ITER The way to a benign and limitless new energy source

A global collaboration has been formed to test the feasibility of fusion
Preparations of the ITER Vacuum Vessel Construction

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23rd IAEA FEC, Daejeon, Korea

Presented by J. S. Bak
Prepared by IO, F4E, INDA, KODA, RFDA and VV IPT
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IV. Summary
Overall Description of the ITER Vacuum Vessel

A torus shaped double wall structure
To provide high vacuum for plasma and primary radioactivity confinement boundary
To support in-vessel components (blanket, divertor, etc)

Main vessel
9 x 40 deg. Sector

In-wall shielding

Equatorial

Upper

Lower

Ports

VV supports
(Dual hinge type)

<table>
<thead>
<tr>
<th>Major dimensions</th>
<th>Weight (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer diameter (m)</td>
<td>19.4</td>
</tr>
<tr>
<td>Height (m)</td>
<td>11.4</td>
</tr>
<tr>
<td>Double wall thickness (m)</td>
<td>0.34–0.75</td>
</tr>
<tr>
<td>Interior surface (m²)</td>
<td>850</td>
</tr>
<tr>
<td>Interior volume (m³)</td>
<td>1600</td>
</tr>
<tr>
<td>Main vessel</td>
<td>1611</td>
</tr>
<tr>
<td>Shielding</td>
<td>1733</td>
</tr>
<tr>
<td>Ports</td>
<td>1781</td>
</tr>
<tr>
<td>Supports</td>
<td>111</td>
</tr>
<tr>
<td>Total</td>
<td>5236</td>
</tr>
</tbody>
</table>
Design Development since 1998

- Size reduction
  - Height: 14.4 m → 11.3 m
  - Width: 8.9 m → 6.4 m
- New flexible support housing
- Reduced No. of lower ports
- Relocation of VV supports
- 3D shaped inner shell in outboard area
- Design modifications for interfaces
  - In-vessel coil (IVC), field joint, ports, VV supports, IWS, etc
## Technical & Regulatory Requirements

### Technical requirements

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>316L(N)-ITER Grade with special requirements</td>
</tr>
<tr>
<td>Design load</td>
<td>Dead weight, coolant pressure, various electromagnetic loads</td>
</tr>
<tr>
<td>Tolerance</td>
<td>Accurate field joint fit-up and precise assembly of in-vessel components</td>
</tr>
</tbody>
</table>
| Welding Inspection | Full penetration welding  
100% volumetric NDE even at single side accessing region |
| Testing          | Baking condition: 200 °C  
Testing pressure: 3.72 MPa, Vacuum leak rate: < $10^{-8}$ Pa-m$^3$/s |

### Regulatory requirements

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Description</th>
</tr>
</thead>
</table>
| Quality and safety | SIC (Safety Important Class) components  
Implementation of French safety and quality order 1984 |
| Nuclear pressure vessel | French order of nuclear pressure equipment (ESPN)  
Agreed Notified Body (ANB) involvement for conformity assessment |
## Technical Requirement: Materials

### Main features of VV materials

<table>
<thead>
<tr>
<th>Items</th>
<th>Description</th>
</tr>
</thead>
</table>
| **Material types**            | • Main vessel: SS 316L(N)-IG  
• Port: SS 316L(N)-IG, 304, 304L  
• VV support: steel 660, Inconel 718  
• In-wall shielding: 304B4, 304B7, 430 |
| **Special requirements for 316L(N)-IG** | • Nitrogen control (0.06 ~ 0.08 wt.%) to keep consistent strength  
• Limitation of impurities:  
  - Co (0.05 wt.%): reduction of contact dose and gamma heating  
  - Nb (0.01 wt.%): reduction of activated waist  
  - Boron (0.0001 wt.%): limit He production |

### Status of material supplier contracts

<table>
<thead>
<tr>
<th>Items</th>
<th>KO</th>
<th>RF</th>
<th>IN</th>
<th>EU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate</td>
<td>ArcelorMittal</td>
<td>ArcelorMittal</td>
<td>ArcelorMittal</td>
<td>TBD</td>
</tr>
<tr>
<td>Forging</td>
<td>KIND</td>
<td>Avienna</td>
<td>N/A</td>
<td>TBD</td>
</tr>
<tr>
<td>Borated steel</td>
<td>TBD</td>
<td>N/A</td>
<td>TBD</td>
<td>N/A</td>
</tr>
</tbody>
</table>
## Regulatory Requirements

### Status of ITER VV conformity assessment by the ANB

- According to regulatory requirement such as ESPN, the conformity of the ITER VV shall be assessed by the ANB (Agreed Notified Body).

