(MPT/1-2Ra) Overview on Decade Development of Plasma-Facing Components at ASIPP

and

(MPT/1-2Rb) Advances in Understanding of High-Z Materials Erosion & Re-deposition in Low-Z Wall Environment in DIII-D

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Overview on Decade Development of Plasma-Facing Components at ASIPP

(MPT/1-2Ra) by

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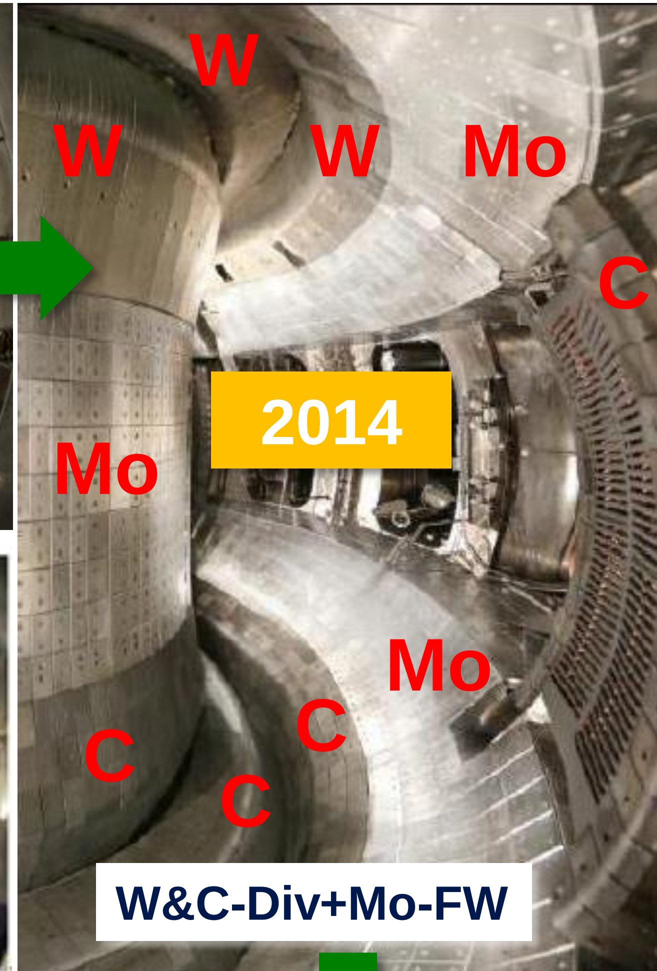
PFM/C evolution in EAST

