



HCCB TBS Layout Configuration

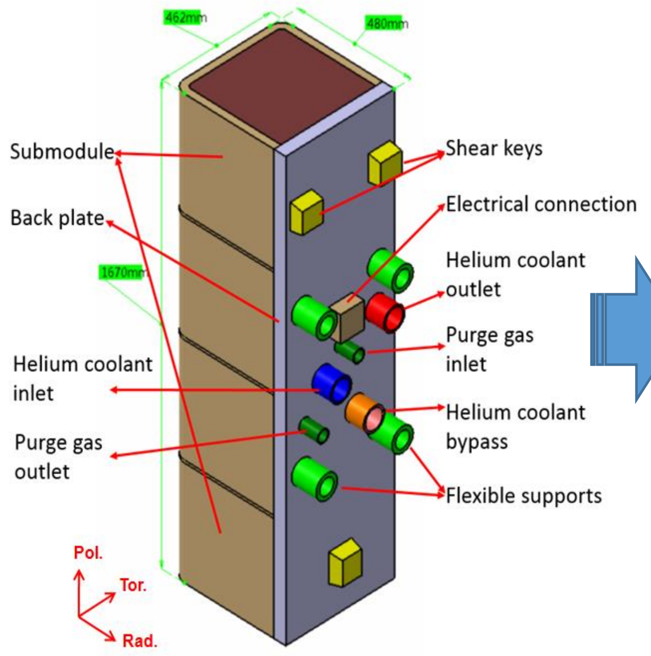
Design Optimization for HCCB TBM-set

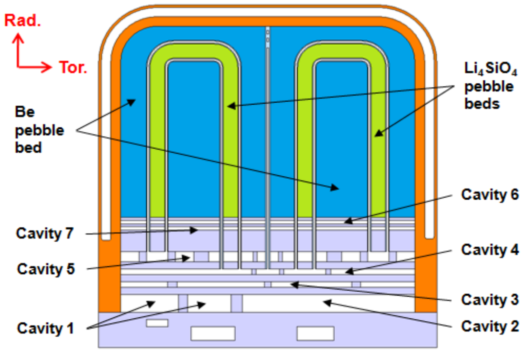
Since conceptual design, the HCCB TBM was significantly simplified considering the material performance, manufacturability and ALARA principle.

Main optimization：

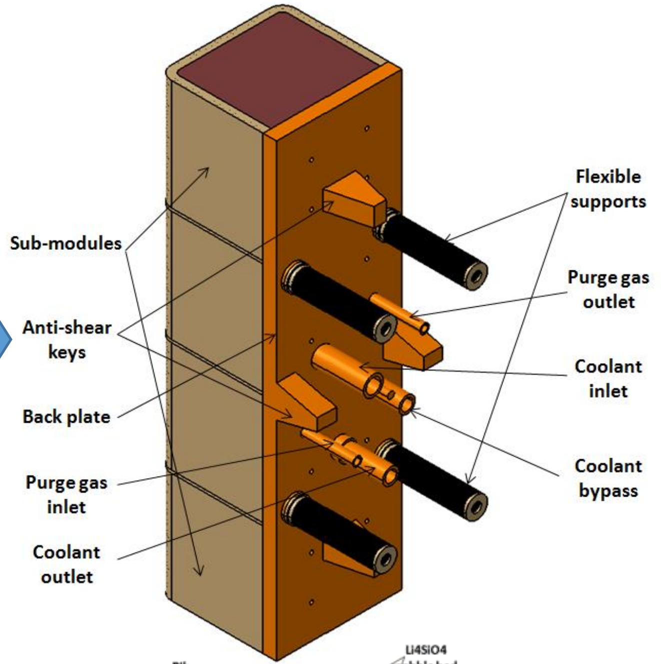
- Simplification of back plate
- Multiplier pebble bed: Binary → Unitary
- Enrichment Li6 increase
- Design configuration update
- TPR is slightly increased to ~0.061g/FPD
- TES parameters: 0.3MPa, 0.3g/s