#### Conformity assessment procedure by the ANB

<table>
<thead>
<tr>
<th>Phases</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase I</td>
<td>Preliminary design assessment</td>
</tr>
<tr>
<td>Phase II</td>
<td>Fabrication assessment at supplier’s factory</td>
</tr>
<tr>
<td>Phase III</td>
<td>Final assembly and installation assessment at the ITER site</td>
</tr>
</tbody>
</table>

#### Current status

<table>
<thead>
<tr>
<th>Status</th>
<th>Detail description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase I (ongoing)</td>
<td>ANB’s approval of the preliminary design: Oct 2009</td>
</tr>
<tr>
<td></td>
<td>Additional approval for modified reference design: Jul 2010</td>
</tr>
<tr>
<td></td>
<td>Additional approval for modified port &amp; VV supports: Mar 2011</td>
</tr>
</tbody>
</table>
## Procurement Sharing

<table>
<thead>
<tr>
<th>EU</th>
<th>Description</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Items 7 Sectors of Main Vessel</td>
<td>92.06 kIUA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(39%)</td>
</tr>
<tr>
<td>RF</td>
<td>Description</td>
<td>Total Cost</td>
</tr>
<tr>
<td></td>
<td>Items 18 Upper Ports</td>
<td>20.86 kIUA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(9%)</td>
</tr>
<tr>
<td>KO</td>
<td>Description</td>
<td>Total Cost</td>
</tr>
<tr>
<td></td>
<td>Items 2 Sectors of Main Vessel</td>
<td>84.06 kIUA</td>
</tr>
<tr>
<td></td>
<td>17 Eq. &amp; 9 Lower Ports</td>
<td>(36%)</td>
</tr>
<tr>
<td></td>
<td>In-Wall Shields/ribs</td>
<td>37.30 kIUA</td>
</tr>
<tr>
<td>IN</td>
<td>Description</td>
<td>Total Cost</td>
</tr>
<tr>
<td></td>
<td>Items In-Wall Shields/ribs</td>
<td>37.30 kIUA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(16%)</td>
</tr>
</tbody>
</table>

**Total 234.28 kIUA**  
8% of total In-kind
Procurement Delivery

Upper Port

Lower Port PSE (7 EA)

Upper Port Central

Upper Port PSE (2 EA)

7 Sectors

IWS

IWS

ITER site

2 Sectors, EQ & NB, Lower Port

DA to DA

DA to ITER site

NB Port PSE (2 EA)
### Status of Procurement Arrangements and Contract Awards

<table>
<thead>
<tr>
<th>Item</th>
<th>DA</th>
<th>EU</th>
<th>KO</th>
<th>RF</th>
<th>IN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>MV: 7 Sectors</td>
<td>MV: 2 Sectors Eq. &amp; lower ports</td>
<td>Upper ports</td>
<td>In wall shielding Shield ribs</td>
<td></td>
</tr>
<tr>
<td>Contract award</td>
<td>08 Oct 2010</td>
<td>15 Jan 2010</td>
<td>09 Jun 2009</td>
<td>01 Sep 2010</td>
<td></td>
</tr>
</tbody>
</table>

**DA**
- **EU**: AMW Consortium (Ansaldo, Mangiarotti, Walter Tosto)
- **KO**: Hyundai Heavy Industries (HHI)
- **RF**: Efremov Institute
- **IN**: M/s Avasarala Tech.
• Integrated Project Schedule (IPS) approval: IC Extraordinary Meeting (Jul 2010)
• Free issued items (in-wall shielding, port stub extension) to sector fabrication shop can become a critical path. Schedule for interfaces is under discussion.
R&D Activity for Manufacturing: EU (1/2)

1. Welding distortion analysis
   • Verification: heat input experiment
   • Very close results between analysis and test

2. Bolted shield rib concept
   • Alternative method to reduce weld quantity
   • Assessment of both technology and costs

3. Two parts housing concept design
   • Background: difficult outer shell assembly
   • Preliminary results show feasibility

SYSWELD (AREVA)

Inner shell
Outer shell
Flexible support housing
Two parts housing

Bolts pre-stress

60 mm
1. Local machining tool
   - Inner shell: thread and bore
   - Outer shell: welding preparation (J-groove)

