Engineering of In-vessel Components for ITER

T. Hirai
ITER Organization, In-Vessel Component, Divertor Section
Contents

1. ITER Project
2. ITER In-vessel Components: Divertor and Blanket
3. Plasma-facing Units
   - Materials, Design, Manufacturing, Non-Destructive Tests -
4. Steel support structures (divertor cassette body, shield blanket module)
   - Design, Manufacturing, Non-Destructive Tests -
5. In-kind Procurement Management
6. Status and milestones
ITER The way to fusion power

- ITER ("the way") is the essential next step in the development of fusion

- The world's biggest fusion energy research project, and one of the most challenging and innovative scientific projects in the world today.

- Its objective:
  - to demonstrate the **scientific and technological feasibility of fusion power**
  - demonstrate extended **burn of DT plasmas**, with steady state as the ultimate goal.
  - integrate and test all essential fusion power reactor technologies and components.
  - demonstrate safety and environmental acceptability of fusion.

**Tokamak – 29 m high x 28 m dia. & ~23000 t**
ITER Site

ITER Headquarters:
Saint Paul-lès-Durance, Provence-Alpes-Côte d'Azur, France.
Site next to Cadarache, nuclear research center, CEA
ITER Site in 2011

2.5 million m³ of earth leveled

Construction beginning of first buildings on the ITER platform
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ITER In-Vessel Components

- 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 MPa water pressure, ~70 °C
ITER Divertor

Divertor system main functions:

• Exhaust the major part of the plasma thermal power (including alpha power)

• Minimize the helium and impurities content in the plasma
Divertor design

**Vertical targets:** promote detachment sending neutrals back towards the separatrix strike points

**Dome:** compresses neutrals for better pumping

**Baffles:** protect edges of vertical targets → smooth transition

**Large conductance** between divertor channels increases outer divertor neutral density and makes detachment more symmetric

To pump
PFCs are qualified for time averaged, steady state loads based on SOLPS simulations for burning plasma, H-mode baseline operation (CFC targets)

- 10 MWm\(^{-2}\) on lower part of vertical targets
- 5 MWm\(^{-2}\) on the baffles, dome and reflector plates
Divertor RH equipments

Divertor RH equipment is comprised of Two main types of “cassette mover”:
- **Cassette Multifunctional Mover (CMM)**
- **Cassette Toroidal Mover (CTM)**

Each are to be equipped with a manipulator arm and RH tooling.

Three lower ports at port #2, #8 and #14 are allocated for Divertor Remote Handling.
Summary of Divertor Terminology and Materials

- CFC and W: armour
- XM-19: all multilinks (lugs and links)
- C63200: hollow pins of multilinks
- 316L(N)-IG: support structures
- 316L pipe: steel pipes
- CuCrZr-IG: heat sink
- Steel 660: bolts

W (tritium phase)

Ni-Al bronze (C63200)
ITER Blanket Modules

- Module 1-6
- Module 7-10
- Module 11-18

FW Panel (separable)

Shield Block (semi-permanent)

~1240 – 2000 mm

~850 – 1240 mm
Design Heat load on blanket

Outboard flat top heat load (550 MW)

- Group 1: 1 – 2 MW/m²
  - Normal heat flux panels
- Group 2: 3.5 – 5 MW/m²
  - Enhanced heat flux panels

See talk by R. Mitteau
Blanket RH equipments

- 4 equatorial ports located at 0, 100, 180 and 280 degrees
- RH operation by In-vessel transporter (IVT) system (handling load 4.5 ton)
Summary of Blanket Terminology and Materials

- **316L(N)-IG**: armour
- **CuCrZr-IG**: heat sink
- **316L(N)-IG**: support structures and shield block
- **316L pipe**: Steel pipes
- **Inconel 718**: attachments (axial supports)
- **C63200**: attachments (pads etc.)