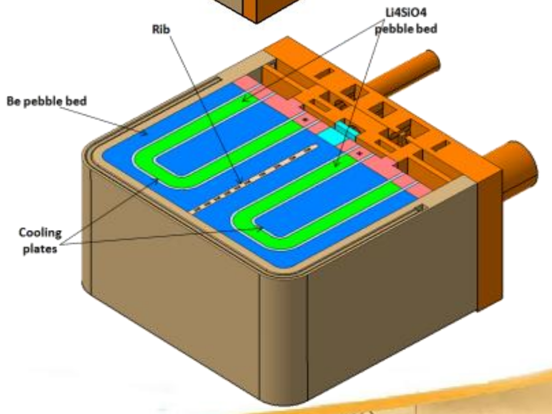
Conceptual design





Optimized design

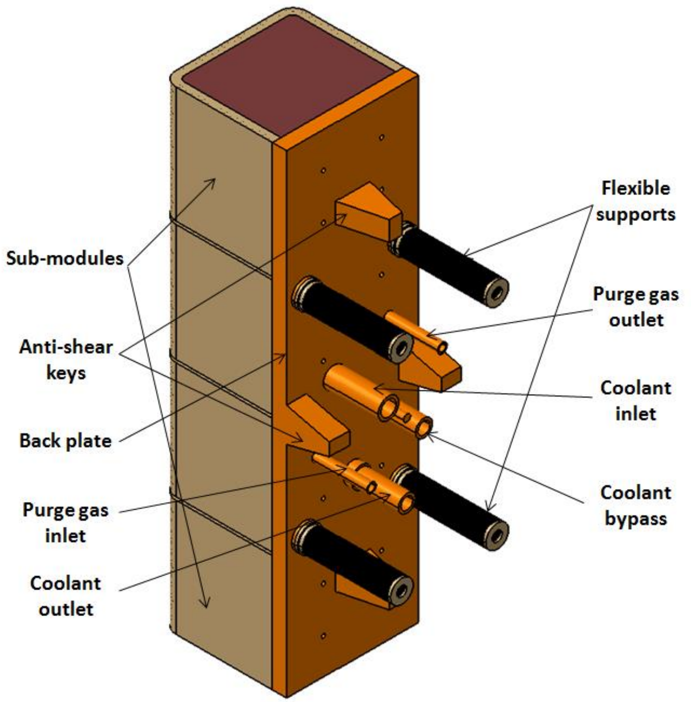


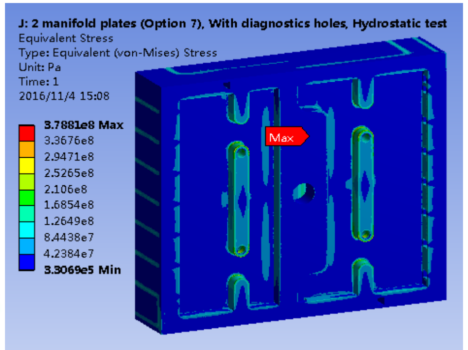


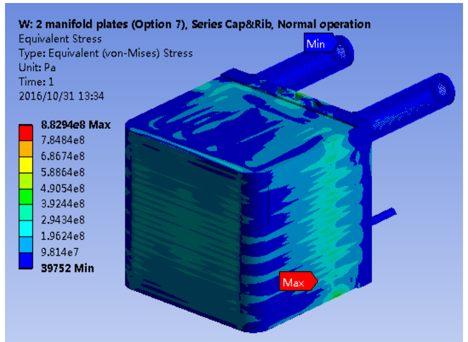
Design Optimization for HCCB TBM-set

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	0.061g/FPD







Analysis validation

	Pm	Pm+Pb	Pm+Pb+△Q
Normal	<84MPa	127MPa	500MPa
Hydrostatic test	<162MPa	311MPa	-
In-box LOCA	<174.7MPa	224MPa	-

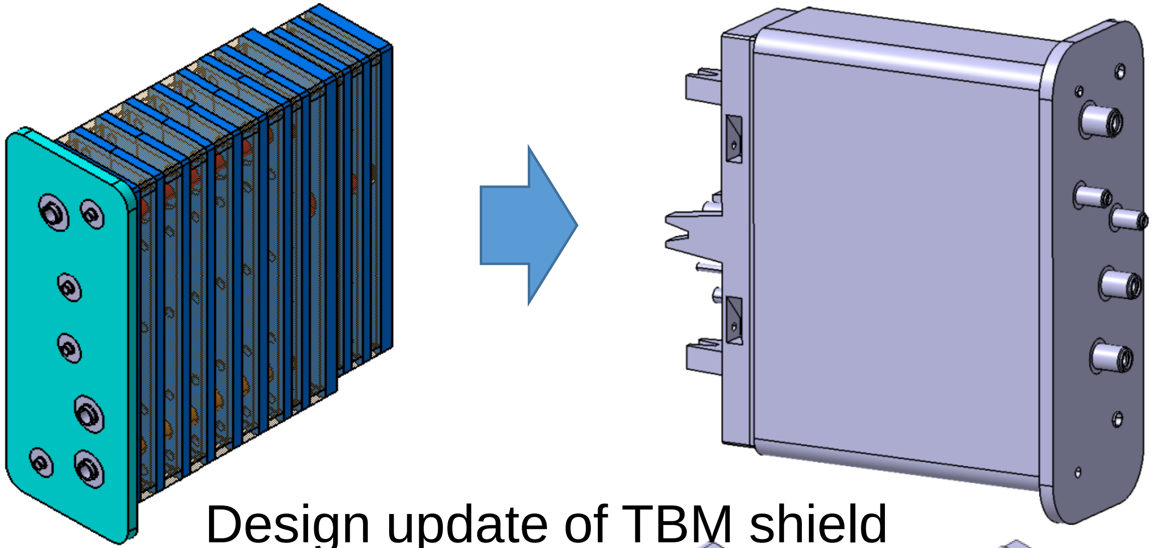
Design Optimization for HCCB TBM-set

Based on fabrication technology R&D and engineering analyses, HCCB TBM shield was further optimized:

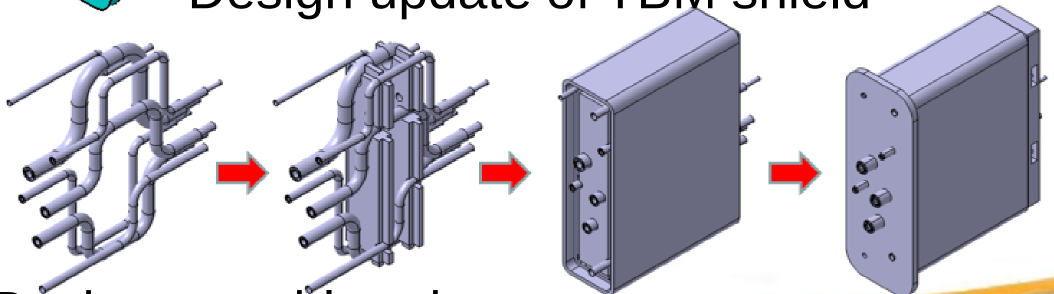
- Reduce the total length to increase the interspace with TBM with similar shielding capability
- Optimize pipe configuration, thickness of shell, supporting structure to simplify the manufacturing

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



Basic assembly scheme

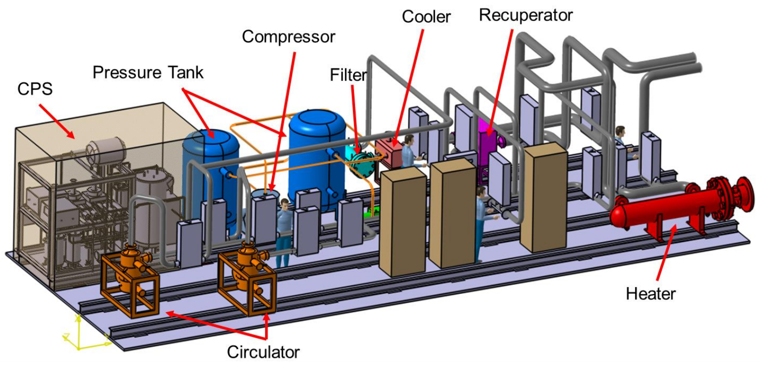
Design Optimization for HCCB TBS Ancillary Systems

