High heat flux experiment on F82H divertor mockup for DEMO

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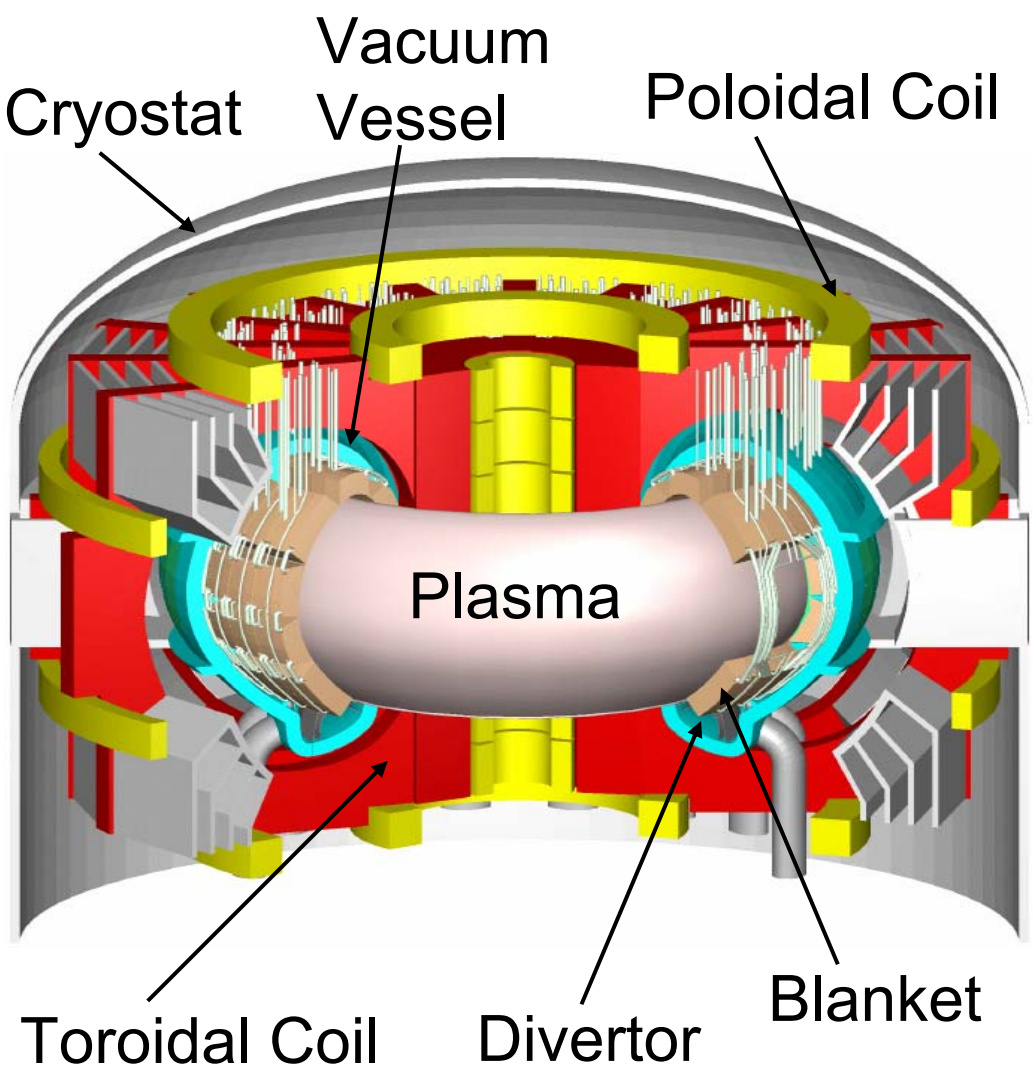
Workshop Agenda

Contents

- DEMO Fusion Plant Design
- Numerical analysis of thermal fatigue experiment
- Experimental results
- Summary
- Latest activity

DEMO Fusion Plant Design in JAERI

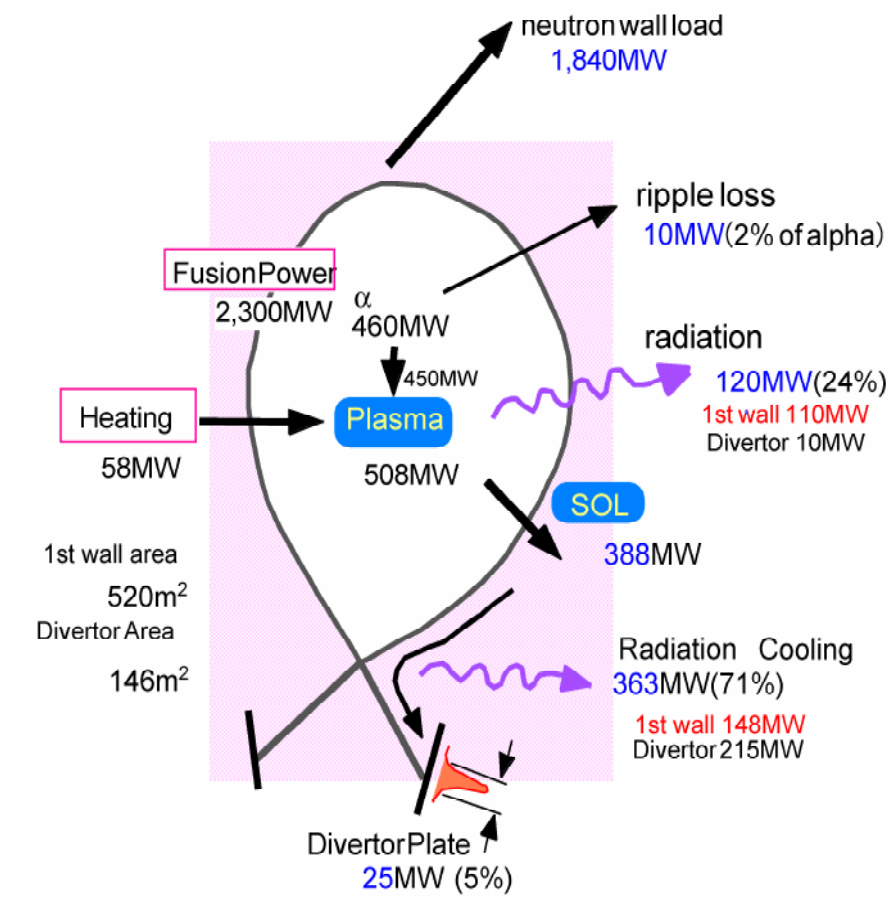


<Design Parameter>

	ITER	DEMO
R/a	6.2/2.0	5.8/1.45
B (T)	5.3	9.5
B_{max} (T)	12-13.5	20
I_p (MA)	15-17	12
P_{fus} (GW)	0.5-0.7	2.3
I_{BS}/I_p	~0.2	0.8
Q	10-20	~40
b_N	~2	~4
Coolant	water 4MPa 100°C	water TBD TBD
PFM	Be/CFC/W	W (If necessary for FW)

Power Flow to the DEMO divertor

Fusion DEMO plant designed by JAERI



[T. Konishi et al. presented at ISFNT6 (2002)]

- Total energy of 250MW will deposit to the divertor in the DEMO plant.
- Heat flux to the divertor plate is about 10 MW/m^2, which is equivalent to the ITER divertor.
- However, materials with high thermal conductivity, such as CFC and copper, cannot be utilized for the DEMO divertor from the neutron irradiation damage point of view.

