Overview of the ITER divertor

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(and the F4E In Vessel Divertor Team)

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DISCLAIMER: data are given for information only and cannot be considered as binding for the on-going Call for Tender.
1. Introduction
- To absorb radiation and particle heat fluxes from the plasma while allowing neutral particles to be exhausted to the Vacuum System.
- To minimize the influx of impurities to the plasma.
- To provide shielding to reduce heat and neutron loads in the vacuum vessel and ex-vessel components.
- To house an array of diagnostics.
Design parameters

Total power 150 MW
Surface heat flux (from 5-to 20MW/m²)
Neutron volumetric heating : max 10 MW/m³
Neutron damage: 0.2-0.3 dpa
Disruption heat loads:
   10-100MJ/m² x 0.1-10ms x 300 cycles
ELMs heat loads: 0.5-1.5 MJ/m² – freq. 1 Hz
2. Divertor System
54 Cassette Bodies, of which

- 16 diagnostic & instrumented cassettes
- 3 operational instrumented cassettes

The divertor system

54 Outer Vertical Targets
54 Inner Vertical Targets
54 Domes
The inner and outer vertical targets (VTs) are the PFCs that, in their lower part, intercept the magnetic field lines, and therefore remove the heat load coming from plasma via conduction, convection, and radiation.
The divertor dome

The “Umbrella”, which is located below the separatrix, baffles neutrals, particularly helium.

The inner and outer neutral “Particle Reflector Plates” protect the CB from plasma radiation.
## Divertor materials

<table>
<thead>
<tr>
<th>Armour</th>
<th>Material</th>
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</thead>
<tbody>
<tr>
<td>Compliant layer</td>
<td>Copper</td>
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<tr>
<td>Heat Sink</td>
<td>CuCrZr</td>
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<tr>
<td>Steel Structure</td>
<td>316L(N)-IG / XM-19</td>
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<tr>
<td>Links and bolts</td>
<td>A660</td>
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<tr>
<td>Pins</td>
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</tbody>
</table>
Divertor full W version

- Inner and Outer Vertical Target (IVT and OVT)
- Dome Umbrella
- Nose
- Inner and Outer Particle Reflector Plate
- Knuckle
- Cassette Body
- Plasma-Facing Unit (PFU) of OVT
Diagnostics (current baseline)

54 Cassette Bodies, of which

- 6 diagnostic cassettes
  - 3 in front of the RH Ports (also referred to as "Central Cassettes")
  - 2 in front of the Diagnostic Ports
  - 1 in front of one of the four Cryopump Ports
- 10 instrumented cassettes
  - located on each side of 5 diagnostic cassettes (except in Port #04)
- 1 cassette with modifications for the Lower Vertical Neutron camera in Port #02
- 37 standard cassettes
3. Thermo-hydraulics
Thermal loads

– The PFCs shall withstand 3000 equivalent pulses of 400 s duration at nominal parameters, including 300 slow transients for CFC-W and 5000 (normal)+300 (slow transient) for the full W divertor.

– During normal operational conditions the targets:
  • have a design surface heat flux up to 10 MW/m² (strike point region) and 5 MW/m² (baffle region).

– Under slow transient conditions the targets:
  • lower divertor vertical target geometry has a design surface heat flux up to 20 MW/m² for sub-pulses of less than 10 s and 10 MW/m² for 2s in the baffle.

– The dome shall sustain heat fluxes of up to 5 MW/m².

– The umbrella and the particle reflector plates shall sustain local heat flux up to 10 MW/m², which can be transiently swept across the surface (about 2 s) as the plasma is returned to its correct position.
Thermo-hydraulics

- Uniform thermal hydraulics parameters have been adopted for Divertor, Blanket and ELMs coils
  - inlet pressure 3 MPa
  - inlet temperature 70 °C
  - Pressure drop <1.6 MPa
  - Flow rate ~950 kg/s

- The DT saturation outlet is kept unchanged to ensure Critical heat Flux margin > 1.4

- Periodically the Divertor surfaces are backed using water at 240°C and 4.4 MPa at a flow rate that is 10% of the nominal flow rate.

- Baking using N2 gas at 350°C and 1.0 MPa is performed when required to proceed to subsequent plasma operation phase (to enhance the effectiveness of tritium removal from dust).
High heat flux components (targets)
High heat flux components (dome)
The cassette cooling path
4. Remote Handling
• The Divertor is designed for relatively frequent remote assembly and disassembly.

