PFMC for CFETR

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Outline

- ITER-like PFMC for EAST
  - Strategy of PFMC for EAST
  - Status of R & D for W/Cu-PFMC
- PFMC for CFETR and technology readiness
  - Three phases of CFETR
  - Plasma-facing, heat sink and structural materials
  - Water-cooling vs He-cooling
  - Rough schedule for PFMC in China
- Summary

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Strategy of PFMC for EAST

PFMC corresponding to different phases

- Initial phase (2006-2007), PFM was SS plate bolted to the support w/o active cooling
- First phase (2008-2010) with limited heating (max. heat flux onto divertor ~ $2MW/m^2$), PFM is mainly SiC-coated doped graphite tiles bolted to Cu heat sink
- Transition phase (2011-2013) TZM on FW, still C on Div
- Second phase (2014-) with more heating (>10MW), PFCs will be changed into actively-cooled W/Cu-PFC gradually (max. heat removal from divertor ~$10MW/m^2$) ⇨ ITER-like PFMC
- Future phases He-cooled PFMC (500^0C); flowing Li wall

Status of R & D for W/Cu-PFMC

EAST W/Cu Project

- **Divertor:**

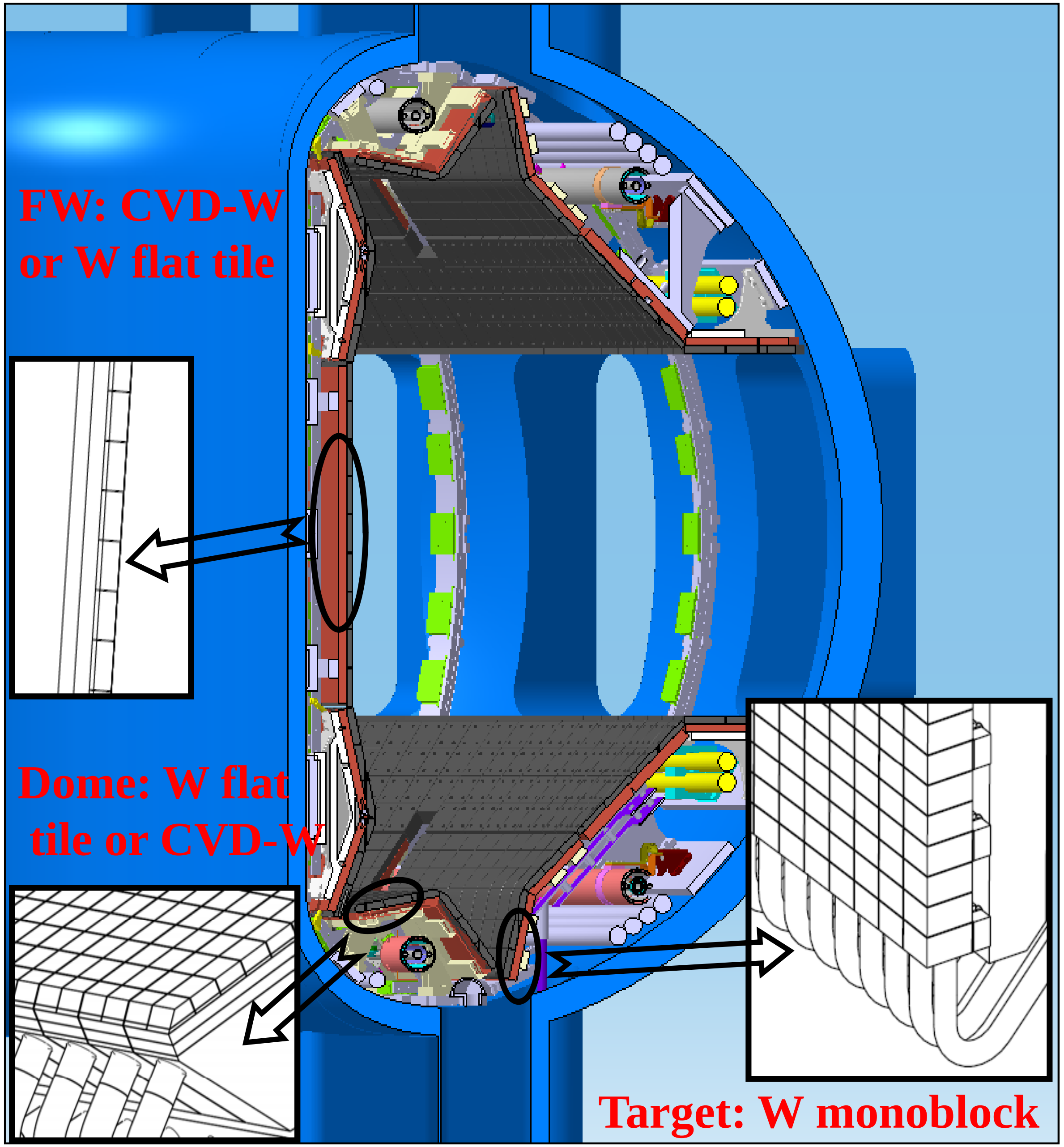
  ITER-like configuration and structure, i.e., Monoblock targets and W Flat type or CVD-W dome

