Thermal and mechanical analyses supporting the defects acceptance criteria definition for the ITER first wall

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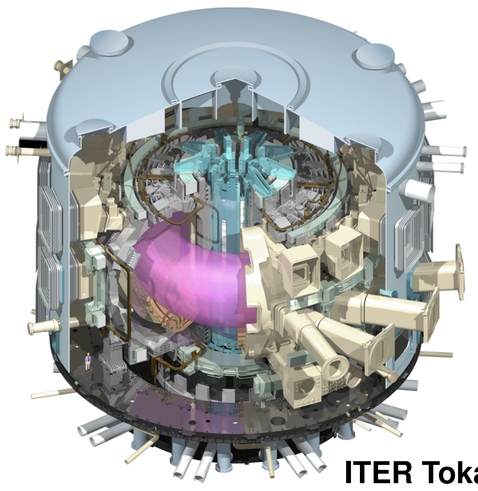
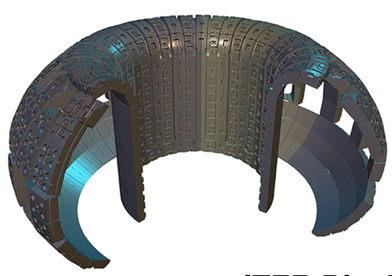
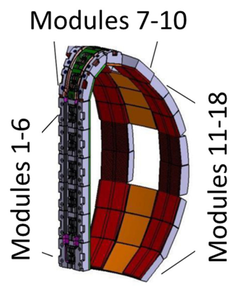
Overview and Context

- ITER Blanket System is one of the most challenging systems in ITER
- This poster aims to present the status of the models and analyses developed to support, in cooperation with experimental tests, the FW bond acceptance criteria definition
- Thermal and mechanical analyses have been performed using 3D and 2D models based on a section of the plasma facing component



ITER Tokamak



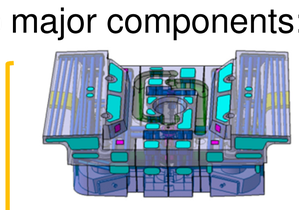


ITER Blanket System

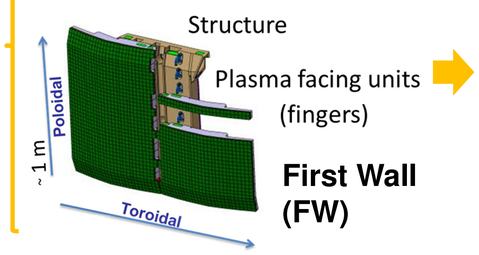
ITER Blanket System

FUNCTIONS
- Contribute in absorbing radiation and particle heat fluxes from the plasma
- Shielding → less heat and neutron loads in vacuum vessel and coils
- Plasma-facing surface (low influx of impurities to the plasma)
- Provide limiting surfaces during startup and shutdown

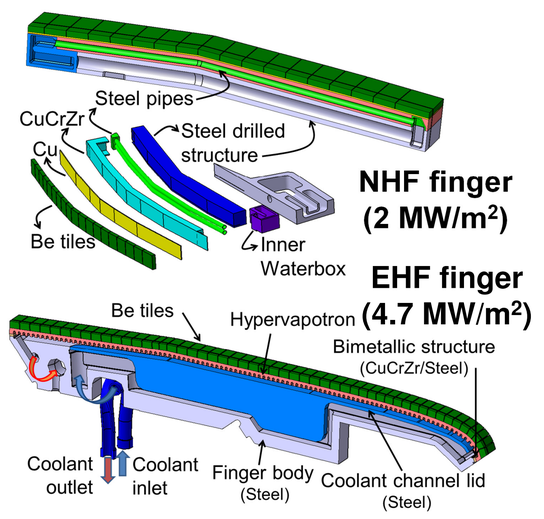
DESIGN
- Blanket system consists of 440 Blanket Modules (BM). It covers ~600m^2
- Maximum total thermal load: 736 MW
- Maximum allowable mass per module: 4.5 tons
- Two major components: FW & SB



Shield Block (SB)



First Wall (FW)

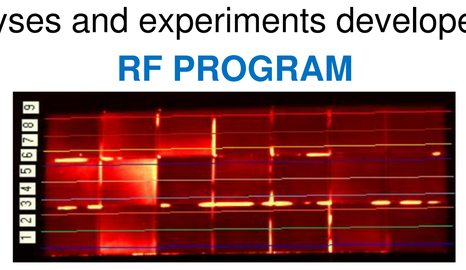


FW bond acceptance criteria: R&D activities

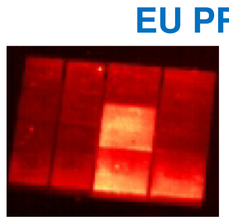
- **FW Beryllium armor** → Surface facing the plasma is arranged with tiles made of beryllium, a light metal, for controlling plasma contamination
- **Beryllium tiles** → Bonded to a water cooled CuCrZr heat sink → Manufacturing is delicate → Bonding defects may occur (local absence of contact)
- **Defect acceptance criteria definition** → Methodology that would define the defect size that would be acceptable to operation. This is done by a combination of analyses and experiments developed in collaboration between ITER and procuring DAs (Russia-RF, Europe-EU, China-CN)

