Advanced Qualification Methodology for Actively Cooled High Heat Flux Plasma Facing Components

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EFDA
EUROPEAN FUSION DEVELOPMENT AGREEMENT

ITER

IPP

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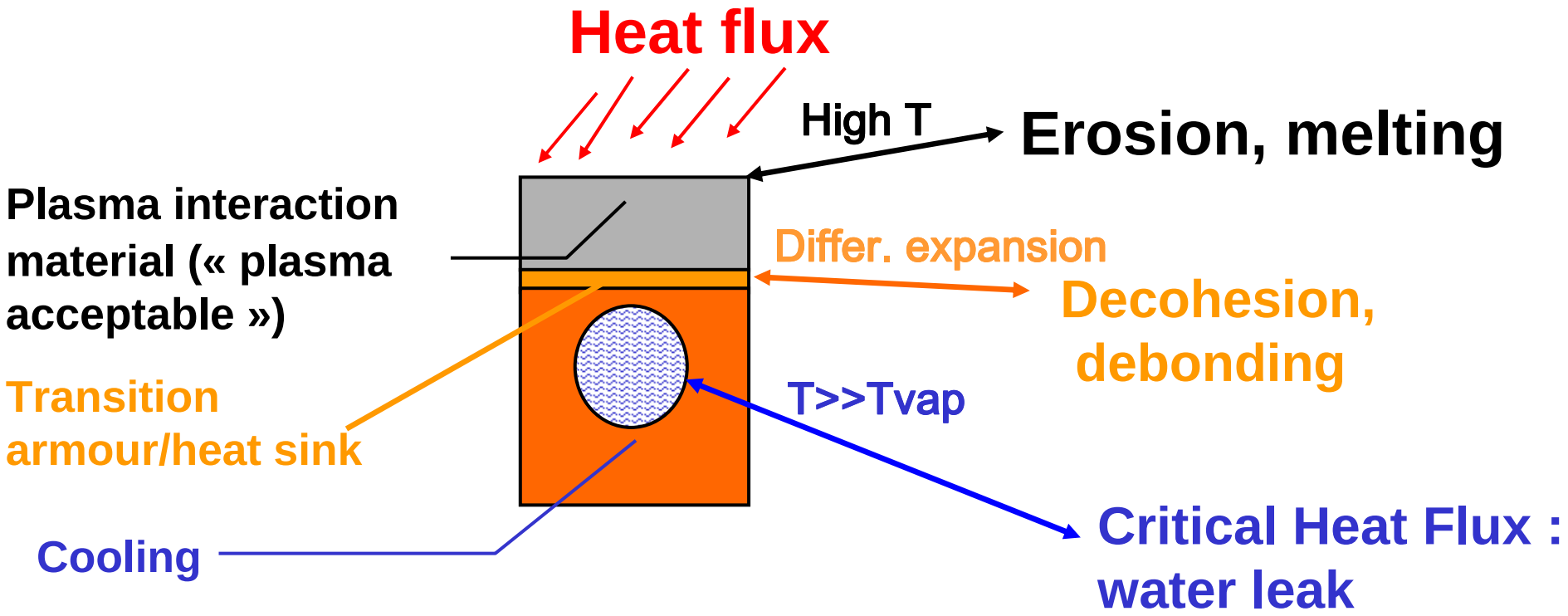
High Heat Flux Plasma Facing Components Challenge
Steady state power exhaust capability : 5 –20 MW/m²



Armour / heat sink joint is the key

The long and winding road towards reliable PFC…

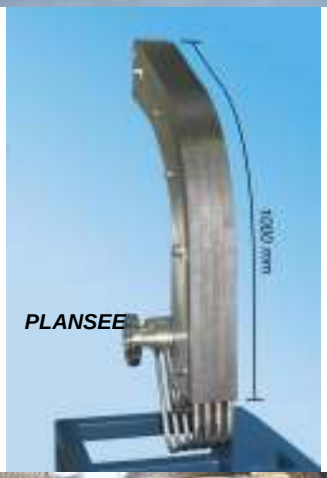
Time (years!!!)

R&D

Mock ups, prototypes
Need to be qualified destructive and
Non Destructive Examination (NDE)

Industrial capability

Ensure, control manufacturing quality
NDE methods development



Operation

Adaptation of NDE (or develop others?)
methods from ex to in-situ?