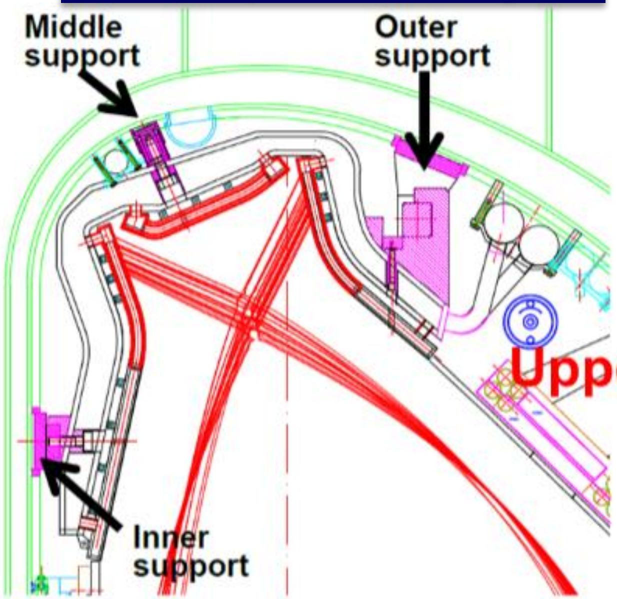


1^{st} plasma

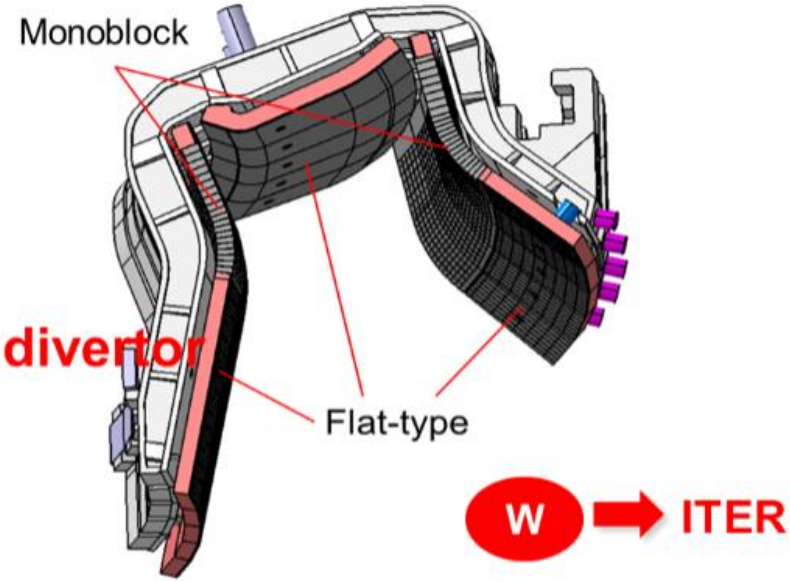
2018~2019 / Full W PFC

W/Cu upper divertor design

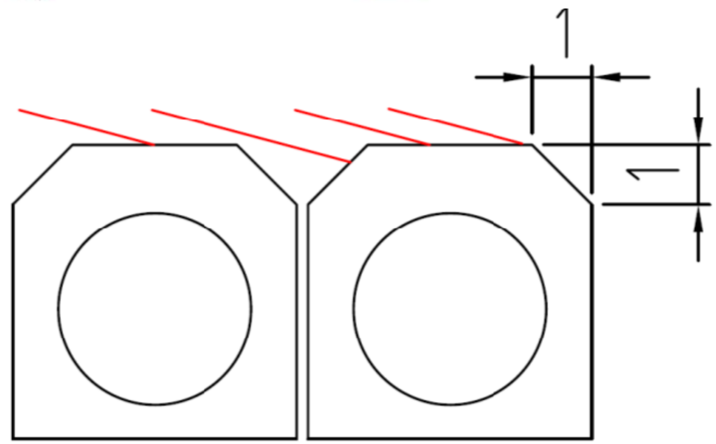
Conceptual design



Engineering design

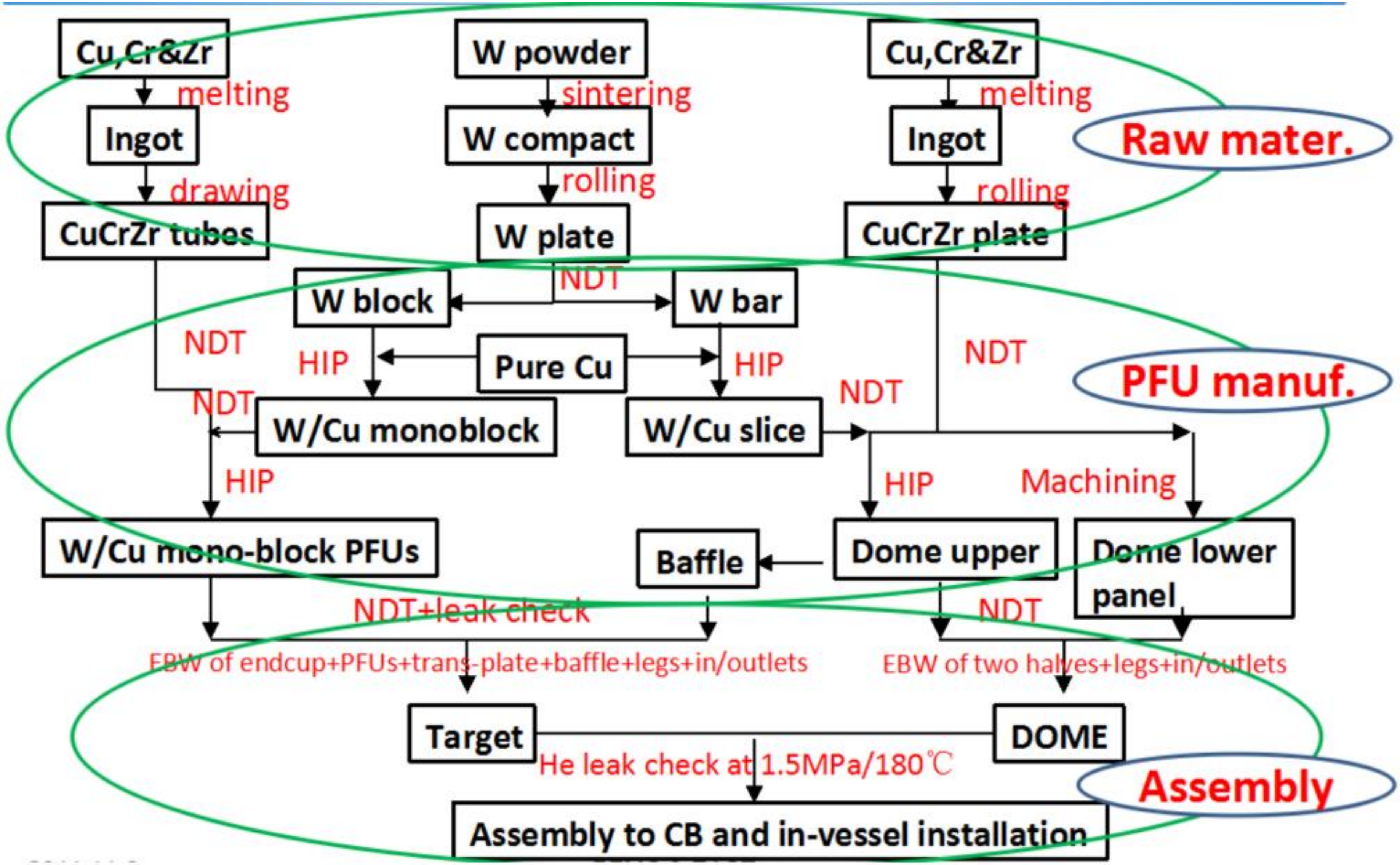


- **ITER-like W monoblocks**
  -divertor targets (10 MW/m²)
- **Flat type W/Cu PFCs**
  -divertor dome and baffles (5 MW/m²)



Dual chamfering for EAST

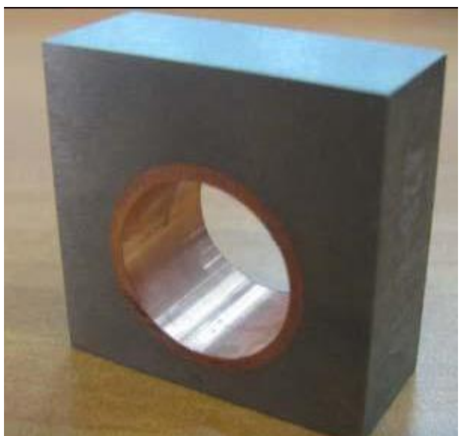
Flowchart of manufacturing

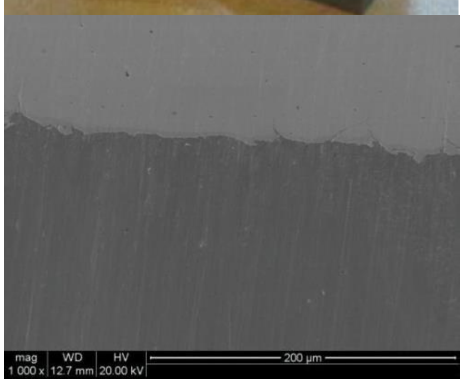


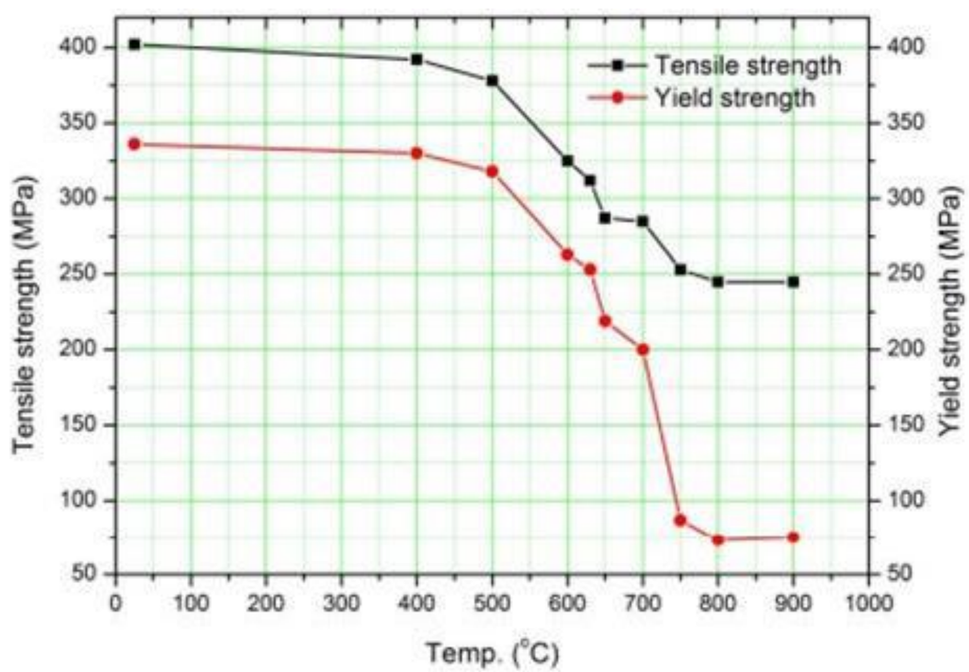
HIP technology is widely used in the bonding of W/Cu and Cu/CuCrZr.

ITER-like monoblock W/Cu PFC

- W/Cu monoblocks are prepared employing **HIP (900 ºC, 100 MPa)**.
- W/Cu PFUs are manufactured successfully by **HIP (600 ºC, 100 MPa)**. Properties of CuCrZr after HIP satisfy the requirement.
- US-NDT results: Bondings between monoblocks/OFC/CuCrZr are excellent.



