Development of Tungsten Monoblock Technology for ITER Full-Tungsten Divertor in Japan

FIP: 1-1

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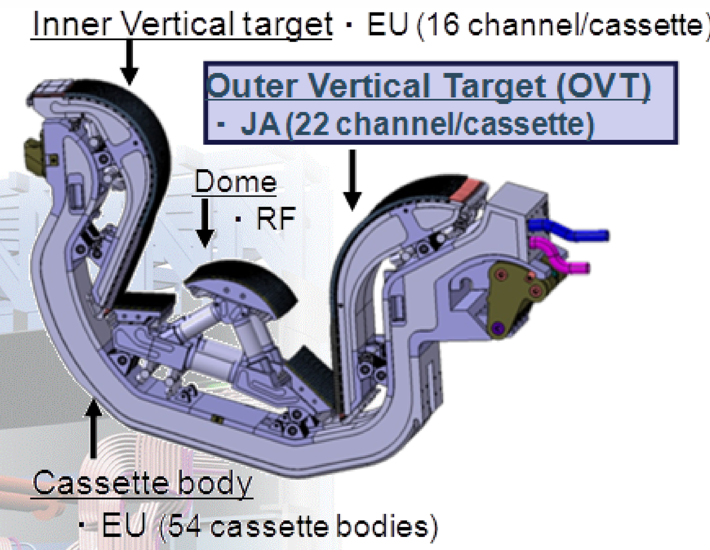
1 Situation of ITER divertor

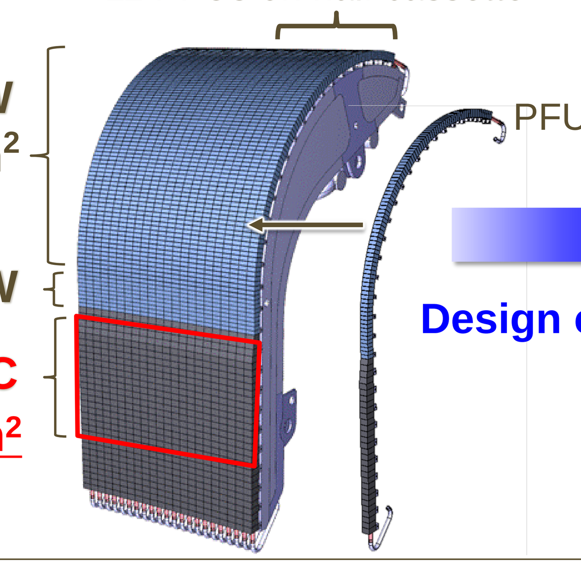
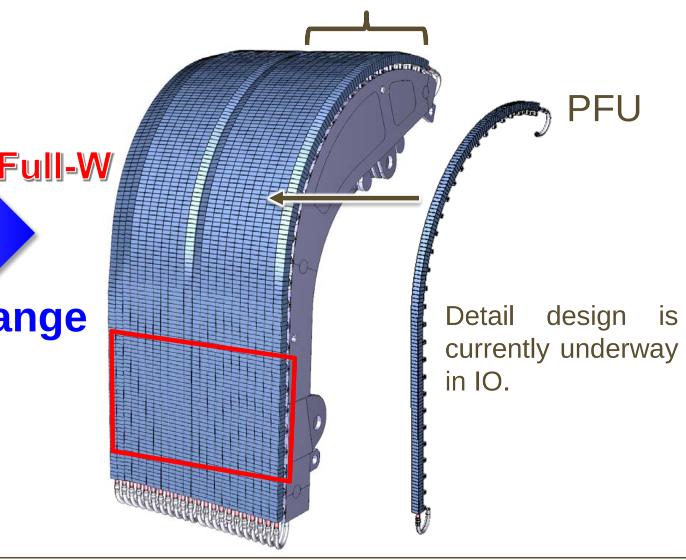


- In 2011, ITER Organization (IO) proposed to start with full-tungsten (W) divertor target. ITER Council (IC) endorsed recommendation to delay the decision on the specific choice of divertor for up to two years.
  - Toward the final selection of the armor material, Japan Atomic Energy Agency (JAEA) and IO signed the task agreement on the "Full-W Outer Vertical Target Qualification Program" on December 2012.
  - Small-scale mock-ups with the W monoblocks have been provided to investigate a thermal performance against high heat flux (HHF).