Outline

- **Non Destructive Examination (NDE) methods for PFC characterisation and reception (developed at CEA)**

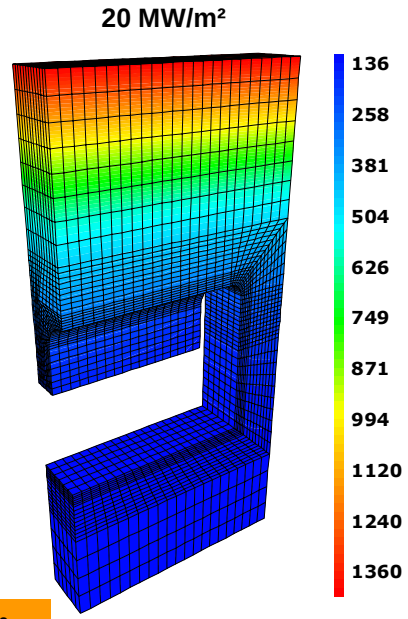
- **Towards PFC in-situ (health) monitoring**

Characterising PFC

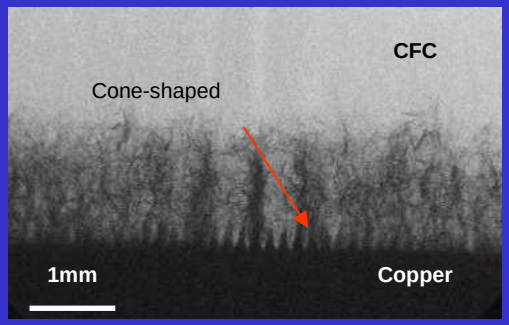
Many examination methods
However non functional
(X rays, US, …)

High heat flux tests :
Nearly full simulation
But costly, destructive…

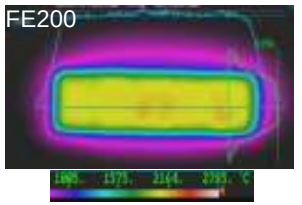
JOINT TEMPERATURE ⇨ **> 30 MW/m²**

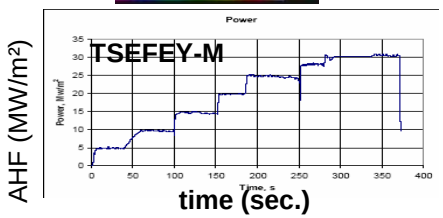


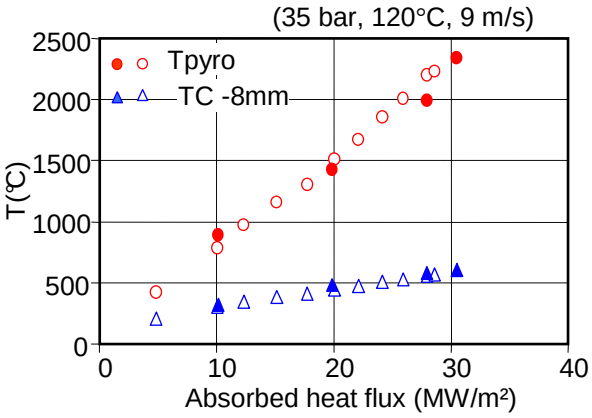
Active **M**etal **C**asting



Infiltration of the compliant copper layer: AMC® flat tile concept



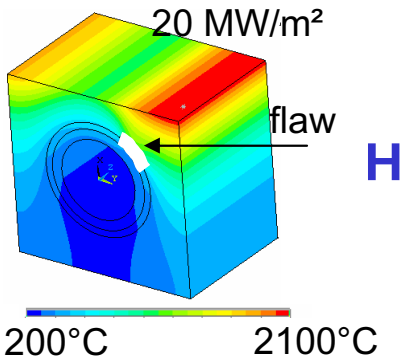




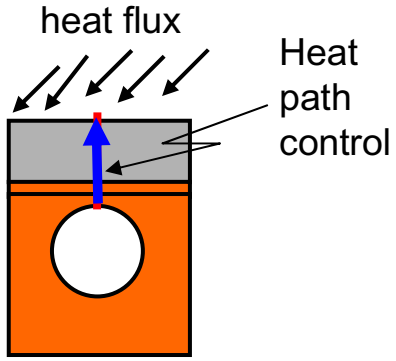
[Escourbiac, SOFT 2004]

