Fatigue Lifetime and Power Handling Capability of Actively Cooled Plasma Facing Components for ITER Divertor

Presented by **M. Missirlian***

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Outline

- **Context**
- **Main Features of Tested Components**
- **Testing Procedure / Aim**
- **Qualification of Manufacturing**
- **Damage Valuation *after* Thermal Fatigue Testing**
- **Summary & Conclusion**

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Context

ITER REQUIREMENT *(normal operation)*

- **Phase 1: "Mixed CFC / W"**

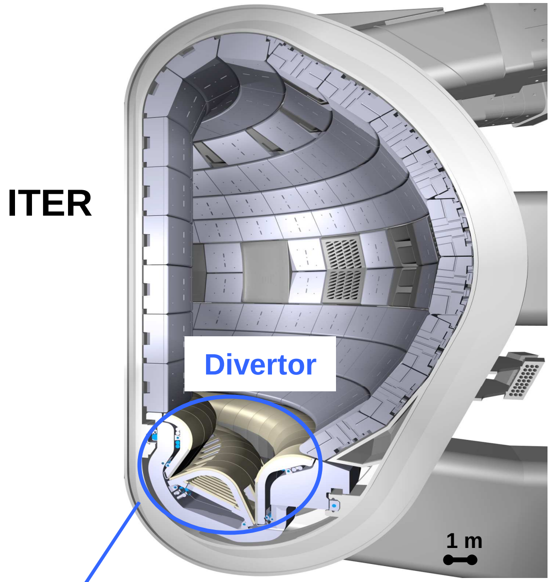
Target *(strike-point region)* / **CFC armour**:
10 MW/m² steady state, 3000 pulses;
20 MW/m² during 10 seconds, 300 pulses

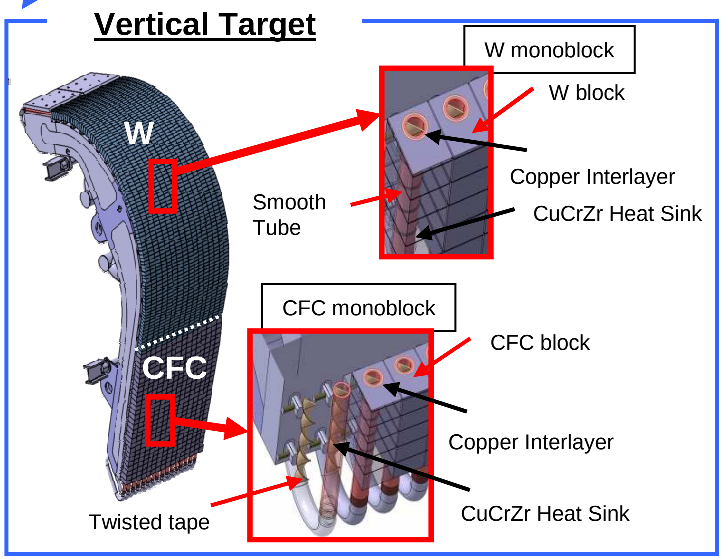
Target *(baffle region)* / **W armour**:
5 MW/m² steady state, 3000 pulses
10 MW/m² during 2 seconds, 300 pulses

⇩

- **Phase 2: "Full W"**

↳ *W up to 20 MW/m² in steady state !*





Next *(near-term)* **Step**

- Qualification of different grades CFC/W (Phase 1)
- Minimize the manufacturing risk/cost during the series production (Phase 1)
  - ↳ Develop and qualify a *(reliable)* **"Repairing process"**
- Assessment of **consolidated technology CFC/W** (Phase 1 & 2)
  - ↳ Manufacturing quality/reproducibility;
  - ↳ Performance under thermal fatigue (Strike-point region)
- Investigation about combined effects (Phase 1 & 2)
  - ↳ Stationary Heat Loads + Transient Elms + Neutron Irradiation

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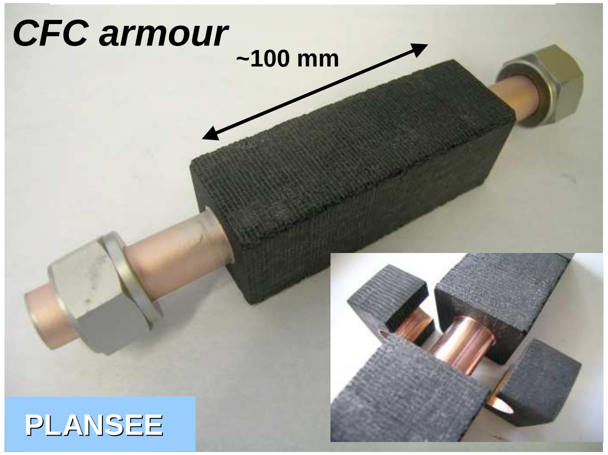
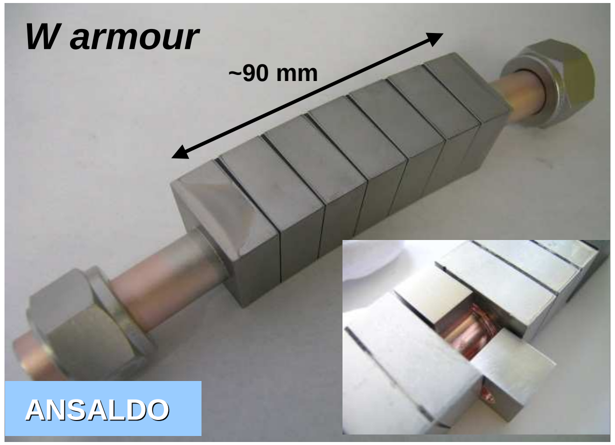
Main Features of Tested Components (1/2)

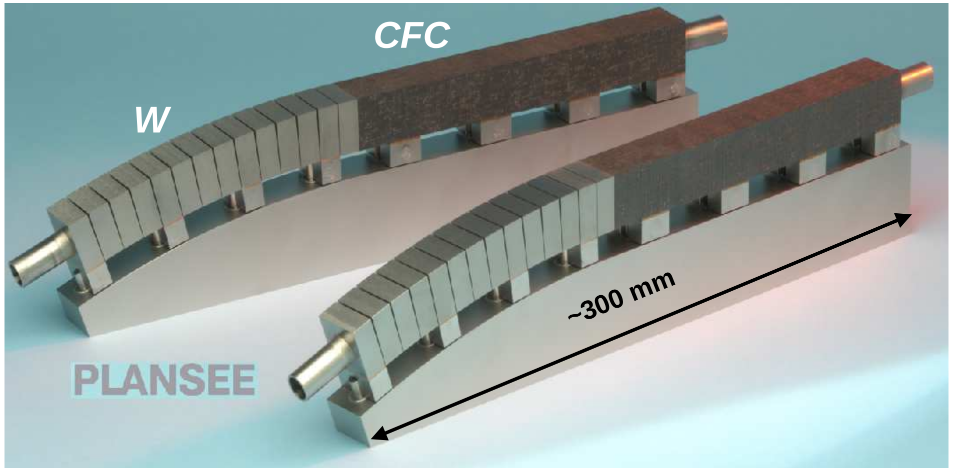
CFC or W Components
(small-scale)





