

DE LA RECHERCHE À L'INDUSTRIE

cea den

# EXPERIMENTAL INVESTIGATION OF THE RADIATIVE PROPERTIES OF THE NA-COOLED FAST PROJECT REACTOR ASTRID VESSELS

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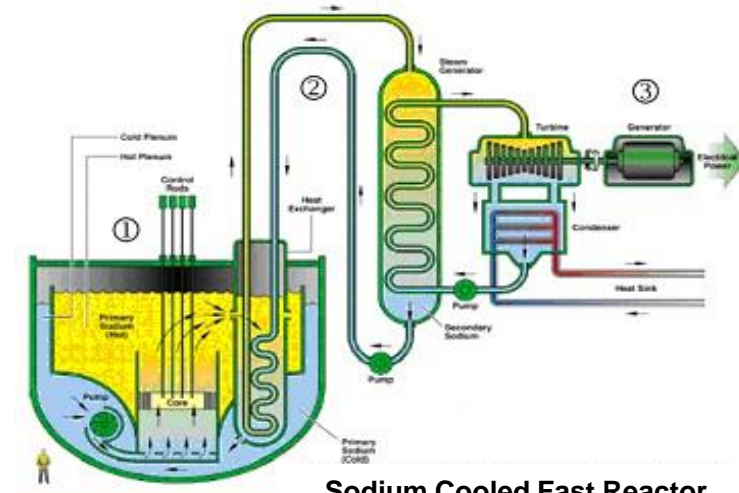
CEA Saclay  
DEN/DANS/DPC/SCCME/LM2T

ASTRID is a project of SFR reactor → Generation IV

- Efficiency of the fuel cycle
- Proliferation
- Security

ASTRID design specifications:

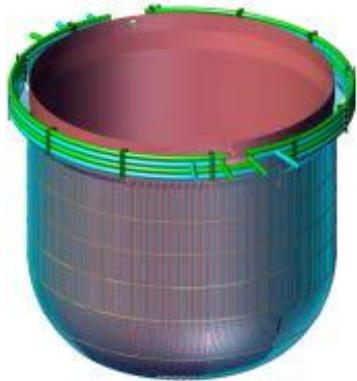
- Two-vessel design → separated by  $N_2$
- EPuR system → release of the residual heat



Radiative exchange between the primary ( $T=650-700\text{ °C}$ ) and secondary ( $T=350\text{ °C}$ ) vessels

Emissivity measurement on steel samples between  $500\text{ °C}$  and  $800\text{ °C}$

**Out-of-nominal functioning of ASTRID**



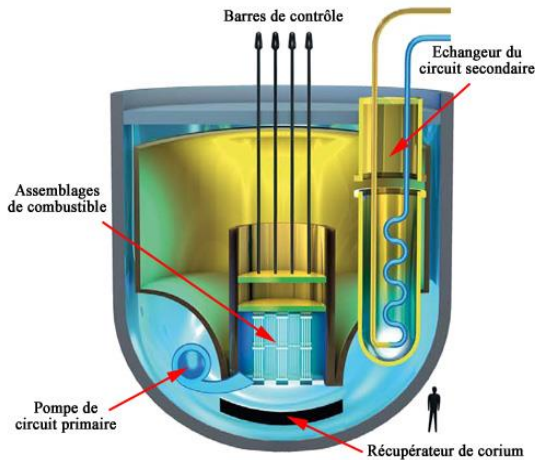
**Release of the residual heat of decay**