  Max. heat flux capability of divertor targets ~10MW/m^2

- **First wall:**

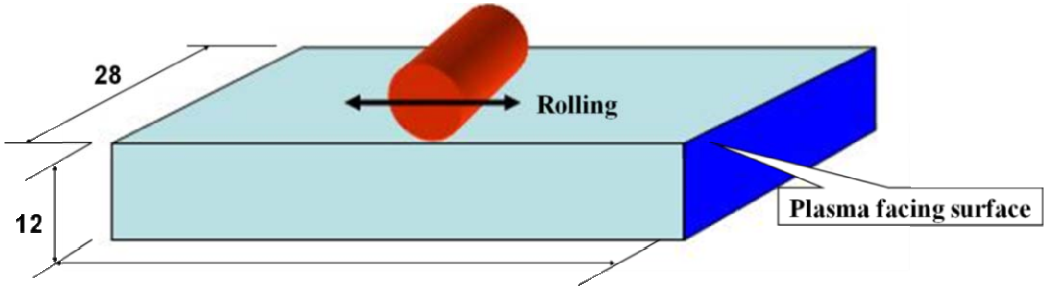
  CVD-W or W flat type

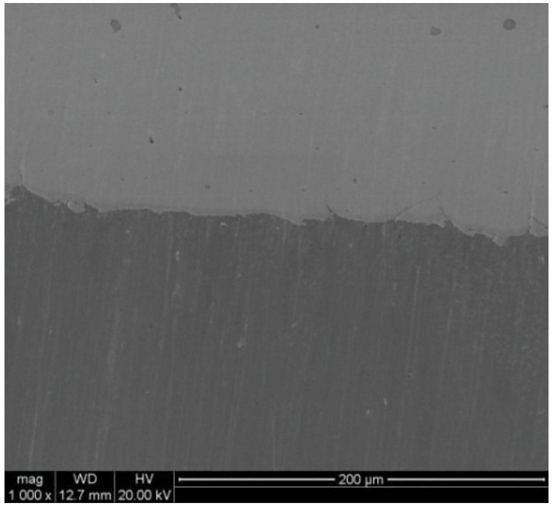
  Max. heat flux capability 3~5MW/m^2



ITER-like W/Cu monoblocks

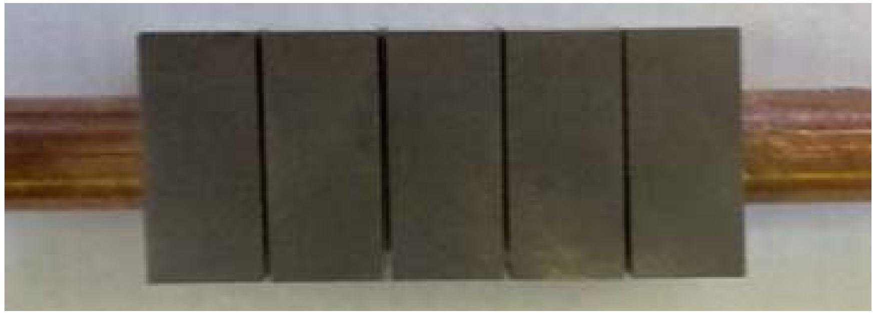
- ITER grade W has been manufactured in batch scale
- W/Cu monoblocks prepared by means of HIP technology
- ITER-like W/Cu mockups in collaboration with domestic and foreign institutions