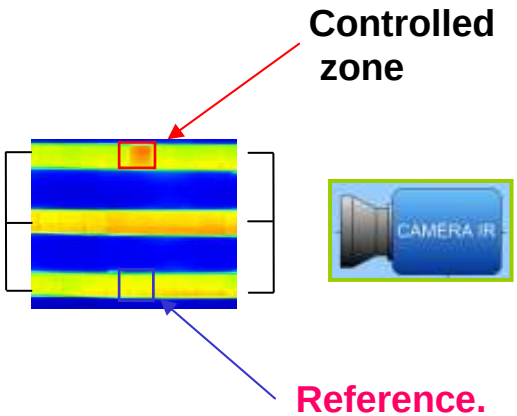
A functional NDE : SATIR

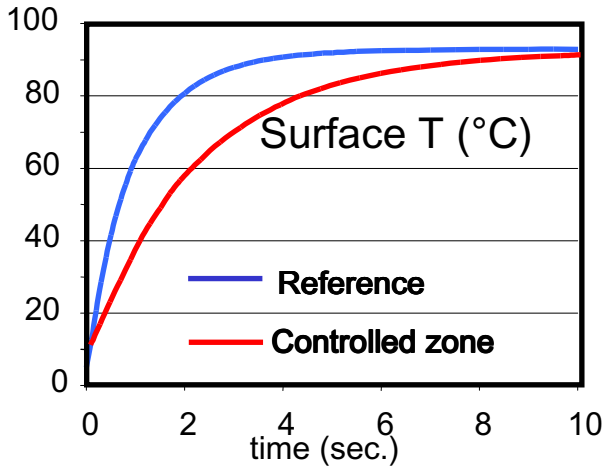
French acronym for Infra Red Acquisition and Data Processing device

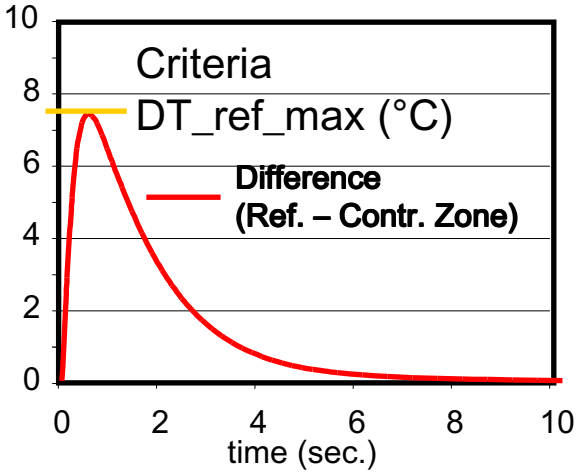


Heat load generated by hot and cold water flowing successively in cooling tube







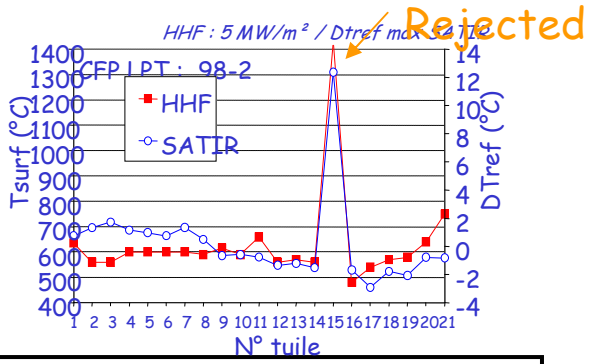


Output : Mapping of quantitative criteria DTref

SATIR achievements, limitations and improvements

Achievements

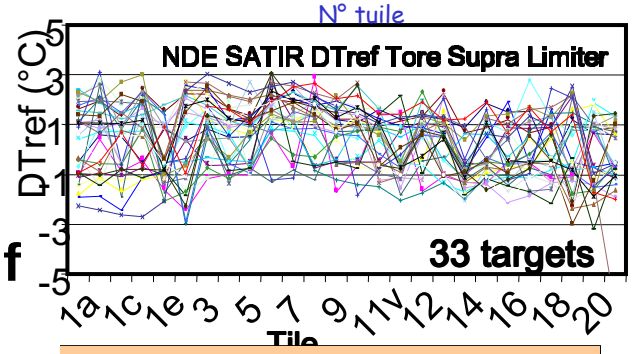
good correlation with HHF tests



Limitations

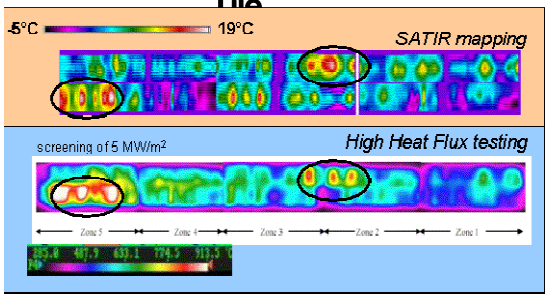
Intrinsic variability (λ, e…)