**Experimental support to the investigation of the radiative properties of ASTRID vessels**

**Development of an innovative technique for the estimation of emissivity**

**Experimental setup**

**Image processing**



Scheme of the ASTRID reactor

# Background on radiative transfer

## Emissivity

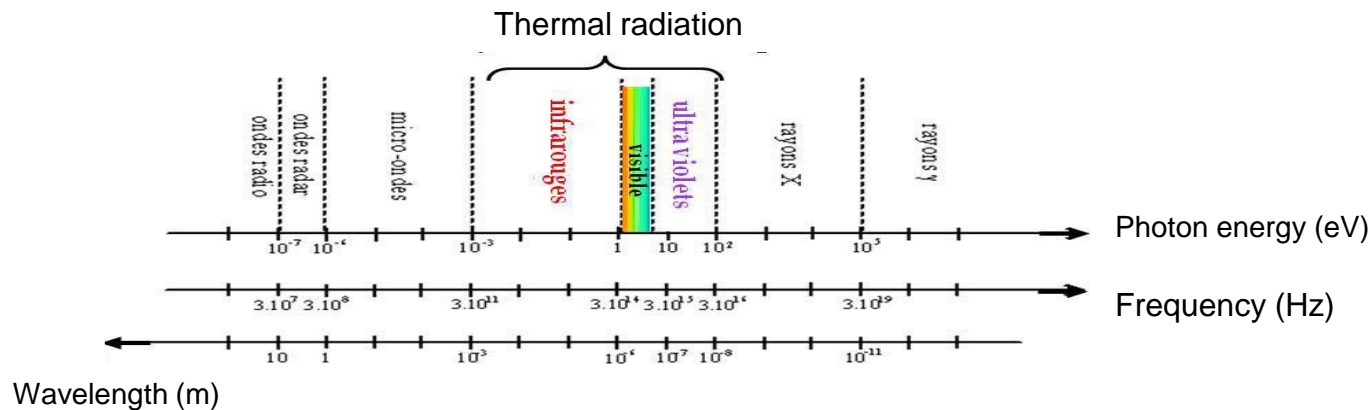
Blackbody is an ideal radiating body → at a given temperature it emits the maximum energy

The radiative properties of a real body are evaluated by comparison with the ideal emission of the blackbody.

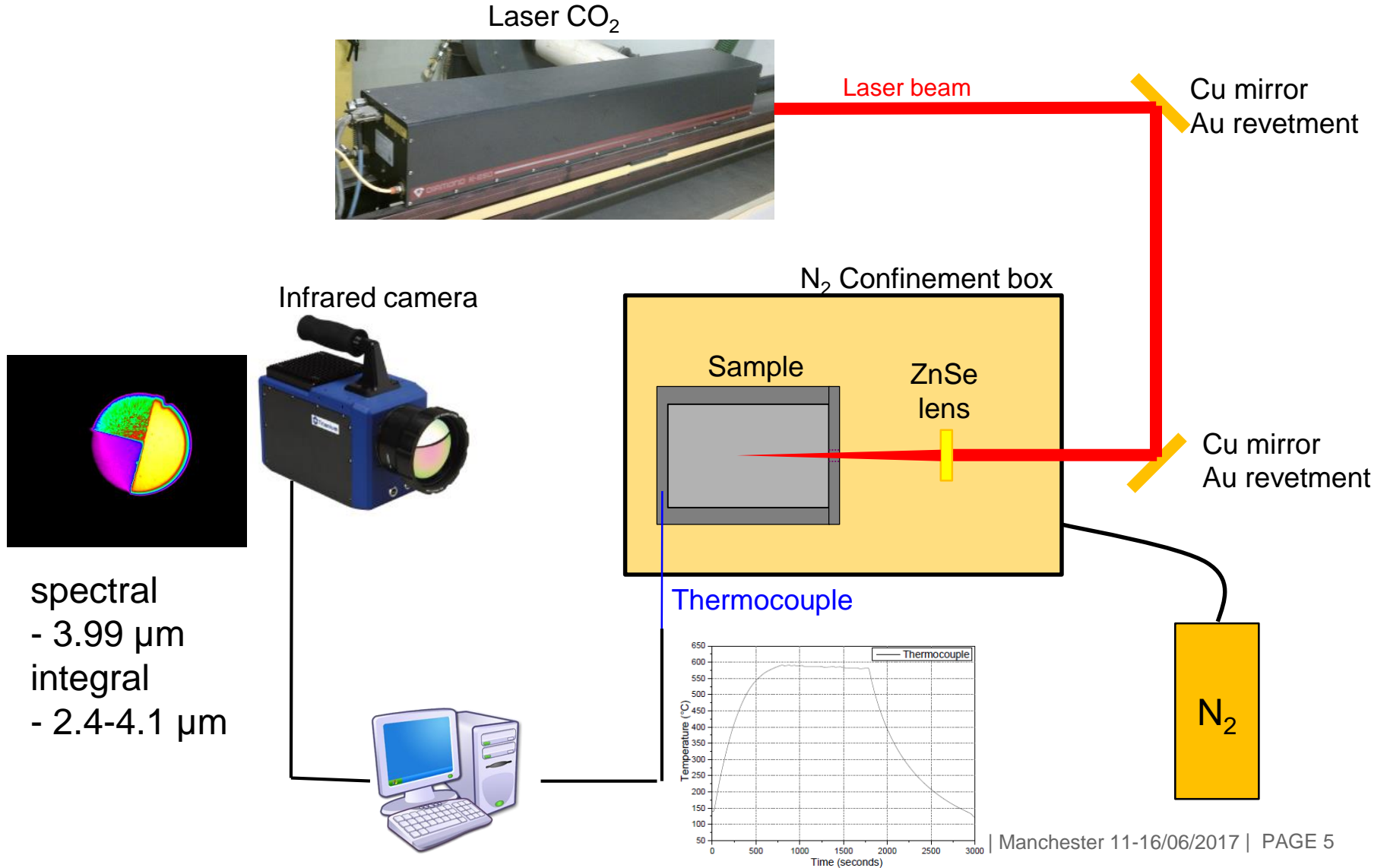
The **emissivity** or **emission factor** (ranging from 0 for a non emitting body to 1 for an ideal blackbody) can be defined as the ratio between the energy emitted by the real body and a blackbody at the same temperature (considering the same spectral range)

