Actively Cooled Plasma Facing Components for KSTAR

(Possible Collaboration between Korea and the United States)

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Outline

- A Brief Review of Divertor R&D for ITER
- Why Has The US Pursued The W Rod Concept?
- Other Applications of W Rods As PFCs
- Possible Application on KSTAR
- Issues To Be Resolved
- Benefits to ITER
- Possible Collaboration Between the US and Korea
- Budget Estimates
- Conclusions

A Brief Review of Divertor R&D for ITER

- **Three options were investigated for the plasma facing surface of the ITER divertor**
  - **Be tiles or plasma sprayed coating on CuCrZr (adopted only for the first wall)**
  - **CFC tiles on a CuCrZr Alloy heat sink (the baseline design)**
  - **W on CuCrZr alloy heat sink (either W tiles or rods or a plasma sprayer coating) (W is the backup PFM because of T retention concerns in redeposited C)**

A Brief Review of Divertor R&D for ITER

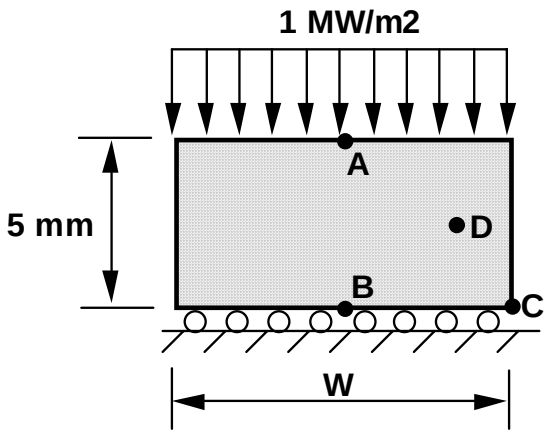
- The US pursued the Be and W options for the ITER Divertor
- Testing on the W rod concept has revealed the this option can meet all the ITER requirements with some lingering concerns about ELM and disruption damage.

Why Has The US Pursued The W Rod Concept?

- Thermal stresses are greatly reduced by the divided surface (next slide)
- The small spaces between the rods provide space for melted material to accumulate when melting occurs due to disruptions or ELMS
- 3 mm rods achieve good stress reduction without excessive numbers of parts to handle
- Tritium retention is reduced with W compared to C
- High temperature baking is not required with Be FW

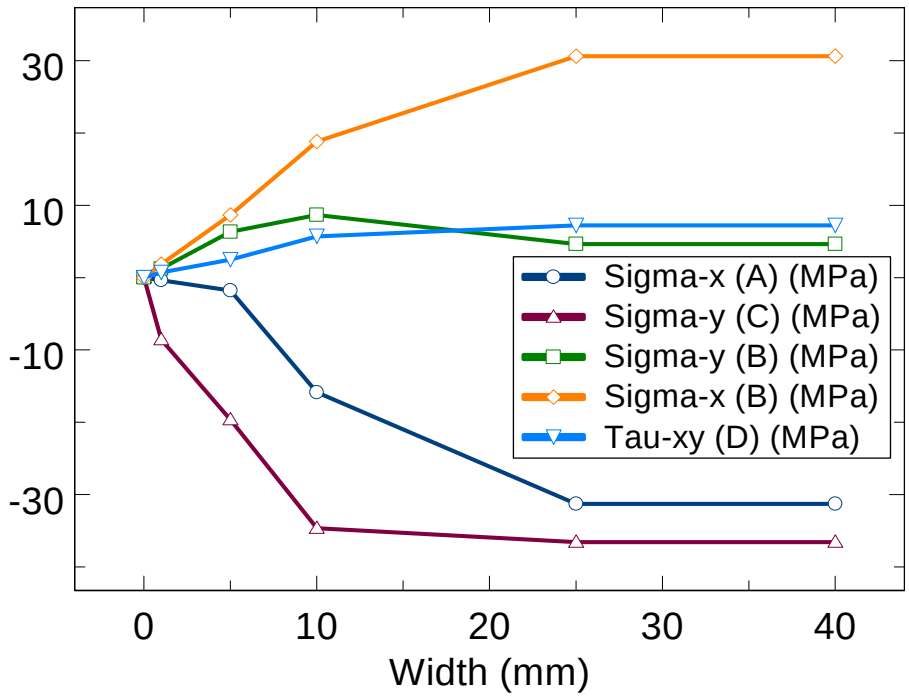
Stress Minimization Analysis Showed Divided Surfaces Are Preferred