+ uncertainties from NDE itself (camera, emissivity, reflexion, ….)



Measurements accuracy increased

however, marginally



Improved NDE development required

SATIR new developments through image processing

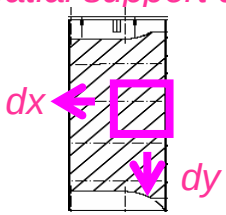
$$T(x,y,t) = f(x,y,t) + g(x,y,t)$$

Defect free element

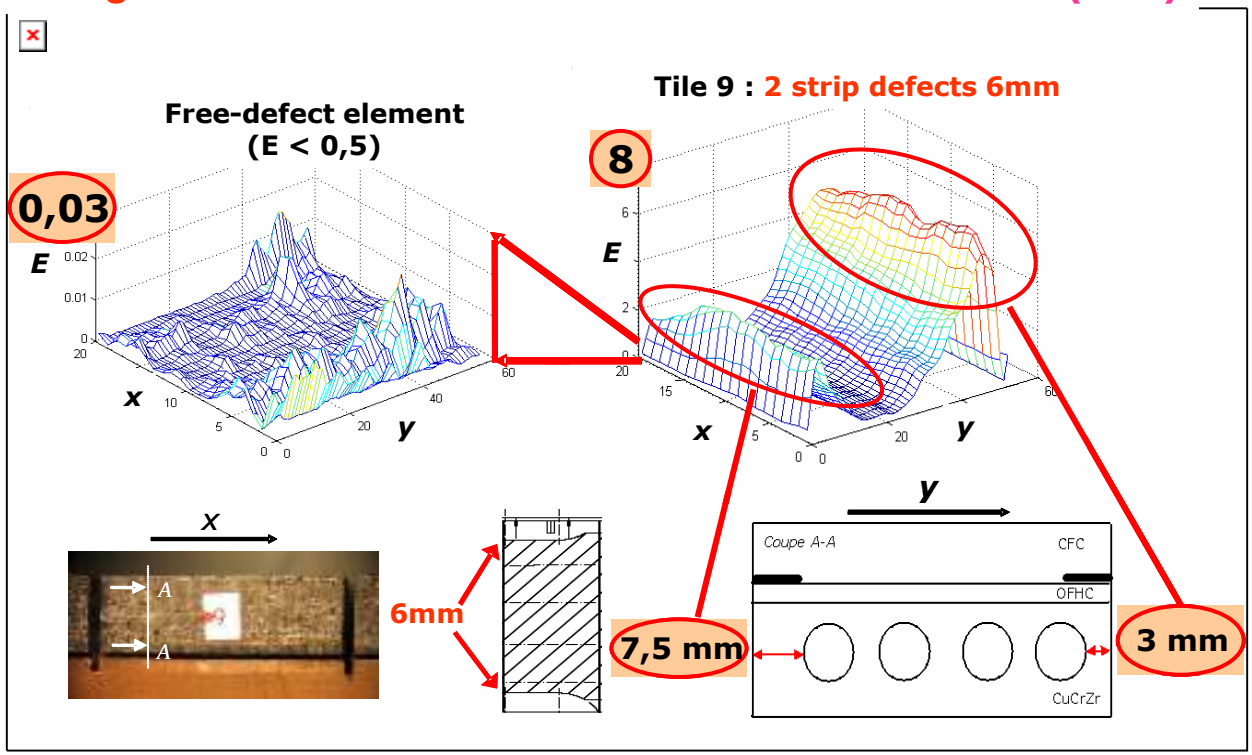
Installation noise + defect impact

Spatial autocorrelation :

of the estimation of g(x,y,t) on spatial support dx, dy



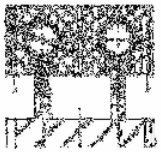
Energetical criterion of the autocorrelation function (AFE)