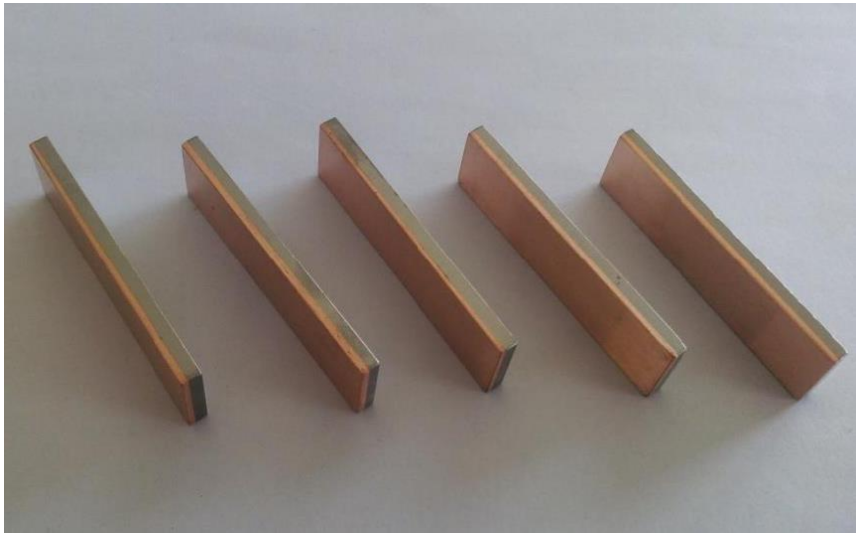


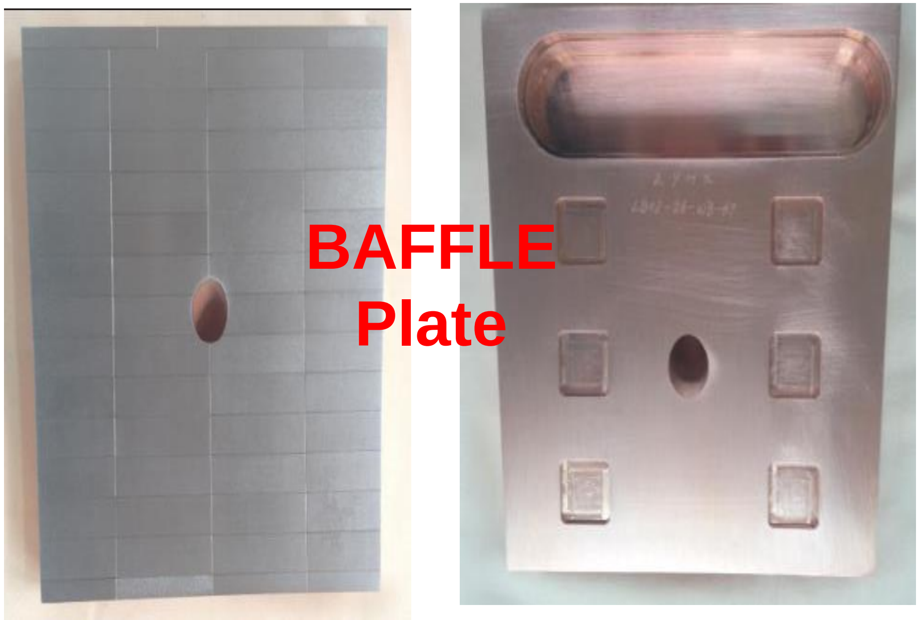


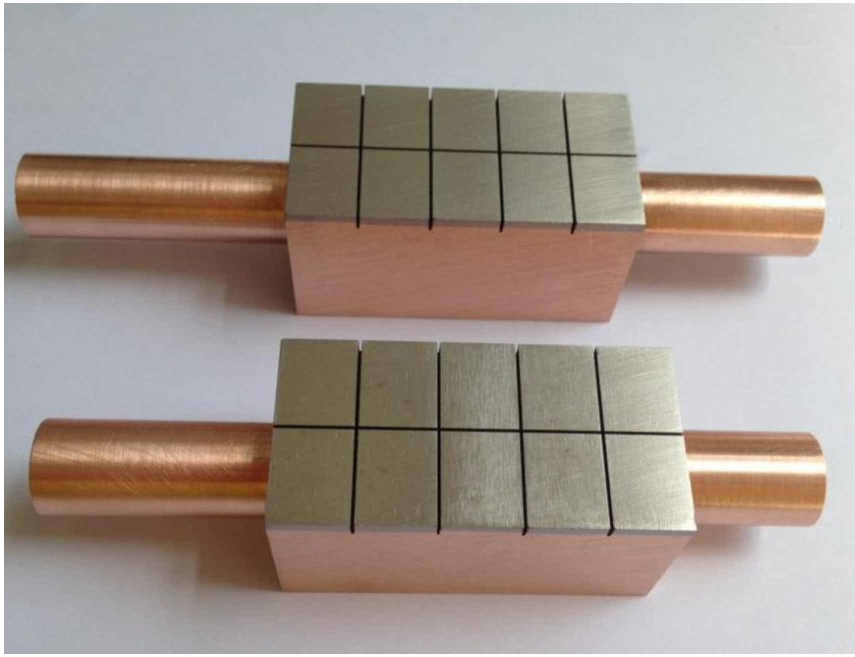
Annealing behavior of CuCrZr tube

Flat-type W/Cu PFCs

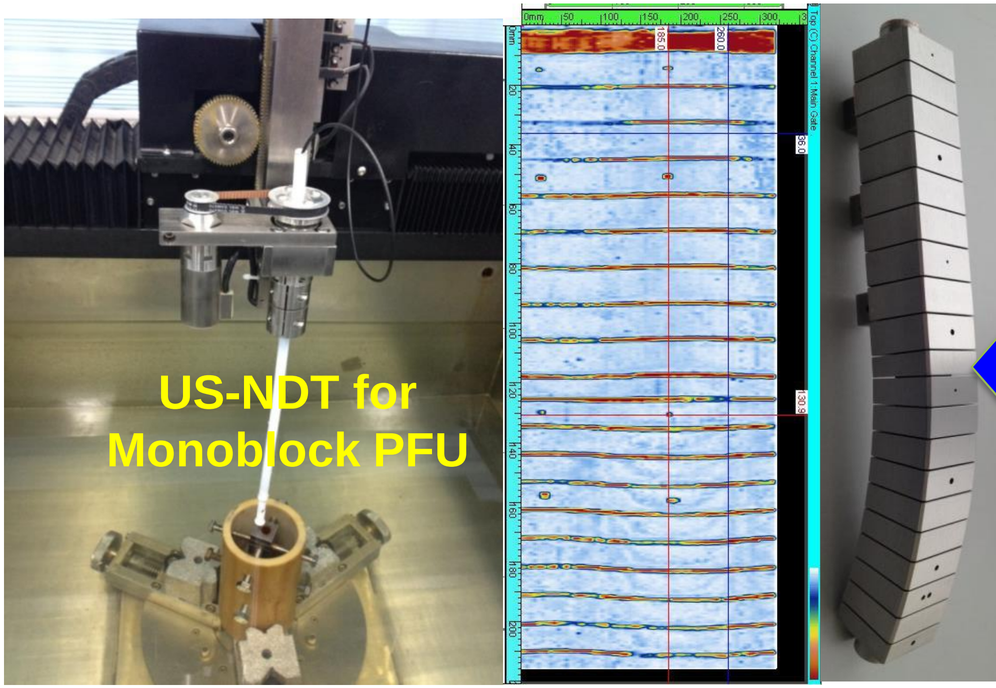
- **Casting + HIP: The interface of W/Cu were joined by casting. (1200^{0}C), and then the interface of Cu/CuCrZr was bonded by HIP at lower temperature of 500~600 ^{0}C.**
- **NDT results: bondings between W tiles/OFC/CuCrZr plate are excellent.**