ABAQUS Finite Element Model



- 2-D plane stress
- Elastic behavior
- Temp. dependent props.
- 2000 elements (8-node quad)

Tungsten, 5 mm thick



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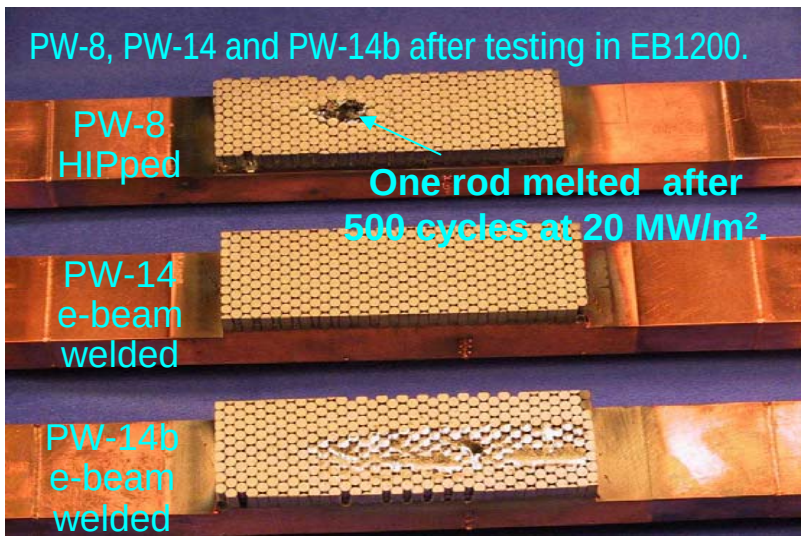
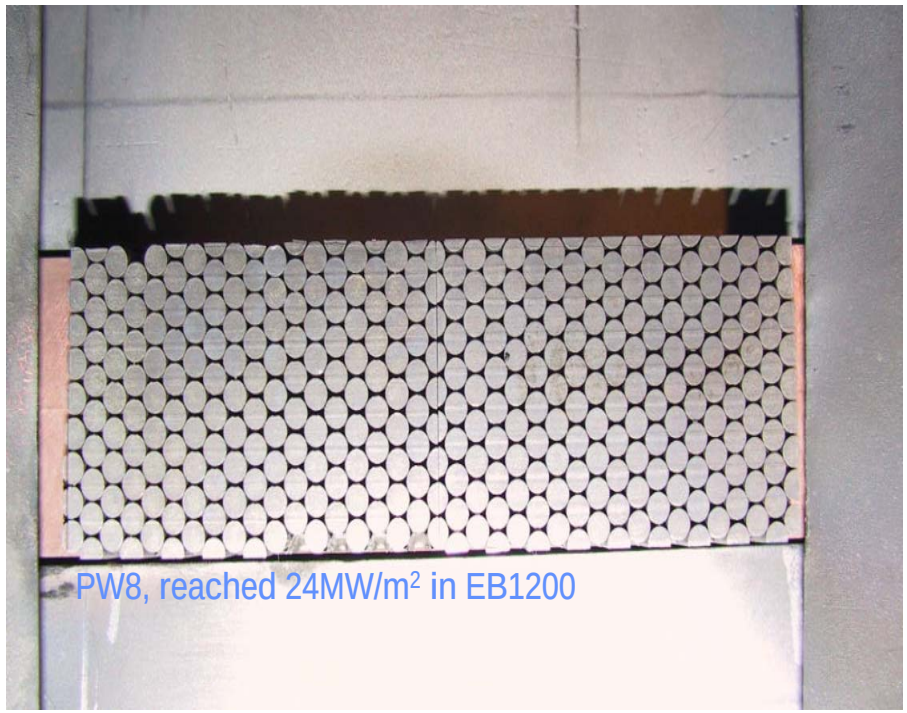
W Rod PFC Testing Results