Main design parameters

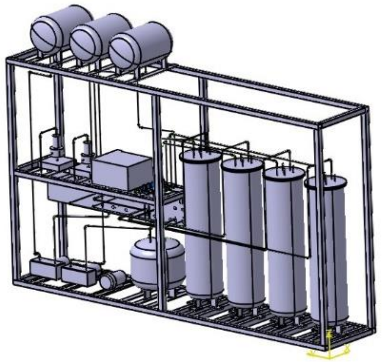
Parameters	**Values** (HCS)
Main structural material Supporting structure material	SS316L SS304
Primary coolant circuit - Pressure - Total flow rate - Pressure drop - Inlet/outlet temperature	Helium 8 MPa 1.04 kg/s ~0.5 MPa 500ºC/300ºC
Interface with CCWS - Pressure - Total low rate - Inlet/outlet temperature	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 review comments, safety and interface requirements:

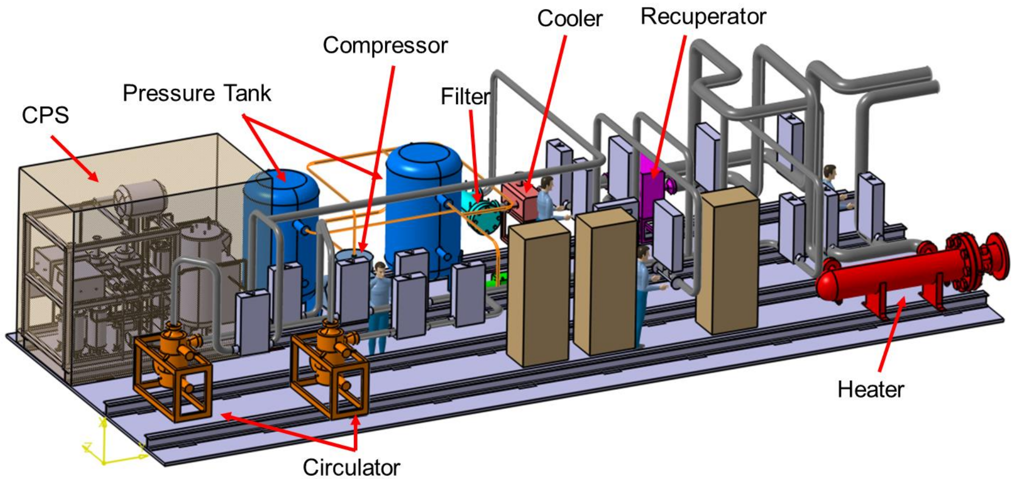
- Configuration update based on equipment investigation, PFD and PID diagrams update
- System performance assessment, structural analysis