Be: armour

See talk by V. Barabash

**First wall Panel** (Plasma-Facing Finger)

**Shield Block**

- BM-04
- SB-04

- Central slot
- Coaxial connector
- FWP attachment
### Number of components

<table>
<thead>
<tr>
<th>Comp.</th>
<th>Break-down</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Divertor</td>
<td>OVT PFU</td>
<td>1320</td>
</tr>
<tr>
<td></td>
<td>IVT PFU</td>
<td>960</td>
</tr>
<tr>
<td></td>
<td>Dome PFU</td>
<td>2040</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blanket</td>
<td>NHF FW panel</td>
<td>218</td>
</tr>
<tr>
<td></td>
<td>EHF FW panel</td>
<td>222</td>
</tr>
<tr>
<td>Divertor</td>
<td>OVT Steel Support</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>IVT Steel Support</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Dome Steel Support</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Cassette Body</td>
<td>60</td>
</tr>
<tr>
<td>Blanket</td>
<td>Blanket Shield Module</td>
<td>440</td>
</tr>
</tbody>
</table>

- **NHF FW panel**: 440 + 11 spares with ~20 main variants
- **EHF FW panel**: 222
- **OVT Steel Support**: 60 x (54 + 6 spares)
- **IVT Steel Support**: 60 x (54 + 6 spares)
- **Dome Steel Support**: 60 x (54 + 6 spares)
- **Cassette Body**: 60 x (54 + 6 spares)
- **Blanket Shield Module**: 440 about ~40 main variants

<table>
<thead>
<tr>
<th>Comp.</th>
<th>Break-down</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Divertor</td>
<td>W monoblock for VTs</td>
<td>216 k</td>
</tr>
<tr>
<td></td>
<td>CFC monoblock for VTs</td>
<td>66 k</td>
</tr>
<tr>
<td></td>
<td>W tile for Dome</td>
<td>99 k</td>
</tr>
<tr>
<td>Blanket</td>
<td>Be tile</td>
<td>~ 1M</td>
</tr>
</tbody>
</table>

- **W monoblock for VTs**: (96 x 22 + 93 x 16) x 60
- **CFC monoblock for VTs**: (30 x 22 + 28 x 16) x 60
- **W tile for Dome**: (30 x 10 + 72 x 12 + 40 x 12) x 60
### Overview of Material Mass

<table>
<thead>
<tr>
<th>Material</th>
<th>Application</th>
<th>Mass (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Divertor components</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>Armor material</td>
<td>53</td>
</tr>
<tr>
<td>CFC</td>
<td>Armor material</td>
<td>3</td>
</tr>
<tr>
<td>Cu and Cu alloy</td>
<td>Pipes, heat sink, functional material</td>
<td>10</td>
</tr>
<tr>
<td>Steel</td>
<td>Structural parts, pipes</td>
<td>430</td>
</tr>
<tr>
<td>Ni Al bronze</td>
<td>Knuckle &amp; Nose, pins</td>
<td>21</td>
</tr>
<tr>
<td><strong>Blanket components</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Be</td>
<td>Armor material</td>
<td>10</td>
</tr>
<tr>
<td>Cu and Cu alloy</td>
<td>Pipes, heat sink, functional material</td>
<td>85</td>
</tr>
<tr>
<td>Steel</td>
<td>Structural parts, pipes</td>
<td>1400</td>
</tr>
<tr>
<td>Ni Al bronze</td>
<td>Pads, etc.</td>
<td>tbc</td>
</tr>
</tbody>
</table>
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6. Status and milestones
Divertor Armour 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
Specification of Divertor Armor Materials / CFC and W

- **CFC**
  - Requirements
    - Carbon content $> 99.99\%C$
    - Average density
    - Thermal conductivity in x-, y-, z-directions at RT and at 800 °C
    - Tensile strength in x-, y-, z-directions
      (Thermal expansion in x-, y-, z-directions up to 1000 °C)
  - 100 % Visual inspection, 100% dimension control, 100% density measurement

- **W** (Standard specification based on ASTM B 760-86)
  - Requirements
    - Chemical composition $\geq 99.94\%W$
    - Density $\geq 19.0 \text{ g/cm}^3$
    - Defined rolled direction, Stress relieved condition (not recrystallized)
    - Grain size – Microstructure (3 or finer ASTM E 112)
    - Hardness: HV30 $\geq 410$
  - Dimension measurement, 100 % Visual inspection, 100% Ultrasonic inspection
Specification of Blanket Armour material / Beryllium

- **Beryllium**
  - Requirements
    - Chemical composition $\geq 99.0\%$Be (impurity, $\leq 0.0030\text{wt}\%$U, etc)
    - Density $\geq 99.0\%$
    - Average grain size $< 0.020$ mm (ASTM E112)
    - Tensile Properties at RT