Material combination of tungsten and RAFs (F82H) is a primary candidate for the DEMO divertor.

R&D issues of F82H for DEMO divertor application

Mechanical behavior at elevated temperature

Creep

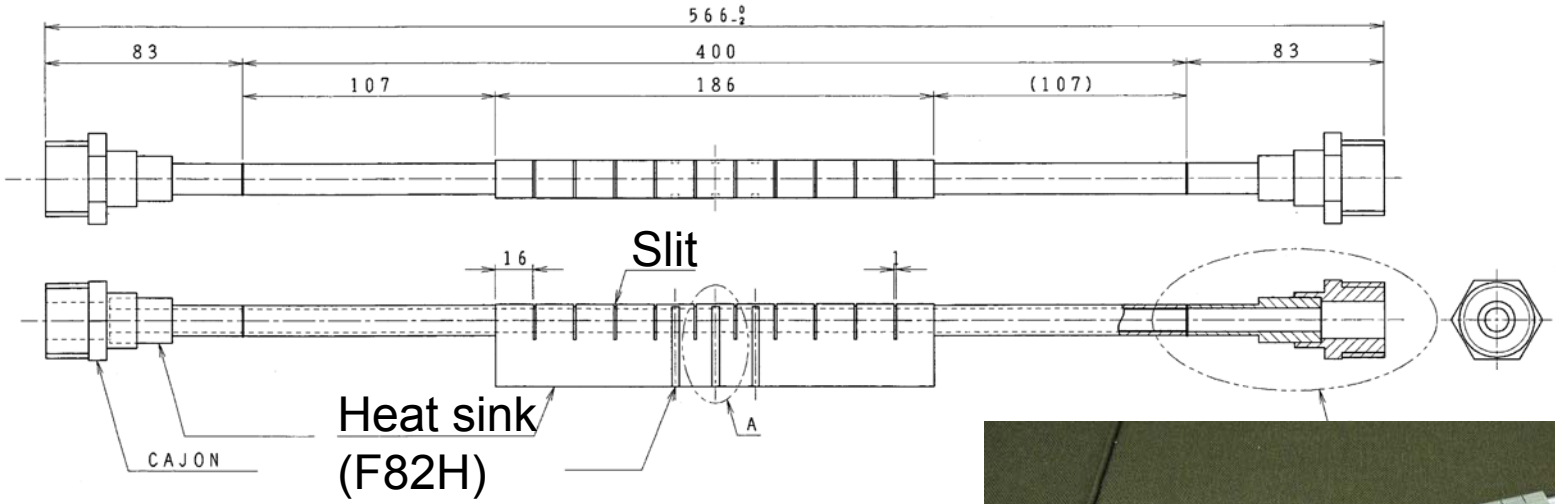
Fatigue (aiming at a component test in ITER for DEMO divertor development)

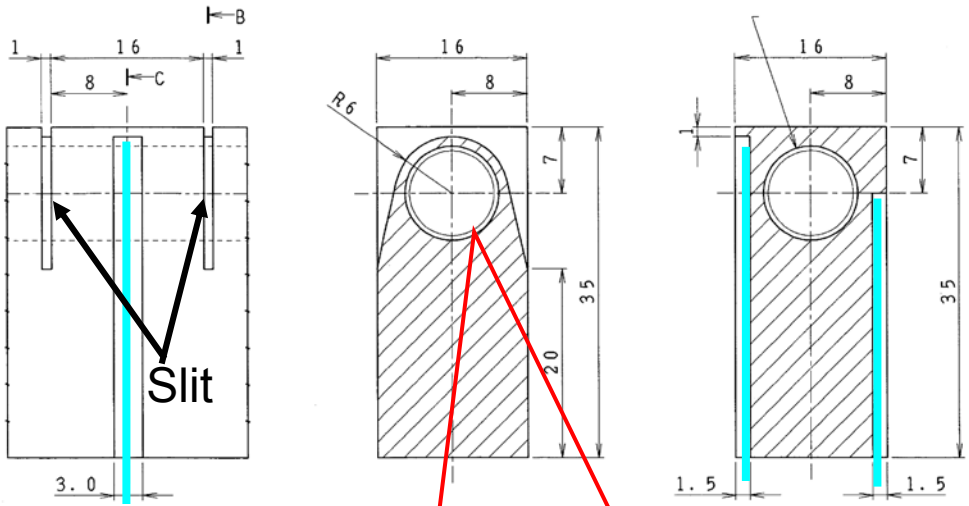
Bonding method for tungsten/F82H joint

Braze

Solid state bond (Diffusion bond, Spark plasma sintering(SPS), etc…)

Divertor mockup for thermal fatigue test





Thermocouple

Screw thread (M10, Pitch 1.5)

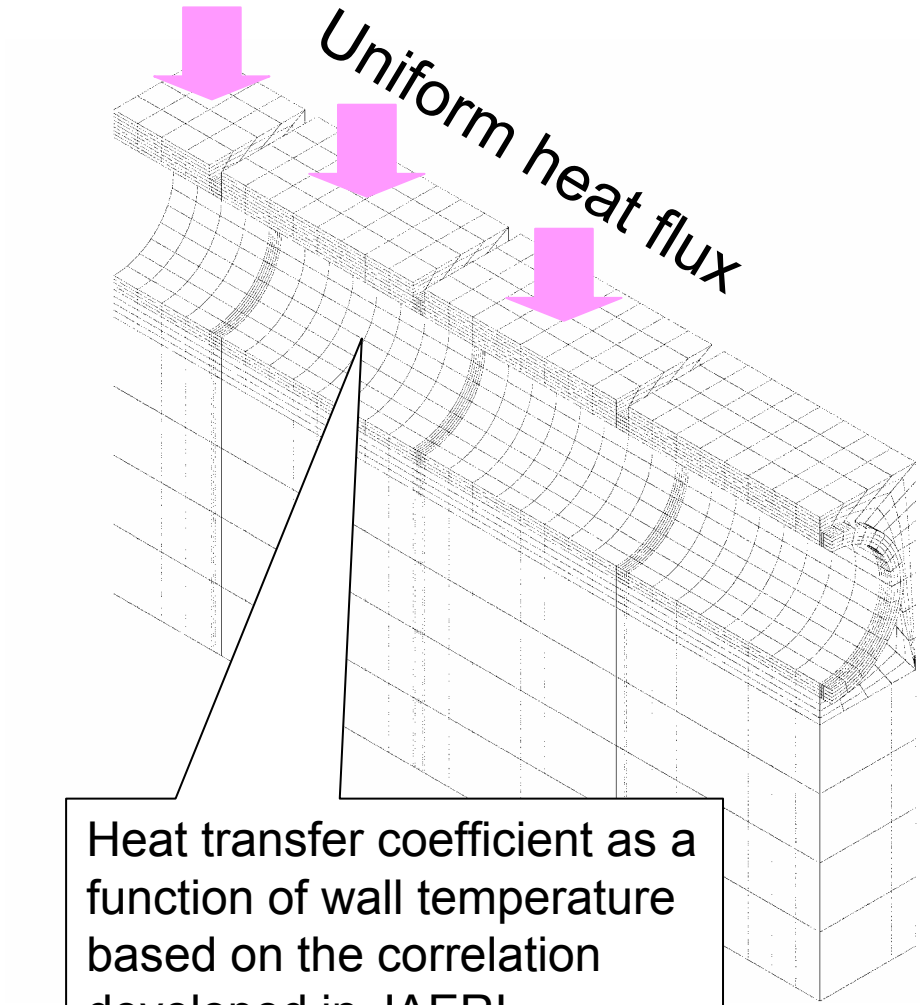
Whole body is a full-scratch-build from a single F82H plate.
(No weld/No braze part)

Rigidity of lower part of the heat sink enhance the stress and strain concentration at the slits.