2. Auto-TIG welding machine
   - Automatic narrow gap welding
   - Verified by mock-up R&D

3. UT device (phased array)
   - Machine I for automatic outer shell tests
   - Machine II for circular tests

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LECAD & TRITECH (Slovenia)

SIMIC S.p.A.
1. Assessment of shell thickness reduction

- Nominal design thickness of shell: 60 mm
- Expected maximum thickness reduction from industrial experience < 7%

**Thickness reduction map**

- Min. 55.8 mm 7% (4.2 mm)
- Min. 57.6 mm 4% (2.4 mm)
- Min. 58.8 mm 2% (1.2 mm)

**Load condition**: VDE(SD)$_{TM}$ + ICE II, *Allowable stress = 220 MPa*

- Thickness = 60 mm (Nominal thickness)
- Thickness = 54 mm (10% reduced thickness)

- $P_L + P_b = 177$ MPa
- $P_L + P_b = 198$ MPa

- The VV with 10% reduced thickness has structural margin according to the RCC-MR.
- Confirmation from the ANB is expected before the start of fabrication.
2. Welding distortion analysis (upper segment)

- Assessments before and after distortion control by conventional jigs: out of tolerance
- Additional control: Tensioning method (heating restraint jigs)

3. Design analysis of the VV support

- From elastic & limit analyses, the structural design of the hinge support complies with the RCC-MR code.
- Thermal design of the support is feasible according to heat transfer analysis.
Status of Mock-up Fabrication

VVP: VV Poloidal Sector Mock-up
VAT: VV Advanced Technology Seg.
VIS: VV Inboard Segment Mock-up
VLTM: VV Lower-seg. Triangular-support Mock-up
VUS: VV Upper Segment Mock-up
VLPM: VV Lower Port Mock-up

Upper port stub extension (partial)
In-wall shielding (water jet cutting)
Mock-up Fabrication: EU

1. E-beam welding evaluation
   • Full scale inboard segment mock-up
   • Horizontal EBW
   • Long seam EBW to minimize distortion
   ➔ 1/10 of conventional TIG welding

2. VVPSM: VV Poloidal Sector Mock-up
   • Full scale poloidal sector (40°) fabrication
   • Heavy restraint structure to minimize distortion
   • Successful assembly welding of inboard and upper segments
   ➔ 85%: ±5 mm, 15%: ±10 mm

Ref: ITR/P1-38
Mock-up Fabrication: KO (1/2)

1. VISM: VV Inboard Segment Mock-up
   • Electron beam welding: Housings, manifold supports, intermodular keys
   • Assembly welding of divertor rail to inboard segment
   • Distortion minimization

2. VUSM: VV Upper Segment Mock-up
   • Narrow gap TIG welding + PT/RT/UT evaluation
   • Process of outer shell fit-up (flexible support housing interface)
   • Fixture design + analysis + distortion minimization

3. VLPM: VV Lower Port Mock-up
   • Development of fabrication procedure
   • R150 bending without severe thickness reduction
   • Welding and NDE method with narrow welding space

4. VLTM: VV Lower segment Triangular support Mock-up
   • Copper cladding feasibility (3 mm)
   • Design simplification
   • Fabrication feasibility study
Mock-up Fabrication: KO (2/2)

- Forming die (inside)
- Forming die (outside)
- Forming die (pre-test)
- Inboard shell bending
- Hole machining
- Manifold support
- Intermodular key
- Centering key
- Inboard EBW (LN Laser in Daejeon)

Ref: ITR/P1-42
Summary

1. After more than 10 years of evolution, the *ITER Vacuum Vessel design was frozen in May 2010* and was subsequently approved by the ANB as the preliminary design.

2. The Procurement Arrangements with each DA involved in the Vacuum Vessel and the resulting *industry contracts have been signed by October 2010*.

3. The procurement schedule for the Vacuum Vessel is being adjusted to satisfy the requirements for First Plasma in 2019 with *delivery of the first sector to IO in March 2015*.

4. *Preparations for manufacturing the main Vacuum Vessel are proceeding well* with the DAs responsible for the main Vacuum Vessel performing R&D and building mock-ups to minimize mistakes and errors during manufacturing.

5. Nuclear codes apply in the manufacturing of the ITER Vacuum Vessel which consequently will have to go through stringent controls *necessitating close cooperation between the IO, ANB, responsible DAs and industry*.
Cooperation makes work easier.