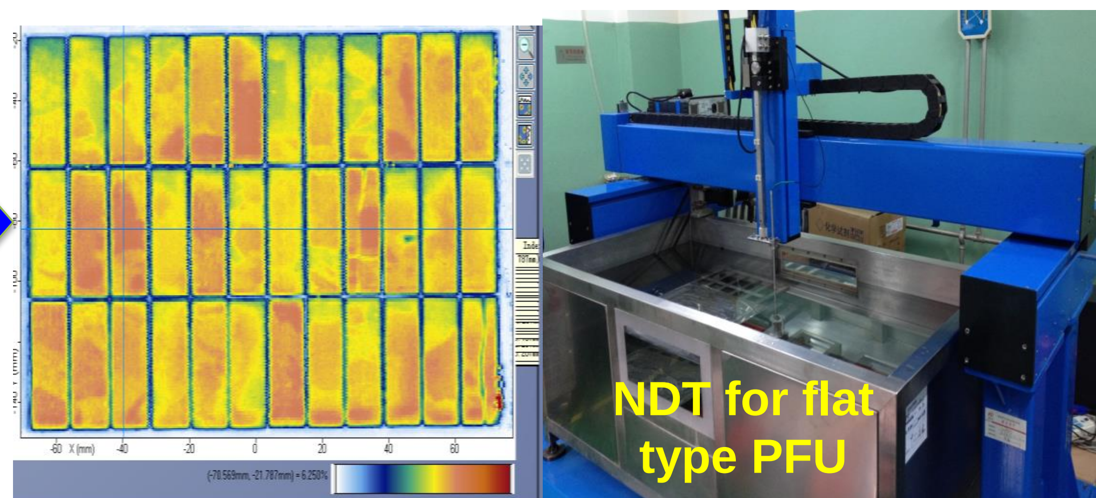


US-NDT for W/Cu PFCs



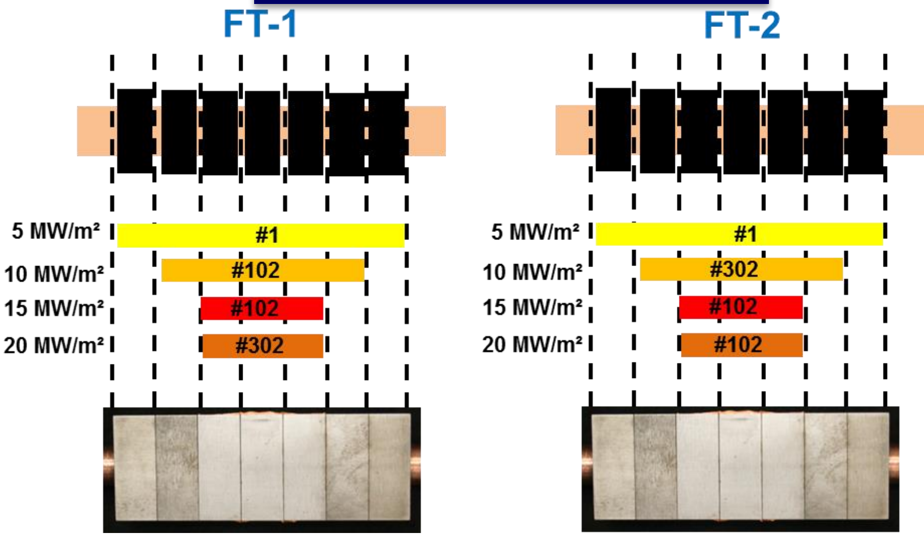
- Single probe: scanning the inner surface.
- The defects of Φ1 mm in the interface of W/Cu and Cu/CuCuZr was detected clearly using this set-up.
- 15000 W/Cu mono-blocks and 720 PFUs tested.

- More than 30000 W/Cu slices and 240 flat PFUs have been tested by this set-up with detection limit of Φ1 mm.



High heat flux test of W/Cu PFCs

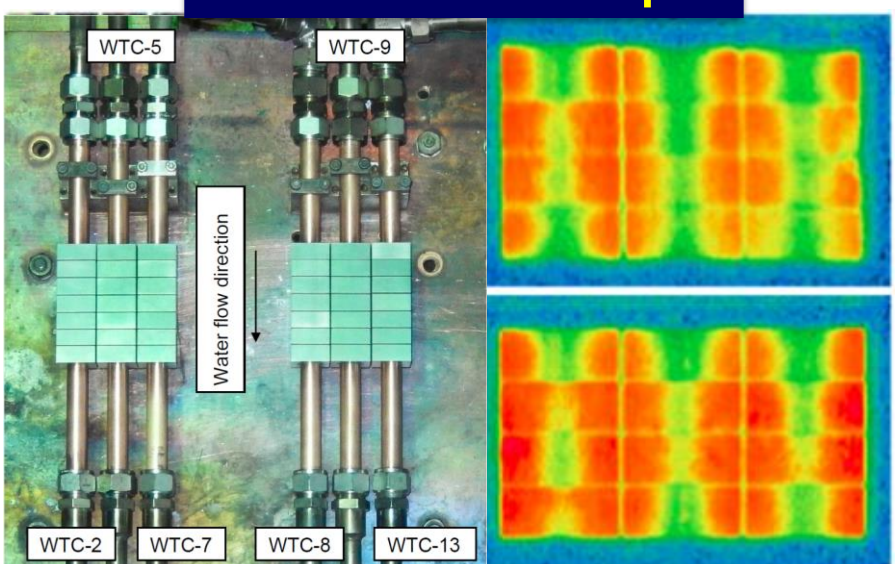
Flat type mock-ups



In cooperation with CEA

- **FT-1 withstood 102 cycles at 10 MW/m², 102 cycles at 15 MW/m², 302 cycles at 20 MW/m².**
- **FT-2 withstood 302 cycles at 10 MW/m², 102 cycles at 15 MW/m², 102 cycles at 20 MW/m².**

