Preliminary considerations on the basis of engineering and technology of divertor design for CFETR

Minyou Ye

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Introduction

- ❑ **Tokamak**
- ❑ **Stellarator**

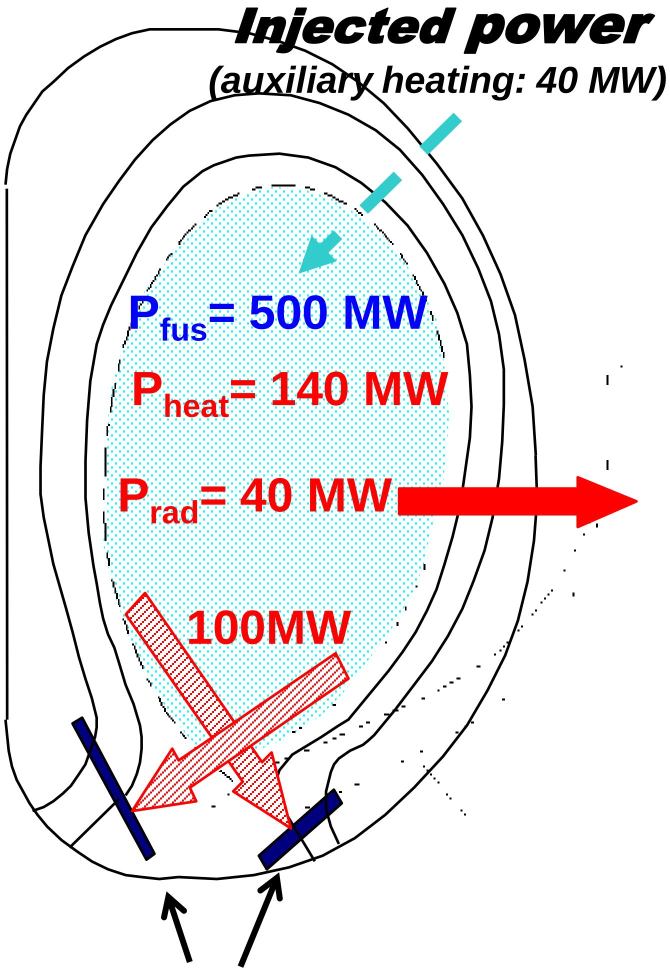
→ **Whichever case, need Divertor Configuration**

- ❑ **D-T burning plasmas**
- ❑ **Steady state operation**

→ **Challenges for Divertor design**

Main Functions of Divertor:

- Exhaust the major part of the plasma thermal power
- Minimize the influx of impurities to the plasma
- Remove the fusion reaction helium ash and unburnt fuel.



Fusion power	**500 MW**
α-heating + auxiliary heating	**140MW**
Loss: Bremstrahlung+ Synchroton Radiation	**40MW**
Power load without additional radiation:	**100MW**
Wetted area: 2*U*width of strike zone (2 *40 * 0.05)	**~ $4.0\ m^2$**
Power load	**~ $25 MW/m^2$**

above technical limit ($10\ MW/m^2$)

Require divertor detachment to reduce heat load to < 10 MW/m2

Divertor : Design criteria and design requirements

General objectives and criteria are:

(a) withstanding a peak heat flux of at least 10-15 MW/m^2,
(b) A modular design instead of large plate structures is required to reduce the thermal stresses,
(c) keeping the divertor operating temperature window at the lower boundary higher than the ductile–brittle transition temperature (DBTT) limit and at the upper boundary lower than the re-crystallization temperature (RCT) limit of the structural components made of refractory alloys under irradiation,
(d) the divertor has to survive a certain number of thermal cycles (100–1000) between operating temperature and RT during operation.

Design features have to be accounted for:

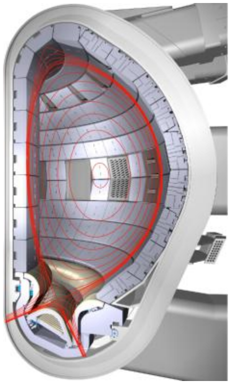
(a) materials choices

(b) transport of the cooling agent as closely as possible to the target plates in order to maintain the max. structure temperature as low as possible,
(c) short heat conduction paths from the plasma-facing side to the cooled surface to maintain the maximum structure temperature below the RCT limit,
(d) achieving high heat transfer coefficients while keeping the coolant mass flow rate,
(e) joint constructions between the divertor components withstanding the thermocyclic loadings

Divertor Design Basis

- **The existing ITER divertor design and technology：**

The ITER divertor is ready for procurement but it is an experimental component and the operational regimes that will allow its use without risk have to be demonstrated. But, Full W divertor design is not ready!