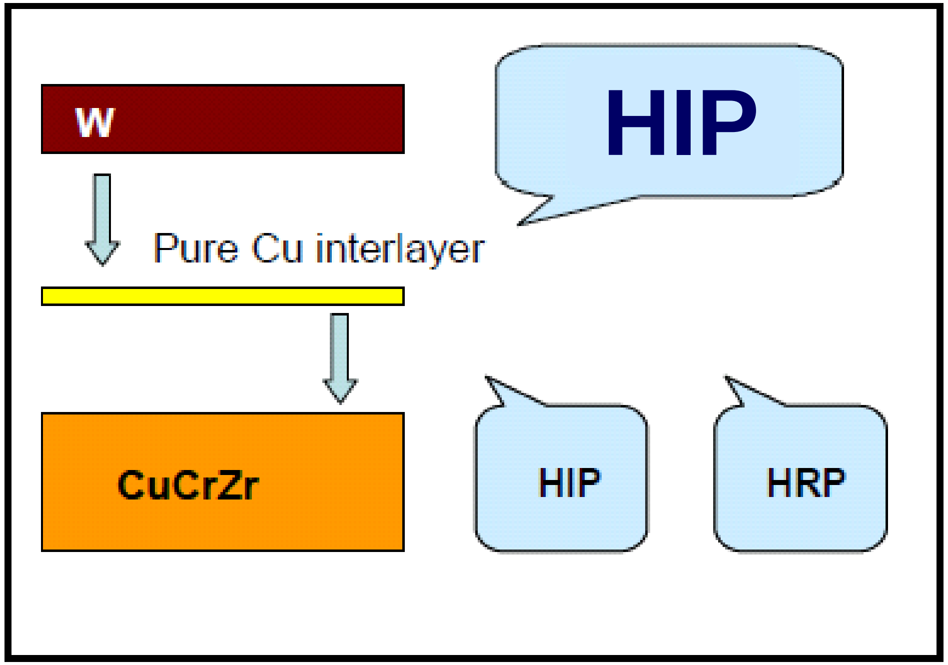


ITER-like Monoblock W/Cu PFMC

- W/Cu mockup with five W tiles was manufactured successfully by Hot Radial Pressing (HRP), showing good bonding between monoblocks and CuCrZr tube.



- The first test W/Cu mockup with four W monoblock tiles was manufactured by Hot Isostatic Pressing (HIP). And the technology will be kept improving.