Thermal and stress analyses

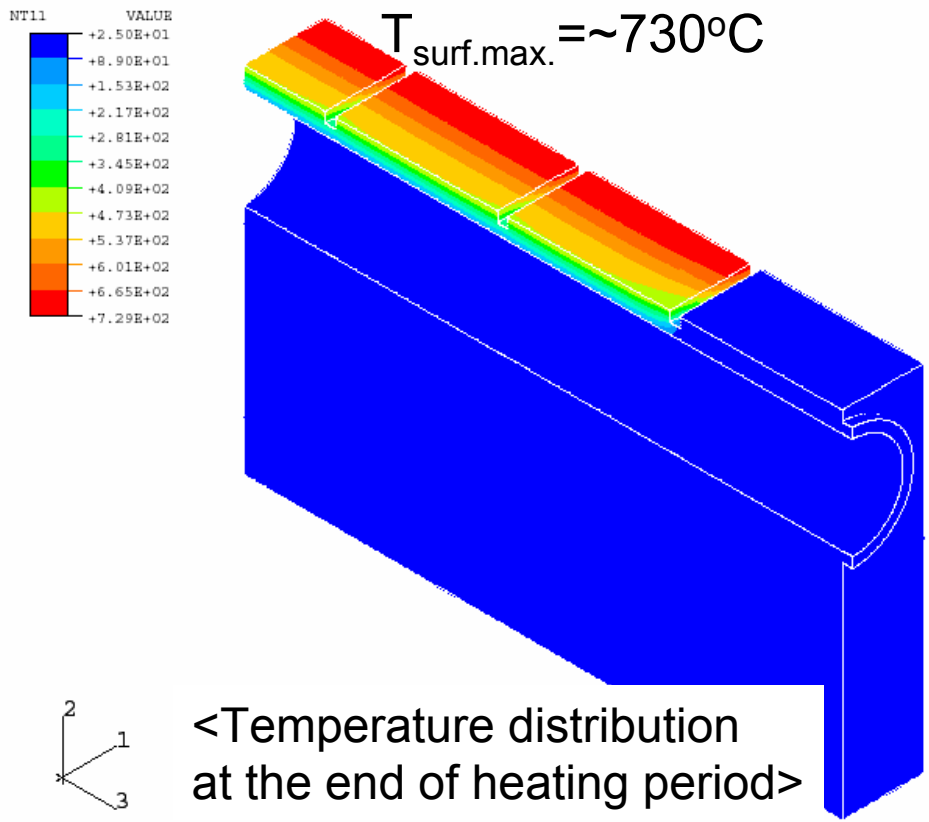
Analytical conditions

- 20 nodes isoparametric element
- Uniform heat flux = 3, 5 MW/m^2
- T_{init} (reference temp.) = 25 ^oC
- Temperature dependent material properties of F82H are taken into account. [JAERI-Tech 97-038 (in Japanese)]
- Three thermal cycles were simulated to stabilize the stress/strain behavior of the mockup in the elastoplastic stress analysis.
- The effect of the screw thread was taken into account as an enhanced heat transfer coefficient in the thermal analysis, but not modeled in the stress analysis.

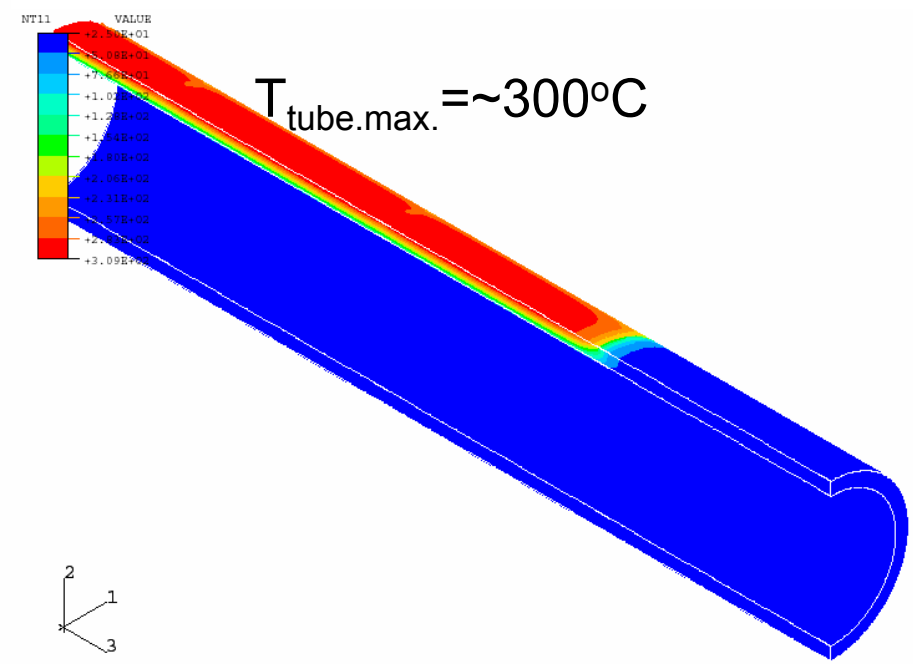


Heat transfer coefficient as a function of wall temperature based on the correlation developed in JAERI
[M. Araki et al., Int. J. Heat Mass Tranfer 39 (14) 1996]

Results of thermal analysis
- @5MW/m^2 -



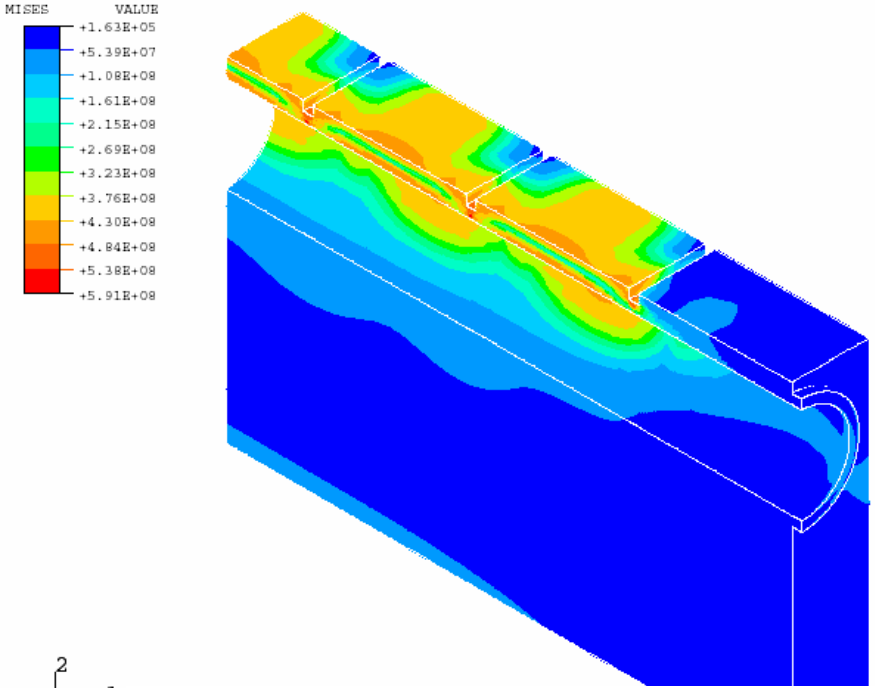
<Temperature distribution at the end of heating period>