- ***8 components Plansee***
- ***8 components Ansaldo***

Vertical Target Prototypes
(medium scale)



- ***2 components Plansee***
- ***1 component Ansaldo***

ITER GEOMETRY

- **19 Components** *(~70 CFC and ~95 W monoblock tiles)*
- **12 CFC/*W* *'repaired'* tiles distributed out 11 components**

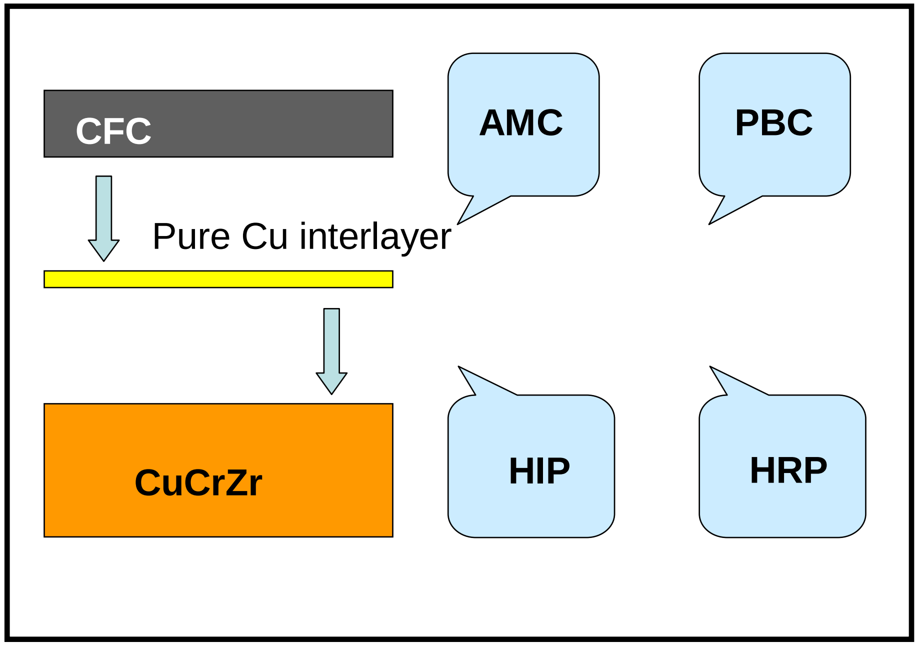
Additional step of bonding for repairing process

Main Features of Tested Components (2/2)

Materials and Armour to Heat sink bonding Technology

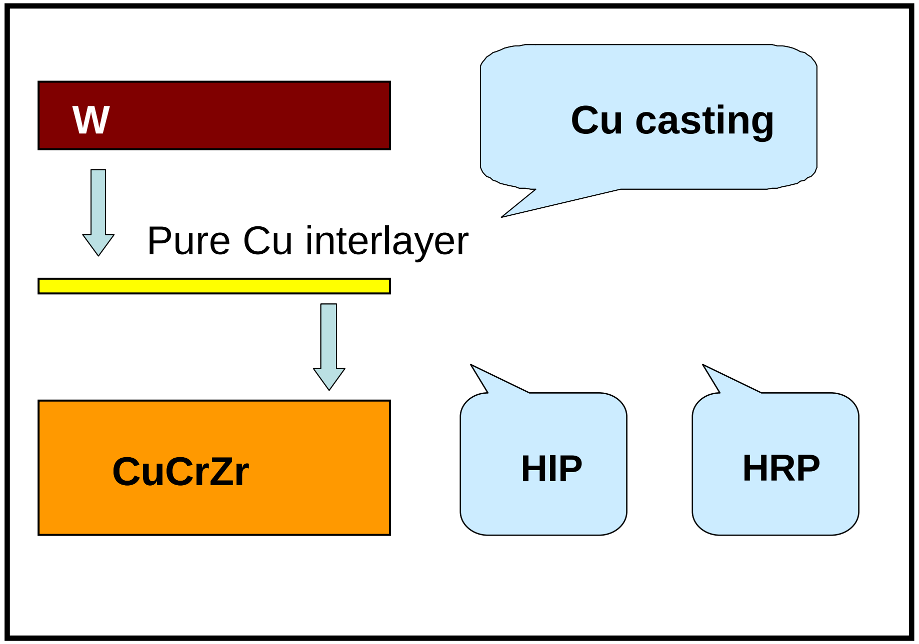
- **CFC**

	Plansee	**Ansaldo**
	SNECMA NB41	**SNECMA NB41** *or* **NB31**



- **TUNGSTEN**

	Plansee	**Ansaldo**
	Pure W (rod)	**Pure W (sheet plate)**



AMC® *: Active Metal Casting*

PBC® *: Pre-Brazed Casting*

HIP® *: Hot Isostatic Pressing*

HRP® *: Hot Radial Pressing*

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Testing Procedure / Aim (1/2)

Testing Procedure

Pre-examination: Visual and IR thermography
(SATIR Facility, Cadarache)

FE200 Facilty *(Le Creusot, France)*

Initial thermal mapping at 5 MW/m²

Thermal Cycling **up to 20 MW/m²**

Final thermal mapping at 5 MW/m²

Post-examination: Visual and IR thermography
(SATIR Facility, Cadarache)