- **Development of W PFC continues to show improvement in capability and reliability**





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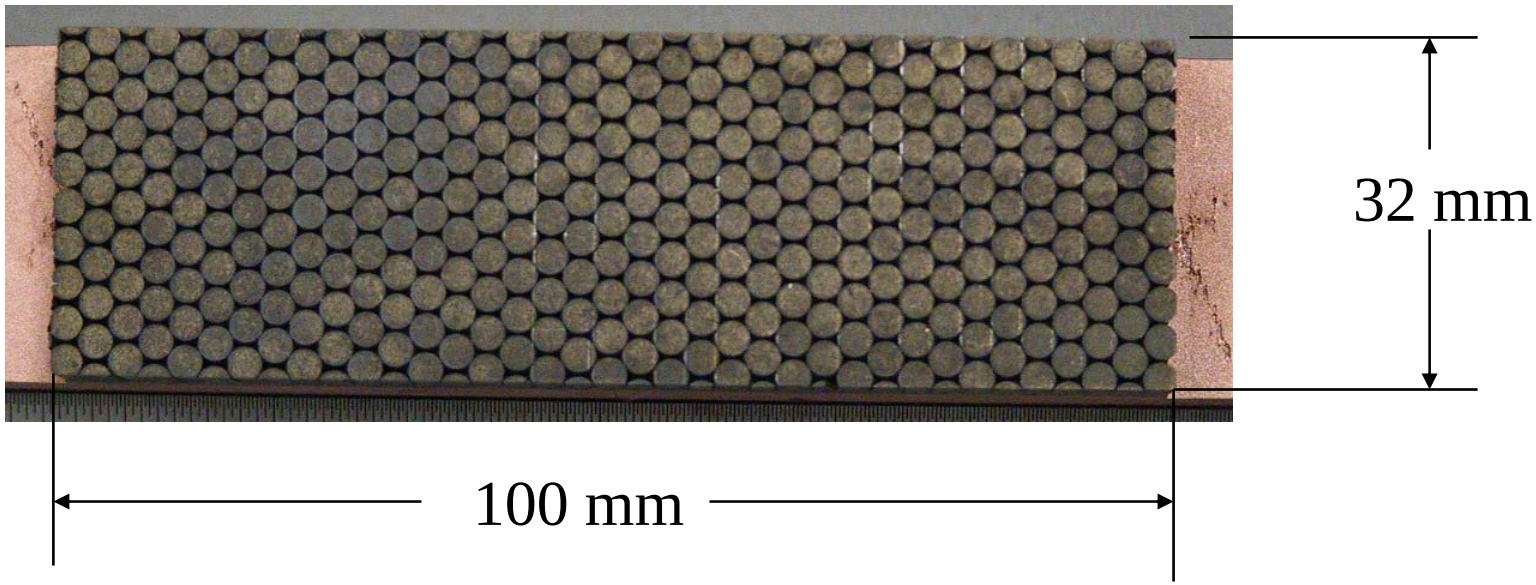
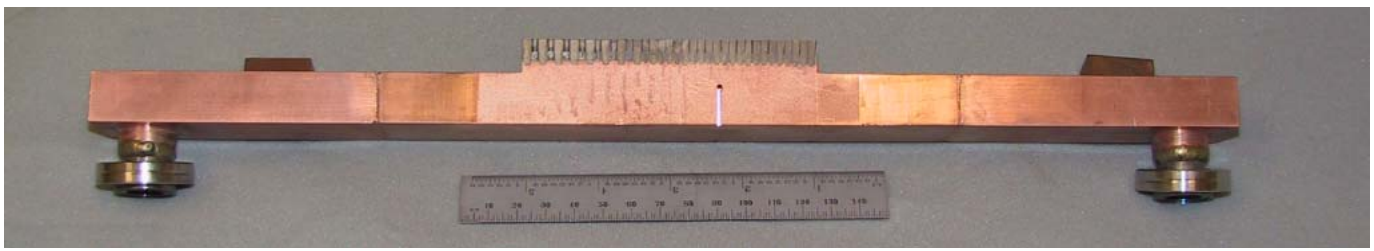
Tungsten Rod PFC Prototype