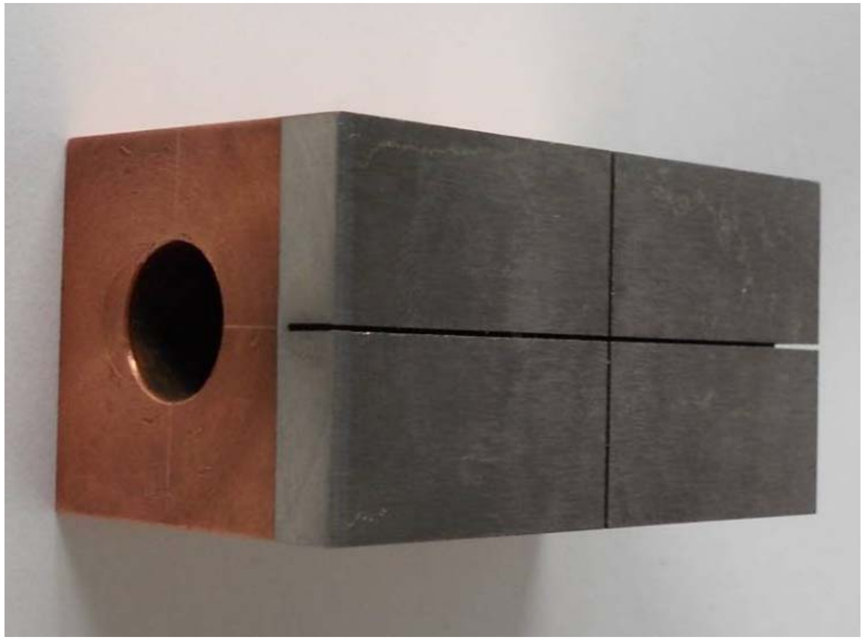
Innovative technology combinations

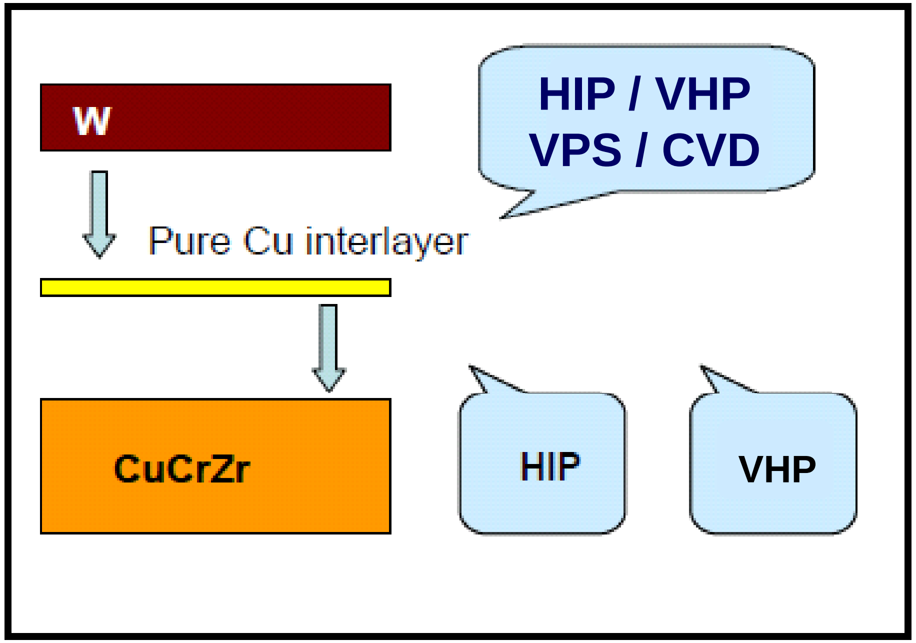
- HIP + HIP
- HIP + HRP

Flat-type W/Cu PFMC

Flat-type W/Cu mockups have been being manufactured by means of various technologies

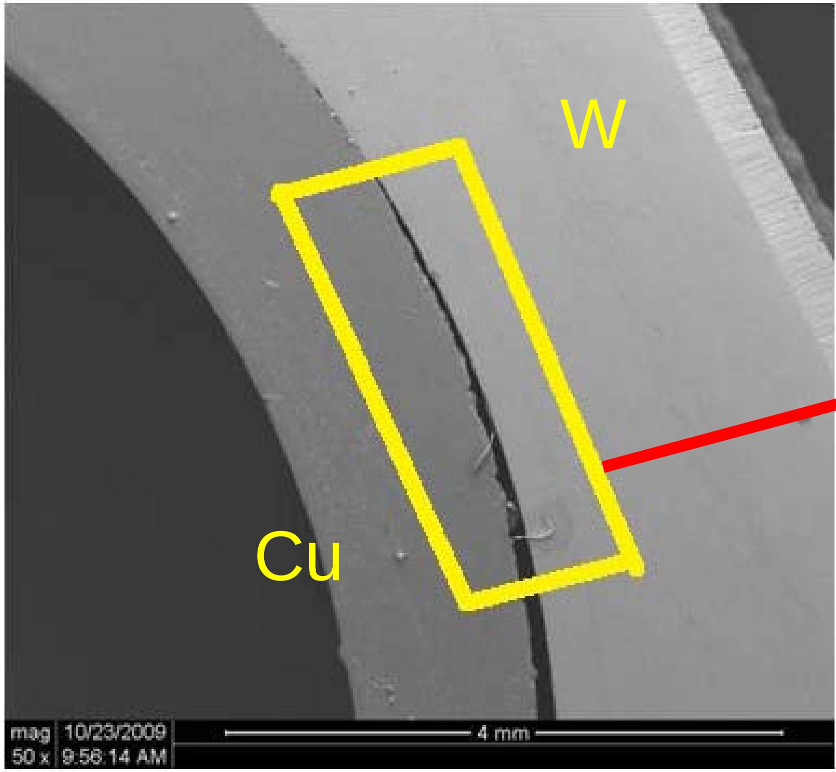
- **Two-step HIP or VHP:** The interface of W/Cu were joined by HIP or vacuum hot pressing (VHP) at higher temperature of ~900℃, and then the interface of Cu/CuCrZr was bonded by VHP or HIP at lower temperature of 500~600℃.
- **VPS & CVD coatings:** Cu/CuCrZr by VHP / HIP, then coating.