Technical achievements demonstrated by JAEA provided an essential boost for full-W divertor.

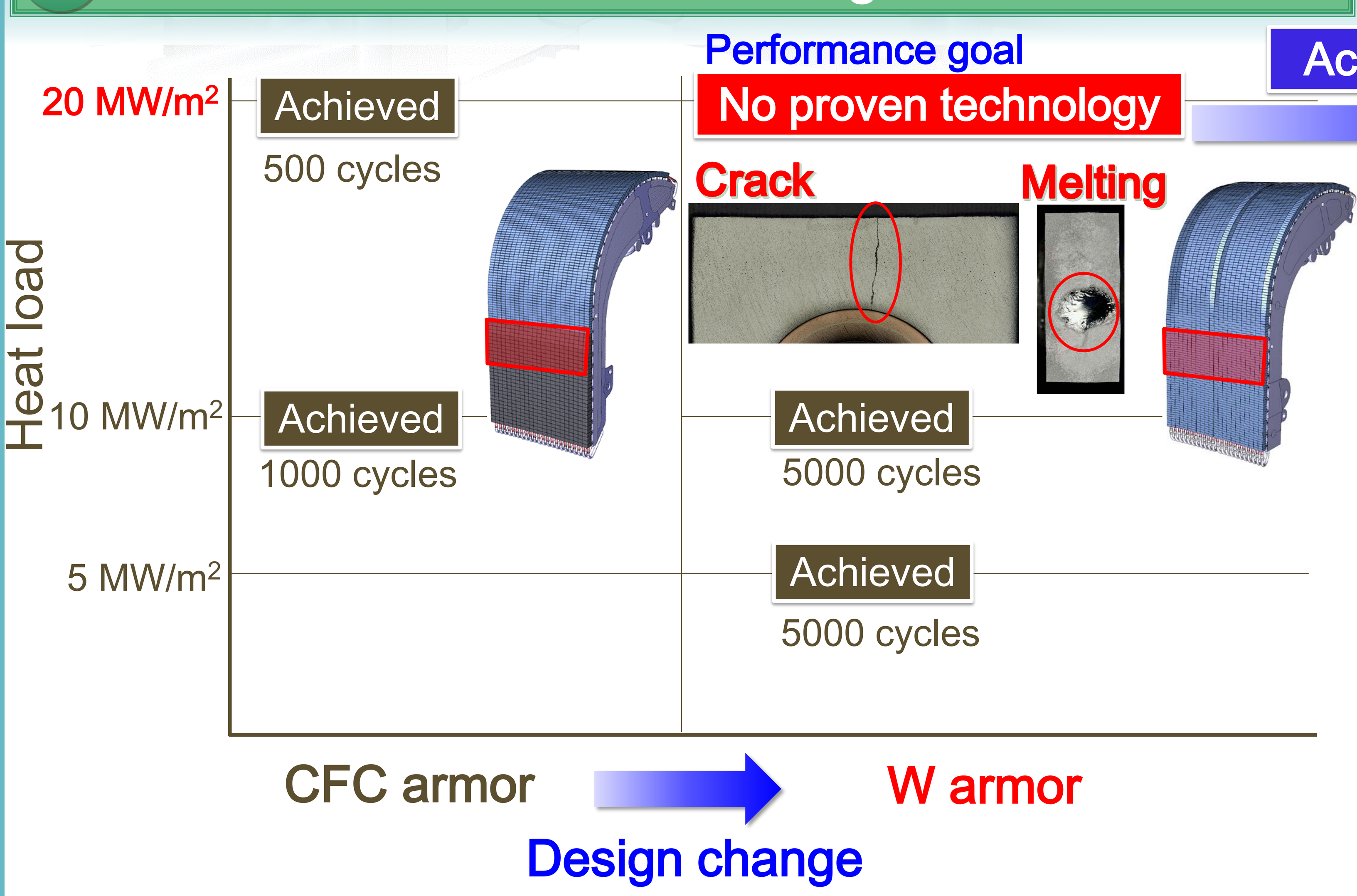
- In 2013, IC approved the first ITER divertor make use of all-W plasma-facing components as baseline.

