PFC components development from ITER to DEMO

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- ITER PFC achievements and useful experience
- Thin FW concept
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Introduction

- PFC group at Efremov Institute works for ITER project for many years

- We are responsible for delivery to ITER both W-armoured divertor components (~25% of divertor PFC area) and Be-armoured FW panels (40% of full FW).

- Currently we are starting to manufacture full scale prototypes of divertor dome and FW panel (#14) as a final qualification procedure before serial production

- Recently we were shortly involved in RF project of tokamak based VNS (by B. Kuteev)

- This gave us possibility to refresh some DEMO PFC problems and to prepare this presentation

- Our involvement in DEMO still very shallow. We understand the general problems and trends, but are not familiar with particular projects, approaches, numbers …
## Comparison of PFC operational condition for ITER and DEMO

<table>
<thead>
<tr>
<th></th>
<th>ITER</th>
<th>“DEMO”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak neutron flux at wall, ( MW/m^2 )</td>
<td>0.73</td>
<td>1-3</td>
</tr>
<tr>
<td>Duty factor, %</td>
<td>&lt; 3</td>
<td>&gt;30</td>
</tr>
<tr>
<td>Peak neutron fluence /damage ( MWa/m^2 / dpa )</td>
<td>0.5 / 5 (Cu)</td>
<td>≥5 / ≥50</td>
</tr>
<tr>
<td>Start of DT operation</td>
<td>2028</td>
<td>≥2035</td>
</tr>
<tr>
<td>Heat loads, ( MW/m^2 )</td>
<td>5 / 20</td>
<td>&lt;5 / &lt;20</td>
</tr>
<tr>
<td>FW / Div</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of cycles</td>
<td>3x10^4</td>
<td>10^4-10^5</td>
</tr>
<tr>
<td>Staging / replacing</td>
<td>FW -1 replacement, Divertor – 2-3</td>
<td>2-3 stages</td>
</tr>
<tr>
<td>Structural materials /coolants</td>
<td>CuCrZr and SS-316 / H(_2)O (4MPa, 150C)</td>
<td>Fer. St., V alloys / He, LM, hot water but for 1(^{st}) stage: Cu and H(_2)O</td>
</tr>
</tbody>
</table>

**Notes:**
- The table compares the operational conditions of the ITER and DEMO. Key parameters include peak neutron flux, duty factor, peak neutron fluence/damage, start of DT operation, heat loads, number of cycles, staging/replacing, and structural materials/coolants.
- **ITER** and **DEMO** refer to the International Thermonuclear Experimental Reactor and a DEMO reactor, respectively.
ITER PFC achievements and useful experience. W-armoured components

Divertor structure composition: W-Cu-CuCrZr-SS. Two design options/cases:
- flat tile on hypervapotron heat-sink for 5 MW/m² N=5000 cycles and 10 MW/m² N=300
- monoblock tile on tubular heat-sink for 10 MW/m² N=5000 and 20 MW/m² N=300

The maximal heat load for W-Cu-CuCrZr composition was achieved on macrobrush mockup, which survived:
- 1000 cycles at 20 MW/m²,
- + 1500 cycles at 27 MW/m²,
- + 2 cycles at ≥ 40 MW/m².
ITER PFC achievements and useful experience. Be-armoured components

FW structure composition: W-CuCrZr-SS. Two design options/cases:
- thin SS tube heat-sink in Cu matrix for moderate heat load 2 MW/m² N=15000 cycles
- hypervapotron CuCrZr heat-sink for enhanced heat load 5 MW/m² N=15000

The maximal heat load for Be-CuCrZr composition was achieved on ITER limiter mockup, which survived:
- 4500 cycles at 12 MW/m²,
- + few cycles at 15 MW/m²

Efremov-SNLA, 1999
ITER PFC achievements and useful experience.