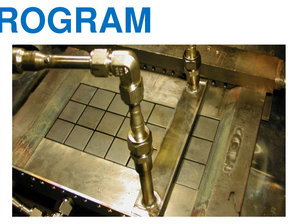
Some examples of mock-ups and IR analysis

RF PROGRAM

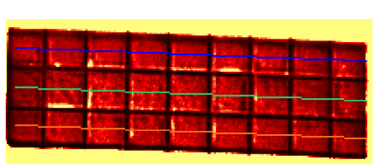


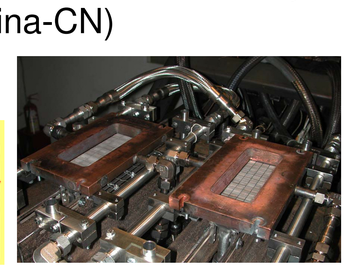
EU PROGRAM





CN PROGRAM

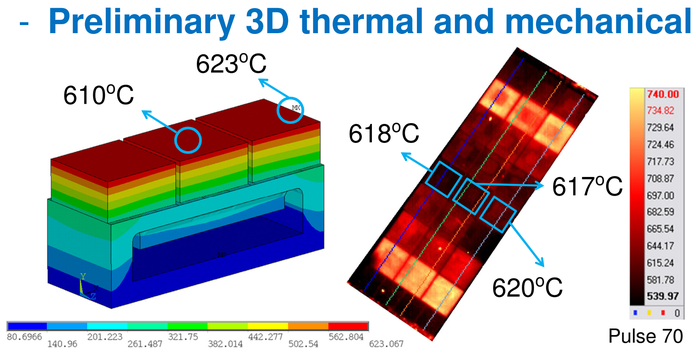


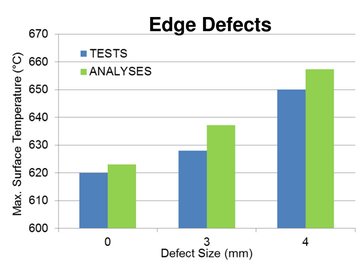


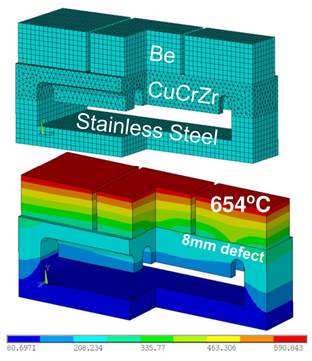
- **Experimental activity** → Tests performed by electron beam heating gun on mock-ups Be tiles → Several cases of debonding were found (detected by overheating with IR) → An important effort improving the manufacturing has been done → Analyses can help on the understanding and optimisation

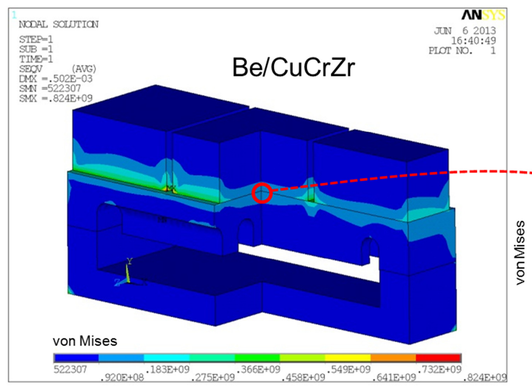
Analyses supporting the experimental activities

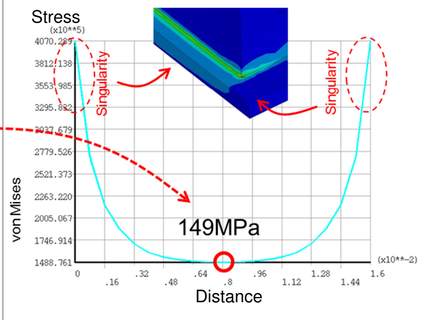
- **Preliminary 3D thermal and mechanical analyses:**



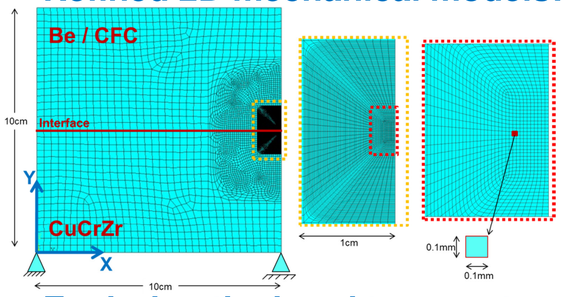


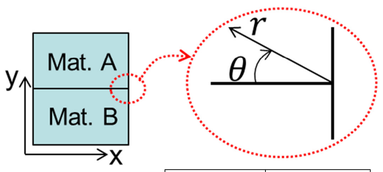






- **Refined 2D mechanical models: singularity and elasto-plastic analyses:**





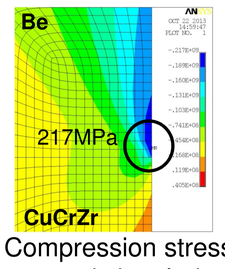
$$\sigma(r,\theta) = \frac{K}{\left(\frac{r}{L}\right)^{\alpha}} \cdot f(\theta) + \sigma_0(\theta)$$