**NB: emissivity is an intrinsic property of the material.**

**NB2: in general, emissivity depends on temperature and on the condition of the surface sample**



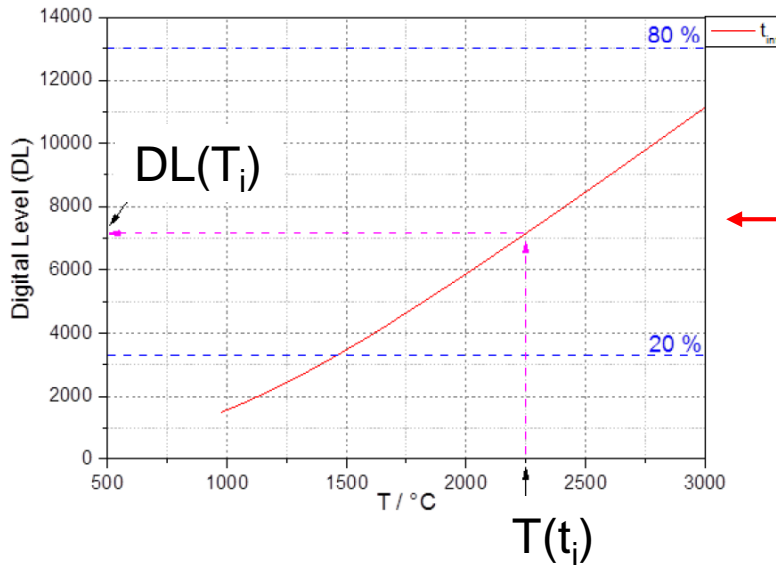
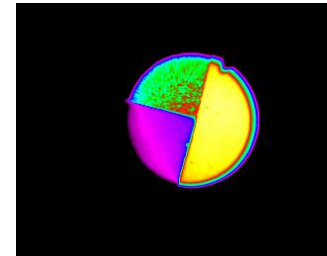
# Experimental setup



# Infrared images processing

For each infrared image recorded by the infrared camera, a synchronized acquisition of the true temperature is available from the thermocouple.

$$\longrightarrow DL_{\text{measured}}(t_i), T(t_i)$$



Using the direct correlation between temperature, integration time and  $DL(T)$  (i.e., the calibration curves provided by FLIR®), the temperature measured by the thermocouple can be used to obtain the  $DL(T)$ .

**NB:** This value corresponds to the digital level which would have been measured by the infrared camera if the investigated object was a perfect blackbody.