No need of reference component

[Cismondi PFMC11 2006]

Application to ITER CFC monoblock

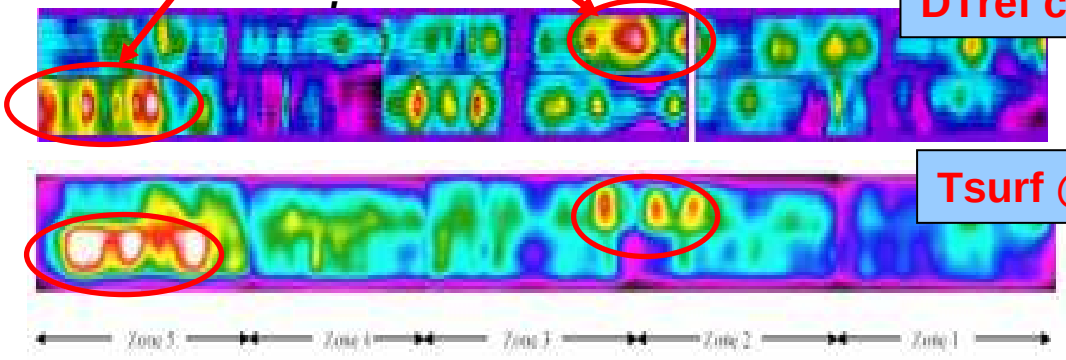


Thermal discontinuities

DTref cartography

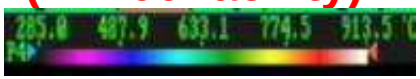
SATIR + REF

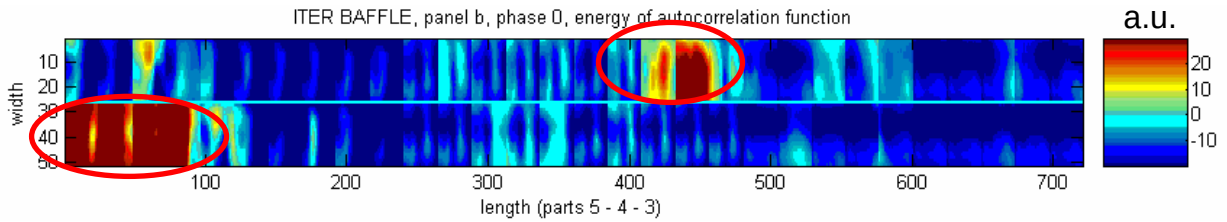
-5℃ 19℃



Tsurf @ 5 MW/m²

HHF testing (FE200 facility)



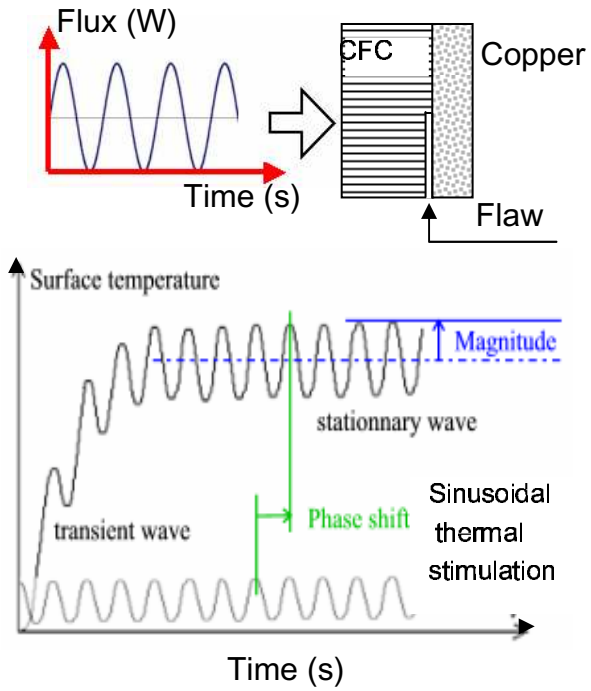


SATIR REF "free"

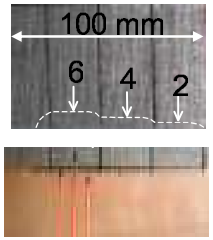
Complementary tool : Lock-in thermography