Metallographic *(Post-mortem)* examination

Aim

***'Monoblock'* Concept** *(CFC/W armour)*

- Recent/Consolidated Technologies
- Repairing process *(series production)*

Qualification of Manufacturing

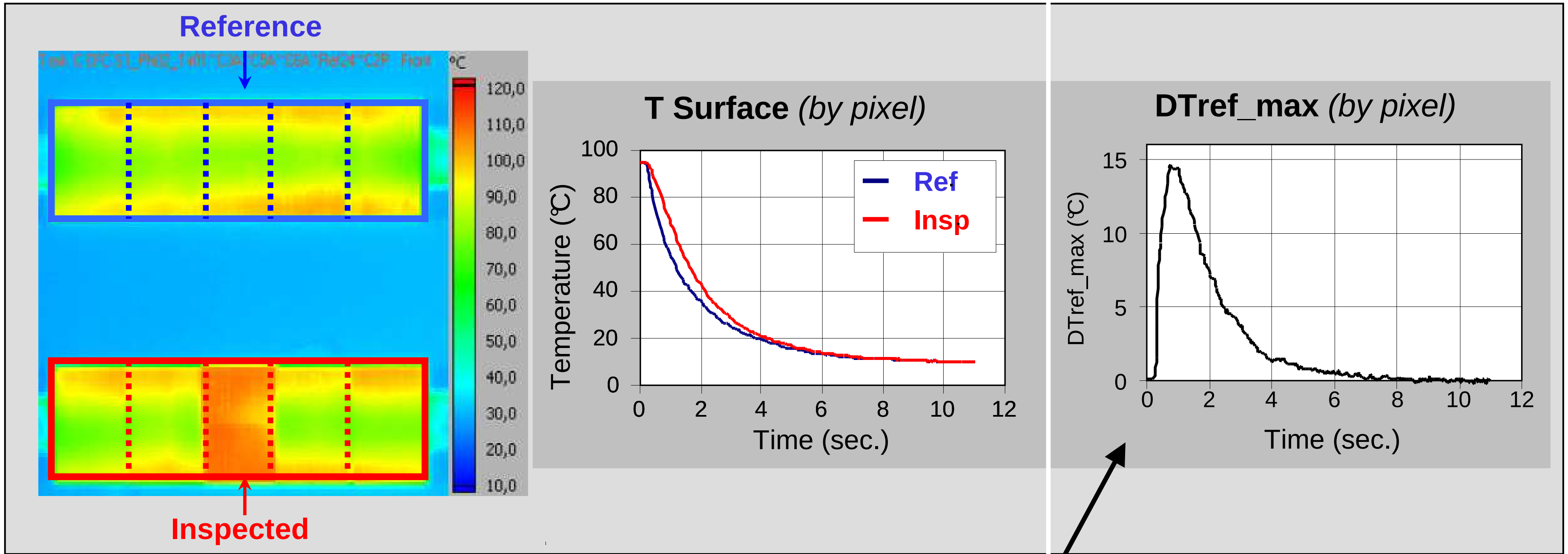
Assessment of Fatigue Lifetime

Damage valuation
***after* Thermal Fatigue**

Testing Procedure / Aim (2/2)

Control of Heat Transfer Capability of PFCs by Integrated NDT
(**SATIR**: Infra Red Acquisition and Data Processing Device)

- Principle : Infra-Red transient monitoring during hot/cold (100℃/5℃) water shock :
Low heat transfer capability is detected by a slower temperature surface response



Ref. *A. Durocher (SOFT-2008)*

- Output of the SATIR Control : Cartography of quantitative criteria DTref_max

↳ Inspection of each face *(front, right, left)* of each monoblock tile of each component !

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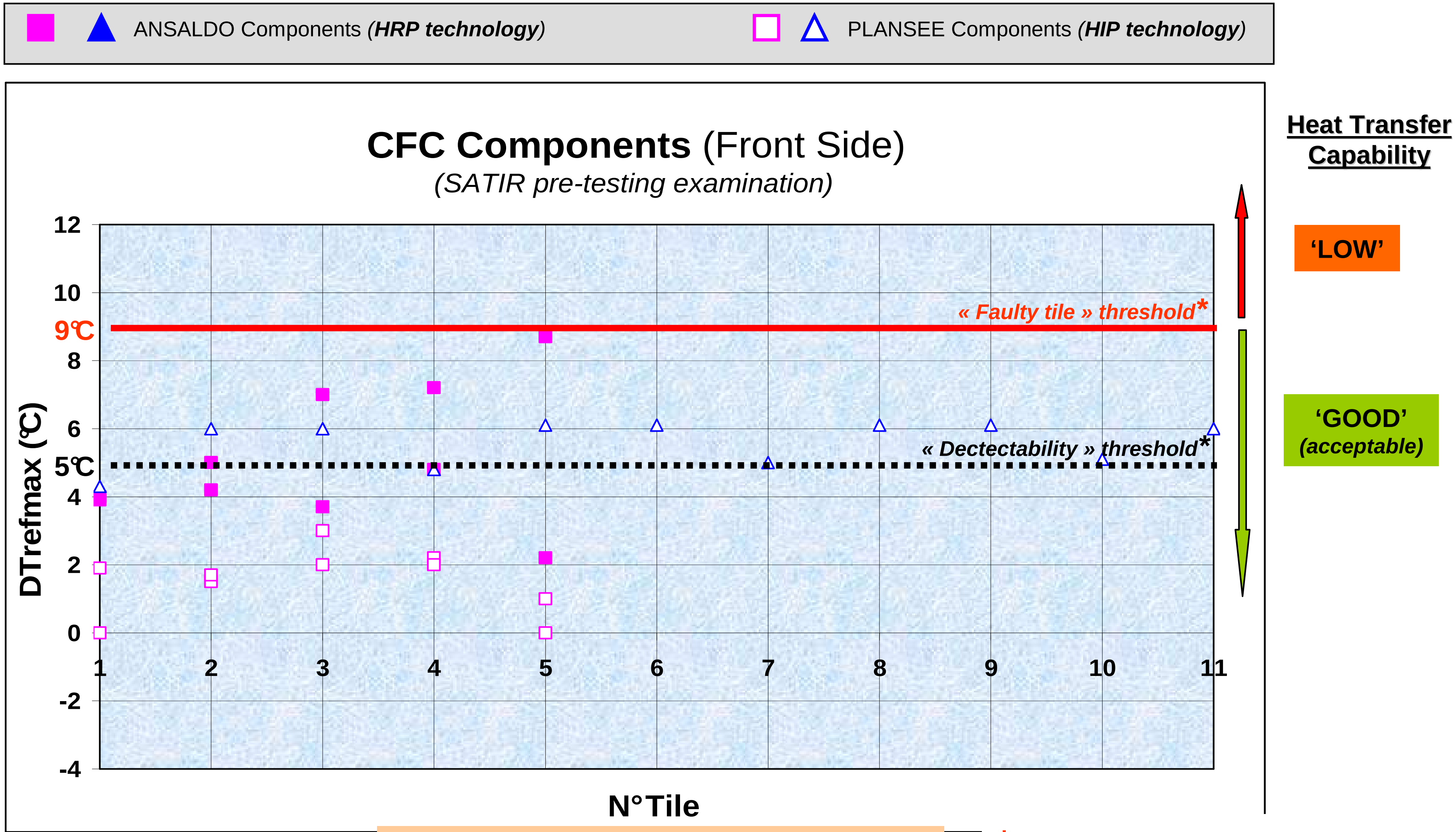
Qualification of **CFC** armoured components