*From the camera point of view, everything it is looking at is a blackbody*

Using the definition of emissivity

$$DL_{\text{measured}}(t_i) = \varepsilon(\lambda)DL(T_i)$$

# What can be tested?

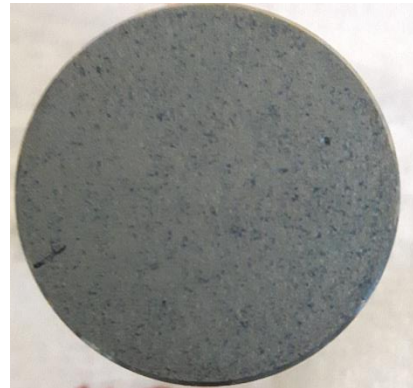
→ **Surface coatings:** nature of material coating ( $\text{Cr}_2\text{O}_3$ , black corundum, ...)

→ **Surface treatments:** e.g. laser ablation.

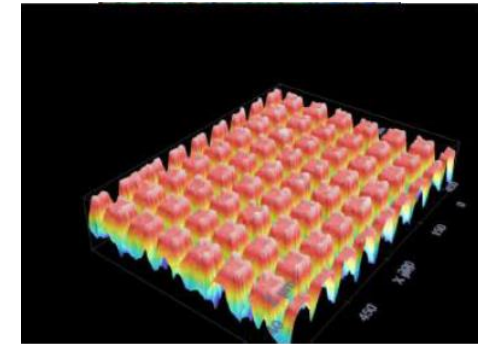
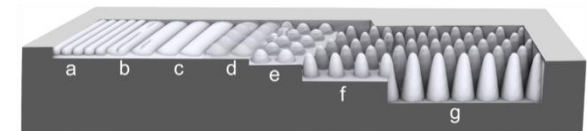
→ **Oxidized surfaces**



**Surface coating**



**Oxidation**

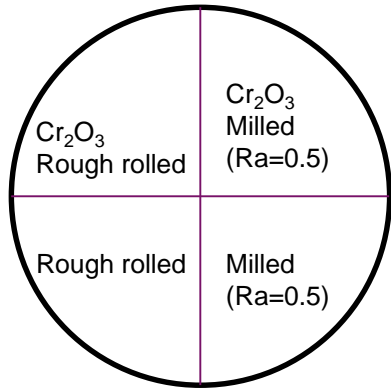


**laser ablation**

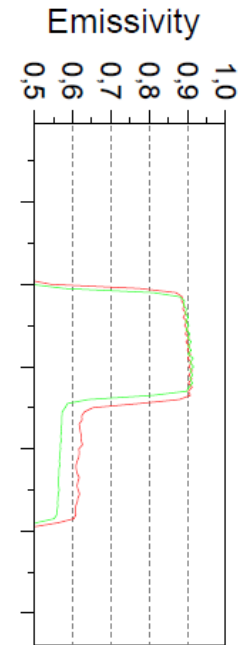
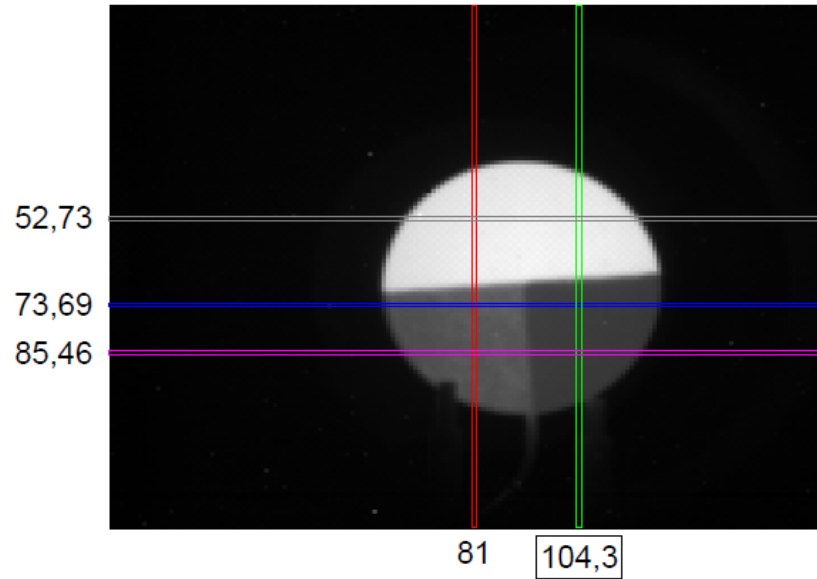
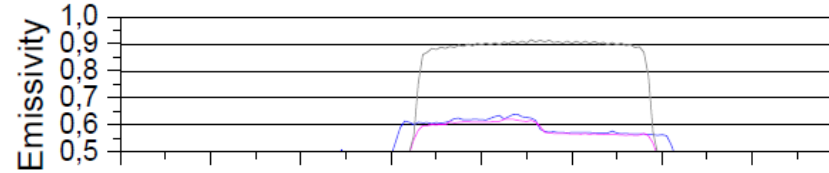
**SPECTRAL EMISSIVITY RESULTS AT  
3,99  $\mu\text{m}$**