Monoblock mock-ups

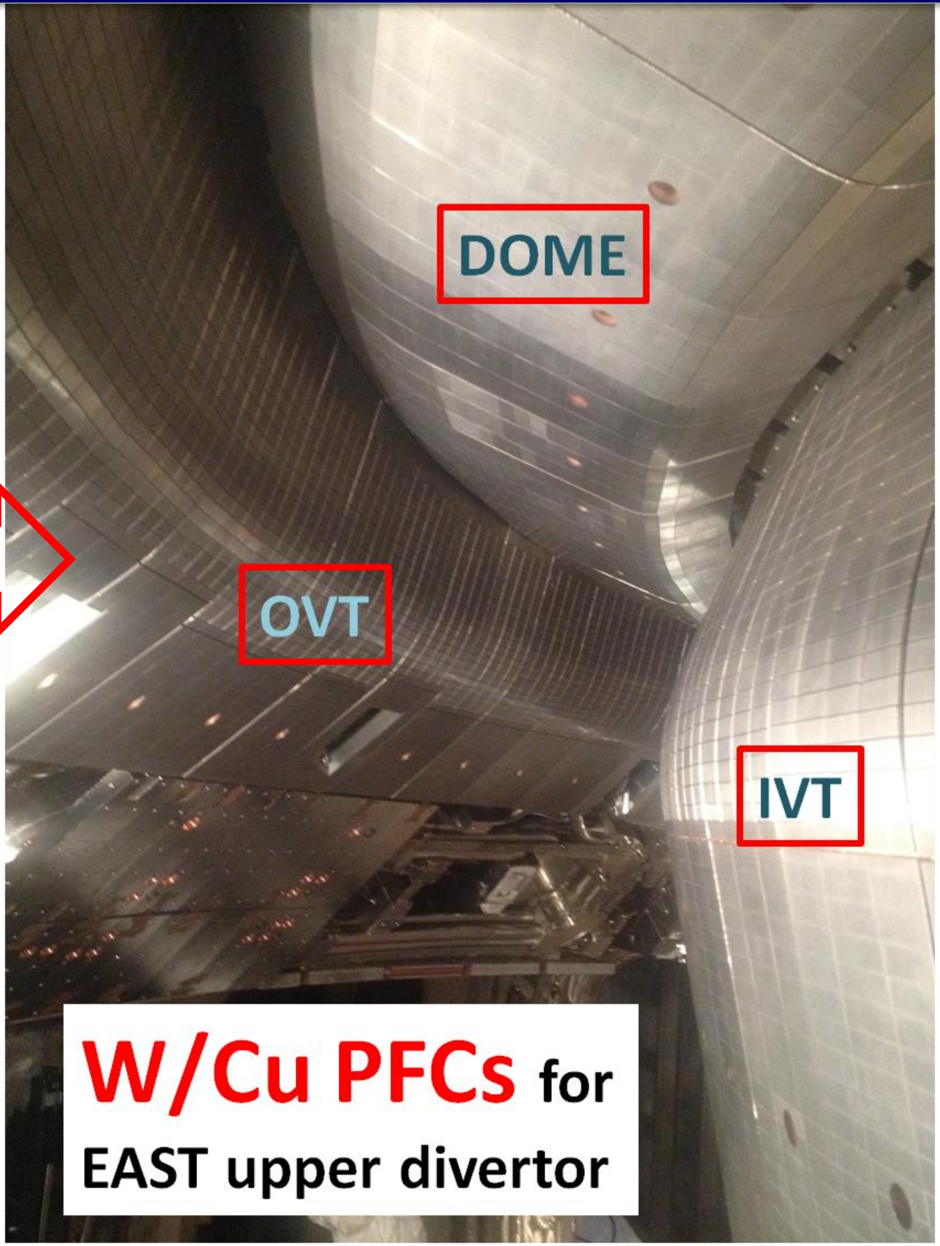


In cooperation with ITER

- **6 small scale monoblock mock-ups were tested on IDTF (ITER Divertor Test Facility).**
- **All the mock-ups withstood 5000 cycles at 10 MW/m² and 1000 cycles at 20 MW/m² in accordance with the qualification program.**

Grand view of the W/Cu divertor for EAST

PFCs+CB assembly: 80
IVT/OVT/DOME: 80 each
Monoblock PFUs: 720
Monoblock W: 15,000
Flat-type PFUs: 240
Flat W tiles: 24,000
E-beam seam: > 4000
W raw powders: > 10 tons
CuCrZr plates: > 8 tons
CuCrZr tubes: 720 pcs/360m

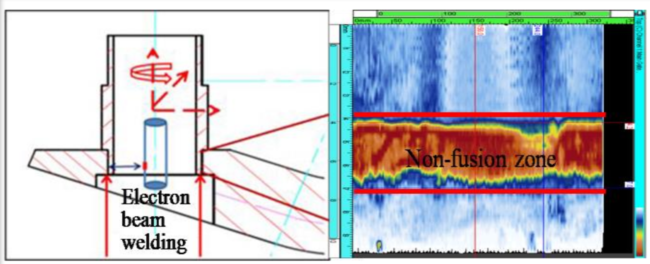


Performance of W/Cu divertor during campaigns

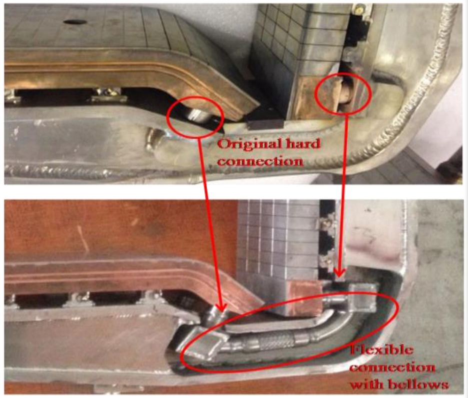
In 2014 EAST campaign, first commissioning of the upper W/Cu divertor failed.

Three practical measures

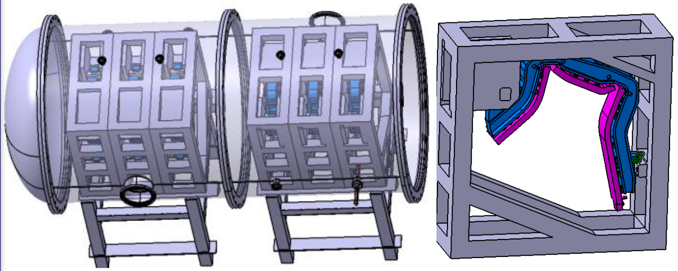
In the 2015 and 2016 spring campaigns, the W/Cu upper divertor withstood more severe irradiation by EAST plasma and no similar leaks occurred.



Improving NDT for welding seam of tube-plate joints inspection



Optimizing cooling tube connection using bellows



Performing baking and high pressure helium leak check on whole assembled div. modules

Section summary

- **The W/Cu upper divertor for EAST was finished in the spring of 2014. HIP technology was used in the bonding of W/Cu and Cu/CuCrZr. NDT quality control system has been established for quality control;**
- **In collaboration with IO and CEA teams, we have demonstrated capability to resist 5000 cycles at 10 MW/m^2 plus 1000 cycles at 20 MW/m^2 for small scale monoblock mockups, and surprisingly over 300 cycles at 20 MW/m^2 for the flat-type ones.**
- **Commissioning of the EAST W/Cu divertor in 2014 was unsatisfactory and then several practical measures were implemented, which has improved welding quality and general reliability significantly.**
- **The experience and lessons learned from batch production and commissioning are valuable for ITER engineering validation and tungsten-related plasma physics.**

Disclaimer: **The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.**

Advances in Understanding of High-Z Material Erosion and Re-deposition in Low-Z Wall Environment in DIII-D

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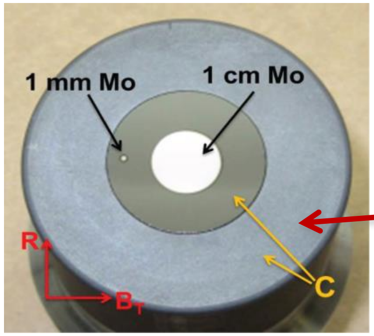
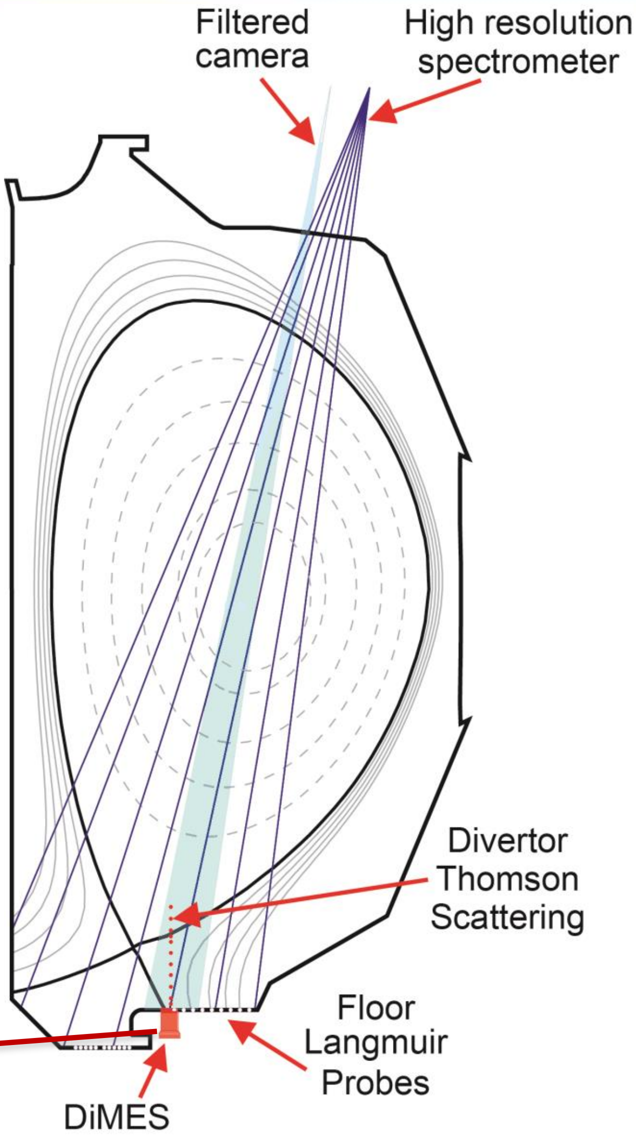
Pre-characterized Samples Exposed to Reproducible Well-diagnosed Plasma Discharges Using DiMES