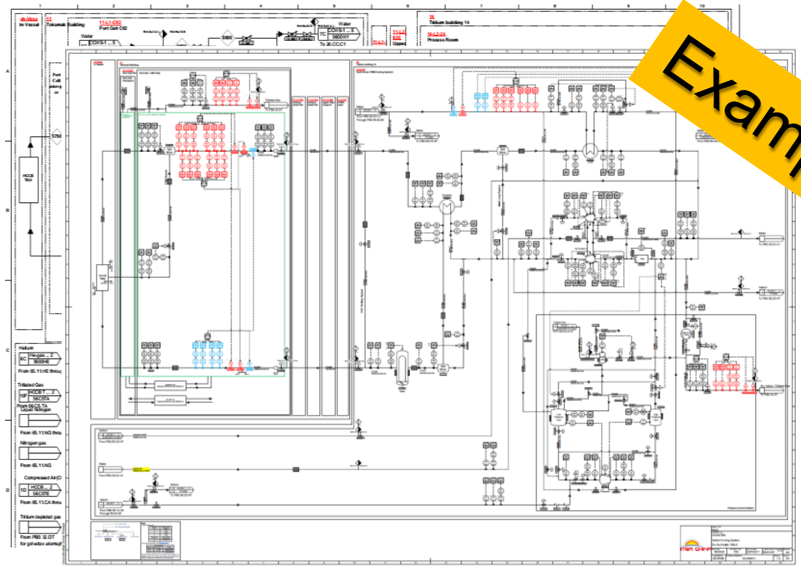
HCS Design


TES Design

Design Optimization for HCCB TBS Ancillary Systems



New configuration of HCS

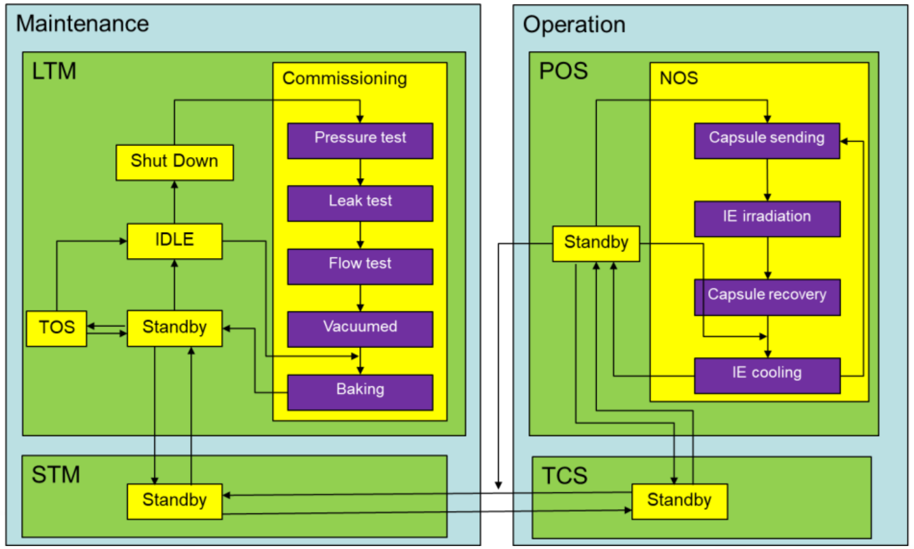


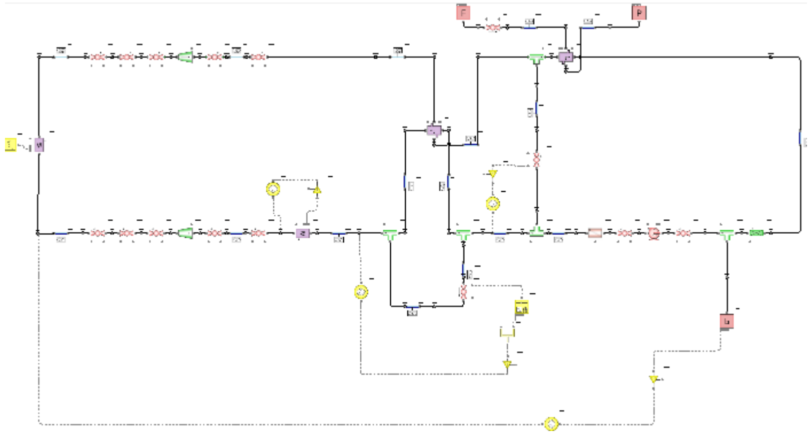
Updated PFD and PID

Example for all ancillary systems

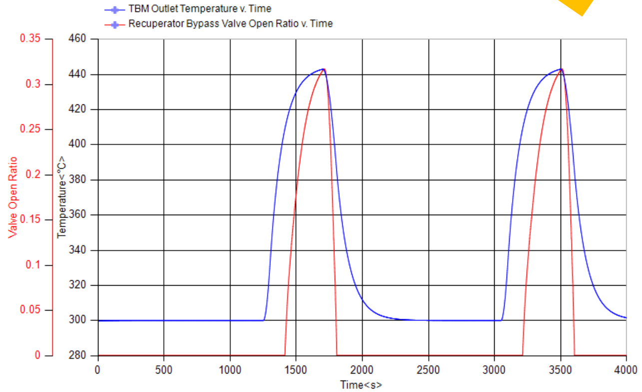
TBM Outlet Temperature vs. Plasma Pulse

Operation states and transition path





Performance analysis model for HCS

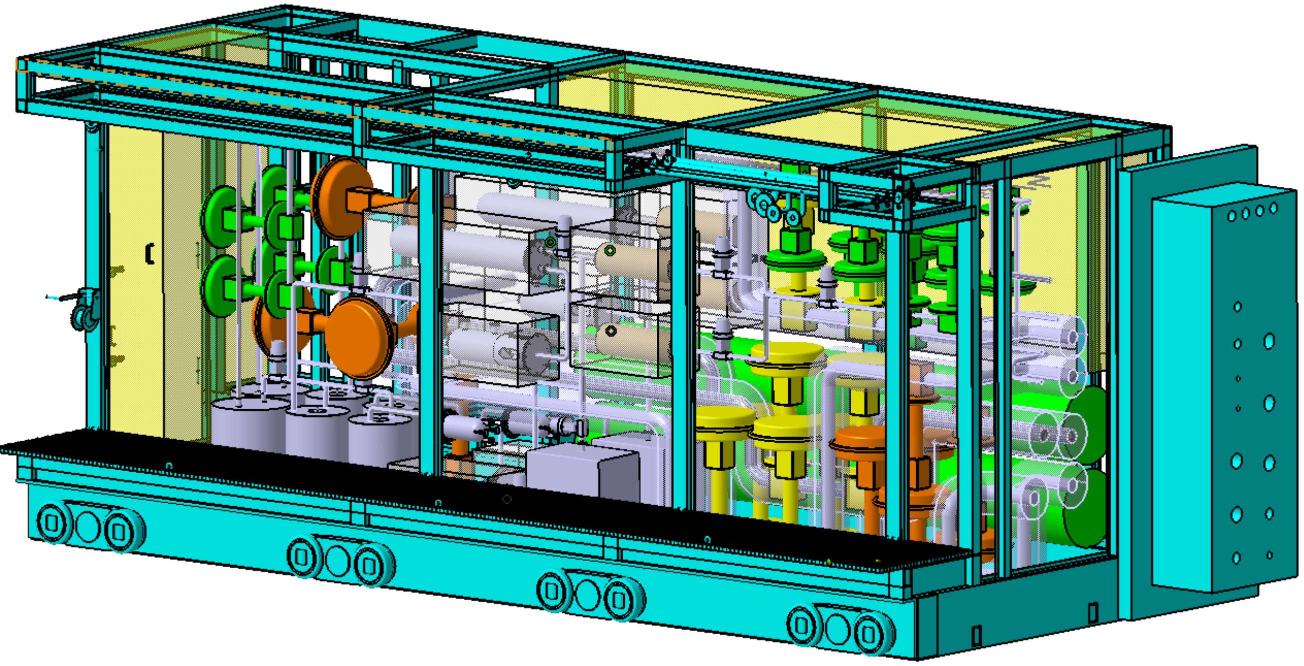


Bypass Valve Open Ratio vs. TBM Outlet Temperature

HCCB TBS System integration

AEU integration

- Component design for HCCB TBS in AEU has been updated.
- Uncertainty of IN withdraw → two sets of HCCB TBS components for AEU.



Component configuration in AEU

Components and equipment in TBS 5

Components		Dimension	insulation layer/mm	Mass/kg	Material	Work Under Maximum ambient temperature 60°C , (Y/N)
TES	Cooler 1	D200xH700mm	100	40	316L	Y
	Cooler 2	D200xH700mm	100	40	316L	Y
	Ionization chamber 1	D500xL700mm	/	40	316L	Uncertain,need further evaluation
	Ionization chamber 2	D500xL700mm	/	40	316L	Uncertain,need further evaluation
	Molecular Sieve Bed	D150xH400mm	/	35	316L	Y
	Measurement unit	400x400x500mm	/	30	316L	Uncertain,need further evaluation
	Reduction Bed	D380xH800mm	120	110	316L	Y
	Relief Tank	2m^3	/	300	316L	Y
	Particle Filter 1	D100xH400mm	100	10	316L	Y
	Particle Filter 2	D100xH400mm	100	10	316L	Y
	Compressor	D550xL750mm	/	100	316L	Uncertain,need further evaluation
	Pipes(2)	DN25/80s	100(only outlet)	/	316L	Y
NAS	Pipes(2)	DN6/40s	/	/	316L	Y
DA	Pipes(1)	DN50/10s	/	/	316L	Y
HCS	Pipes(3)	DN80/80s	100	/	316L	Y
	Mixer	D120×L200mm	100	TBD	316L	Y

R&D Progress – material development

- Improved the material specification of RAFM steel and completed the fabrication of 4 ingots (5-tons) and 10 tons section bar of CLF-1. Prepared the two standards for CLF-1 steel and one for CLAM.
- Completed the trial certificate with NB and obtained the 3.2 certificate based on RCC-MR.
- Completed ion implantation experiment and He(0.1%H) compatibility experiment for CLF-1.