  100% Visual inspection, Radiographic inspection, dimension check for each block

See talk by V. Barabash
Divertor vertical targets

- **W monoblock**: 5 MW/m²
- **Copper Interlayer:**
- **CuCrZr Heat Sink:**
- **W monoblock**
- **Smooth Tube**: 10 MW/m²
- **CFC monoblock**
  - 20 MW/m²
  - 10 sec
  - For first divertor set
- **CFC monoblock**: 
- **Copper Interlayer**: 
- **CuCrZr Heat Sink**: 

Twisted tape: To increase the margins against the Critical Heat Flux
Divertor Dome

- **W Flat Tiles**
- **5 MW / m²**
- **316L(N)-IG**
- **Copper Interlayer**
- **CuCrZr Heat Sink**
- **W Tile**

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T Hirai, PFMC-13 Rosenheim Germany May 2011
Design of First Wall Panel

I shape beam to poloidal torque mitigation

Slitting to reduce Eddy current

- Slits to reduce EM loads, additional slits on the back were introduced to minimize the thermal expansion and bowing (mitigation of EM load)

See talk by R. Mitteau
Blanket Normal and Enhanced Heat flux modules

Normal heat flux finger:
concept with Steel Cooling Pipes

Enhanced heat flux finger:
concept with rectangular channels

Cu Alloy
SS Back Plate
SS Tube
Be Tile

50 mm
10 mm

Copper alloy heat sink

Hot isostatic pressing
Tolerance / General and Specific Tolerance

General Tolerances described in Standards do NOT always meet our requirements
ISO 2768-1:1989 Tolerances for linear and angular dimensions …
ISO 2768-2:1989 Geometrical tolerances …

Table 1 – Permissible deviations for linear dimensions except for broken edges
(external radii and chamfer heights, see table 2)

<table>
<thead>
<tr>
<th>Tolerance class</th>
<th>Designation</th>
<th>Description</th>
<th>Permissible deviations for basic size range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>over 3 up to 6</td>
</tr>
<tr>
<td>Designation</td>
<td>Description</td>
<td>Values in millimetres</td>
<td>0,51 up to 3</td>
</tr>
<tr>
<td>f</td>
<td>fine</td>
<td>±0,05</td>
<td>±0,05</td>
</tr>
<tr>
<td>m</td>
<td>medium</td>
<td>±0,1</td>
<td>±0,1</td>
</tr>
<tr>
<td>c</td>
<td>coarse</td>
<td>±0,2</td>
<td>±0,3</td>
</tr>
<tr>
<td>v</td>
<td>very coarse</td>
<td>—</td>
<td>±0,5</td>
</tr>
</tbody>
</table>

1) For nominal sizes below 0,5 mm, the deviations shall be indicated adjacent to the relevant nominal size(s).

Approach (Specific Tolerance): Priority on the Functionality
- Ensure mechanical and plasma operation performances
- Leave the manufacturer as much freedom as possible.

N.B. Tolerance directly impact on manufacturing cost.
Tolerance for Divertor PFUs

Geometrical tolerance considering Operational requirements at global and local scales

- All monoblocks in 0.5 mm tolerance range
- Steps of neighboring blocks, smaller than 0.3 mm

- Indicate requirements in terms of PFC surface envelop
- Freedom to allocate the tolerances depending on manufacturing processes
- Simplify the control of the components
Concerning Tolerances …

- **Dimension tolerance**
  - e.g. linear dimensions, angular dimensions

- **Geometrical tolerance**
  - e.g. Straightness, Flatness (single feature, form), Profile, (single or related features)
  - Perpendicularity, Parallelism, … (related orientation), Coaxiality, Symmetry (related position), …

**To achieve required tolerance, …**

- Identify poor tolerance operation (joining (welding) and assembly)

- Recover by Higher tolerance operation (machining) and custom machining of tolerance compensators

N.B.
Selection of appropriate Datums is essential for: (1) Precise manufacturing; and (2) dimension and geometrical control
Assembly tolerances and needs to protect the edges

Accumulation of contributors to global misalignment of Plasma-facing surfaces

→ Step at the Plasma-Facing surfaces  → Need to protect edge (tilting/shaping)

<table>
<thead>
<tr>
<th></th>
<th>Divertor cassettes</th>
<th>Blanket modules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembly tolerance</td>
<td>± 1.5 mm</td>
<td>± 2.5 mm</td>
</tr>
</tbody>
</table>
Alignment of Divertor PFCs

The PFCs shall be angled to avoid exposing the leading edges of the armour to the Scrape-Off Layer (SOL), otherwise the near normal incidence of the SOL on these edges would cause large amounts of carbon to be evaporated (or tungsten melted) with the inherent risk of poisoning of the plasma and/or inducing a critical heat flux event in the water coolant.