Rods 7
mm long

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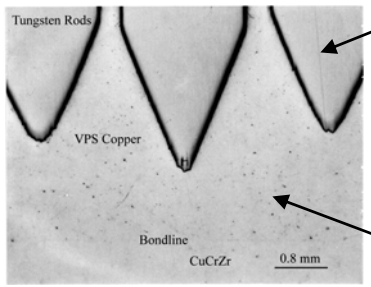
Progress in PFC Capability Was Enabled by Fundamental Analysis

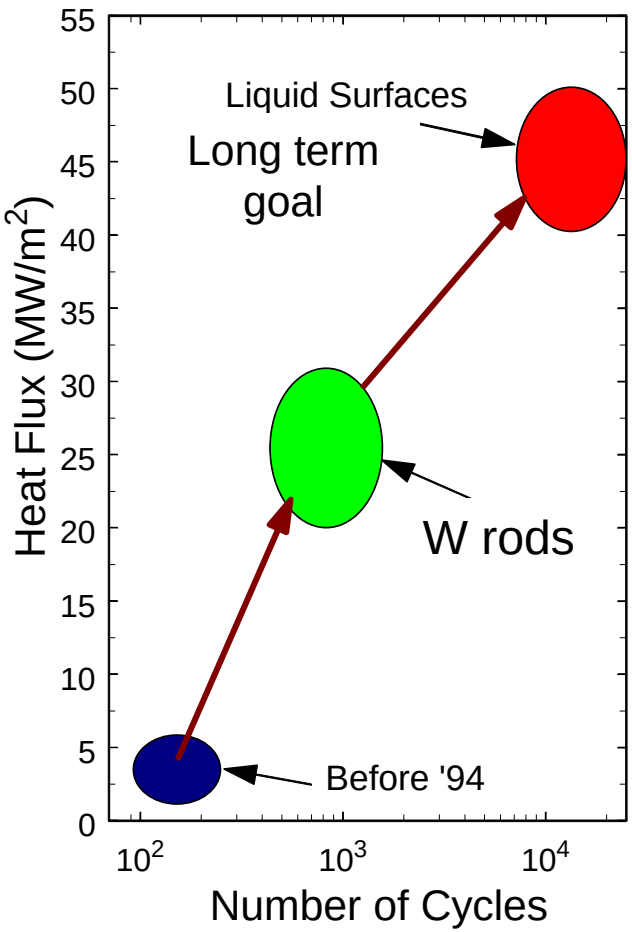


W

Cu

Tungsten rod component

Progress in Heat Removal Capability



Progress:

- **Reduction of stress using rods on the surface**
- **Low temperature joining**
- **Improved heat transfer enhancement**