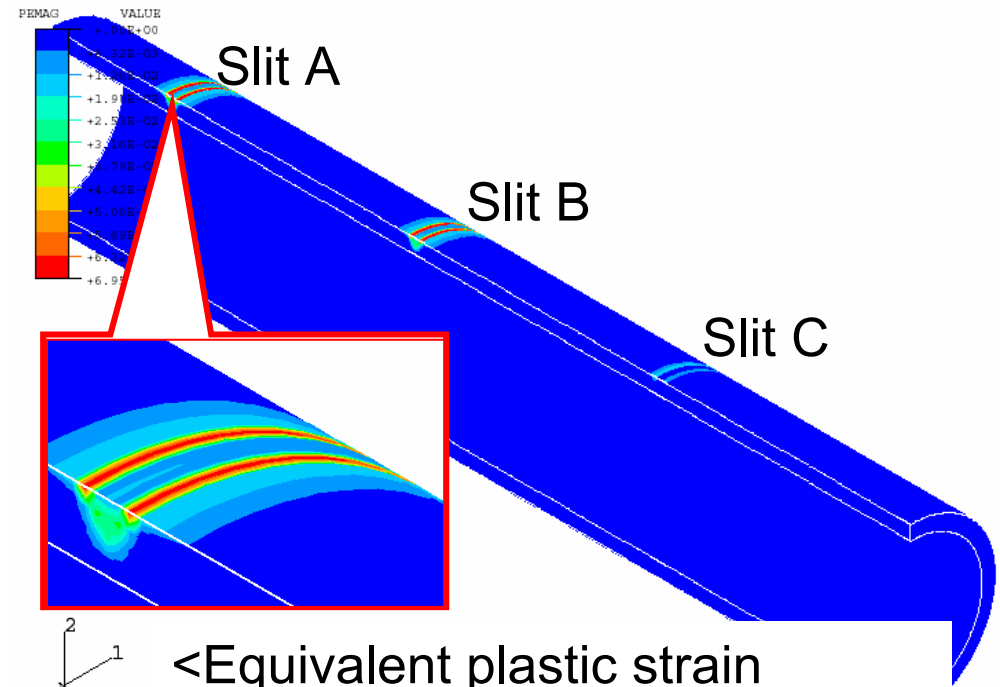
<Close up view of tube region>

- The temperature field reaches steady state within 10 s.
- The maximum temperature exceeds the allowable temperature of F82H (550°C).
- However, the temperature of the tube region is below this limit.

Results of elastoplastic stress analysis 1
- @5MW/m^2 -



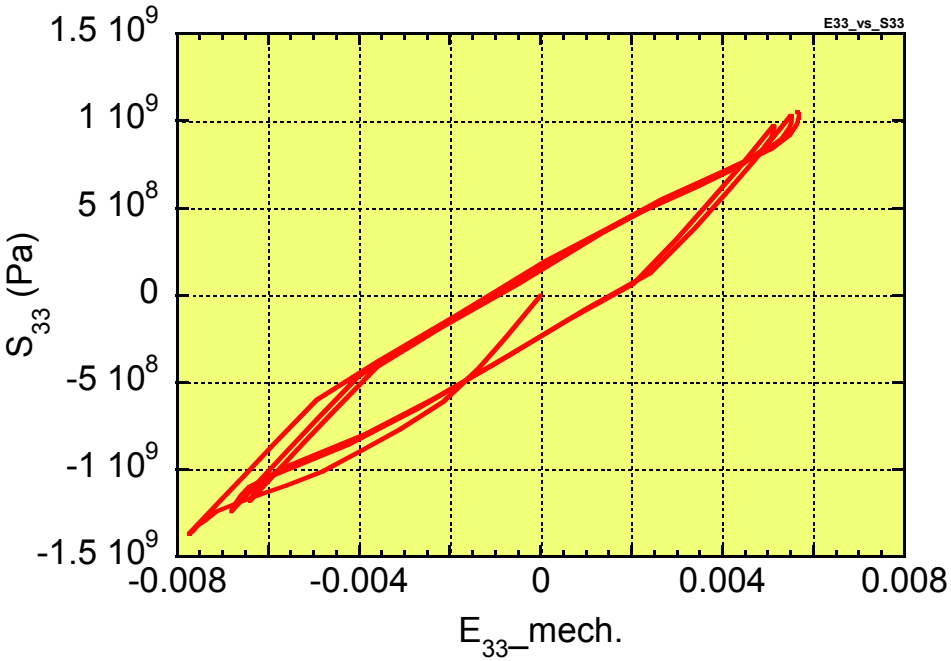
<Mises stress distribution at the end of 3rd heating period>



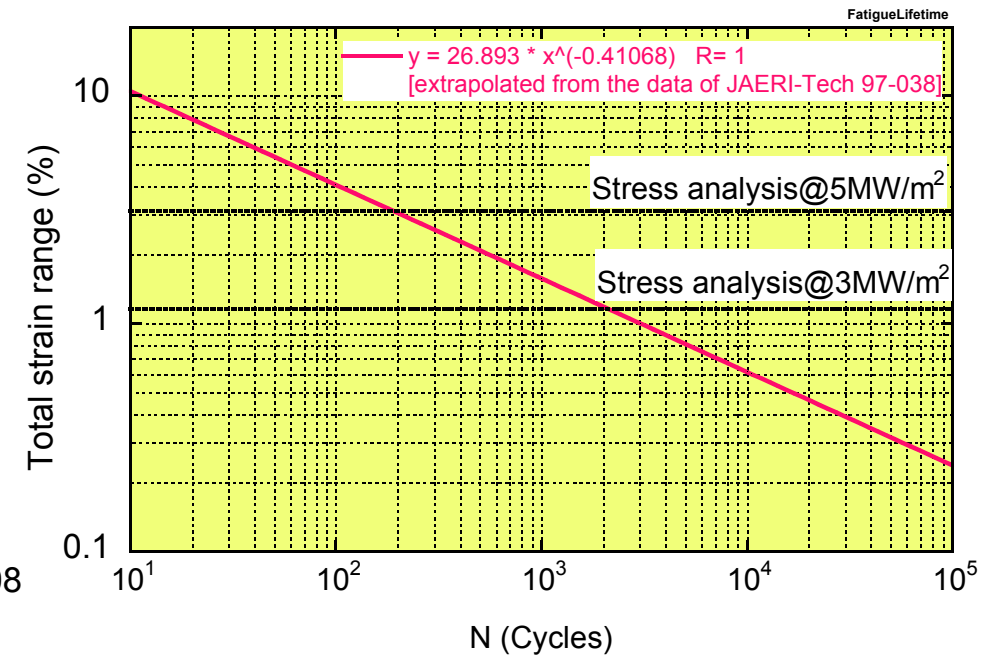
<Equivalent plastic strain distribution of the tube region at the end of 3rd heating period>

- Large stress and strain concentration appeared at the slits.
- Lifetime of the mockup was evaluated using the maximum mechanical strain range of the slit 'A'.