A nominal step in the toroidal direction between adjacent targets of 3 mm is taken as a requirement.
Summary of First Wall shaping

- BM #1-6: Central column, HFS start-up, Toroidal & poloidal shaping
- BM #7-10: Secondary divertor region, Toroidal & poloidal shaping
- BM #11-18: Outboard LFS start-up/ramp-down, Toroidal shaping

See talk by R. Mitteau
Manufacturing of armour joints

Armour to heat sink joints

Beryllium

CFC or tungsten

Compliance layer/ diffusion barrier

Compliance layer (OFCu)

CuCrZr

CuCrZr
Manufacturing / Monoblock type PFUs

Selection of reliable and cost-effective manufacturing route(s) is DAs’ responsibility.

Selection of reliable and cost-effective manufacturing route(s) is DAs’ responsibility.
NDT of Plasma-Facing Units

**Armor to heat sink joint**
Metal / Metal joints 100%
**Ultrasonic Test**

CFC/Cu joint 100%
**Transient Infrared Thermography**
or thermal mapping by HHF facility
If UT examination is not applicable
NDT of Plasma-Facing Units: UT for metallic armor joints

- Ultrasonic Test for metallic armor joints (EN 583)

  Pulse echo technique or transmission technique

  Indications of defects ↔ Echo from defects

  Important parameters
  - Probe (frequency & dimensions)
  - Coupling media
  - Scanning scheme
  - Calibration blocks
  etc.

W or CFC

CuCrZr

Cu
NDT of Plasma-Facing Units: Infra-Red test

Transient Infrared Thermography for CFC-Cu joints

Indications of defects ← Difference of transient thermal responses

Important parameters
- Thermal transition rate
- Homogeneous flow distribution and flow rate between channels
- Data acquisition and process
- Calibration
  etc.

Source: CEA/Plansee
Acceptance Criteria for Plasma-Facing Units

Requirements for Calibration modules:

- Defects in the CFC/Cu joint
  - Location $\theta = 0^\circ$, size $\Delta \theta = 40, 50, 60, 70^\circ$
  - Location $\theta = 45^\circ$, size $\Delta \theta = 40, 50, 60, 70^\circ$

- Correlation between defect size and defect location vs thermal response
### Acceptance Criteria for Plasma-Facing Units

#### Acceptance criteria

<table>
<thead>
<tr>
<th>Monoblock geometry (sampling rate)</th>
<th>( \Delta \theta )</th>
<th>Location, ( \theta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFC/Cu (100%)</td>
<td>&lt; 50° (^{a})</td>
<td>Within ± 120°</td>
</tr>
<tr>
<td>Cu/CuCrZr in CFC part (100%)</td>
<td>&lt; 40°</td>
<td>Within ± 120°</td>
</tr>
<tr>
<td></td>
<td>&lt; 60°</td>
<td>Outside ± 120°</td>
</tr>
<tr>
<td>W/Cu, Cu/CuCrZr (100%)</td>
<td>&lt; 50°</td>
<td>Within ± 120° in the critical area</td>
</tr>
<tr>
<td></td>
<td>&lt; 70°</td>
<td>Outside ± 120° or outside the critical area</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flat tile geometry (sampling rate)</th>
<th>Size of defect</th>
</tr>
</thead>
<tbody>
<tr>
<td>W/Cu, Cu/CuCrZr (100%)</td>
<td>No defect shall have one dimension greater than 4 mm</td>
</tr>
<tr>
<td>CuCrZr/Steel (100%)</td>
<td>No defect shall have one dimension greater than 2 mm</td>
</tr>
</tbody>
</table>

\(^{a}\) Acceptance criteria is defined by NB31 calibration modules
Repairing Technology

Heat flux performances of the repaired monoblocks are equivalent to those of the non-repaired ones. This shall be demonstrated by the manufacturing and testing of at least 4 relevant mock-ups with repaired and non-repaired monoblocks.
Divertor PFUs HHF tests