2 What's difference between CFC and Full-W divertor design?

	CFC divertor OVT design	Full-W divertor OVT design
Baffle: W 5-10MW/m^2; Straight part of W; Target: CFC 10-20MW/m^2	11 PFUs on half cassette 	11 PFUs on half cassette 
Operation phase	H/He	H/He/DD/DT
Armor materials	Target: CFC Baffle: W	Target: Tungsten (W) Baffle: W
Heat Load	Target: 10-20MW/m^2, Baffle: 5-10MW/m^2 (steady state)	
Coolant	Water, 70^{o}C, 4MPa	

Concerning the development and validation of the W monoblock technology that withstands **20MW/m^2 surface heat flux**, R&D of a full-W divertor was started.

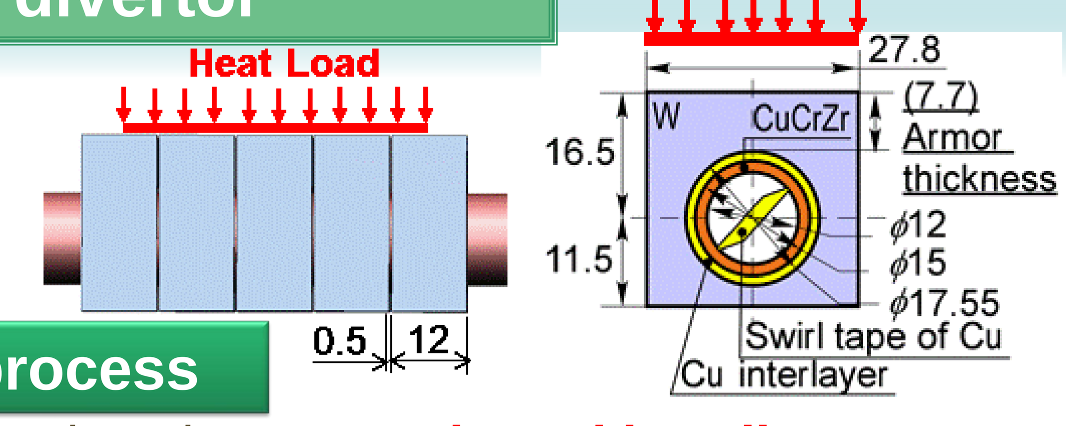
3 What's the technical challenge for W divertor?



A huge leap is necessary to go to the non-attainment region. The development and validation of the W monoblock technology that withstands 20 MW/m^2 were "**challenge**".

4 R&D on the full-W divertor

Small-scale mock-ups



Two-phased bonding process

Key point of the manufacturing is to be a **two-phased bonding process**.

- Before the R&D, two joint surfaces were bonded at the same time.
- The W/Cu joint is bonded before the brazing onto the CuCrZr tube. Improvements are
  - Ultrasonic testing (UT) for each joint with higher accuracy ,
  - Position tolerances of the Cu/CuCrZr.

These operations can reduce the rejection rate of PFUs due to deficient bonding interface.

Bonding methods

Three kinds of Bonding methods for the W/Cu joint with durability to high heat flux of 20 MW/m2 were obtained.

(1) Direct casting of copper, (2) Diffusion bonding, (3) HIP bonding

Different bonding methods help hedge a risk of the series product of ITER divertor.