- **Understanding of High-Z material erosion**
  - Sheath effect
  - Background impurities
- **DIII-D Experiments**
  - Thin Mo/W coating sample
  - Net erosion & redeposition measured via Rutherford backscattering (RBS)
  - 1 cm sample + 1 mm samples to measure net + gross erosion
  - Gross erosion measured also spectroscopically using S/XB coefficient
- **The 3D Monte Carlo code ERO**
  - Plasma-surface interaction
  - Local impurity transport
  - OEDGE background plasma as input: n_e, T_e, $E_{//}$, $v_{//}$





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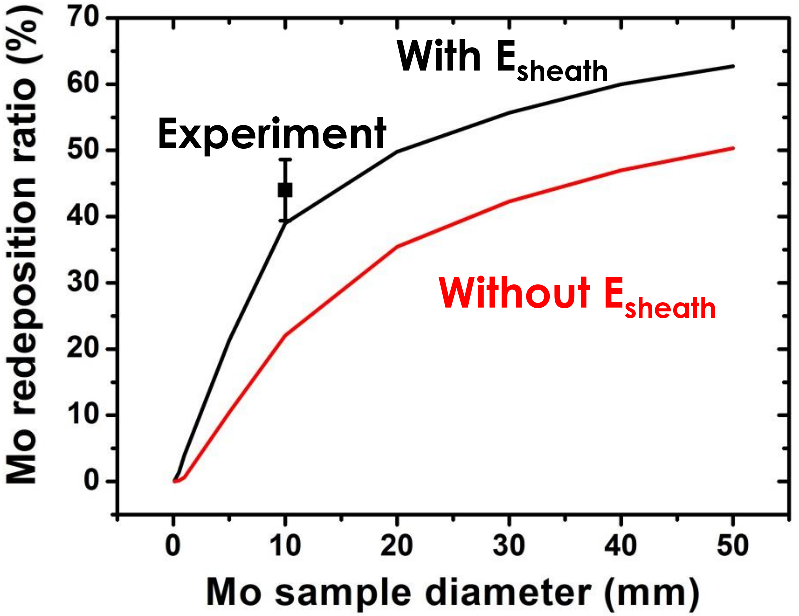
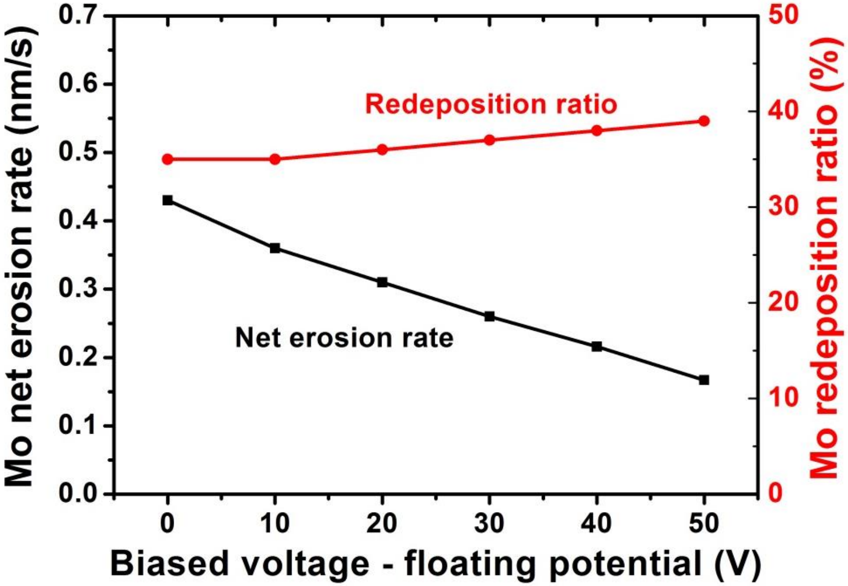
The High Redeposition Ratio from ERO Simulation Strongly Depends on Magnetic Pre-sheath Electric Field

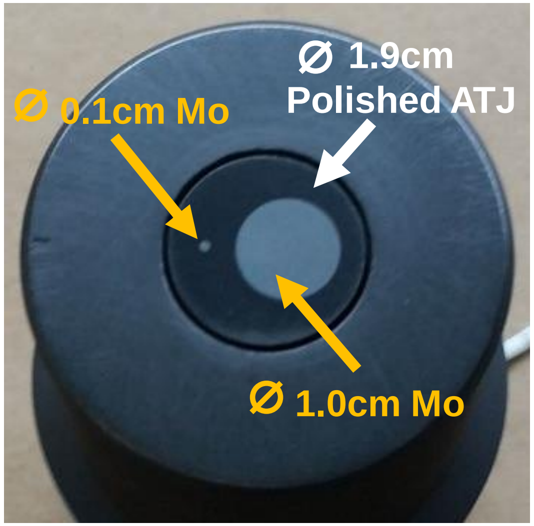
- **Magnetic pre-sheath dominates for small angle between B and surface**
  - Strong E field
  - n_e decay with potential drop
- **Larger gyroradius due to strong E field enhances the prompt redeposition**
- **Decreasing the sheath potential drop can suppress both gross and net erosion Rate**
  - The redeposition ratios are not reduced because the density is increased at the same time
  - The gross erosion rate is reduced for lower ion incident energy



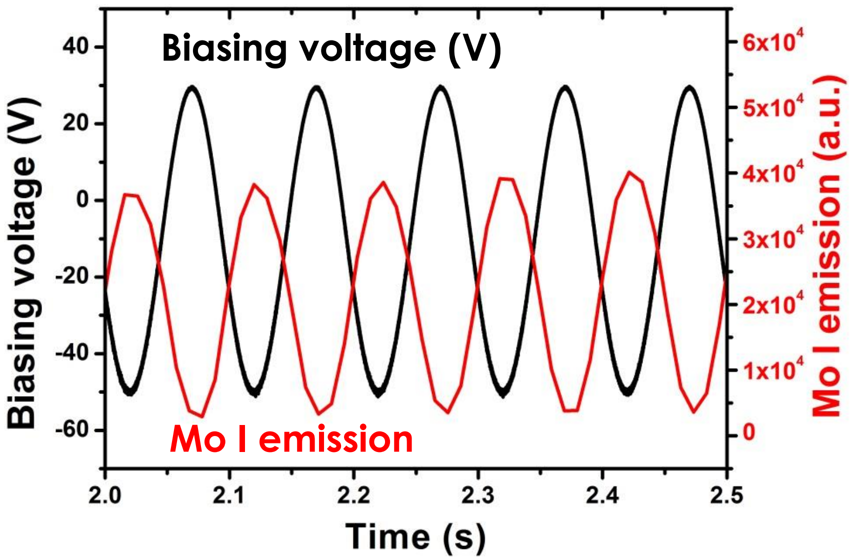


Modifying Sheath Potential by External Biasing Changes Mo Gross Erosion Rate Significantly