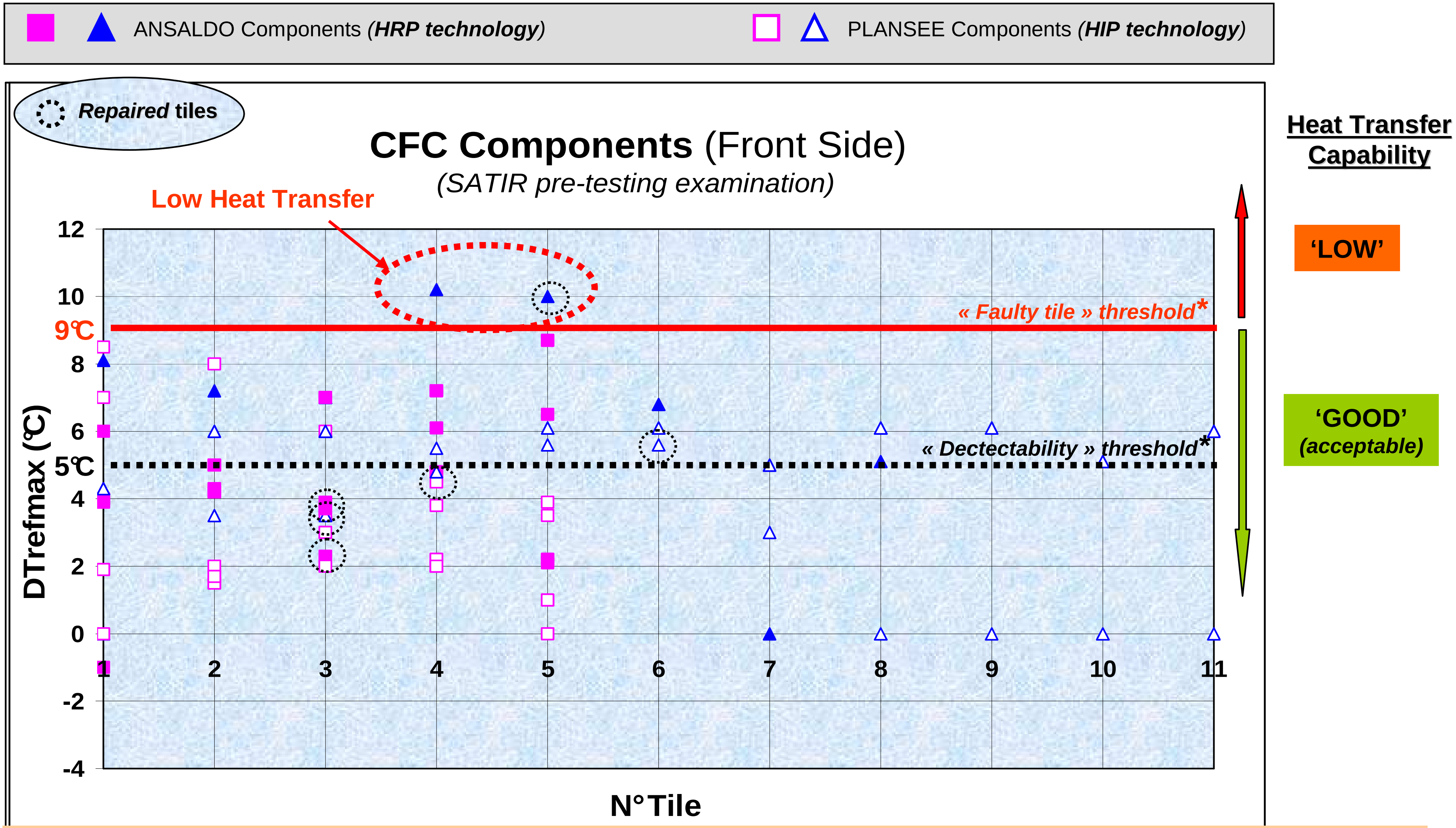
SATIR Pre-Examination *for 'Not-repaired'* / *'Repaired'* **Components (1/3)**