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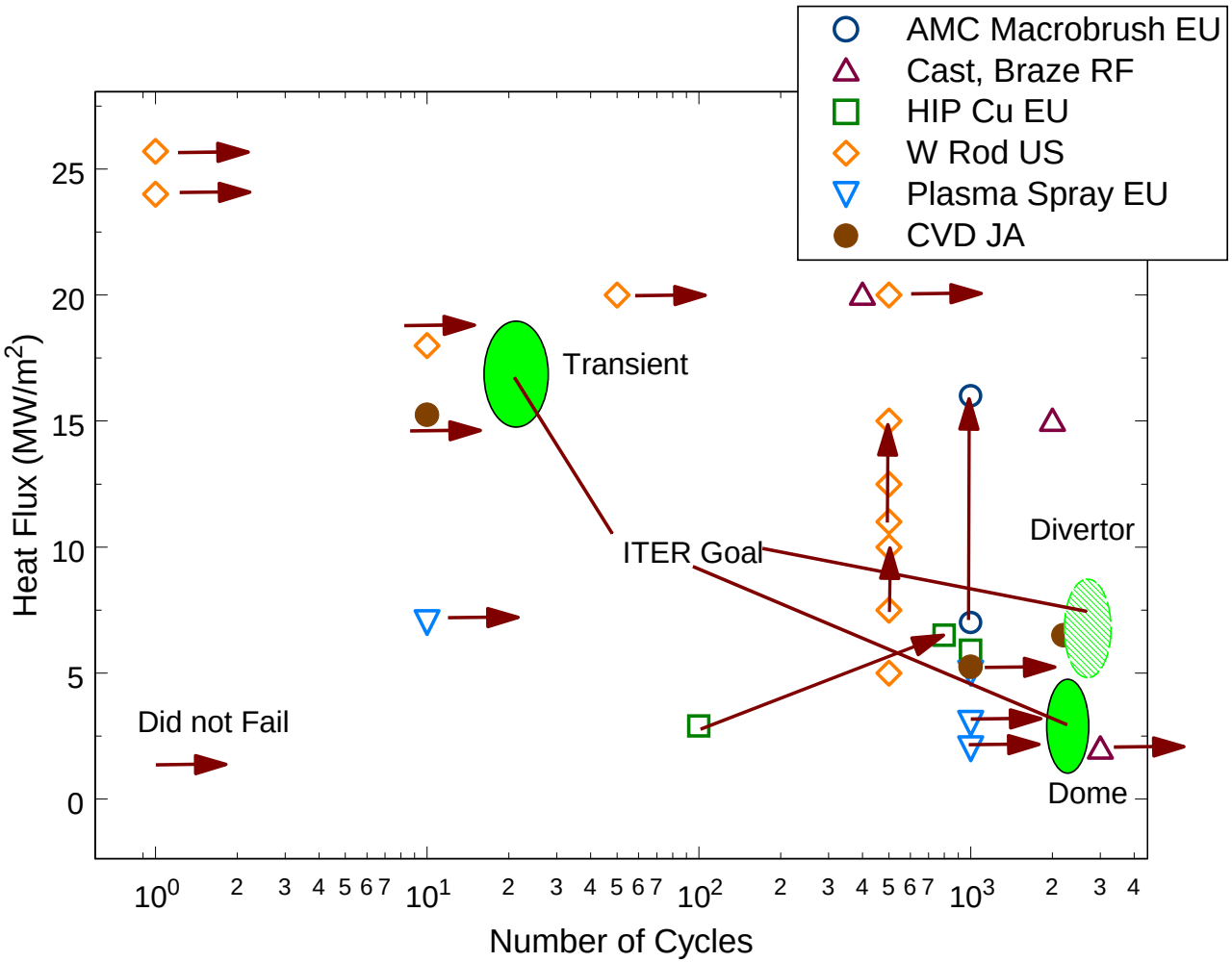
Results of W PFC Testing for ITER



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Other Applications of W Rods As PFCs