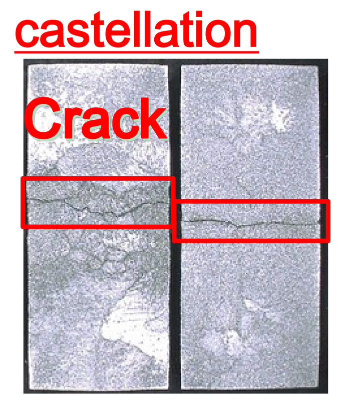
5 High heat flux (HHF) test at IDTF in Efremov institute

Small-scale mock-ups

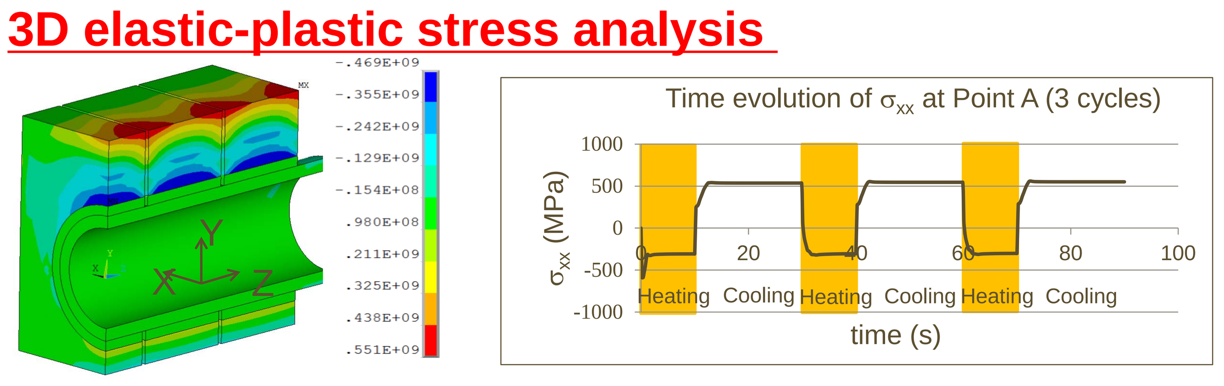
After the HHF testing of 10 MW/m2 × 5000 cycles and 20 MW/m2 × 1000 cycles

Recrystallization of the W armor without a macroscopic crack.
Gaps of 0.5 mm contacted by deformation of W.