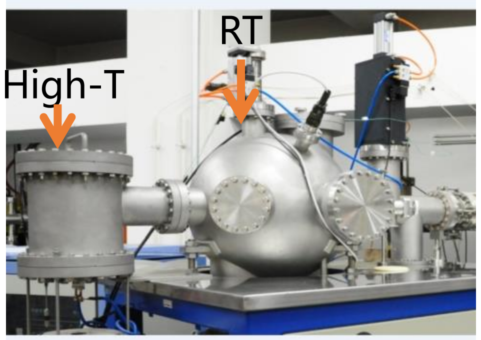
VCM ingot

VAR Ingot

Bar and forging

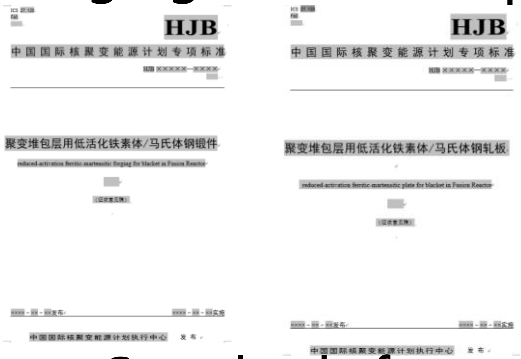
NDT for plates

Mechanical properties testing



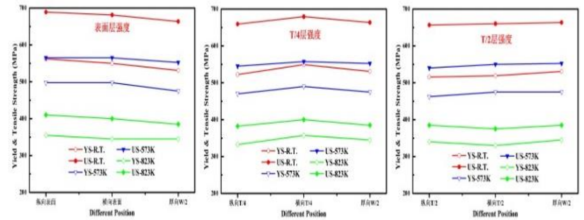
Ion implantation experiment

Compatibility experiment



Standards for forging and plate

3.2 certificate



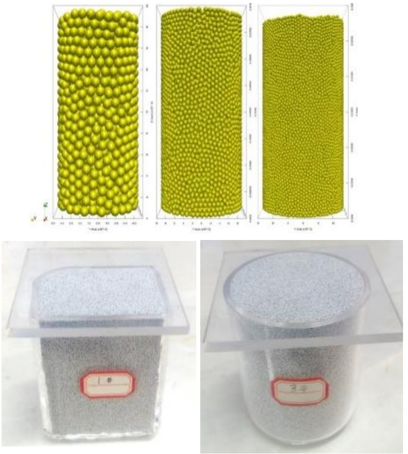
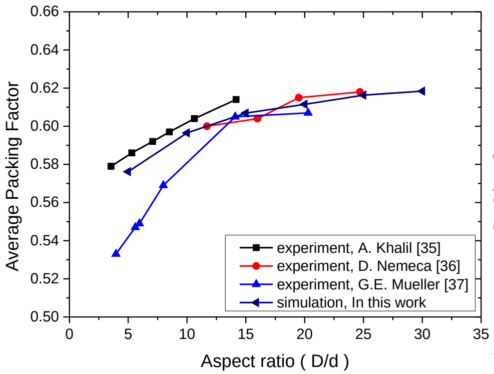
Tensile at Surface, T/4, T/2

Refer: **FIP/P3-22**
H.LIAO

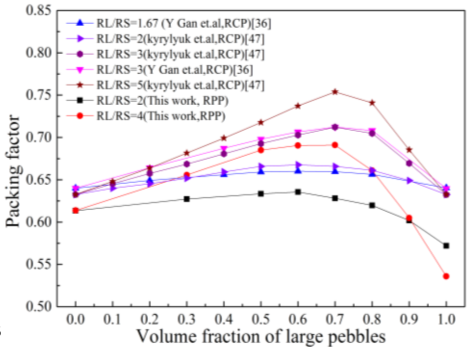
R&D Progress – material development

- Completed the beryllium pebble fabrication facility improvement and achieved the production capability of 10kg scale; Completed He^{+4} implantation experiment for beryllium;
- Studied unitary/binary pebble bed (PB), U-shape and compressed PB by DEM and experiments.

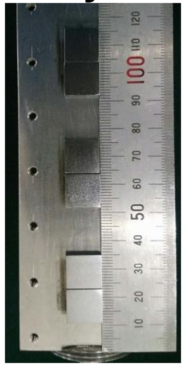

Beryllium pebble fabrication facility and product

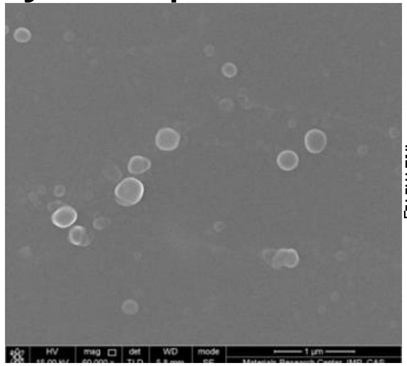



Unitary pebble bed

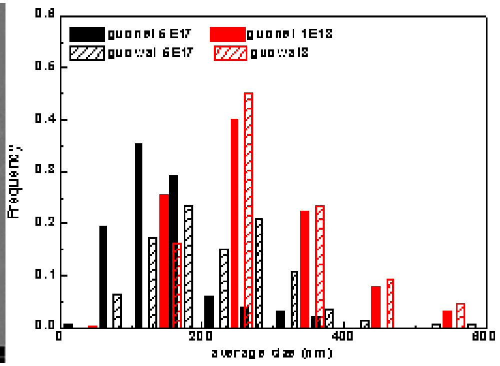


Binary pebble bed

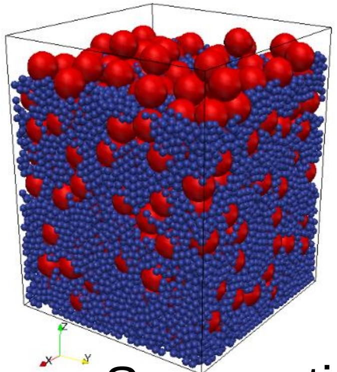
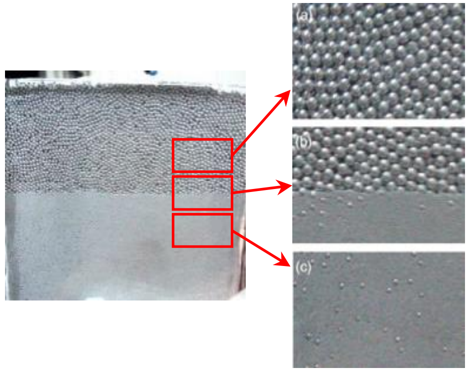