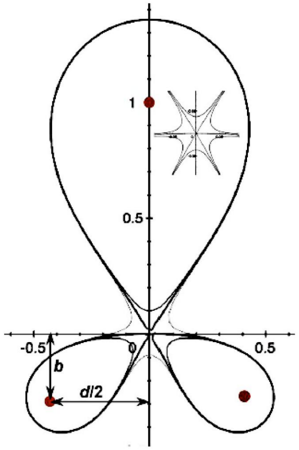
- **Experiences and achievements from current as well as projected tokamaks**:

EAST, KSTAR, TORE-SUPRA, JT-60SA, JET, ASDEX-U, DIII-D and HL-2A……

- **Development of new divertor concept for reactor:**

- Snow-flake divertor to reduce peak heat load
- negative triangularity operation for divertor concept

(recommendation from Prof. M. Kikuchi)



Snow-flake divertor

D. D. Ryutov, PoP 14, 064502 2007

- **Development of materials for PFM, structure**

Divertor System (ITER as example)

Subsystems to Integrate in lower part of vacuum vessel:

-**divertor cassettes with plasma facing components**

-cooling system to exhaust plasma and neutronic heat deposition

-**cryopumps to exhaust neutralized gas**

-**diagnostics to monitor plasma re-attachment**

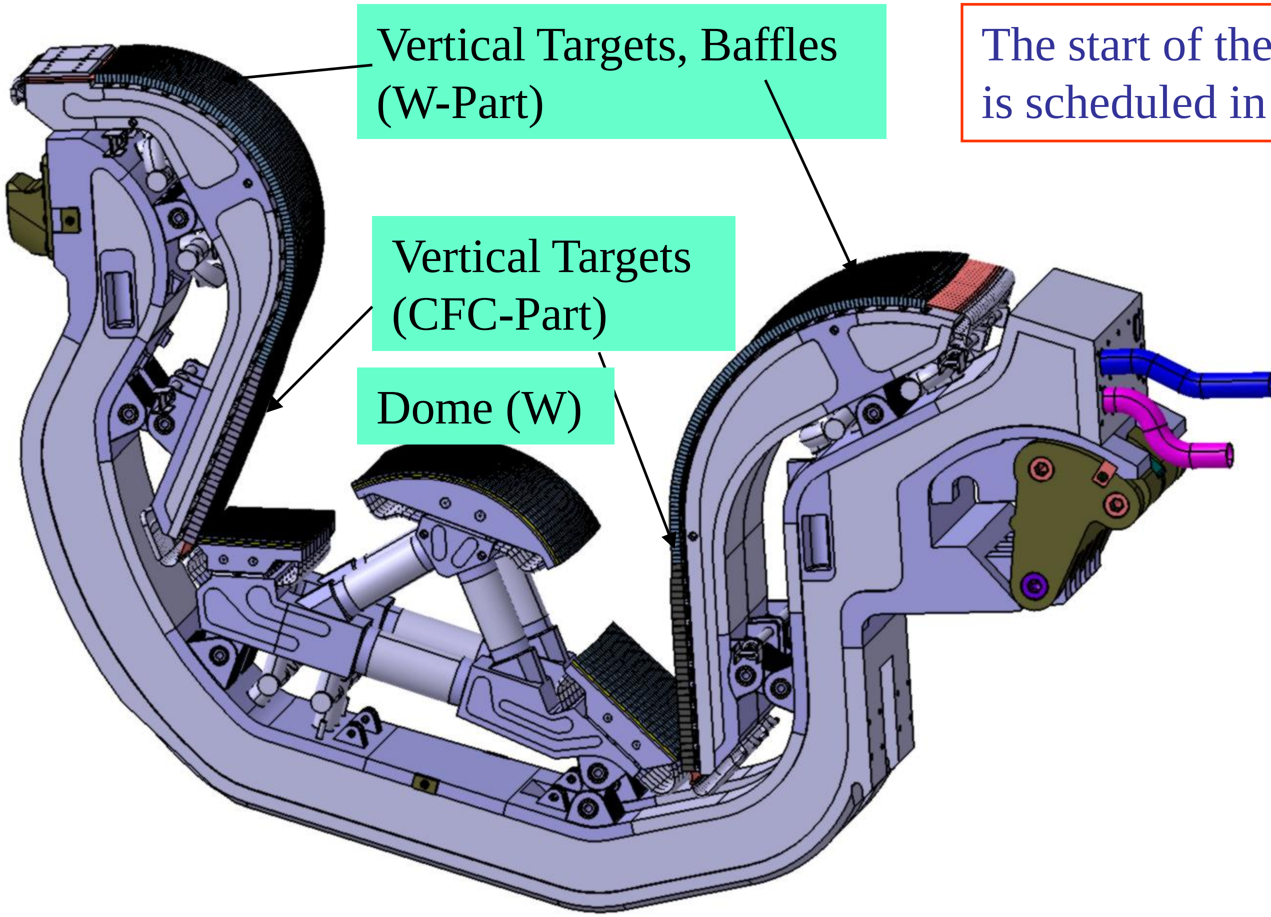
-**Fuelling system to promote plasma detachment / mitigate re-attachment**