# Multi-surface sample

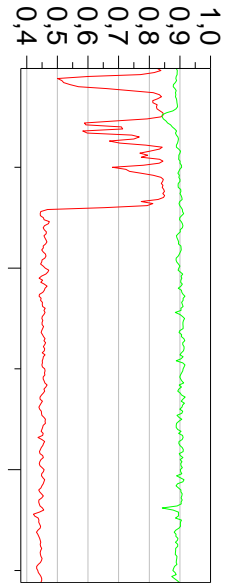
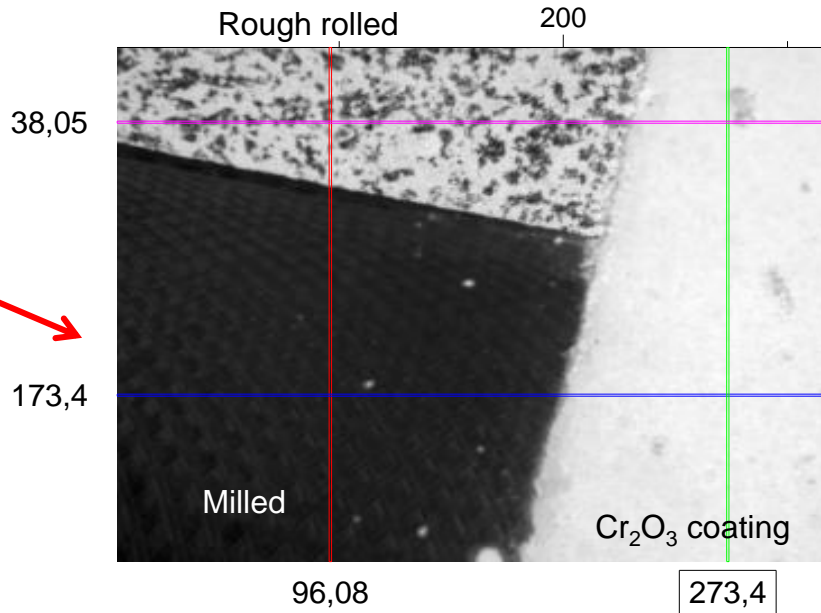
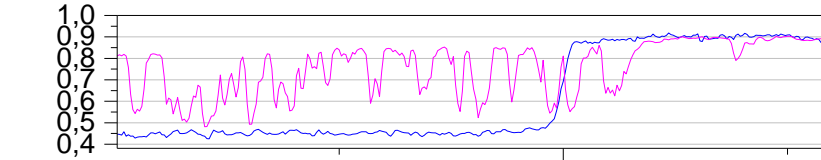
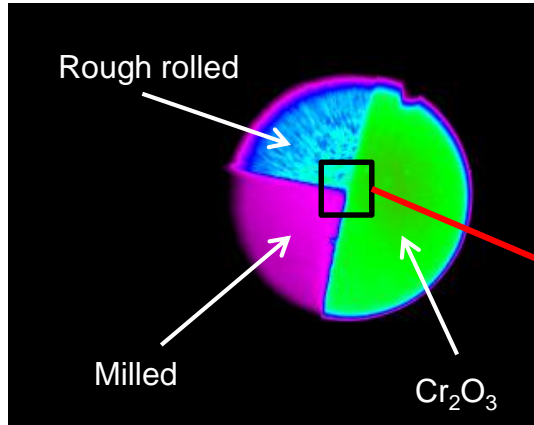