• 6 months is the maximum period that shall be allocated for cassette refurbishment/replacement.

• The replacement time of a single faulty cassette will depend on its toroidal position and, on the average, shall not exceed 2 months.

• Divertor “offline” refurbishment is foreseen.
Divertor RH tools include 2 types of “cassette mover”:

- Cassette Multifunction Mover
- Cassette Toroidal Mover

Each is equipped with a manipulator arm and RH tooling.
Attachment to the inner rail

Preload 5 mm
Attachment to the outer rail

Knuckle locked against the outer rail

video
5. R&D results
CFC-W monoblocks (by HIPping)

CFC-W monoblocks (by HRP)

Vertical Target full and medium-scale mock-ups

- **W monoblocks:**
  - $10 \text{ MW/m}^2 \times 1000$ cycles
- **CFC monoblock**
  - $10 \text{ MW/m}^2 \times 1000$ cycles
  - $20 \text{ MW/m}^2 \times 1000$ cycles
  - $23 \text{ MW/m}^2 \times 1000$ cycles

3000 cycles at $10 \text{ MW/m}^2$ on CFC and W
2000 cycles at $20 \text{ MW/m}^2$ on CFC and $15 \text{ MW/m}^2$ on W
experimental critical heat flux: $35 \text{ MW/m}^2$ on the CFC
The companies involved are: Plansee SE (A) and Ansaldo Ricerche (I)

The selected prototype versions are: full monoblock and mono-flat tile

CFC material: SNECMA NB41
Cassette assembly prototype OLD VERSION for R&D purpose (2006)
Hydraulic testing of divertor prototypes.
Simulation of Remote Assembly of Divertor system
Divertor Cassette RH experiments
Divertor Test Platform 2 Facility (VTT-Tampere Univ.-F)
6. Divertor procurement
## Divertor Procurement Sharing

<table>
<thead>
<tr>
<th>1.7 Divertor</th>
<th>Component</th>
<th>Sharing</th>
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<tbody>
<tr>
<td>P1</td>
<td>1: Cassette Body and Integration</td>
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<td>P2</td>
<td>2A: Outer Vertical Target</td>
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<td>2B: Inner Vertical Target</td>
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<td>2C: Dome</td>
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<td>2D: High Heat Flux Tests</td>
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17.P1 “Divertor Cassette Integration”

- Manufacturing
  - 1 full-scale prototype
  - 54 cassettes
  - 6 spares
- Installation of the PFCs
- Installation of the diagnostics equipments

17.P2-B “Divertor Plasma-Facing Components – Inner Vertical Target”

- Manufacturing
  - 1 full-scale prototype
  - 54 Inner Vertical Target
  - 6 spares

The entire divertor procurement is “build to print”
The Inner Vertical Target procurement package consists mainly of the following phases:

- Procurement of CFC material (prototype + serie)
- Pre-engineering and Prototype manufacturing
- Series production
  - Stage 1 (10%)
  - Stage 2 (30%)
  - Stage 3 (60%)
The procurement of Cassette Bodies and installation of PFCs consist mainly of the following phases:

- Pre-engineering and manufacturing of a full-size CB prototype
- Installation of PFC prototypes onto the cassette assembly prototype
- Cassette Bodies: series fabrication*
  Stage 1 (10%)
  Stage 2 (30%)
  Stage 3 (60%)
- Cassette Assemblies Integration: series assembly*
  Stage 1 (10%)
  Stage 2 (30%)
  Stage 3 (60%)

* Provisionally the number of Stages and the related percentage is assumed equal to the staging of the Targets and Dome.
## Divertor Cassette Body & Integration Procurement Plan

<table>
<thead>
<tr>
<th>Year</th>
<th>Cassette Body (CB) Manufacturing</th>
<th>Cassette Assembly (CA) Integration (including Preparation phase)</th>
<th>CB Prototype Manufacturing</th>
<th>Re-opening of competition for CB series</th>
<th>Contract for CA proto &amp; series</th>
<th>CA Prototype</th>
<th>CA Stage 1</th>
<th>CA Stage 2</th>
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<th>CA Stage 3</th>
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7. Conclusions
The ITER divertor is a demanding system (both from operational and manufacturing point of view) which is now ready for procurement.

The power handling capability and manufacturing tolerances are the key issues for this system. They shall be addressed via full scale prototyping.

The EU divertor inner target pre-production qualification and prototyping phase has commenced and the same is ready to start for the divertor cassette.