-**RH equipment to maintain components and maintenance operations**

System integration : bring together all the component subsystems into one system ensuring that the subsystems function together as a system

ITER Divertor

The start of the full W divertor is scheduled in June 2025



<u>Design parameters</u>

Total power 150 MW

Surface heat flux (MW/m^2)

Steady state (400s,3000 cycles, CFC/W: 10/ 5

Transient (10 s, 300 cycles) : 20

CFETR Divertor Design considerations

Based on the ITER divertor design and technology and EAST divertor update:

- **Optimize divertor configuration**
- **Adopt ITER-like vertical target structure**
- **Reduce peak heat load by partial detachment near the strike points**
- **DT requires a full W divertor** **(** ITER Full W divertor design is not ready!)

Technological Developments of Tungsten:

-Tungsten Coatings (low particle fluencies)

- Massive Tungsten (High particle fluencies , e.g. ITER,)

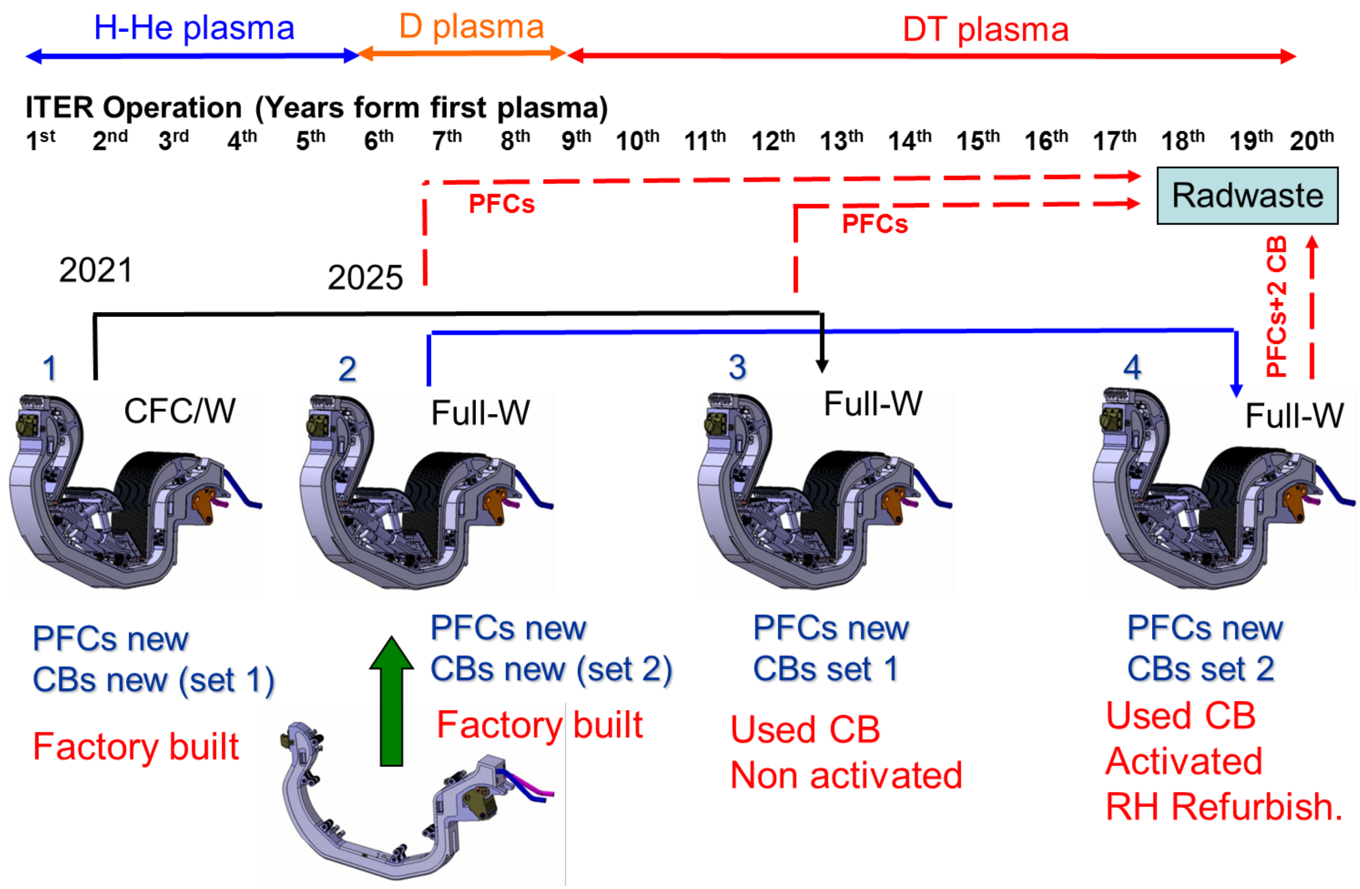
ITER Set of the W divertor: Tentative Roadmap