- **LOCK-IN principle : periodic thermal excitation**

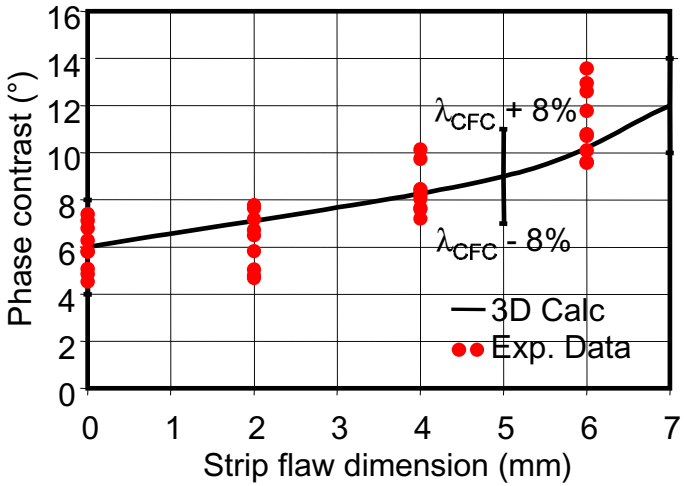
Magnitude and phase-shift of surface temperature depending on thermal path modification : defect or thermal properties variation.



Validation on component with calibrated defects



W7-X
flat tile
design

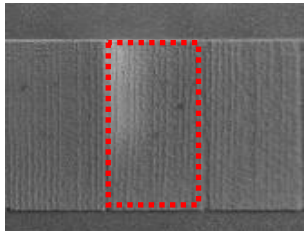


Pros : Easier to operate (no cooling), more versatile

Cons : High sensitivity to experimental parameters

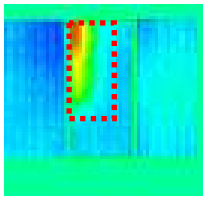
Improving statistitics through data merging