ITER FW cost:

- x2 higher relative to official ITER cost estimate in 2000 (RF estimate 2014)

- 650 m² = 450 tonn = 225 M€

- Material cost: 28% (42% cost of Be). Manufacturing cost: 72% (20% Be machining)

Readiness of industry

- EU, RF, CN and JP


So, good opportunity for DEMO to get prepared and competitive industry
Thin FW concept

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Advantages of thin wall
- Transparent for neutrons
- Low cost
- Easy remote maintenance
- Minimum activated waste

Drawbacks
- Low resistance to EM loads
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1. Effective thickness for neutrons - x 10
**Thin FW concept.**

- Female keys on blanket surface
- Thin inner FW consists of 4 sectors
- Male keys on FW back side

**Maintenance and attachment**

- “Center Post”
- Inner Blanket
- Laser welding joint between FW sectors

**$P_{EM} \text{ max} \sim 2 \text{ MPa}$**

**FW cross-section**
Thin FW concept. Tubular design option
Thin FW concept. Tubular design option

Testing parameters:
Heat load: 1-11 MW/m²
Water cooling: T_{in}=30°C, V = 7 m/s

IR data at 5 MW/m² loading (cycle # 970)

Mock-up successfully survived 1000 cycles at 5 MW/m² and 1000 cycles at 11.3 MW/m².

Thermal analysis at 5 MW/m² ($\alpha=47$ kW/(m²K))
Thin FW concept.  Arched channels - flat tiles option
Thin FW concept. Arched channels - flat tiles option

Testing parameters:
Heat load: 1-11 MW/m²
Water cooling: $T_{in} = 70$ C, $V = 7$ m/s

IR data at 10.5 MW/m² loading (cycle # 95)

Mock-up successfully survived 1000 cycles at 5.5 MW/m² and 1000 cycles at 10.5 MW/m².

Thermal analysis at 10.5 MW/m²
Further development of PFC concepts/options

1. Definition of surface heat fluxes

\[ q^{\text{FW}_{\text{av.}}} = 0.25 \text{ MW/m}^2, \quad q^{\text{FW}_{\text{des.}}} = 5 \text{ MW/m}^2, \quad q^{\text{div}} = 10-20 \text{ MW/m}^2 \]
ITER: \[ q^{\text{FW}_{\text{av.}}} = 0.50 \text{ MW/m}^2, \quad q^{\text{FW}_{\text{des.}}} = 1-5 \text{ MW/m}^2, \quad q^{\text{div}} = 10-20 \text{ MW/m}^2 \]
DEMO: 

2. Selection of heat-sink material

FW: ferritic steels \( q_{\text{ult.}} = 1-5 \text{ MW/m}^2 \); Divertor: Cu-alloys \( q_{\text{ult.}} \approx 20 \text{ MW/m}^2 \), \( D_{\text{ult.}} \approx 5 \text{ dpa} \)
V- and W- alloys ??

3. Coolant selection

FW: \( \text{H}_2\text{O}, \text{He}, \text{LM}, \text{flibe} \) Divertor: \( \text{H}_2\text{O}, \text{free LM (+He)} \)

4. Armour thickness/erosion lifetime

FW: \( \text{W, Be (~ 30 mm at 1 MW/m}^2) \) Divertor: \( \text{W (5-15 mm)} \)

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FW: long term solution visible, heat flux minimization strongly recommended Divertor: solution only for short 1-st phase, non-conventional target for later stages
Further development of PFC concepts/options

Efremov Institute proposal:

- to perform FW mockups manufacturing and HHF testing for various combination of materials (FS, Be, W), design geometries, coolants (H2O, He) to define thermal-mechanical limits/prospects of different combinations;

- to perform development and thermal-mechanical testing of promising DEMO divertor target concept, based on solid target with FS tubes.
Conclusion

- Experience on ITER PFC development and manufacturing have to be used for DEMO PFC (at least for the 1st stage).

- Thin transparent FW concept demonstrates low cost, easily maintained, transparent for neutrons option.

- Prospects for DEMO PFC development are briefly considered.
Easy replaceable/moveable solid targets with heat transfer to fixed heat-sink via LM interlayer (left) or by radiation (right)

Vapor (Li, Be) pot divertor target