Be sample & He^{+4} irradiation facility



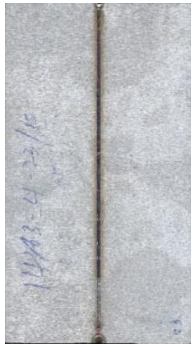
Bubble distribution

Segregation in binary PB

R&D Progress – TBM fabrication technology

- After a large amount of testing and consideration of TBM design, the LB welding and EB welding have been selected as the main welding method, and the TIG welding as supplementary method.
- Based on the TBM updated design and the selected welding methods, the preliminary fabrication procedure of has been prepared.



LB (13mm)

EB (55mm)

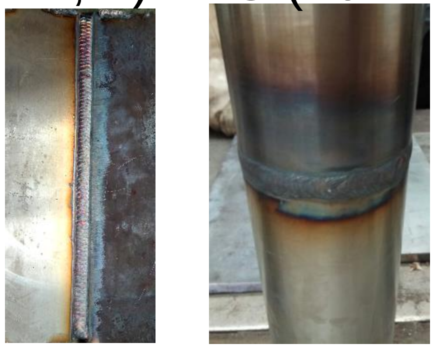
EB (32mm, T)

TIG (10mm)

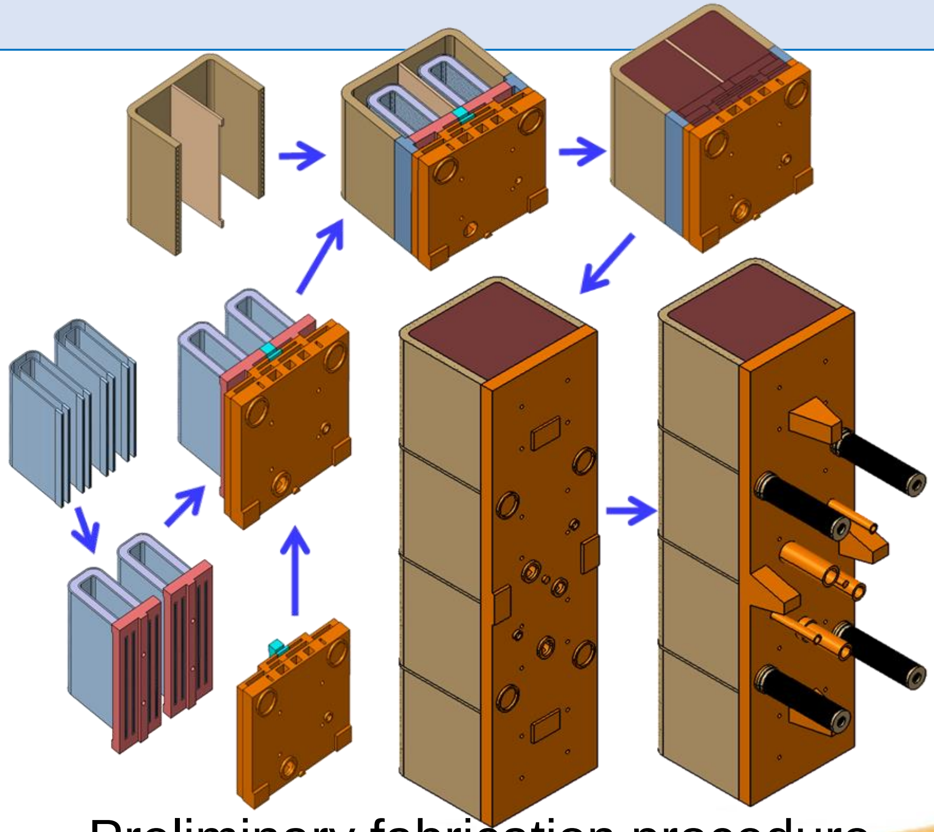
LB (13mm)

LB (30mm) with filler wire

EB (35mm)



TIG dissimilar welding (10mm CLF-1/SS316L)

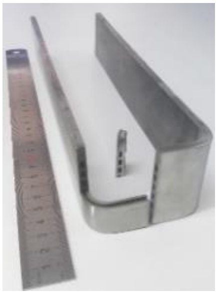


Preliminary fabrication procedure

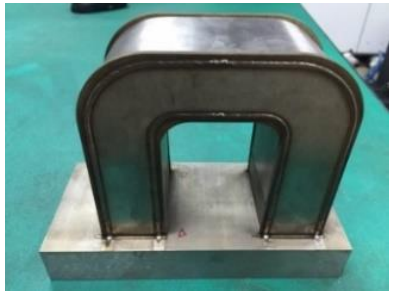
R&D Progress – TBM fabrication technology

◆ The sample of key components and semi-prototype have been fabricated and tested.

FW sample

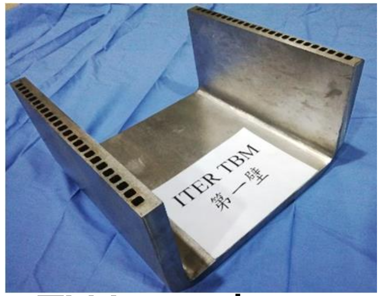


CP sample



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

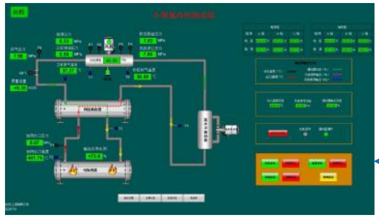
R&D Progress – HCCB TBS Ancillary Systems

- Several testing facilities/loops have been constructed, the related experiments are ongoing to verify the design and operation of ancillary systems. The construction of new testing facilities are under plan.