Overall good bonding quality

****Ref.*** *F. Escourbiac (PFMC-2009)*

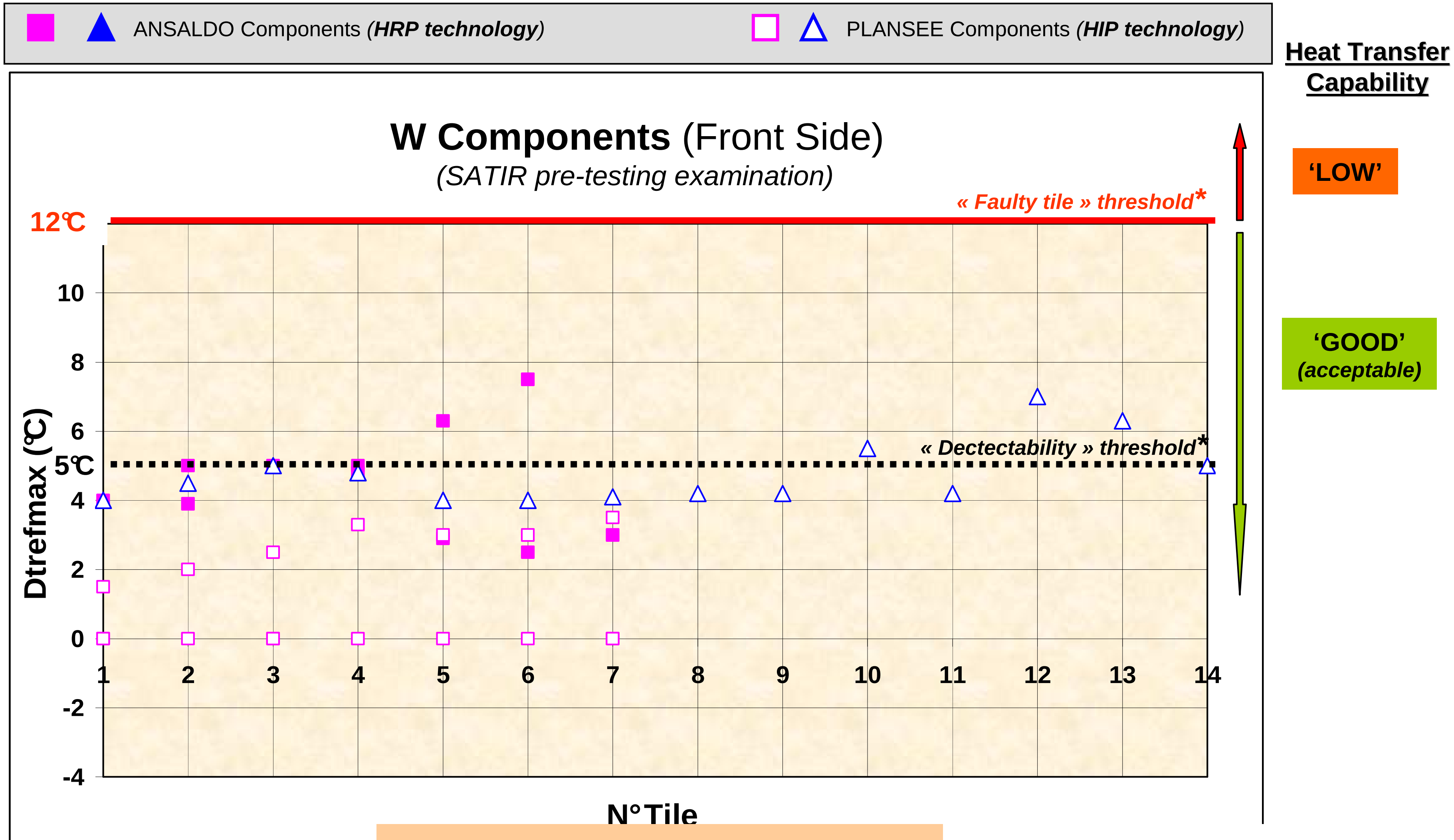
SATIR Pre-Examination *for 'Not-repaired' / 'Repaired'* **Components (2/3)**



Overall good bonding quality / 2 tiles *(~3%)* with low heat transfer capability

Qualification of W armoured components

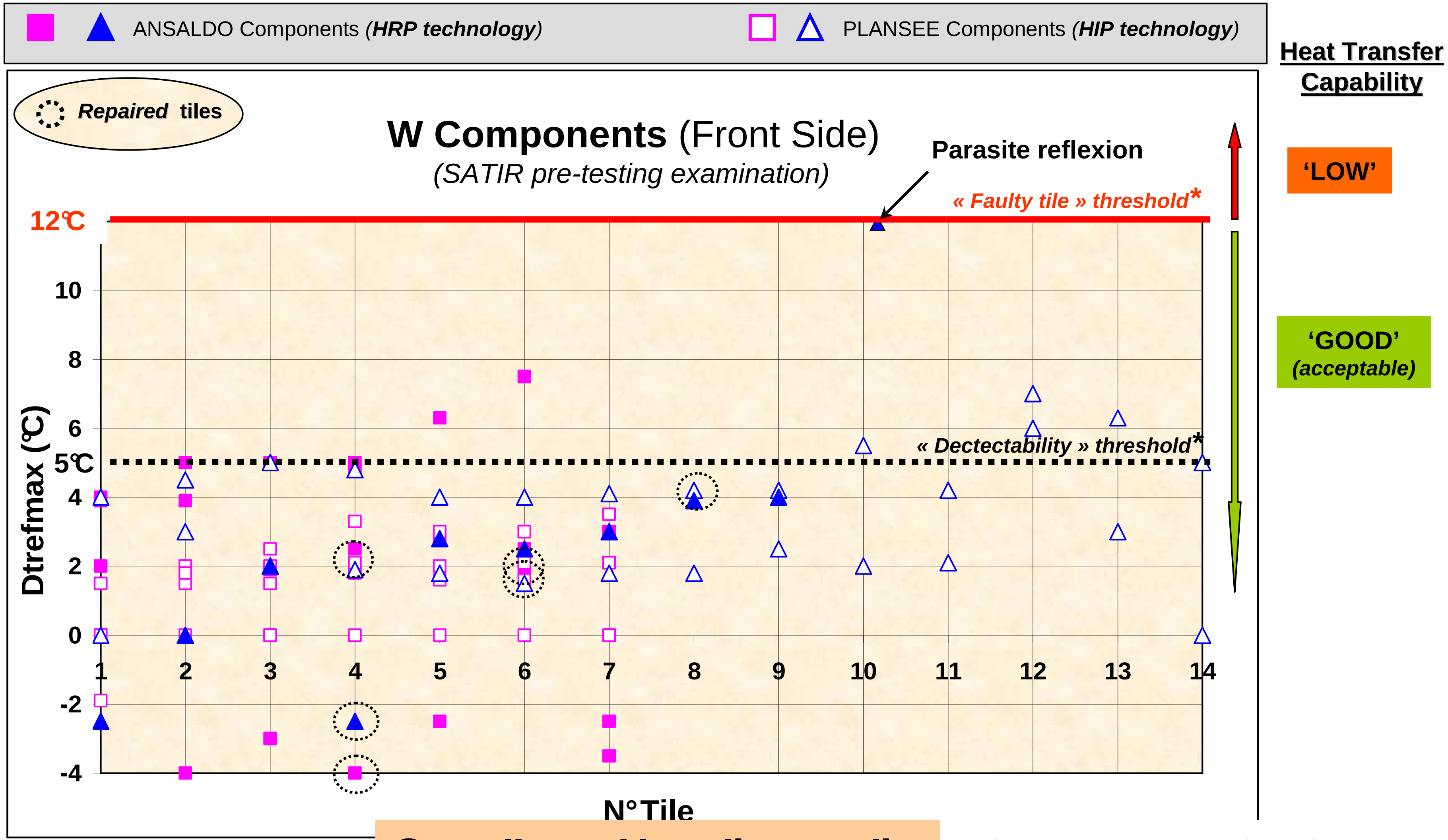
***SATIR Pre-Examination* for 'Not-repaired'** / *'Repaired'* **Components (1/2)**



Overall good bonding quality

* ...scourbiac (PFMC-2009), M. Richou (ICFRM-2009)

SATIR Pre-Examination for 'Not-repaired' / 'Repaired' Components (2/2)



Overall good bonding quality

...scourbiac (PFMC-2009), M. Richou (ICFRM-2009)

Qualification of **CFC/W** armoured components

Summary

- **SATIR PRE-EXAMINATION of 19 components** *(~70 CFC tiles & ~95 W tiles)*
  - ↳ Including 12 *(~7%)* **« repaired » tiles** distributed out 11 components

- **Overall good bonding quality** in terms of « heat transfer capability » **after manufacturing process** for both CFC or W armoured components, whatever the bonding technology !