Results of elastoplastic stress analysis 2 - @5MW/m^2 -



<σ_{33} vs ε_{33} of the slit 'A'>

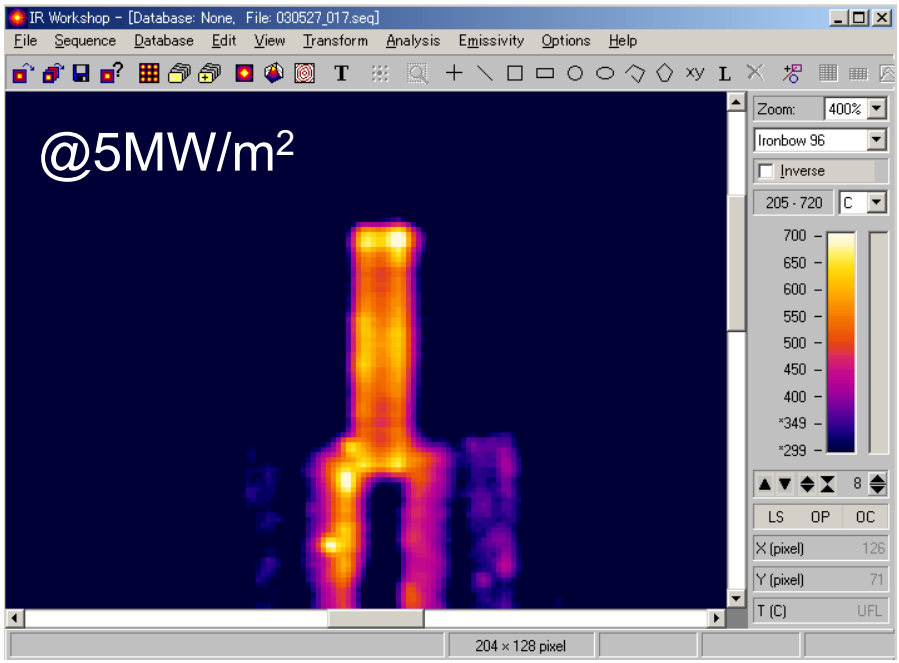


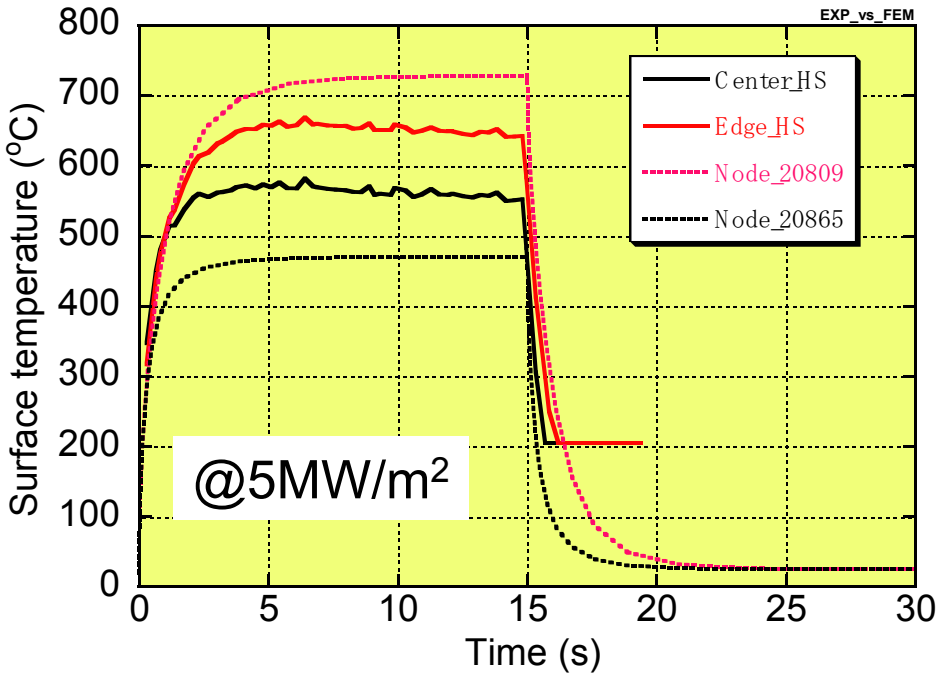
<Fatigue lifetime estimation>

The fatigue lifetime of the mockup is estimated to be 200 cycles at 5 MW/m^2, and 2000 cycles at 3 MW/m^2.

Experiment

- Test facility : JEBIS
- Heat Flux : 3, 5 MW/m^2
- Pulse duration : 15s on/ 15s off
- Coolant : Water at RT