HHFT facility EMS-60

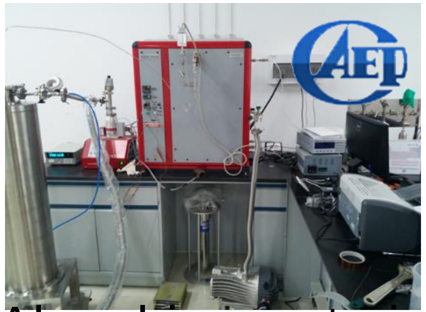
He

HeCEL-1 (0.1kg/s@8MPa&400℃)



Control system and ITER Mini-CODAC

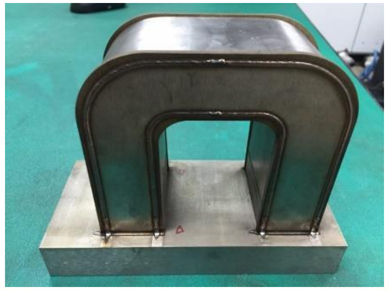
CPS testing facility

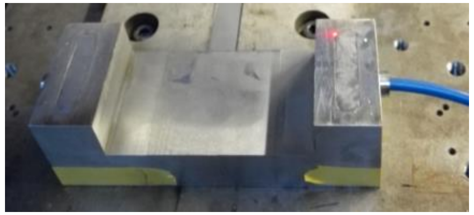


Absorbing material testing facility

TES testing facility

Hydraulic testing sample



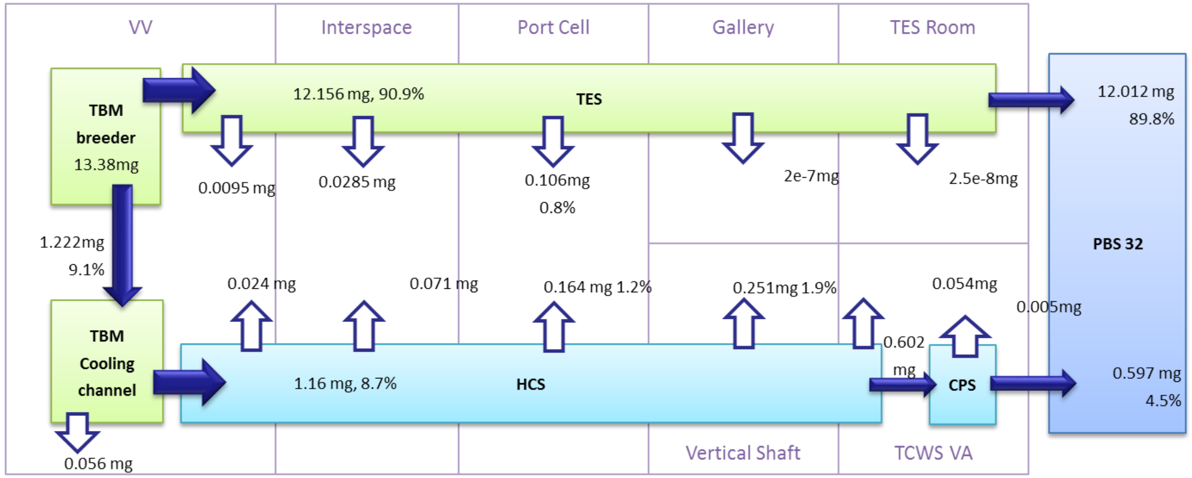


HHFT testing sample

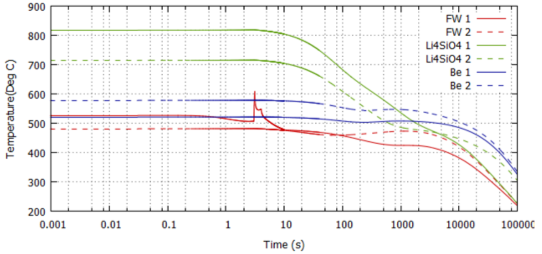
Safety Aspect

The safety work focused on preparing the answering reports of Engagement 9.1.

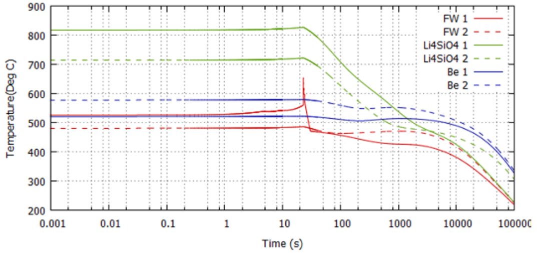
- Design description update and provisions
- Nuclear analysis(incl. benchmark with KO&IN)
- Tritium analysis (incl. benchmark with KO)
- Accident analysis
- Other analysis



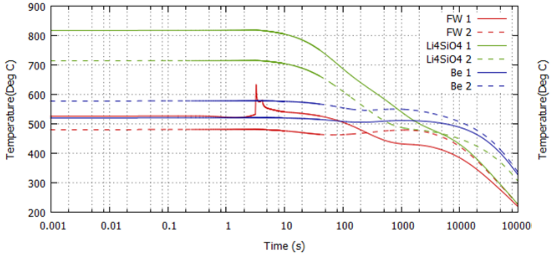
Example of tritium release results



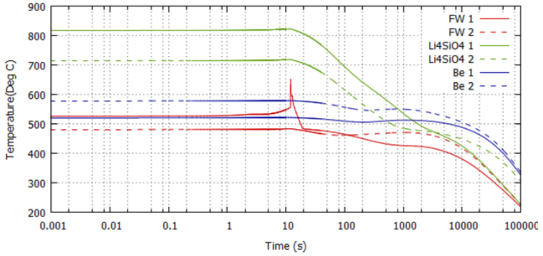
Temperature of CN HCCB TBM during large break area (LOCA in Port Cell)