Example of self-castellation

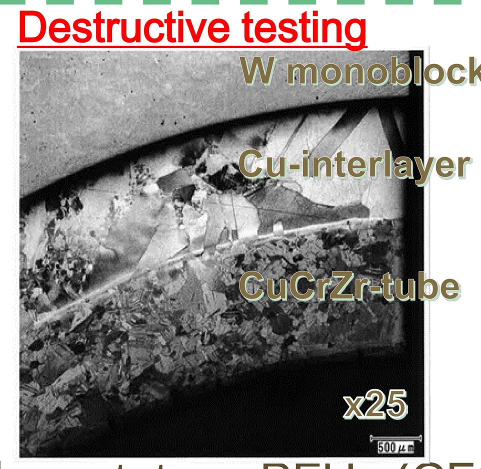


3D elastic-plastic stress analysis



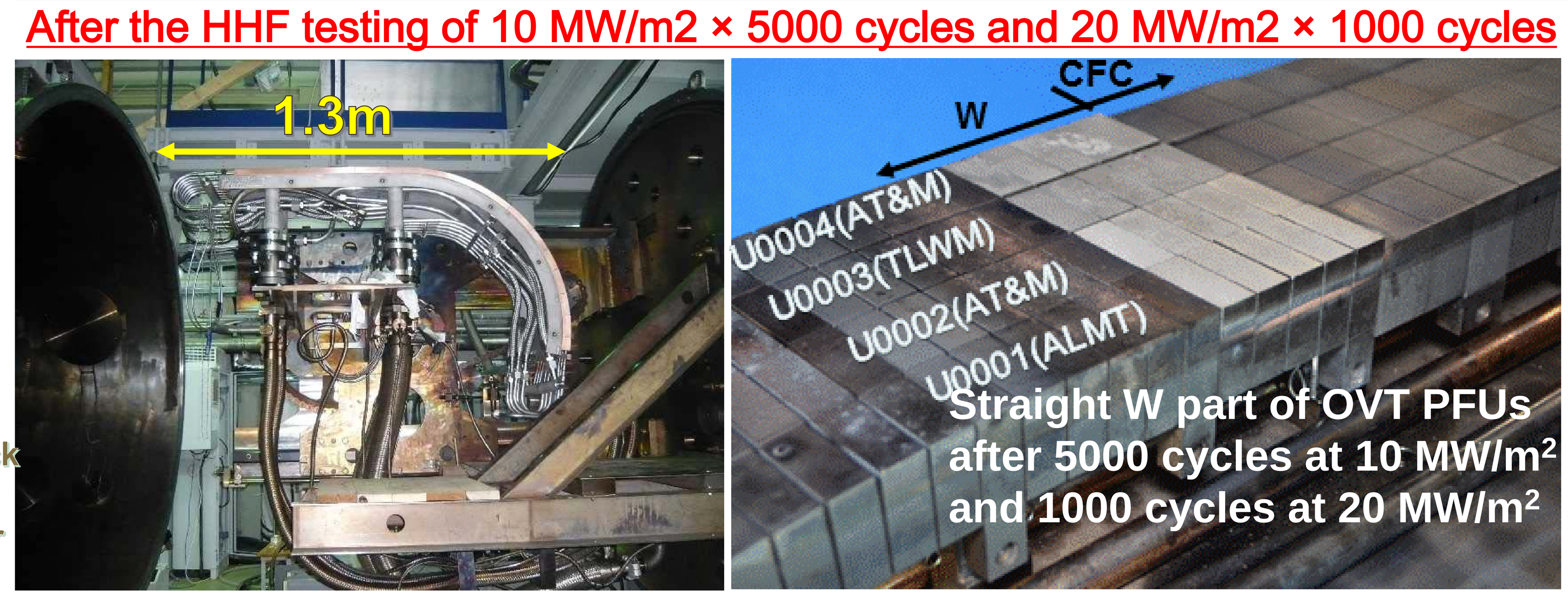
σ_{xx} distribution at the end of 3rd cycle (t = 90s)

Destructive testing



Straight W part of the full-scale prototype PFUs of CFC divertor

After the HHF testing of 10 MW/m2 × 5000 cycles and 20 MW/m2 × 1000 cycles



In so far as straight W part of full-scale prototype of CFC divertor, the result indicates that the current W monoblock technology is acceptable for the requirements of the full-W divertor.

- All W monoblocks of 6 small-scale mock-ups and 4 full-scale prototype PFUs (CFC divertor) withstood 5000 cycles at 10 MW/m^2 and 1000 cycles at 20 MW/m^2.
- None of W monoblock showed macroscopic cracks along the tube axis (so-called, self-castellation) that often appeared in monoblocks after HHF test at 20 MW/m^2.
- Maximum stress 500 MPa appeared in stress analysis is exactly the same as the deformation distribution in the mock-ups after the HHF test.
- The averaged grain sizes remained 90-100 mm after the HHF testing in comparison with average gain size at not heat-affected zone, 76-95 mm.

6 Summary

1 The full-W divertor qualification program

As the first phase for the technology validation and demonstration of the full-W divertor, the small-scale mock-ups were manufactured for HHF testing at IDTF in Efremov institute.

2 Technical achievement

JAEA succeeded in demonstrating that W monoblock technology is able to withstand the heat flux 20 MW/m^2 without the macroscopic crack, traces of melting and degradation of the heat removal capability.

3 Distribution of fruits

Manufacturing full-W divertor is common challenge for the international community. Our result contributes to global development for full-W divertor. It triggers the start of contract talks for corporate transactions between the European and Japanese companies for the manufacturing full-W divertor.

On going activity … scale-up!

Manufacturing 6 full-scale prototype PFUs of full-W ITER divertor will be finished by March 2015.