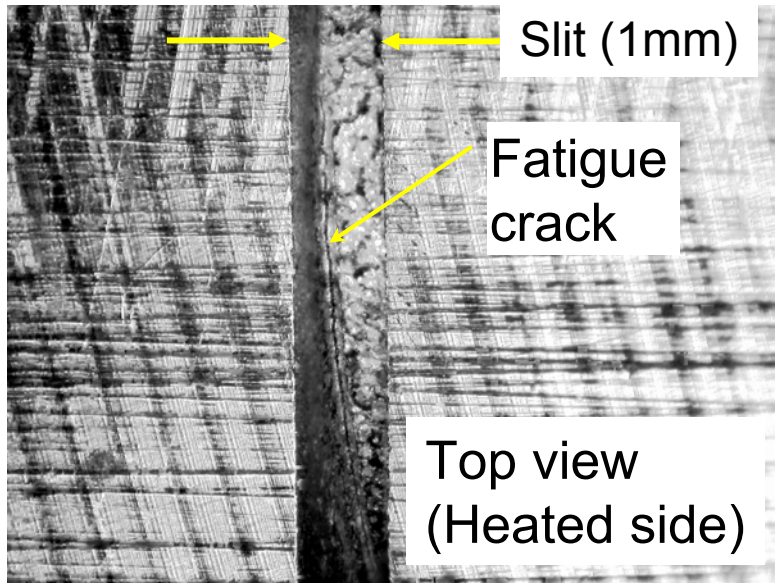


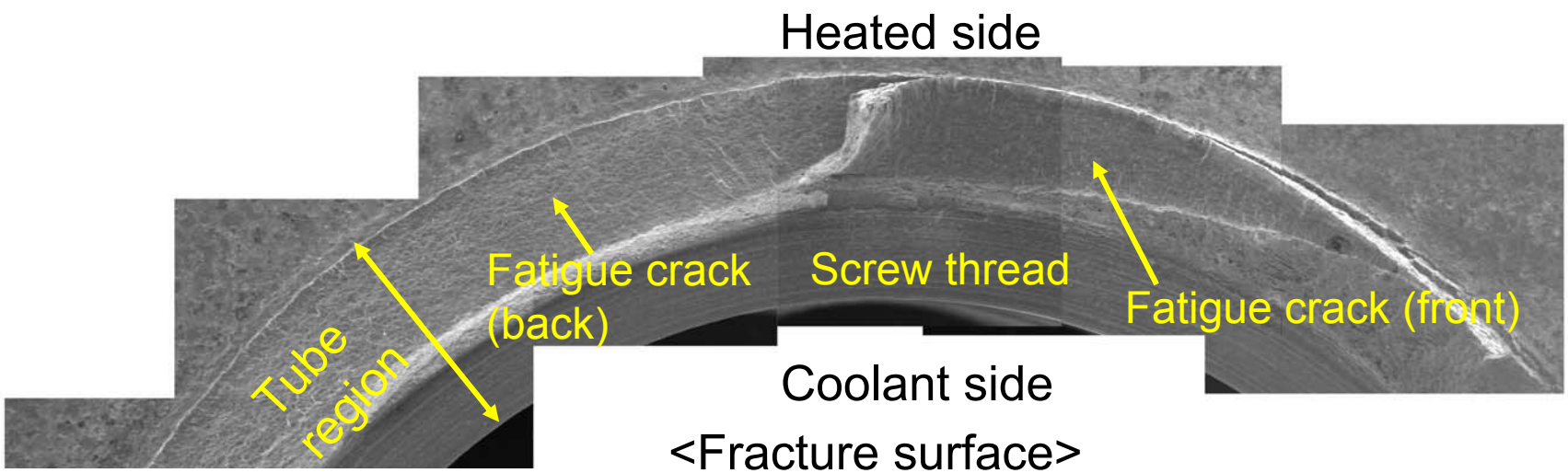
<Typical surface temperature evolution at 5MW/m^2>

Microscopic observation of the fatigue crack 1

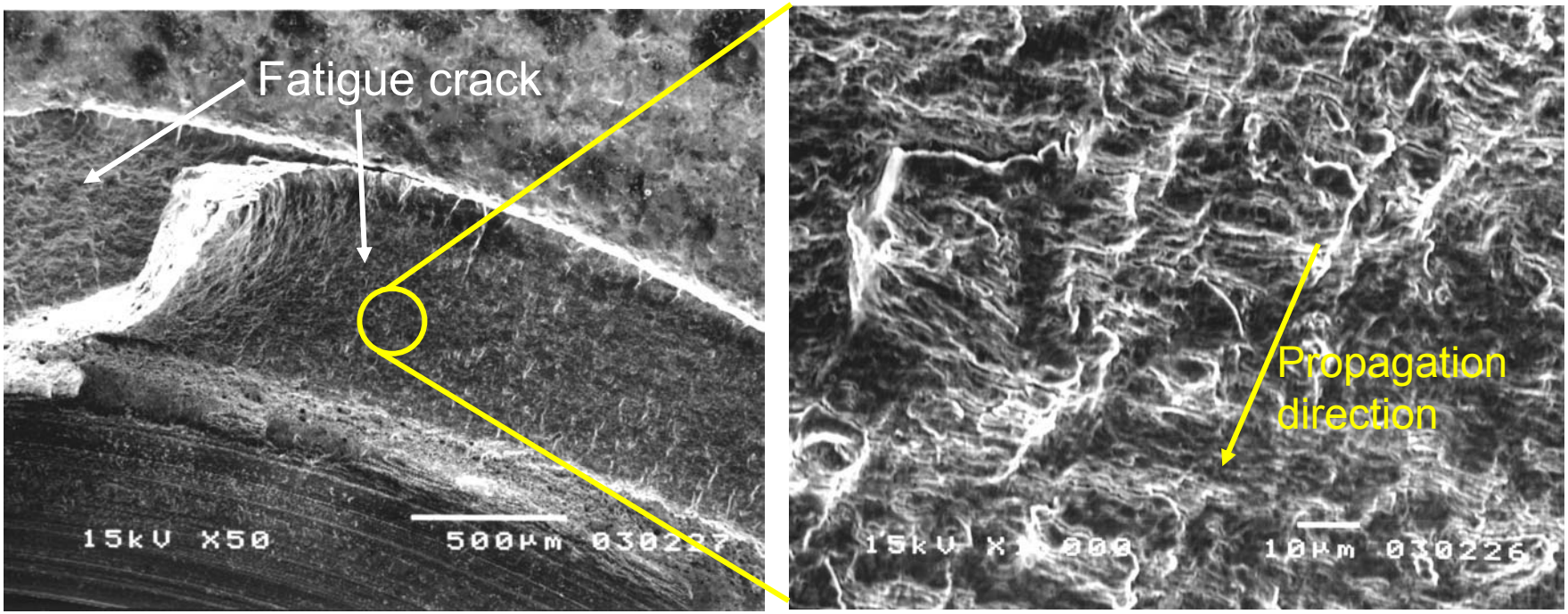
At a heat flux of 5 MW/m^2, the coolant leakage due to fatigue cracking at the slit 'A' occurred at about 650 thermal cycles.

Microscopic observation of the fatigue crack was performed.





Microscopic observation of the fatigue crack 2



The evidence of fatigue crack was clearly observed at the tube region.

The crack propagation rate at the middle of the tube region is ~1μm/cycle.

There are two fatigue cracks initiated from the top surface of the tube region, which follows the result of the elastoplastic analysis.

However, such multi-site cracking occurs stress relaxation at the slit, which may cause the difference of the lifetime between the numerical and the experimental.