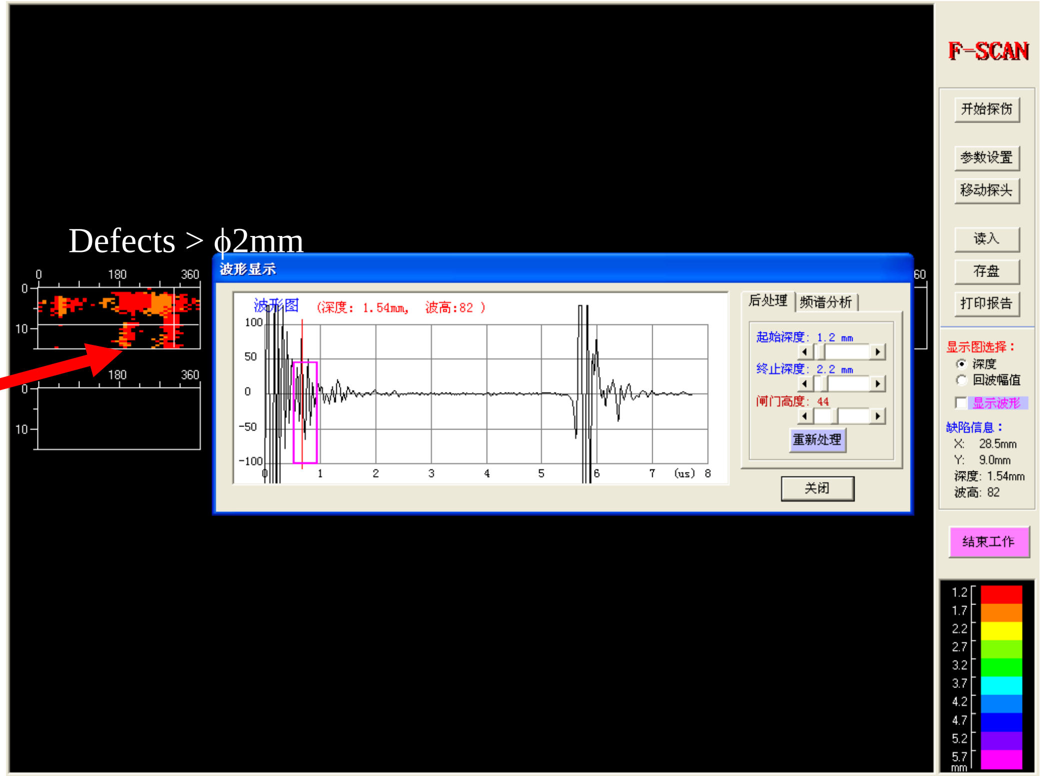




Ultrasonic NDT for monoblock-PFCs

Single reflector sensor, spiral scanning ultrasonic inspection of W/Cu interface



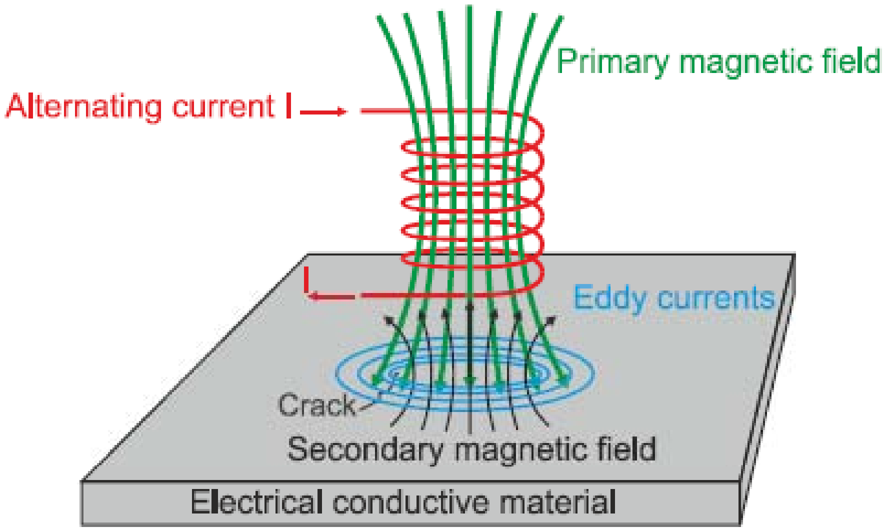


Ultrasonic NDT by single probe proves feasibility to the issue, however showing poor measurement efficiency and difficulty in curved tubes. We are developing a phased array ultrasonic method.

Eddy current NDT for monoblock-PFCs

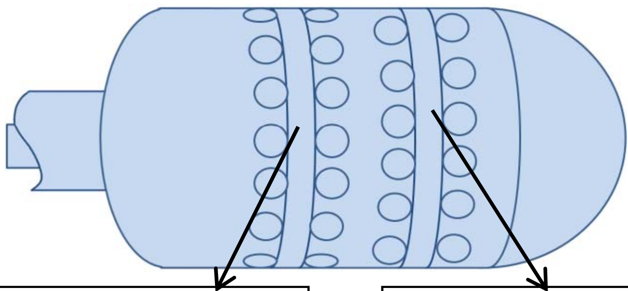
➢ **We are also developing an innovative eddy current NDT method.**

Measurement principle

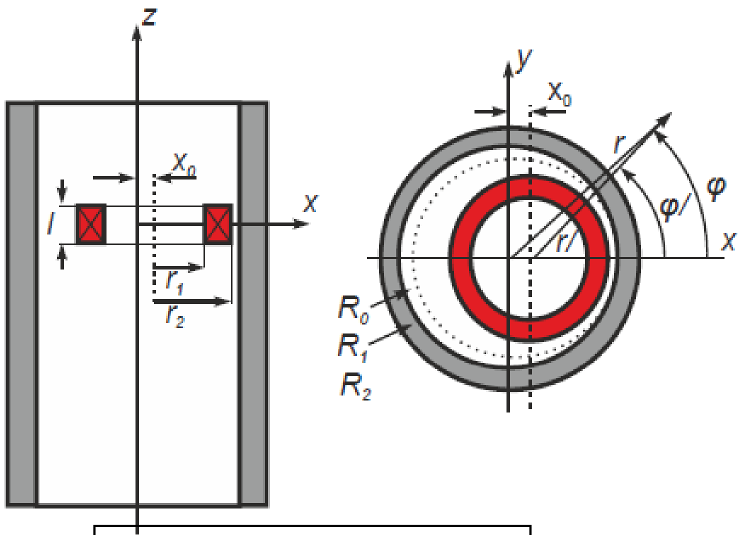


Advantage:
(i) High-speed tube inspection;
(ii) High sensitivity.
To consider:
(i)To reduce lift-off effect;
(ii)To reduce edge effect among blocks;
(iii)To reduce signal-noise ratio by develop multi-frequency technique.

Array probe design



Exciting coil **Detection coil**



Lift-off/fill factor

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Three phases of CFETR

B_{to} : 5.3 / 4.5 T
I_p : 12 / 10/ 07 MA
R_o : 5.5 m
A : 1.6 m
K : 1.8

Phase1：(incl. non- nuclear, 6-8 y)

Ip = 6-7MA, B_T=4.5T, BetaN=1.5

H&CD：50-60MW

Q~1, t> 2 hour, SSO

FTBM, mid-plane FFH BM（T>1.2)

Pfusion ~ 50-100 MW

SN, DN, ITER-W divertor, 3~5dpa

Phase 2: AT H-mode (DT-2, 6-8 y)

Ip=10MA； B_T=5.3T, BetaN=2.5
H&CD: 80-100MW, Q~ 6-8
2-5 hours long pulse, SSO
FTBM, mid-plane FFH BM（T>1.2)
Pfus =300- 400MW, nw: 1MW/m^2
SN, DN, ITER-W divertor, ~ 20dpa

Phase 3: AT H-mode (DT-3, 6-8 y)