L: Characteristic length
α: Stress singularity
K: Stress intensity factor
$\sigma_0(\theta)$: Function dependent on loading
$f(\theta)$: Function dependent on geometry

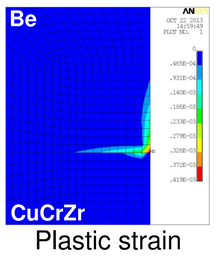
$$\sigma(x) = K \cdot x^{-\alpha}$$ → Simplified version applied to the interface

	Be_{tile}	CFC_{tile}
K_{Shear} (MPa)	6.7	40.3
$K_{X\text{-comp.}}$ (MPa)	101.3	140.5
$K_{Y\text{-comp.}}$ (MPa)	3.1	7.4

Lower stress concentration in case of Be tiles

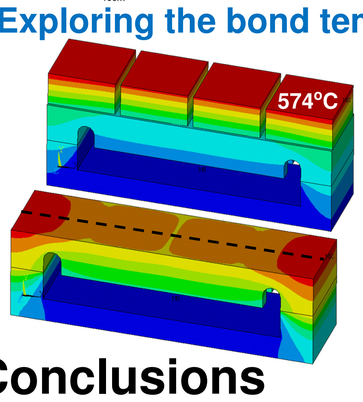


Compression stress around singularity

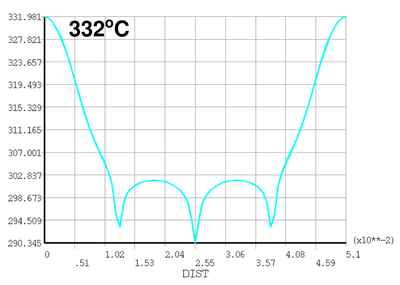


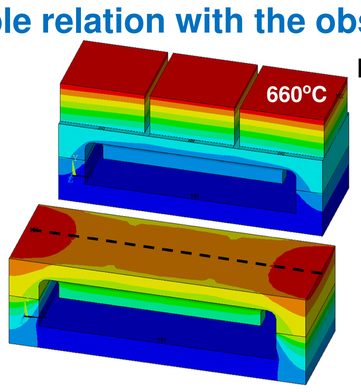
Plastic strain (located only close to singularity)

- **Exploring the bond temperature and its possible relation with the observed bond behavior:**

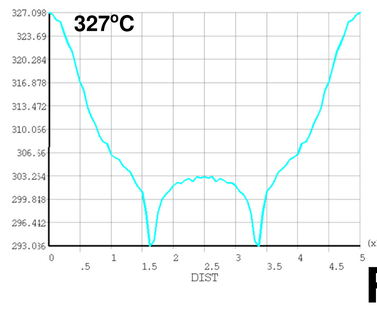


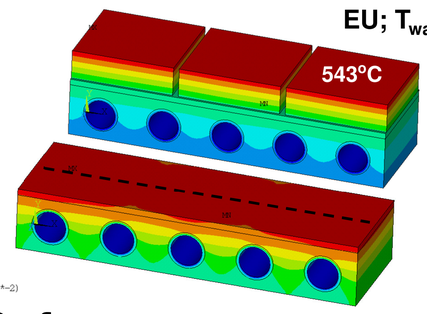
CN; T_{water}=152ºC; 4.7MW/m^2



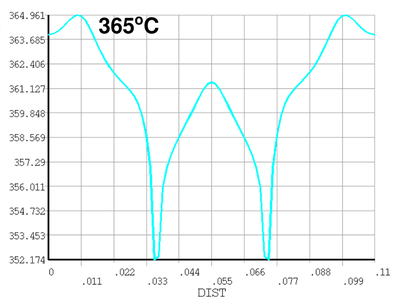


RF; T_{water}=160ºC; 4.7MW/m^2





EU; T_{water}=160ºC; 2MW/m^2



Conclusions

- **The thermal model** → Reproduces accurately the thermal behaviour observed in tests
- **Analysis of the singularity** → Helps to interpret the bond performance
- **Elasto-plastic analysis** → Local plastification is detected at the singularity area
- **Bond temperature analysis** → Clarifies its influence on the general bond behavior

References

1. A.R. Raffray, M. Merola, "Overview of the design and R&D of the ITER blanket system", Fusion Engineering and Design, 2012
2. R. Mitteau, "The design of the ITER first wall panels", Fusion Engineering and Design, 2013
3. B. Bellin, "High heat flux testing of normal heat flux wall mock-ups with calibrated defects", ISFNT Conference, 2013

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

Acknowledgement: The authors are grateful to their colleagues in the ITER Blanket Section and to all external experts in the ITER parties.

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2nd - 4th December 2013

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