Summary

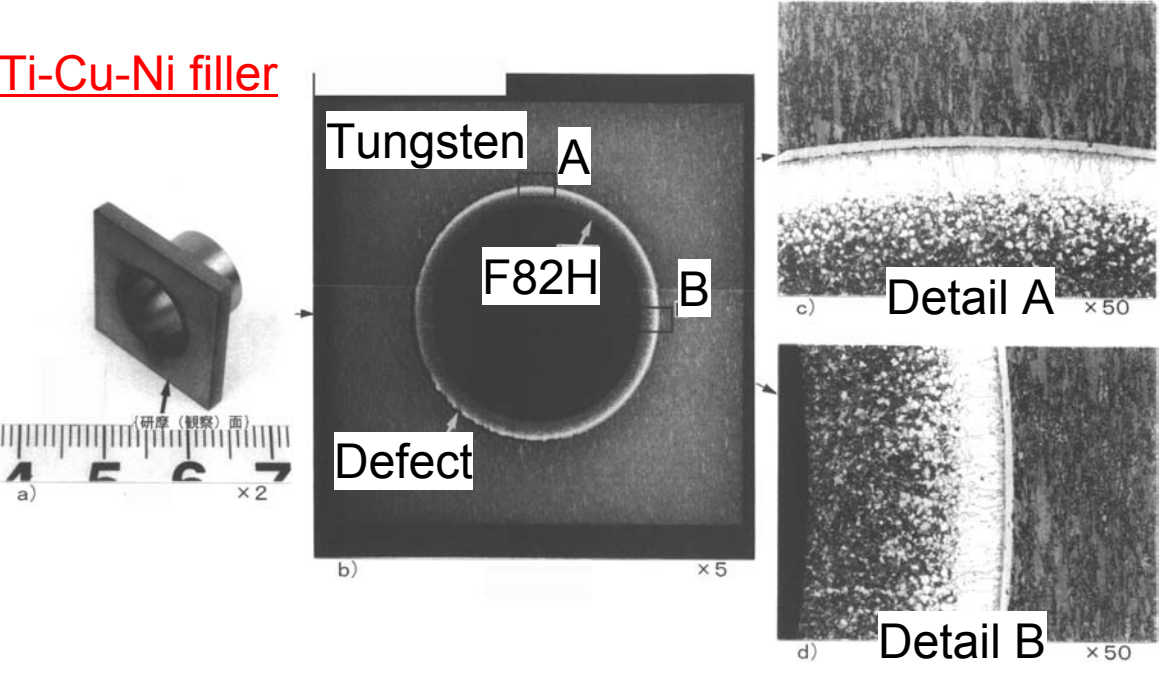
- Thermal fatigue experiment of the F82H divertor mockup was performed in JEBIS at a heat flux of 5MW/m^2.
- Fatigue fracture occurred at about 650 cycles.
- Two cracks were found in a single slit by microscopic observation.
- The location of these cracks is identical with the predicted from the numerical analysis.
- These cracks propagated from the outer surface of the tube region, which means that the screw thread has little effect on the fatigue crack propagation of the mockup.
- The estimated lifetime from the numerical analysis shows 3 times longer than the experimental, which may be caused by the multi-site cracking in a single slit. However, more thermal fatigue data are essential to establish the lifetime evaluation method for the F82H divertor.

Latest activity

- The maximum temperature of F82H part at 10 MW/m^2 should be less than 550 ^{o}C, which cannot be achieved in a flat tile design.
  → Monoblock-shaped divertor is promising.

- To develop monoblock armored divertor mockup, bonding test for F82H/tungsten joint is necessary.

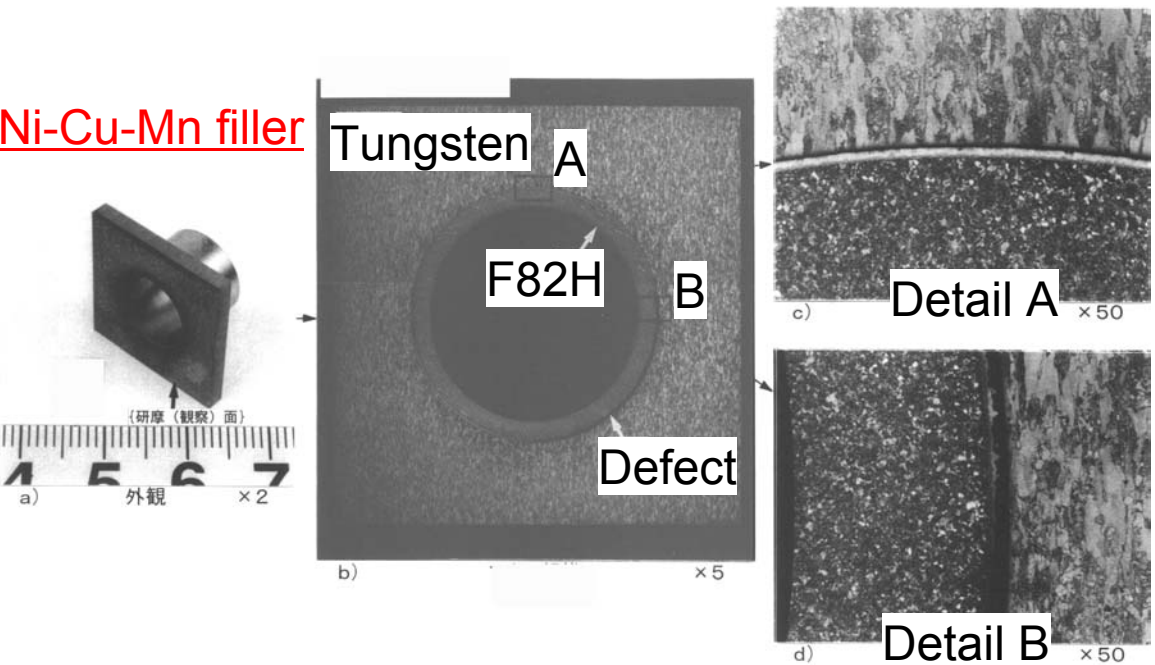
Ti-Cu-Ni filler



- Filler thickness : 0.05mm
- Hold temp. : 960°C, 10min

Some braze defect due to lack of braze material appeared around the braze interface. Ferrite phase (white region in 'Detail A' and 'Detail B') appeared in the F82H tube, which may be caused by decarburization of F82H.

Ni-Cu-Mn filler



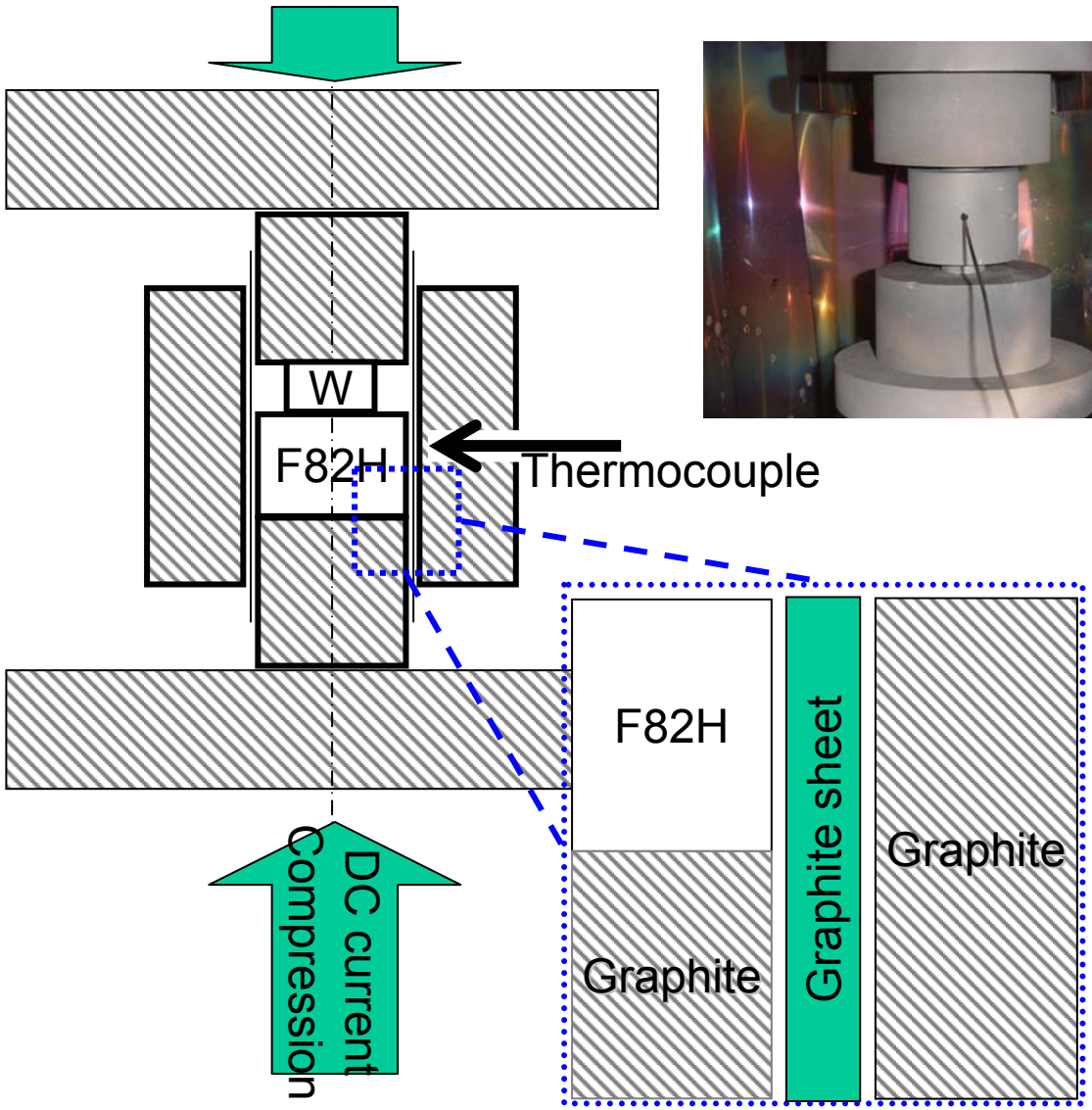
- Filler thickness : 0.05mm
- Hold temp. : 960°C, 10min