LOCKIN CEA
Phase shift

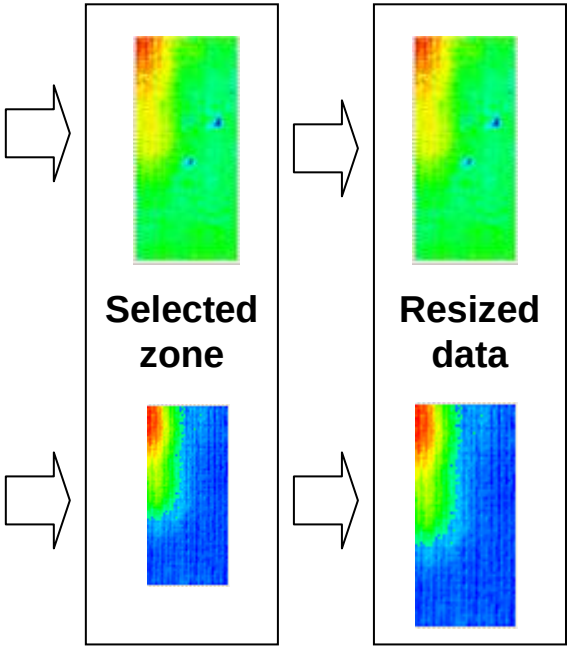


Flaw presence Probability 80%

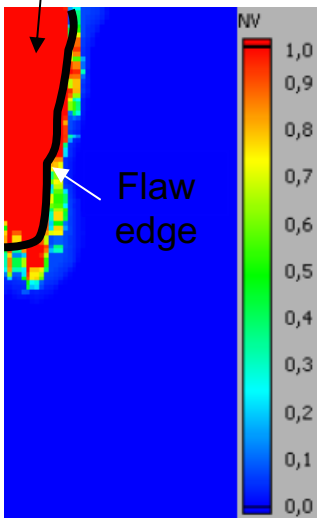
SATIR
DTref



Flaw presence Probability 90%



Flaw presence Probability 99%



W7-X flat tile design

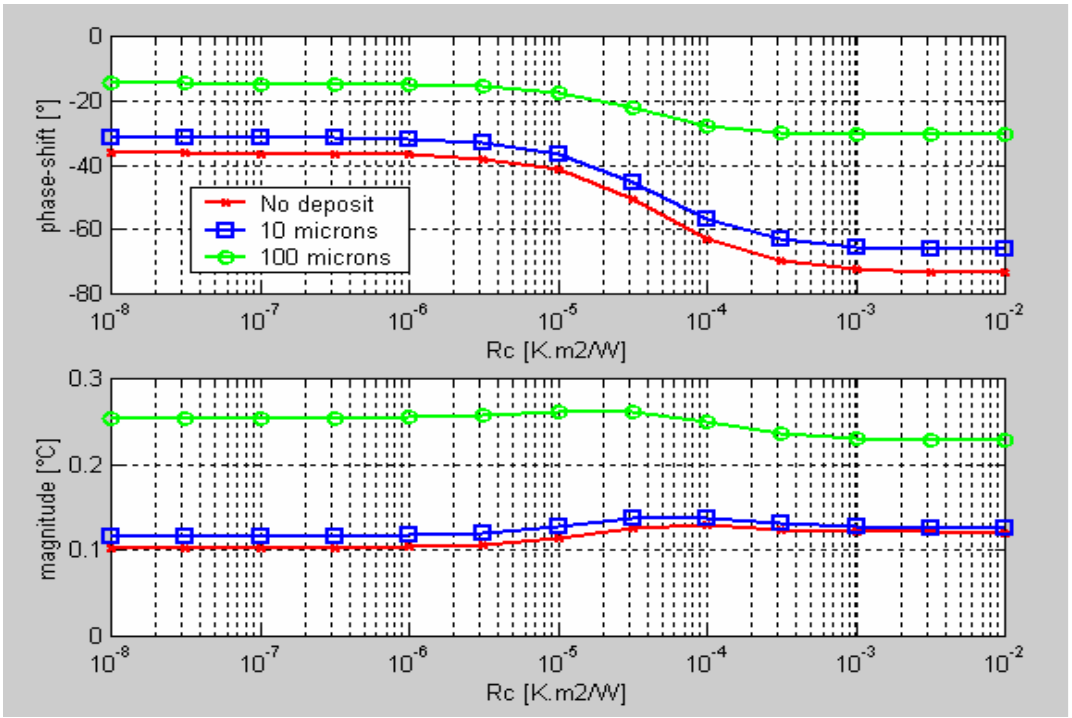
Will increase confidence in flaw detection by use of different data source

Needs however a good statistical analysis to be previously achieved

[A. Durocher et al. , SOFT 2006]

Operational assessments : In-situ lock-in

Lock in system installed on Tore Supra limiter (during vents)