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

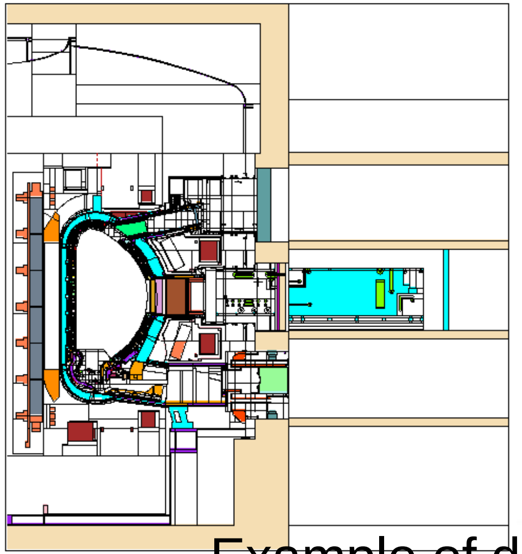


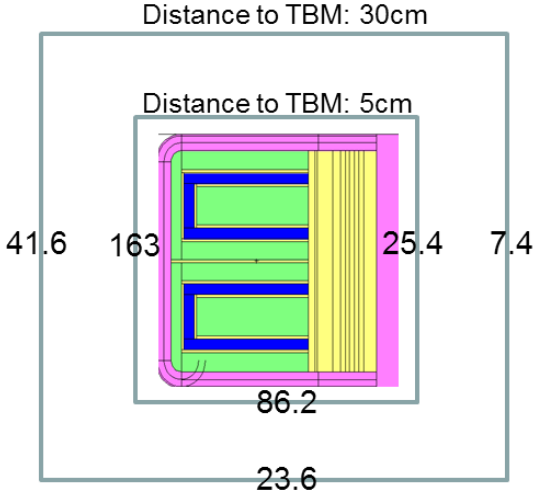
Temperature of CN HCCB TBM during large break area (LOCA in TCWS Vault)



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

Example of accident analysis results



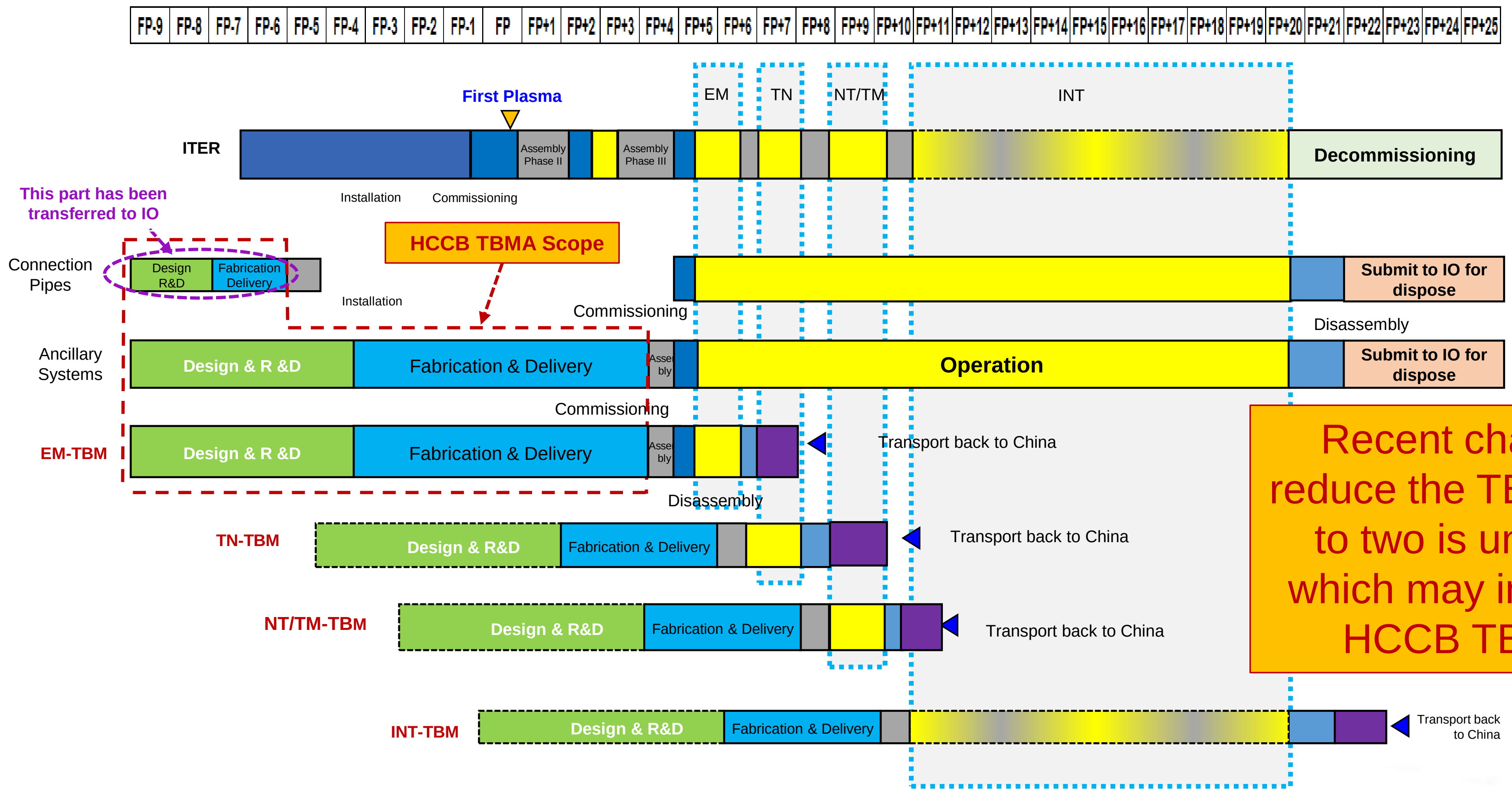


SDDR results for HCCB TBM (1d, Sv/h)

Example of dose rate results

HCCB-TBS Overall Schedule

ITER Commissioning and Operations



Recent change request to reduce the TBM port from three to two is under discussion, which may impact the current HCCB TBMA schedule.

Summary

- CN HCCB TBS is one of the most important part of China fusion development strategy toward DEMO.
- After the conceptual design approval in 2015, the design of the HCCB TBS has been significantly optimized and developed in detail according to the schedule and requirements.
- In order to support the design optimization, a lot of R&D activities have been implemented, including structure material and function materials development, fabrication of TBM mock-up, construction of the testing loops and so on.
- Still many challenges remain and need to be solved during the design phase.

Thank you for your attention !