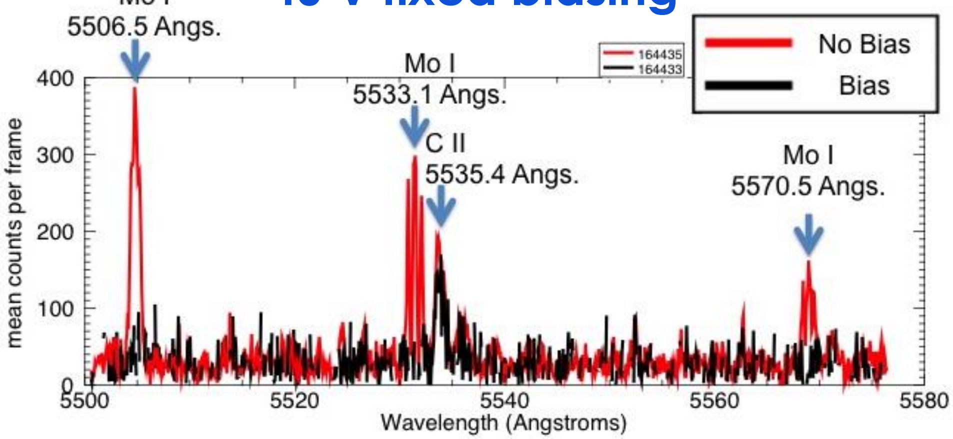
- Central graphite with Mo coating biased
- Gross erosion measured by spectroscopy (Mo I 550 nm)
- Mo erosion suppressed with positive biasing (below RBS detection limit)



10 Hz, from -50 V to 30 V



40 V fixed biasing



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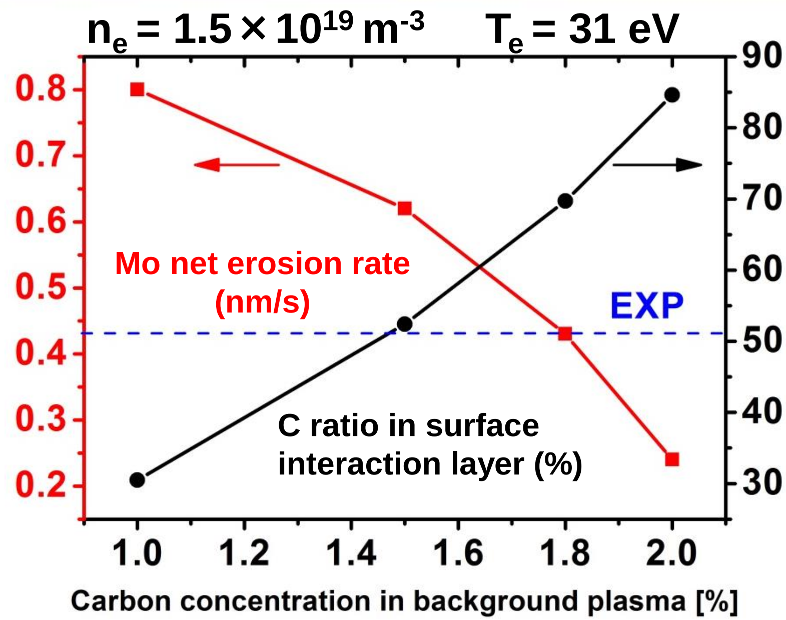
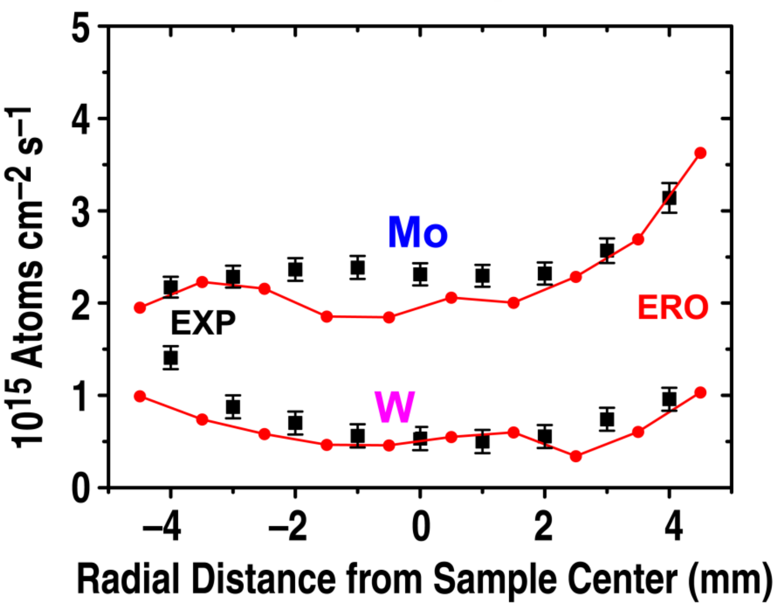
Higher C Concentration in Background Plasma Leads to Lower Net Erosion Rate

- **Assuming 1.8% of C^{3+} concentration in plasma, ERO modeled net erosion rates agree well with the measured values**
- **Net erosion profiles of both Mo and W are well reproduced by ERO modeling**
- **W net erosion rate is much lower than Mo for its lower sputtering yield and higher redeposition ratio due to shorter ionization length**