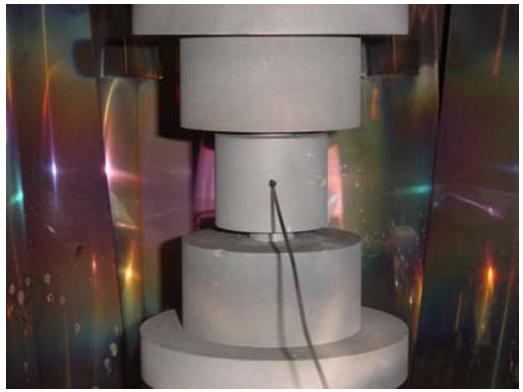
Some braze defect due to lack of braze material appeared around the braze interface.
No ferrite phase appeared.

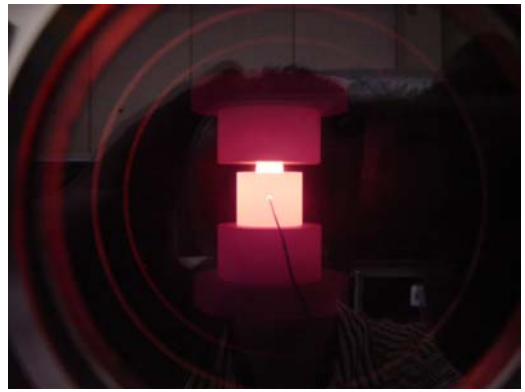
⬇

Monoblock divertor mockup is going to be manufactured using Ni-Cu-Mn braze.

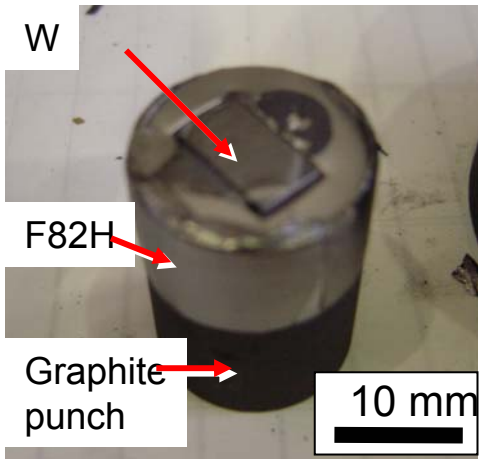
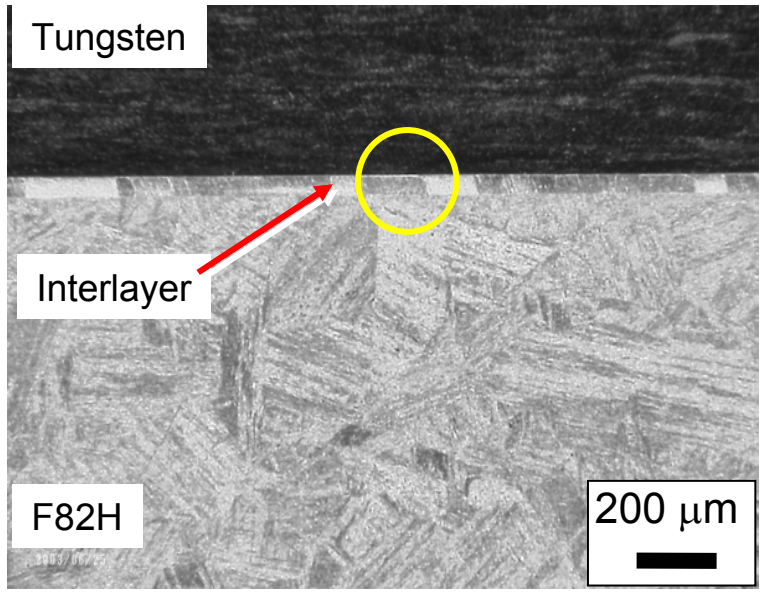
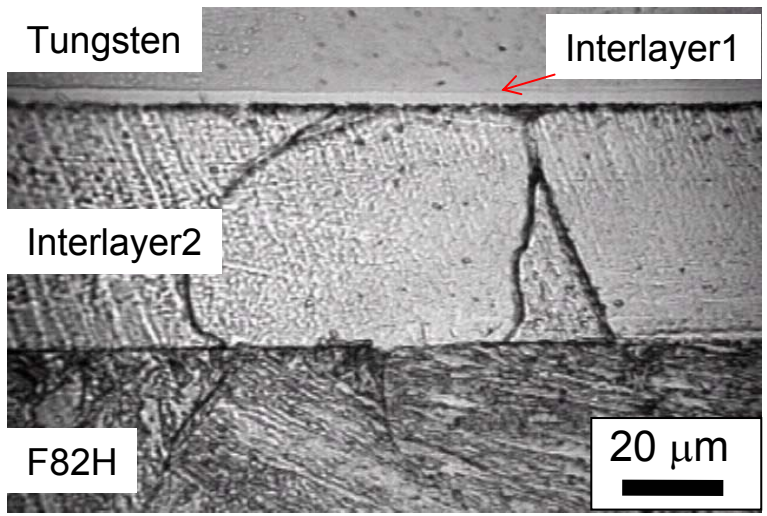
Spark-Plasma-Sintering (SPS)







SPS sintering condition

Temp. :	950℃
Stress :	20MPa
Time :	1800s
Current:	~1000A
Voltage:	~3V
Vacuum:	~15Pa

F82H/W SPS joint