Ip=12MA； B_T=5.3T, BetaN=3.5-4
H&CD: 80-100MW, Q~ 10
Qeng>1, long pulse or SSO
FTBM（T>1.1)
Pfus = 800MW, nw: 2MW/m^2
SN, DN, DEMO-divertor, > 50dpa

PFMC technology readiness in China

PFM for CFETR

- ITER-grade bulk W ⇨ Ready
- W coatings by VPS or CVD ⇨ R & D needed
- New grades of W (nano-structured, alloying or ODS-strengthened) ⇨ Initial R & D

Heat sink & structural materials

- CuCrZr & SS (Phase 1) ⇨ Ready, R & D of CuCrZr tube needed
- RAFM (Phases 2-3) ⇨ Ton level production, lack of n-effects
- ODS-RAFM or Vanadium alloy ⇨ Initial R & D

PFC structure

- Monoblock or flat-W/Cu/CuCrZr ⇨ R & D /1-2Y
- Monoblock or flat-W/RAFM ⇨ Not yet started
- He jet cooled design ⇨ Not yet started

Innovative concept

- Flowing Li wall ⇨ Very initial, nothing considered for T plant !

Water cooling vs. He Cooling

	Water cooling	He cooling
Chemical and neutronic activity	H_2O_2 formation due to neutron < 240^0C corrosion to RAFM	Inertness
Working temperature	> 300^0C (n-defects annealing in RAFM) < material limit	> 500^0C < material limit
Pressure	15MPa @ 300^0C (JP)	< 10MPa
Heat conductivity	High	Low
Cooling structure	Swirl tape, hypervaptron	Jet flow (higher heat removal efficiency)
Foundation	PWR, ITER design	HTR, DEMO concept

ITER design: water @ 4MPa/100^0C

Choice of PFMC

Materials considered	Water cooling	He cooling
W, CuCrZr (heat sink), SS(support) - Phase 1	4MPa/<200^0C, 10-15MW/m^2 CuCrZr (3-5dpa?)	<10MPa/<400^0C 5-10MW/m^2
W, RAFM (heat sink + support) - Phase 1-2	15MPa/300^0C larger P @ higher T 10MW/m^2	<10MPa/<500^0C 5-10MW/m^2
W & alloys, ODS-RAFM (heat sink + support) - Phase 3	15MPa/300^0C or larger P @ higher T 5-10MW/m^2	<10MPa/<600^0C 5-10MW/m^2
Flowing Li wall, Mo/RAFM (heat sink + support), - Phase 3+ ?	<400^0C (Li vaporize) Dangerous: Li + H_2O!	<400^0C (Li vaporize) Much safer: Li + He

Rough schedule for PFMC in China

HT-7/ EAST

ASIPP

	2012	2014	2016	2018	2020	2021	2026	2033	2040
EAST	C+Mo H_2O	W/Cu+Mo H_2O	W/Cu H_2O	W/RAFM H_2O/He?		W/RAFM He	W/ODS-RAFM He		
ITER						First Plas W/Cu/H_2O+Be/Cu/SS/H_2O W or Be/RAFM/He (TBM)	DT Oper		
CFETR					Start construction		Phase 1 3-5dpa W/Cu H_2O	Phase 2 20dpa W/RAFM H_2O/He	Phase 3 50dpa W/ODS-FS He

R & D efforts for CFETR

ITER-like W/Cu/H_2O → 2014 → Phase 1

W/RAFM/H_2O or He → ~ 2020 → Phase 2

W/ODS-RAFM/He → 2025-2030 → Phase3

Flowing Li wall/He? →

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Summary

Selection of PFMC is determined considering materials availability, PWI and radiation effects, cooling media and design, and technology readiness. Choices for CFETR are recommended below:

PHASE 1 – ITER design, i.e., water-cooled W/Cu/CuCrZr (4MPa/<200^{0}C)

PHASE 2 – Water-cooled W/RAFM (15MPa/300^{0}C) or He-cooled W/RAFM (10MPa/<500^{0}C)

PHASE 3 – He-cooled W/ODS-RAFM (10MPa/>500^{0}C)

PHASE 3+ - Flowing Li wall concept (200-400^{0}C)

EAST will act as the best test device for ITER-like PFMC, for both ITER and CFETR (PHASE 1); and a test device for He-cooling PFMC

Thanks for your attention!