Pre-examination in agreement with the **Initial Thermal Mapping** at 5MW/m²

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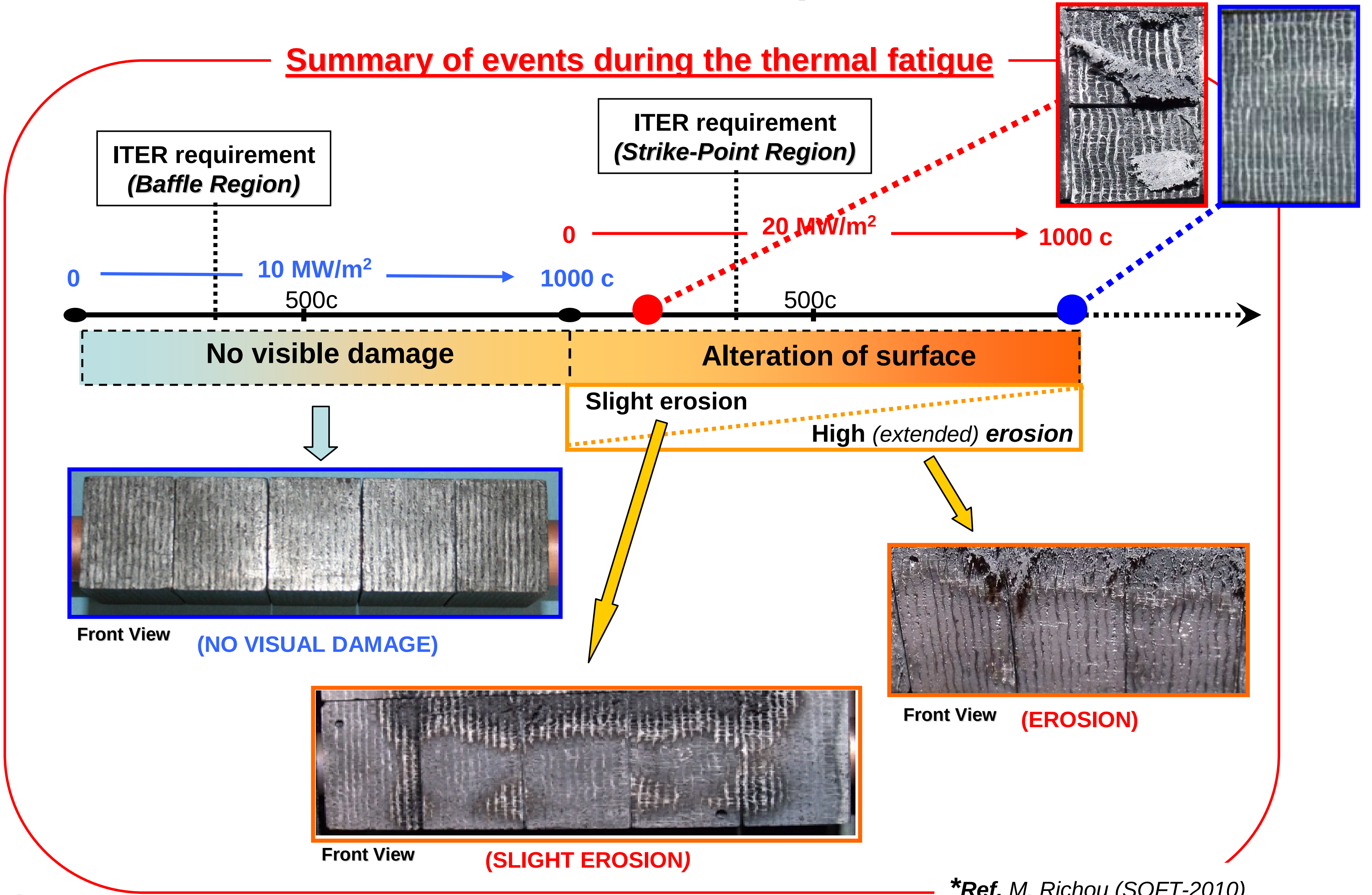
Damage Valuation *after* Thermal Fatigue for CFC armoured components