M. Merola : 1th ITER divertor meeting

- Physics R&D → Continuous process
- Technology R&D small-scale m/ups → end-2014
- Technology R&D semi-proto → 2015 – 2016
- Irradiation → 2016 – 2019

- Design decisions on the basis of the pre-Design phase → end-2014
- Development of 3D CAD models → mid-2015
- Design supporting analysis→ early-2017
- Conceptual Design Review → mid-2017

- Final Design Review → July 2019
- Start procurement → November 2019



H-He plasma
D plasma
DT plasma
ITER Operation (Years form first plasma)
1st 2nd 3rd 4th 5th 6th 7th 8th 9th 10th 11th 12th 13th 14th 15th 16th 17th 18th 19th 20th
Radwaste
PFCs
PFCs
PFCs+2 CB
2021
2025
1
CFC/W
2
Full-W
3
Full-W
4
Full-W
PFCs new
CBs new (set 1)
Factory built
PFCs new
CBs new (set 2)
Factory built
PFCs new
CBs set 1
Used CB
Non activated
PFCs new
CBs set 2
Used CB
Activated
RH Refurbish.

Set of the W divertor: Physics R&D

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There are a number aspects that are or could be potential issues for use of W in ITER

- – Low density start-up/ramp-down and operation at low density and high power
- – Achievement and control of divertor detachment with extrinsic seeding
- – Level of core W concentration compatible with good confinement
- – Compatibility of controlled ELM scenarios with W
- – Damage due to unmitigated transients (ELMs and disruptions)
- – Plasma operation on damaged surfaces
- – Surface cracking following melting or repetitive, sub-threshold ELM loads
- – Material property changes due to alloying with Be
- – Surface morphology changes under exposure to mixed D/T/He fluxes
- – Evaluation of W water-cooled PFC component performance under combined ITER-like ELM/disruption-like and steady-state loads
- – Dust production (due to melt splashing, crack formation)

Set of the W divertor: Technology R&D and Irradiation

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The technology R&D required for the qualification of divertor VTs with a full-W armour, includes the following main sequential phases:

- **Technology R&D**
  - R&D and Manufacturing of small scale mock ups
  - High heat flux performance tests
  - R&D and Manufacturing of semi-prototypes
  - High heat flux performance tests

- **Performance assessment under neutron-irradiation conditions**
  - Manufacturing of small-scale mock-ups
  - Neutron irradiation of the mock-ups
  - Post-irradiation high heat flux performance tests