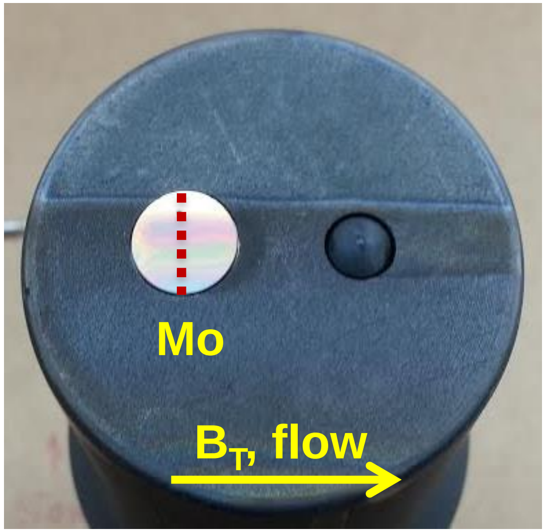


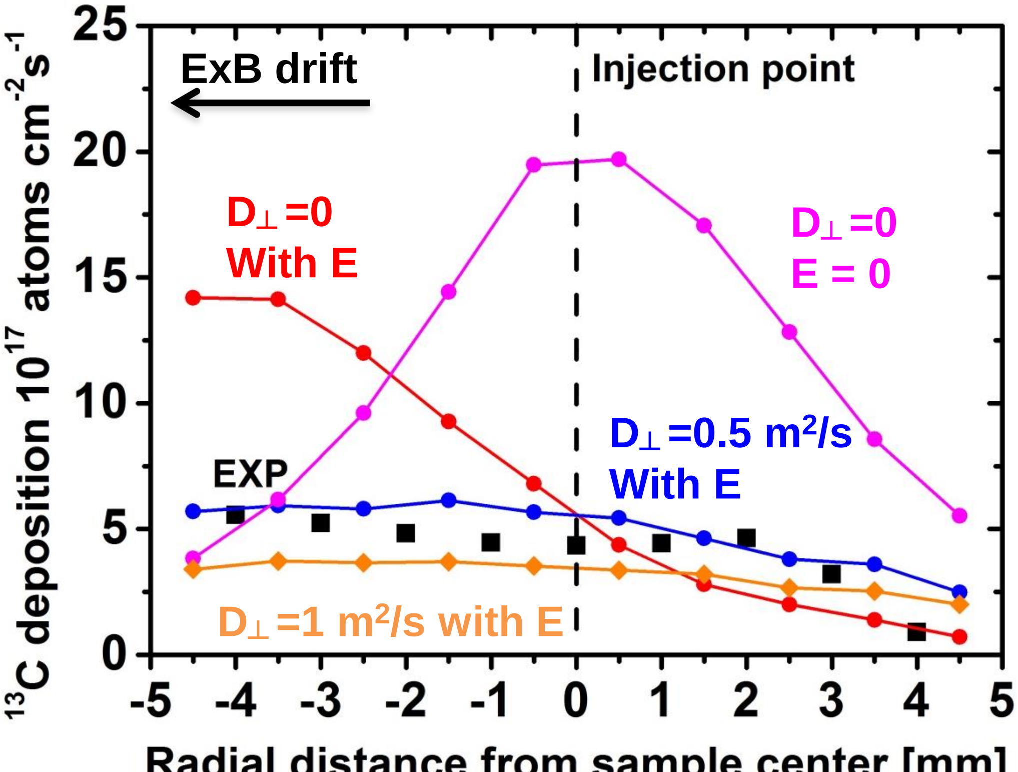


Local Methane Gas Injection can Turn the Surface into a Net Deposition Area

- $^{13}CH_4$ injected ~12 cm upstream from the center of the DiMES (1.8 Torr-l/s)
- The samples imaged by an absolutely calibrated camera (MoI, CH, CI, CII)
- A carbon coating created on the Mo sample protecting the Mo from erosion
- More ^{13}C deposited in radial inboard direction is mainly due to the ExB drift
- Higher $D_\perp$ leads to broader profile and lower ^{13}C deposition on DiMES

Radial profile





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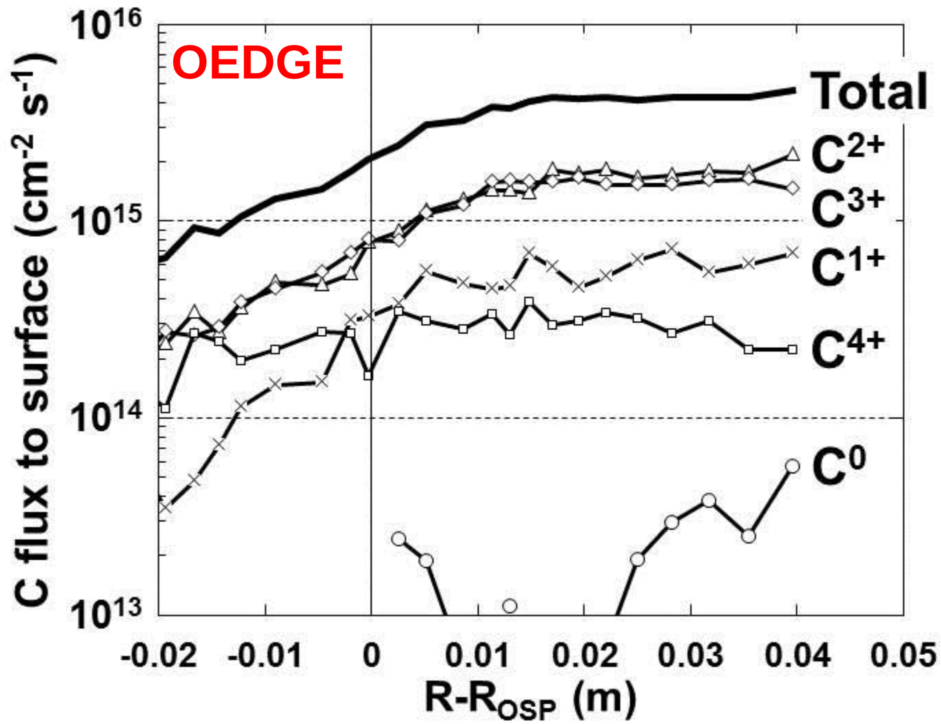
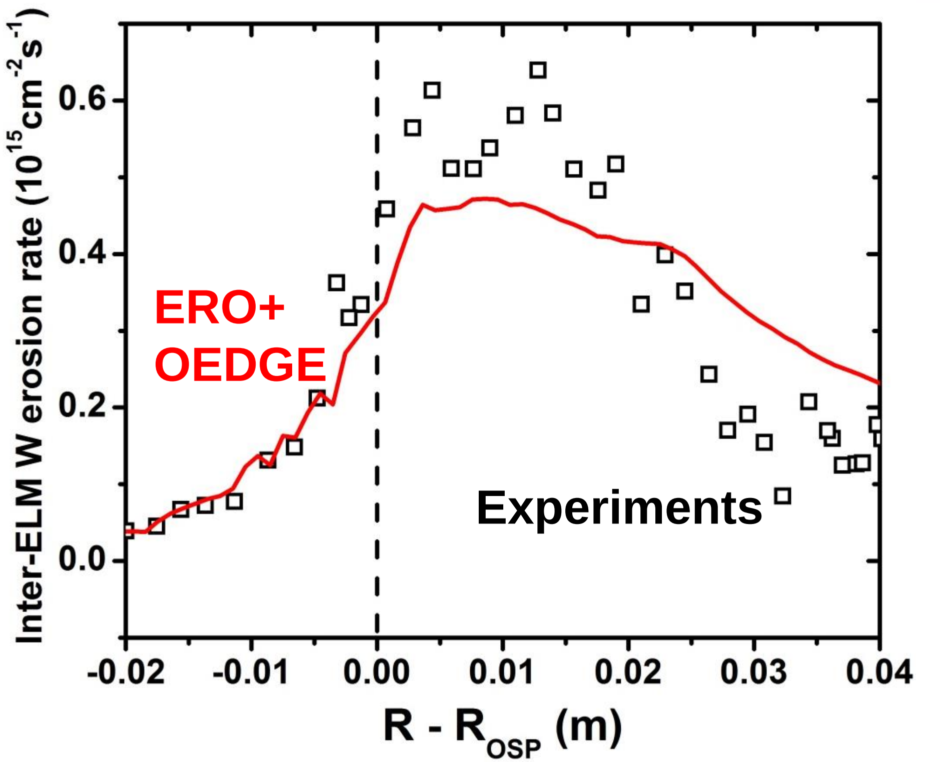
OEDGE/ERO Modeling Demonstrates that Inter-ELM W Erosion is Well Explained by C→W Sputtering





- **High-resolution inter-ELM W erosion profiles were measured by monitoring WI 400.9 nm line intensity with OSP sweeping**
- **charge-state-resolved carbon ion flux in the background plasma is calculated using the OEDGE code**

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Section summary

- **Improved understanding of erosion and redeposition of high-Z materials in a mixed materials environment in DIII-D was achieved**
- **Dedicated experiments coupled with ERO modeling highlight the roles of the sheath potential and background impurities in determining high-Z material erosion**
- **The high-Z materials erosion can be actively controlled with electrical biasing, as well as by local gas puffing**
- **The experimental results are well reproduced by the OEDGE/ERO simulations, allowing better predictions for ITER and future devices**

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