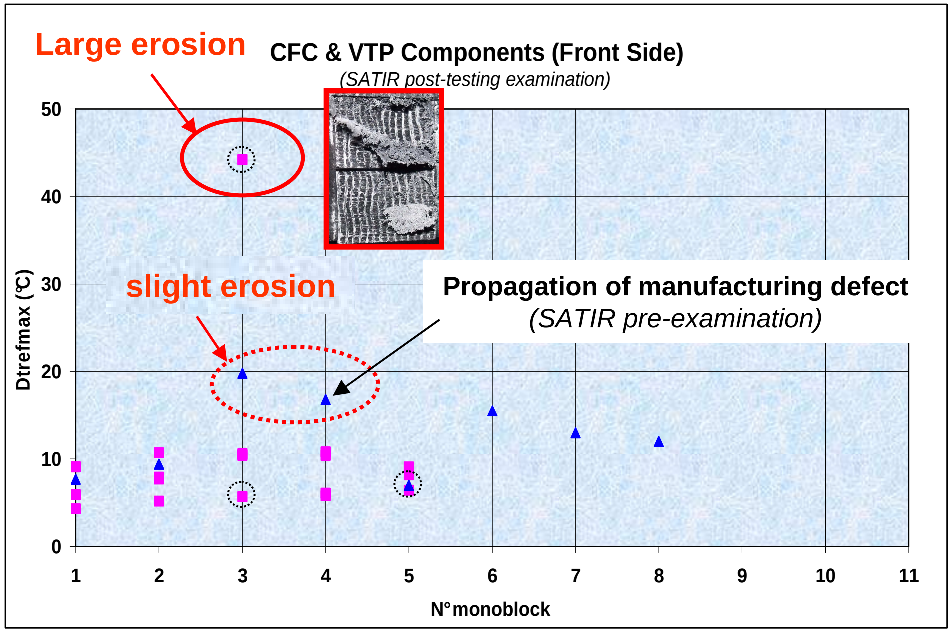


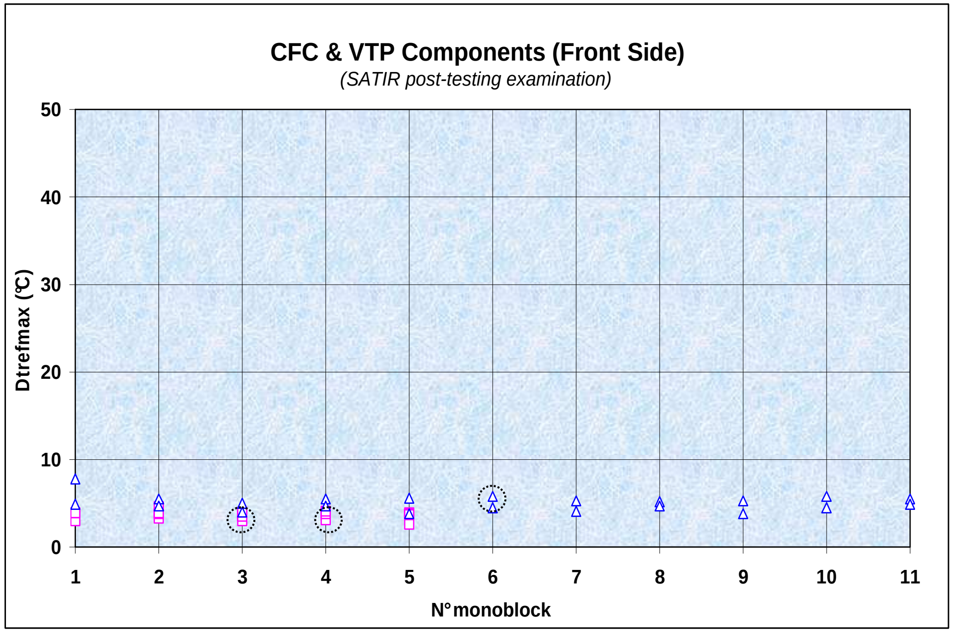
***Ref.** *M. Richou (SOFT-2010)*

Damage Valuation *after* Thermal Fatigue for CFC armoured components

***SATIR Post-Examination* for 'Not-repaired' / 'Repaired' Components**

ANSALDO Components (***HRP technology***) | PLANSEE Components (***HIP technology***)





Repaired tiles

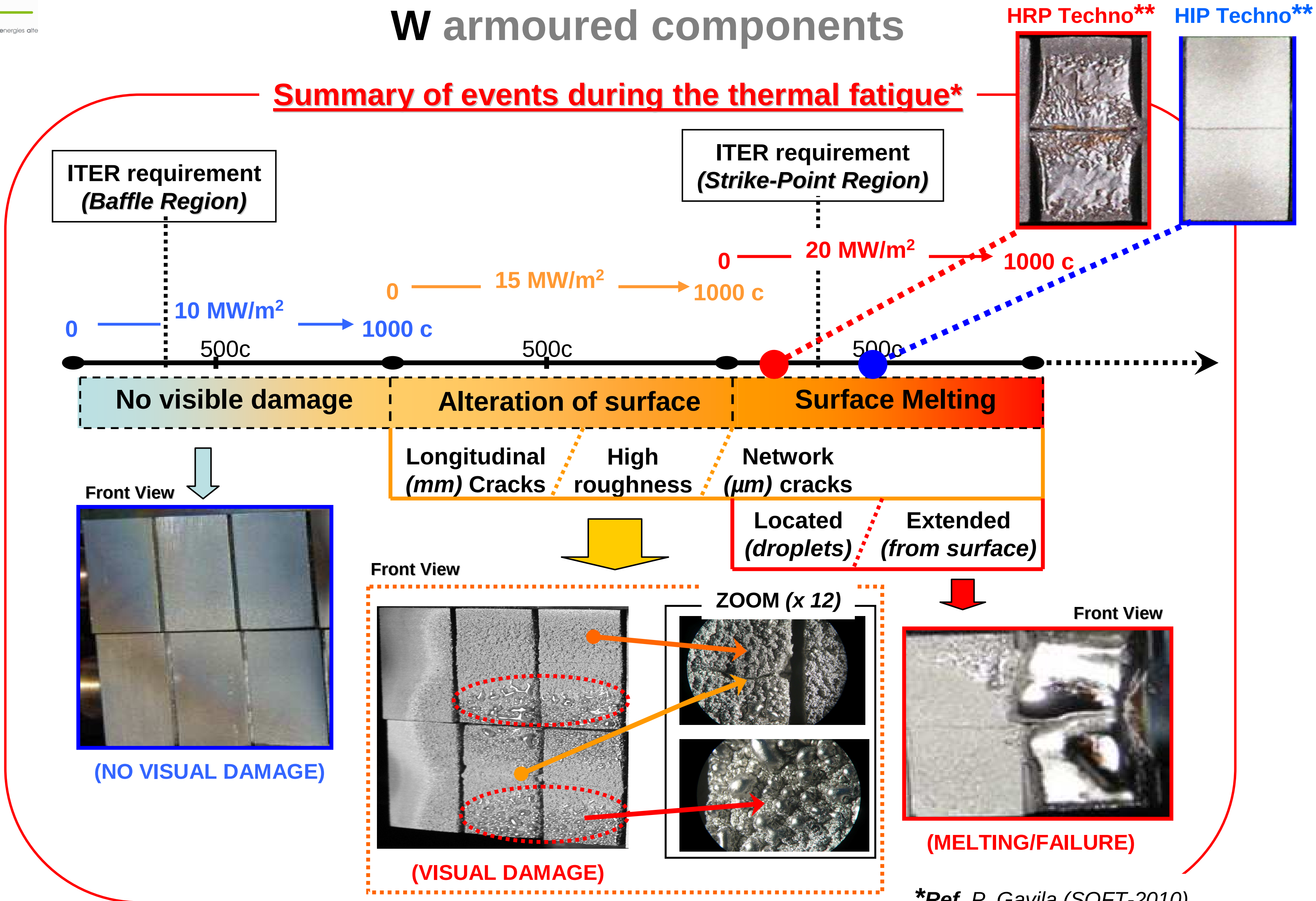
HRP Technology

HIP Technology

Repaired tiles

Surface Erosion (by sublimation) correlated with a degradation of heat transfer capability