Plasma-Facing Unit
Hydraulic Pressure test 100%
He leak test 100%

Thermal fatigue tests in Efremov institute
Performance test for 100% full scale prototype PFU
Series test for 100% of first 10% series production
for 10% of rest of 90% series production

HHF Performance Testing
100 % PFU Full-Scale Prototype
10 MW/m² 1000 cycles at CFC armor part
20 MW/m² 500 cycles at CFC armor part
5 MW/m² 1000 cycles at W armor part

HHF Series Testing
PFU Series Production 19% (100 % of first 10 % + 10 % of the rest (90 %))
10 MW/m² 100 cycles at CFC armor part
3 MW/m² 100 cycles at W armour part
ITER Divertor Test Facility (IDTF) for HHF tests of PFUs

IDTF commissioning in July 2011 at Efremov Institute, Russia

Max. beam power: 800 kW
Max. voltage: 60 kV
Max. Deflection angle: 45°
Design beam diameter: ~15mm
Vacuum chamber: 3 m / diameter 2.2 m

This activity is in the frame of Procurement package (17P2D.RF).
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Structural Design Criteria

- ITER Structural Design Criteria for In-vessel Components (SDC-IC) was developed as a code for ITER in-vessel components (based mainly on RCC-MR). The SDC-IC code takes into account the ITER-specific conditions such as transient EM-loads, high surface heat fluxes, influence of creep and radiation damage etc. Note: Revised version of SDC-IC will be issued in 2011.

- **Four categories of loading conditions:**
  - Cat-I: Operational loads in the performance of its specified service function
  - Cat-II: Likely loads which component must withstand without damage requiring repair
  - Cat-III: Unlikely loads which necessitate shutdown of system and removal of the component from service for inspection or repair.
  - Cat-IV: Extremely Unlikely loads

- **Many considered failure modes, e.g. including:**
  - Failure modes at monotonic “M-type damage” loads (monotonic loads are steadily and regularly increasing loading, or a constant loading)
  - Failure modes at cyclic “C-type damage” loads (e.g., time-independent/ time dependent fatigues, etc.)
Supporting analysis

- Thermo-mechanical
- Electromagnetic (EM)
- Mechanical static and dynamic analysis at EM loads
- Mechanical analysis at load combinations (EM, Thermal, dead weight, seismic accelerations, hydraulic pressure)
- Evaluation of static and cyclic strength of divertor parts
Steel Support Structure of Divertor Vertical Targets
The divertor CB is reusable to minimise activated waste; it provides neutron shielding, routes the water coolant and supports the different PFCs.
**Coolant Flow sequence in Divertor**

**Divertor coolant design parameters**
- Inlet temperature: 70 °C
- Inlet water pressure: 3.0 MPa
- Total pressure drop: < 1.6 MPa
- CHF margin: > 1.4
- Total flow rate: < 1000 kg/s
Blanket Shield Block

- Modules cover 20° sector in the inboard and upper, and 10° sector in outboard
- 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)
- Material: 316LN-IG
- Main Manufacturing process: Drilling, Milling and Welding
Coolant Flow sequence in Blanket

- BMs are cooled in **parallel**
- Plasma-facing fingers cooled in **parallel**
- SB sections are cooled in **parallel**
- FWP – SB cooled in **series**

Blanket coolant design parameters
- Inlet temperature: 70 °C
- Inlet water pressure: 3.0 MPa
- CHF margin: > 1.4
- Total flow rate: < 3.6 ton/s

Hydraulic Scheme (a standard sector)

- 1½" 10S (48.3, 2.77mm) — 2" 10S (60.3, 2.77mm)
Neutronics aspect

1. Radiation Effects
   - Increase of strength, loss of ductility
   - Removal of heat generated by nuclear heating
   - Impact on maintenance strategy due to nuclear heating and activation
   - Re-welding issue due to He-production at the re-welding position

   **Design issues:** Efficient removal of heat generated by nuclear heating
   Reduction of radiation effects at re-welding position

2. Shielding Function

   **Design issues:** Material selection and distribution (metals and water)
   Keep sufficient mass to attenuate neutron flux
   Limit cut-out to suppress neutron streaming

<table>
<thead>
<tr>
<th>Radiation damage in ITER lifetime (steel)</th>
<th>Divertor</th>
<th>Blanket</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 1 dpa</td>
<td>&lt; 2.5 dpa</td>
</tr>
</tbody>
</table>
Manufacturing / Welding operations of In–Vessel Components

