Power Handling in ITER: Divertor and Blanket Design and R&D

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Internal Components Division Head
Outline

ITER Plasma-Facing Components

Blanket System

Divertor

Summary and Conclusions
Outline

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Summary and Conclusions
• Divertor and Blanket directly face the thermonuclear plasma and cover an area of about 210 + 620 m², respectively.

• All these removable components are mechanically attached to the Vacuum Vessel or Vessel Ports.

• Max heat released in the PFCs during nominal pulsed operation: 847 MW
  – 660 MW nuclear power
  – 110 MW alpha heating
  – 77 additional heating

• Removed by three independent water loops (~1200 ks/s each) for the blanket + port plugs and one loop for the divertor (~1000 kg/s), at 3 and 4.2 MPa water pressure, ~100 (inlet), ~150 (outlet) °C
Design inputs for PFCs

- **Surface heat flux** due to the radiative and particle flux from the plasma. This is of particular concern for the next generation of fusion machines where, due to the high number of operating cycles, a thermal fatigue problem is anticipated.

- **Neutron flux from the plasma.** The two main effects of the neutron flux are the volumetric heat deposition and the neutron damage.

- **Electromagnetic loads.** During plasma instabilities eddy currents are induced in the PFCs together with halo currents. These currents interact with the toroidal magnetic field thus resulting in high forces applied to the PFCs.

- **Surface erosion.** The particle flux impinging onto the PFCs causes surface erosion due to physical sputtering (and also chemical sputtering in the case of carbon).
General Configuration for PFCs

- Armour
- Heat Sink
- Cooling Pipes
- Water Coolant
- Steel Support Structure
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Summary and Conclusions
Blanket system main functions:

- Exhaust the majority of the plasma power
- Contribute in providing neutron shielding to superconducting coils
- Provide limiting surfaces that define the plasma boundary during startup and shutdown.
Power Handling in ITER: Divertor and Blanket Design and R&D, M. Merola et al.
Blanket System: Key Facts

Number of Blanket Modules: 440
Max allowable mass per module: 4.5 tons
Total Mass: 1530 tons

Armour: Beryllium
Heat Sink: CuCrZr
Steel Structure: 316L(N)-IG

n-damage (Be / heat sink / steel): 1.6 / 5.3 / 3.4 (FW) 2.3 (SB) dpa

Max total thermal load: 736 MW
Shaping of the First Wall panel

Allow good access for RH Shadow leading edges

Exaggerated shaping
### First Wall Panels: Design Heat Flux

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<tr>
<th>Heat Flux (MW/m²)</th>
<th>Fraction (%)</th>
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<tr>
<td>1.7 - 2.0</td>
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<td>3.0 - 3.9</td>
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<td>4.0 - 6.0</td>
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<td><strong>Total</strong></td>
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**Diagram:**

*ALL BMs maps with Design Heat Flux for the FW panels*
First Wall Panels: cooling concepts

- Water pipes
- Support beam
- Be flat tiles

Normal heat flux finger: concept with Steel Cooling Pipes

Enhanced heat flux finger: concept with rectangular channels
FW Pre-qualification Requirements

- **Objective**
  - Each DA must demonstrate technical capability prior to start procurement
  - 2 phase approach:

  - Demonstration/validation joining of Be/CuCrZr and SS/CuCrZr joint
  - Semi-prototype - Production/validation of large scale components
• Slits to reduce EM loads, additional slits on the back were introduced to minimize the thermal expansion and bowing (mitigation of EM load)
• Cooling holes are optimized for Water/SS ratio (Improving nuclear shielding performance)
• Poloidal coolant arrangement make large cutouts feasible
“At the back” of the Blanket Modules…
“At the back” of the Blanket Modules

Integrate ELM/VS Coils and Blanket Manifolds

Electrical Straps

Flexible attachments
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Divertor system main functions:

• Minimize the helium and impurities content in the plasma

• Exhaust part of the plasma thermal power
Divertor: Key Facts

Number of Cassette Assemblies: 54
Mass per Cassette Assemblies: ~9 tons
Total Mass: ~490 tons
Armour: CFC / Tungsten
Heat Sink: CuCrZr
Steel Structure: 316L(N)-IG / XM-19
Max total thermal load: 204 MW
The PFCs of the first divertor set are designed to withstand 3000 equivalent pulses of 400 s duration at nominal parameters, including 300 slow transients.

During normal operational conditions:
- Vertical target has a design surface heat flux up to 10 MW/m$^2$ (strike point region) and 5 MW/m$^2$ (baffle region).

Under slow transient thermal loading conditions:
- Lower divertor vertical target geometry has a design surface heat flux up to 20 MW/m$^2$ for sub-pulses of less than 10 s.

The dome shall sustain design heat fluxes of up to 5 MW/m$^2$.

The umbrella and the particle reflector plates shall sustain local heat flux up to 10 MW/m$^2$, which can be transiently swept across the surface (about 2 s) as the plasma is returned to its correct position.
**Divertor PFC materials choice**

**Non-active phase (H, He):** CFC at the strike points, W on the baffles

**All-W from the start of D operations**

**Rationale:**

- Carbon easier to learn with
- No melting $\rightarrow$ easier to test ELM and disruption mitigation strategies before nuclear phase
- T-retention expected to be too high in DT phase with CFC targets
Diagnostic Integration: Optical Diagnostic Box

Features to locate and cool diagnostic box integrated in all cassettes

- To allow implementation of mirror box, neutron flux monitor, pickup coils, bolometers
- Pipes plugged when no diagnostic box is required
Main features:

- Three divertor sets \(\rightarrow\) Two divertor replacements
- Off-line refurbishment, 2 sets of cassette bodies

**START WITH CFC/W DIVERTOR**

*ITER Operation (Years from first plasma)*

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2021 \(\rightarrow\) 2025

1. CFC/W
   - PFCs new
   - CBs new (set 1)
   - Factory built

2. Full-W
   - PFCs new
   - CBs new (set 2)
   - Factory built

3. Full-W
   - CBs set 1
   - Used CB
   - Non activated

RADWASTE
Divertor Qualification Prototypes

CFC Armoured Areas
- 1000 cycles at 10 MW/m²
- 1000 cycles at 20 MW/m²

W Armoured Areas
- 1000 cycles at 3 MW/m²
- 1000 cycles at 5 MW/m²

All the 3 Domestic Agencies have qualified
Behaviour under ELM Loads

Thermal exposure at QSPA facility (RF)

- Pre-heating of samples at 500 °C
- 60 degree inclination
- Plasma pulse duration: 500 µs
- Peak absorbed energy density: from 0.5 to 1.5 MJ/m²
- Total number of simulated ELMs: 100 cycles

- **CFC erosion** starts at > 0.6 MJ/m² (~1µm/pulse at 1 MJ/m²)
- **Tungsten** cracking occurs at > 0.2 MJ/m²; melting of tile edges at > 0.4 MJ/m2
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• The ITER plasma facing components are one of the most technically challenging components of the ITER machine

• An extensive R&D effort has been carried out world-wide to develop suitable engineering solutions and technologies for the PFCs

• The ITER Divertor design and R&D has reached a stage of maturity to allow the start of procurement in June 2009

• A conceptual design for the Blanket system was developed
• A First Wall shape is being developed according to the recommendation of the 2007 Design Review
• The Blanket Conceptual Design Review was successfully held in February 2010
• Work is progressing to develop the detail design for the Preliminary Design Review of late-2011.
• Start of Blanket procurement is planned in Early 2013