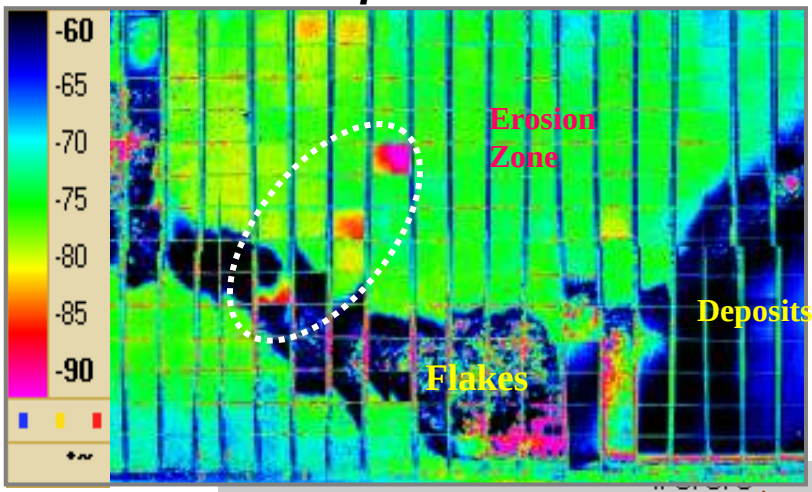


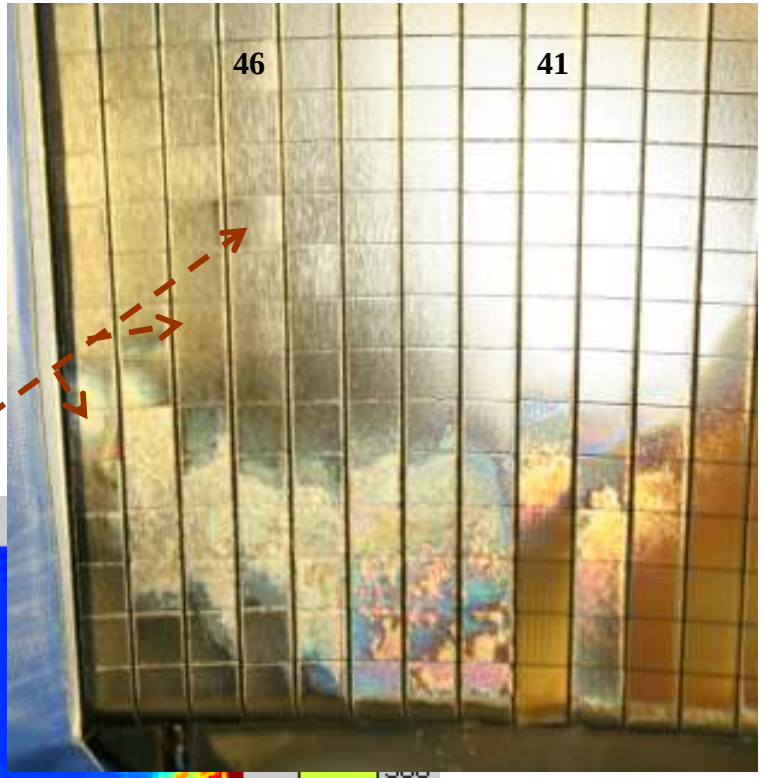
Health monitoring :
investigations towards in situ damage detection

[X. Courtois et al., PFMC wshop 2006]

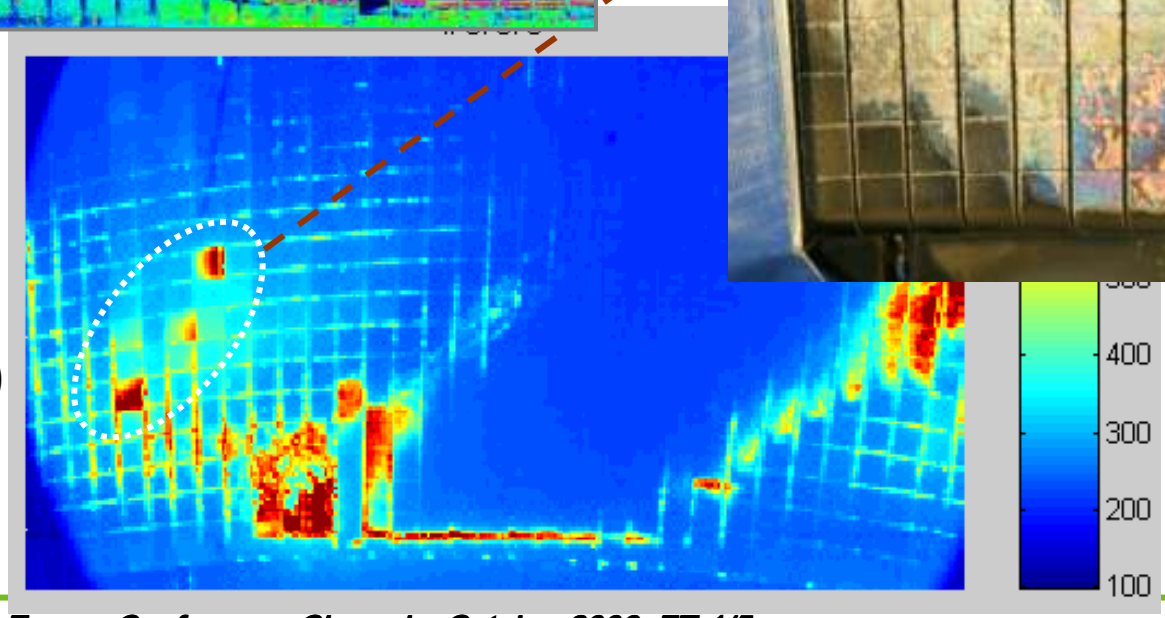
Tore Supra in situ monitoring

Phase-shift





IR image (disruption)



Summary

- **Qualification improvements are essential element for PFCs development, industrialisation and operation (long term programmes).**

- **« Variabilities » during series production cannot be ruled out**
  ⇔ Need of reliable non-destructive examination methods to be developed and qualified before series manufacturing

- **NDE thermographic methods proved to be well adapted; they nevertheless require a « stubborn » development for an efficient use.**

- **Major recent development based on image processing and data merging**

- **Adaptation of these methods and develoment of others for in situ PFCs monitoring are now under investigation.**