Welding is considered as a special process (ISO 9000)
Results i.e. defect free weld is not 100 % sure although inspection

This needs qualifications in order to make everything for the quality before welding

This basically means qualification of everything which concerns welding
  – Welding Procedure Specifications
  – Welders/operators
  – Inspectors
  – Consumables
  – etc

• Commonly used Welding processes: Power beam welding and TIG welding

• Commonly used NDTs: Liquid Penetrant Test (PT), Radiographic Test (RT), Ultrasonic Test (UT)
Manufacturing / Power Beam Welding

Electron Beam welding
Gun: high power electron gun

Laser welding
CO2 laser, Fiber laser, Nd:YAG laser

Features:
* Automatic Welding operated by qualified operator
* Thin to thick thickness (~60 mm thick steel)
* High power density
* Single pass welding
* Low angular distortions

- No use of filler wire -> Risk of hot cracking
Manufacturing: TIG welding

TIG (Tungsten Inert Gas) welding for In-Vessel components:

- **Single pass**
  - Thickness less than 3 mm
  - Normally without filler wire
  - Main application the pipes

- **2. Multi pass**
  - Thickness greater than 3 mm
  - In principle no limit in thickness
  - Use of groove and filler wire
  - Narrow Grooves possible
  - Potential large angular distortions
Manufacturing / Challenges in welding of Austenitic Steel

- **Distortions**
  - Large and accurate structures
  - Austenitic stainless steel
  - Lots of welds

  To avoid
  Welding sequence, Jigs, Final machining, Balance welding i.e. welding from both sides, Minimize melted metal, e.g. Narrow Grooves and Power beam processes; Laser, EB

- **Hot cracking of weld metal**
  - Austenitic stainless steels
  - Rigid structure

  To avoid
  Selection of proper filler material i.e. proper ferrite content

- **All the normal weld defects: Cavities and inclusions**

  Quality level B of EN ISO5817/ EN ISO 13919
Manufacturing / Welding Qualifications

- Qualification of Welding Procedure Specification (WPS)
  - WPS introduced EN ISO 15607 and EN ISO 15609-nn
  - Preliminary WPS is qualified according to EN ISO 15614-nn
  - Qualification if quality level B gained
    - EN ISO 5817 for arc welding
    - EN ISO 13919 serie for power Beam welding
  - Welding Procedure Qualification Record (WPQR)

- The welding qualification for Quality Class 1 components shall be witnessed by ITER recognized Independent Inspection Authority, e.g. Third Party Inspector.

- Welders, operators and NDT personnel shall be qualified (EN 287/ EN1418/ EN 473)

- Other equivalent national or international standards and codes may be acceptable subject to the IO’s written approval.
NDT of welds in Steel Supports

- **Surface** crack examination
  - Visual Test for **welds** (EN 970)
  - Liquid Penetrant Test for **welds** (EN 571)

*N.B. ITER Vacuum Handbook requirement: use of qualified liquid penetrants*

- **Volumetric** examination
  - Radiographic test for **welds** (EN 1435)
  - Ultrasonic Test for **welds** (EN 22825)

- **Acceptance Criteria**
  - Quality level B of EN ISO5817/ EN ISO 13919
  - ITER Vacuum Handbook Attachment 1: Welding

- Other equivalent national or international standards and codes may be acceptable subject to the IO’s written approval.
Testing of PFCs prior to Assembly on a Cassette

(i) Flow test to monitor the flow rate distribution, e.g. Hot water (>80 °C) flow test or other method to monitor flow rates

(ii) Hydraulic pressure (7.6 MPa) test of the cooling system shall be that specified by the Pressure Equipment Directive (EN 13445-5)

(iii) Hot vacuum leak test with an internal pressure of 5 MPa He, and a temperature of 250°C.
Acceptance test of Divertor Cassettes

- Divertor shall be tested during manufacturing and commissioning

  - Testing of Divertor Cassette Assemblies (CAs)
    (i) Hot water flow test
    (ii) Hydraulic pressure test
    (iii) Hydraulic flow test (test in each PFC shall be measured by ultrasonic flow meter or non-intrusive method)
    (iv) Cold He leak test