Damage Valuation *after* Thermal Fatigue for W armoured components



***Ref.** P. Gavila (SOFT-2010)*

****Ref.** M. Richou (SOFT-2010)*

Damage Valuation *after* Thermal Fatigue for **W** armoured components

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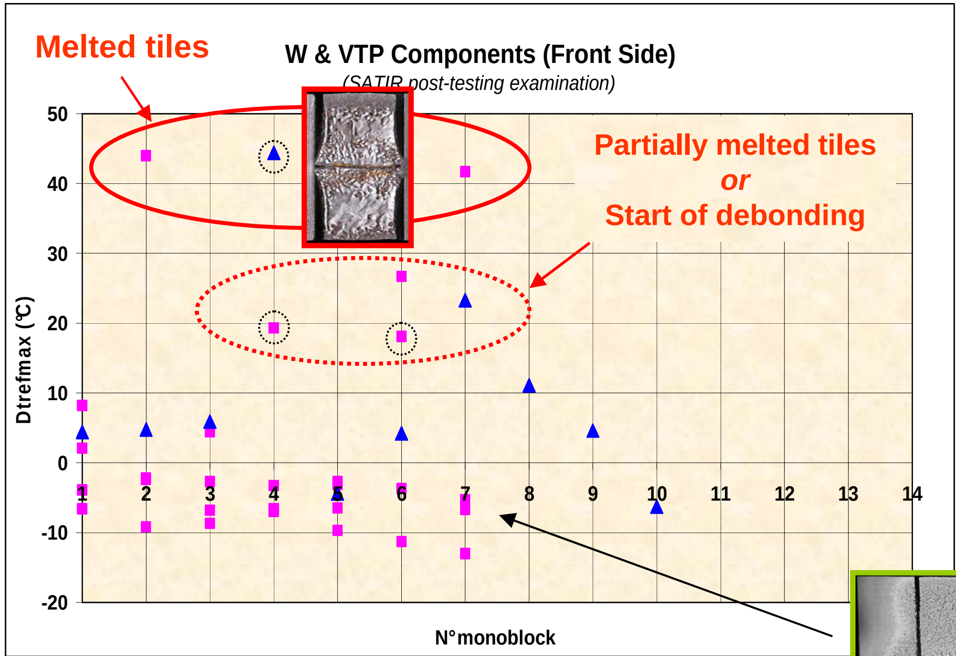
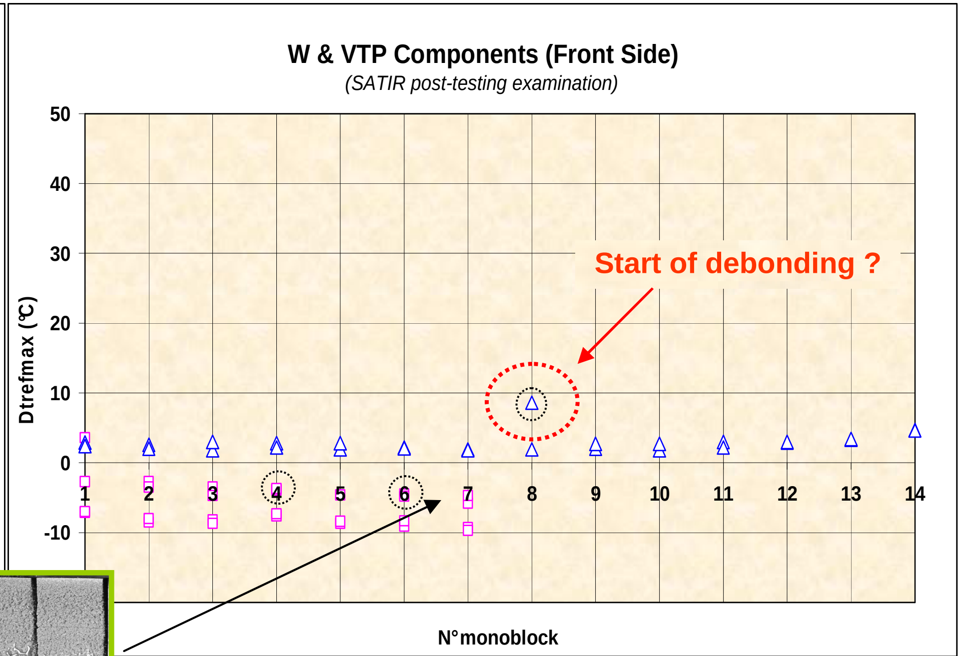
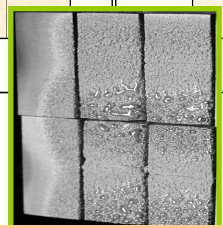
ANSALDO Components (***HRP technology***) | PLANSEE Components (***HIP technology***)



Repaired tiles

HRP Technology





HIP Technology

Repaired tiles

- ***Surface melting correlated with a degradation of heat transfer capability***
- ***Surface alteration does not impair the heat transfer capability***

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Summary & Conclusion

- **Qualification of CFC/W components *after* Manufacturing Phase**
  - **Good bonding quality** of CFC/W armoured components including recent/consolidated *(European)* development: **Optimization/Reliability of bonding technologies, Repairing process**

- **Damage valuation *after* thermal cycling *(up to 20 MW/m²)* in steady state**

ITER REQUIREMENT *(normal operation)*

- **Phase 1: "Mixed CFC / W"**

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Good *(thermomechanical)* **behaviour**

Slight *(located)* **erosion phenomenon**
in surface after 500 cycles
(with a low heat transfer degradation)

Good *(thermomechanical)* **behaviour**

- **Phase 2: "Full W"**

W up to 20 MW/m² in steady state !

- **Start of embrittlement in surface** at **15 MW/m²**
- **Spread of embrittlement in surface** at **20 MW/m²**
  - significant altered surface *(cracks, located surface melting)*

⇨ repairing process validated *(up to 500 cycles)* for HIP techno. and a few cycles for HRP technology

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- **Damage valuation *after* thermal cycling *(up to 20 MW/m²)* in steady state**

Europe has with ITER margin requirements the suitable technologies *(including the repairing process)* **with regard to CFC/W armoured components for ITER divertor heat loads foreseen during the initial** *'non-active'* **phase (Phase 1).**

R&D are still needed for a 'full W' divertor foreseen during the *'active'* **phase (Phase 2), where a prolonged use of W-armoured components above recrystallization** *(high temperature usage)* **and under DBTT should be considered for strike-point region of ITER Divertor.**

THANK YOU FOR YOUR ATTENTION