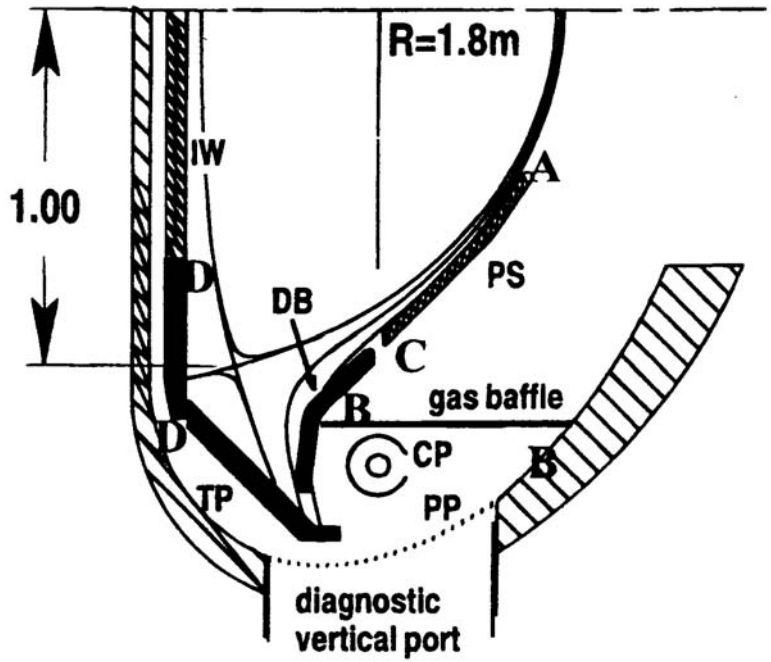
- We designed the divertor for FIRE assuming the use of W rods and a peak heat flux of 9-14 MW/m^2
- We are working with MIT to design a W rod surface for C-MOD (active cooling is not needed an the design uses an Inconel backing for the W rods)

Possible Application on KSTAR

- We propose that the CFC tiles in the KSTAR divertor be replaced by actively cooled W rod modules on a copper alloy substrate
- This would be particularly useful as the pulse length is increased to 300 s and additional heating power is added.
- If all other carbon is removed from the machine, KSTAR would provide a superb simulation of an all metallic ITER PFC option (in case T retention is too large on ITER after initial operation)

Characteristics of the KSTAR Divertor

- Double Null
- Peak Heat Flux 3.5-4.5 MW/m^2
- Duration 20-300 s
- Baseline divertor 3.5 cm thick CFC tiles on a backing plate
- Predicted W operating T
  - 250-520 C depending on the thickness of W and Cu chosen



From Lee, B., et al., Fusion Technol. 37, pp110-123, 2000.

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Issues To Be Resolved

- Access into KSTAR for active water cooling of a W armored divertor
- Eddy current forces would be increased due to the copper alloy heat sink. The increased forces might require strengthening of the mounting points in KSTAR
- A method for accurately installing a new divertor in a potentially activated machine must be found
- Can the first wall be changed to a metal like Be?

Benefits to ITER

- If the results of the initial operation of ITER indicate T retention will be too large, a successful test of W rod PFCs on KSTAR would offer ITER a fully qualified option to the use of C in the divertor.
- Potential problems with starting the plasma with a carbon divertor would be resolved.
- W contamination of the core plasma (if any) would be understood

Possible Collaboration Between the US and Korea

- Conduct a joint design study to examine the possibility of replacing the CFC divertor with an actively cooled W rod Cu alloy heat sink design
  - Attachments
  - Eddy current forces
  - Water cooling access
- Construct prototypes of the proposed design and perform high heat flux testing to confirm performance
- Decide where to fabricate the divertor if the option is acceptable.

Budget Estimates

- The US portion of the cost of the design phase is estimated to be 100-150K$.
- The cost of the testing phase is 50-150 K$ depending on the number of testing cycles.
- The fabrication cost is estimated to be 15±5 M$ based on estimates made for ITER but depends strongly on the details of the design and interface with KSTAR

Conclusions

- KSTAR is in a unique position to provide the final proof that W is a viable option for the divertor in ITER
- The US could assist Korea with the design of a W option for the KSTAR divertor
- Details such as where to manufacture the replacement parts for KSTAR remain to be discussed
- Only modest budgets are needed to take this exciting step