  - On-site Acceptance testing of CAs (if integration site ≠ ITER site)
    (i) Hydraulic pressure test,
    (ii) Cold He leak test

  - In-vessel Testing of Divertor Cassettes
    (i) Pressure test,
    (ii) Water flow test (~1000 kg/s),
    (iii) Cold He leak test
Summary of Inspections/tests for Divertor OVT and CA

- **CuCrZr-IG** (VT, ET, dimension)
- **316L TP** (VT, ET, dimension)
- **CFC** (VT, density, dimension)
- **W** (VT, density, UT, dimension)
- **316L(N)-IG** (VT, UT, dimension)
- **OFCu**

- **OVT PFU coolant tube welds** (VT, PT, RT, ..)
- **Int. Divertor Cassette** (flow test, VT, UT, pressure test, ..)
- **On-site test Divertor Cassette** (flow test, LT, pressure test, ..)
- **DO PFC** (3D, VT, flow test, pressure test, hot He leak test, ..)
- **IVT PFC** (3D, VT, flow test, pressure test, hot He leak test, ..)
- **CB PFC** (3D, VT, flow test, pressure test, hot He leak test, ..)
- **OVT PFU** (dimension, VT, LT, pressure test, hot He leak test, ..)

- **OVT PFU armor joint** (VT, UT, IR-test, ..)

- **Int. OVT PFC, tube welds** (VT, PT, RT, ..)

- **OVT SSS** (3D, VT, LT, pressure test, hot He leak test, ..)

- **Conformity of Material**
  - Armour joint test
  - NDT for welds
  - Pressure and leak tests
  - Commissioning test

- **CuCrZr-IG** (VT, ET, dimension)
- **316L TP** (VT, ET, dimension)
- **CFC** (VT, density, dimension)
- **W** (VT, density, UT, dimension)
- **316L(N)-IG** (VT, UT, dimension)
- **OFCu**

- **OVT PFU coolant tube welds** (VT, PT, RT, ..)
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- **DO PFC** (3D, VT, flow test, pressure test, hot He leak test, ..)
- **IVT PFC** (3D, VT, flow test, pressure test, hot He leak test, ..)
- **CB PFC** (3D, VT, flow test, pressure test, hot He leak test, ..)
- **OVT PFU** (dimension, VT, LT, pressure test, hot He leak test, ..)

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- **Int. OVT PFC, tube welds** (VT, PT, RT, ..)

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- **Conformity of Material**
  - Armour joint test
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## Integration between IO and DAs

### Basic Roles and Responsibilities

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* Depending on type of specification
- **Functional**: Functional requirements by IO and design by DAs
- **Detail Design**: Conceptual design by IO and detailed design by DAs
- **Build-to-print**: Detailed design by IO and fabrication/shop design by DAs

- Management responsibility at IO side, Implementation responsibility at DA sides
Management of In-kind Procurement

- Monitoring Procurement Arrangement (PA) execution:
  - Monthly report, Progress Meeting
  - Control Points corresponding to the PA milestones and reviews at each stage

- Quality Assurance requires Quality plan (QP) and Manufacturing and Inspection Plan (MIP)

- Deviation and Non-conformance: Deviation requests and Non-conformance report to be approved by IO (Quality Assurance), possibly followed by Project Change Request (Configuration Management)

- Traceability: all documentation must be kept, e.g. in IDM (ITER Document Management)
Contents

1. ITER Project
2. ITER In-vessel Components: Divertor and Blanket
3. Plasma-facing Units
   - Materials, Design, Manufacturing, Non-Destructive Tests -
4. Steel support structures (divertor cassette body, shield blanket module)
   - Materials, Design, Manufacturing, Non-Destructive Tests -
5. Management of In-kind Procurement
6. Status and milestones
Status and milestones

**Divertor**
- 2009-2010 → Start Procurement of PFCs and HHF testing
- 2011 → First Prototype HHF tests after Commissioning of IDTF
- End 2011 → Start Procurement of CBs and Divertor Integration
- 2013-2014 → Full Scale Prototype
- 2019-2020 → Last Delivery on Site

**Blanket**
- Feb 2010 → Conceptual Design Review
- End 2011 → Preliminary Design Review
- End 2012 → Final Design Review
- Mid-2013 → Start procurement
- End-2019 → Last Delivery on Site
Thank you for your attention

I would like to appreciate colleagues for their contribution:

ITER Organization