Summary

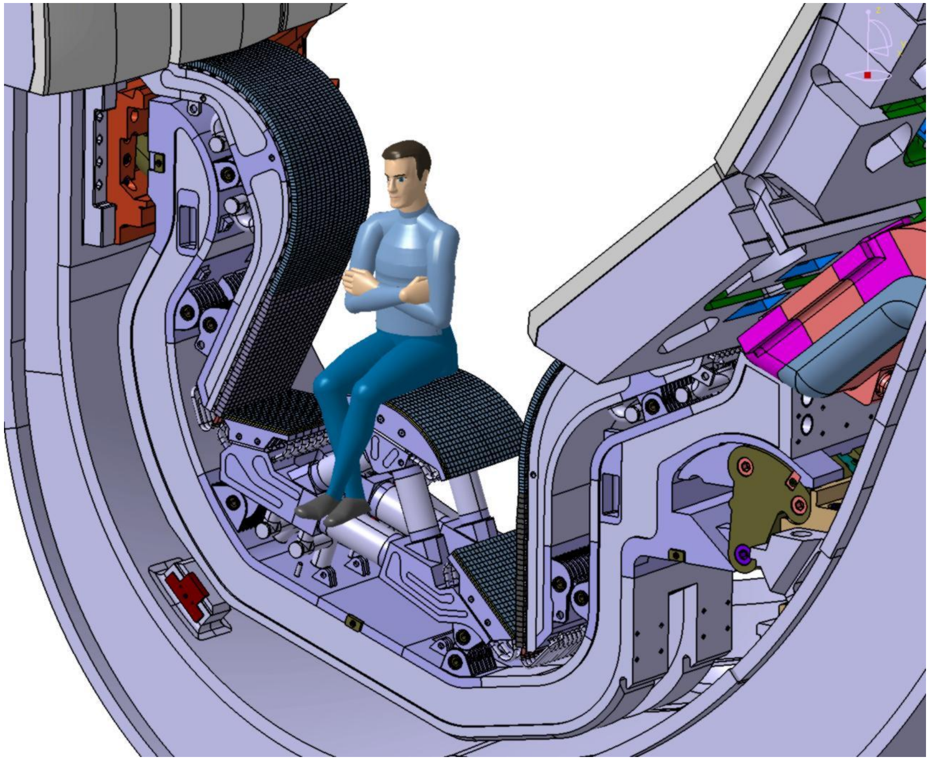
--- The concept design of the divertor system could be finished in three years by using of ITER design basis except for RH

--- A very significant programme of RH will be needed for reactor, but can be defined only once reactor conceptual design is available

--- Technology R&D needs time, more study for full W divertor,

--- The development and optimization of the divertor concept require a close link between the main issues: design, analyses, materials and fabrication technology, and experiments.

Thank you for your attention !

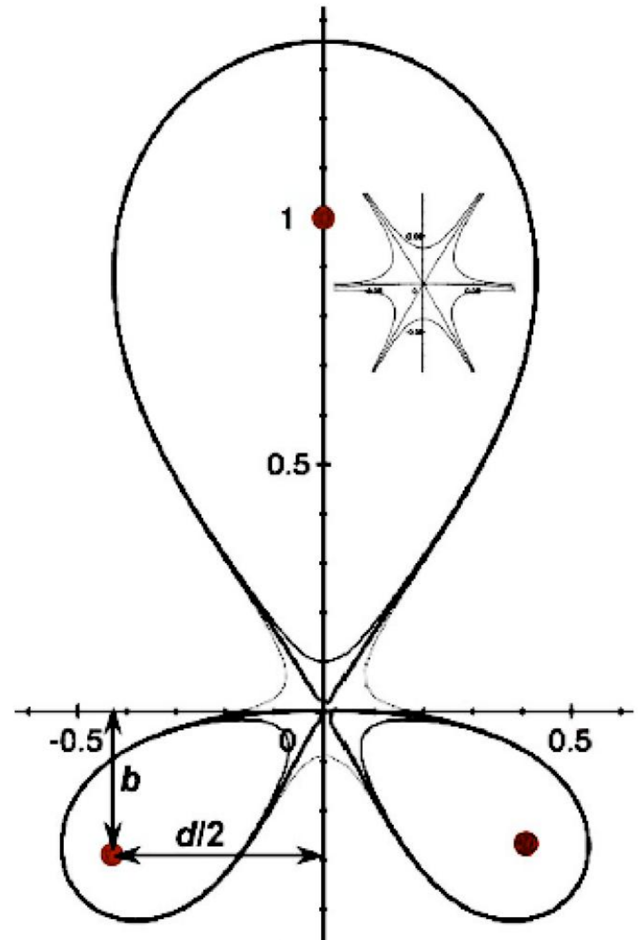


Snow-flake divertor to reduce peak heat load

"SNOWFALKE": USING SECOND-ORDER NULL OF POLOIDAL FIELD TO IMPROVE DIVERTOR PERFORMANCE

Features of snowflake divertors

- Larger flux-expansion near the PF null
- Increased connection length
- Increased magnetic shear in the pedestal region (ELM suppression)
- Modified blob transport (stronger flux-tube squeezing near the null-point)
- Possibility to create this configuration with existing set of PF coils on the existing devices (TCV, NSTX, DIII-D….)
- Possibility to create "snowflake" in ITER-scale machines with PF coils situated outside TF coils



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Divertor System

Materials

Armour	CFC / Tungsten
Compliant layer	Copper
Heat Sink	CuCrZr
Steel Structure	316L(N)-IG / XM-19
Links and bolts	A660
Pins	AlBr

→ See talk of V. Barabash