T=602,5 °C



Cr<sub>2</sub>O<sub>3</sub> coating has the highest emissivity

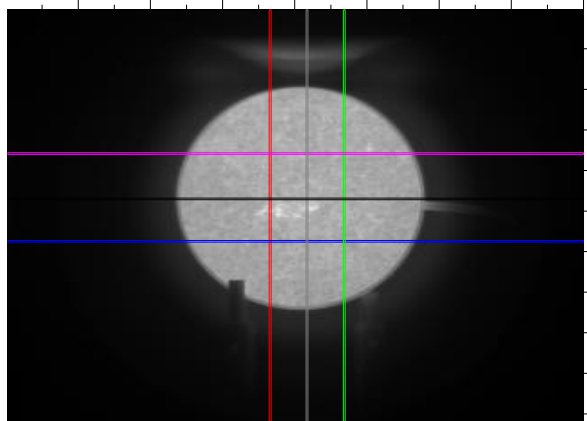
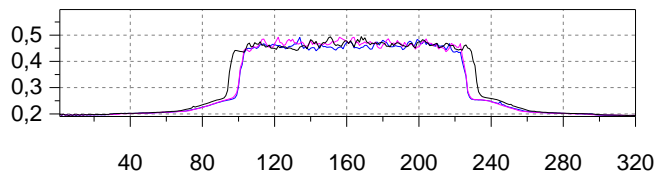
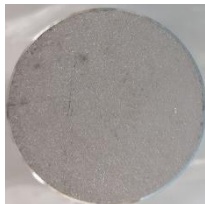
# Multi-surface sample



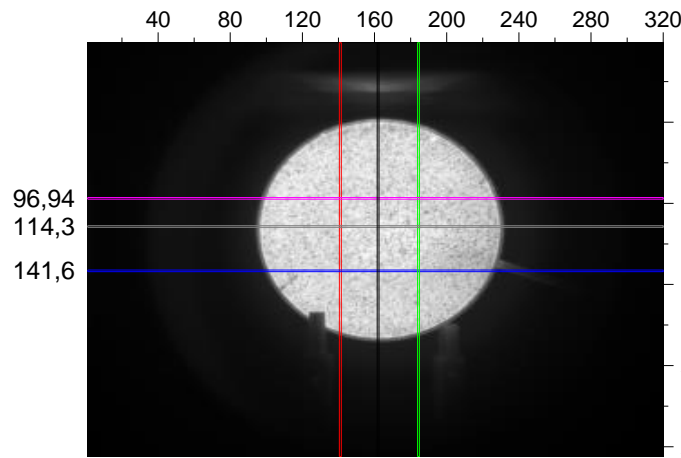
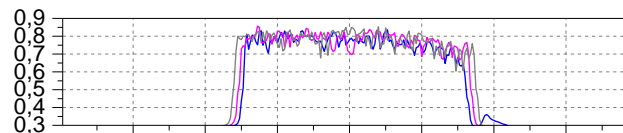
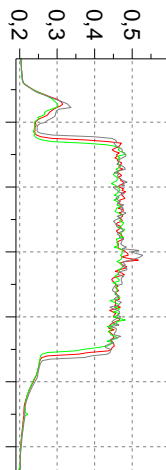
## Macro objective

→ Rough rolled surface is non-homogeneously oxidized

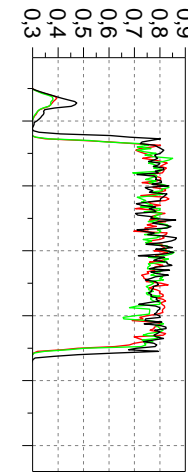
# Measurements under N<sub>2</sub> (less than 0.05 vol% O<sub>2</sub>) As-fabricated steel vs. oxidized steel



14 166,87,4



14 116,284,3



**Oxidation cannot be avoided even under N<sub>2</sub> atmosphere (O<sub>2</sub> residual in the gas mixture)**

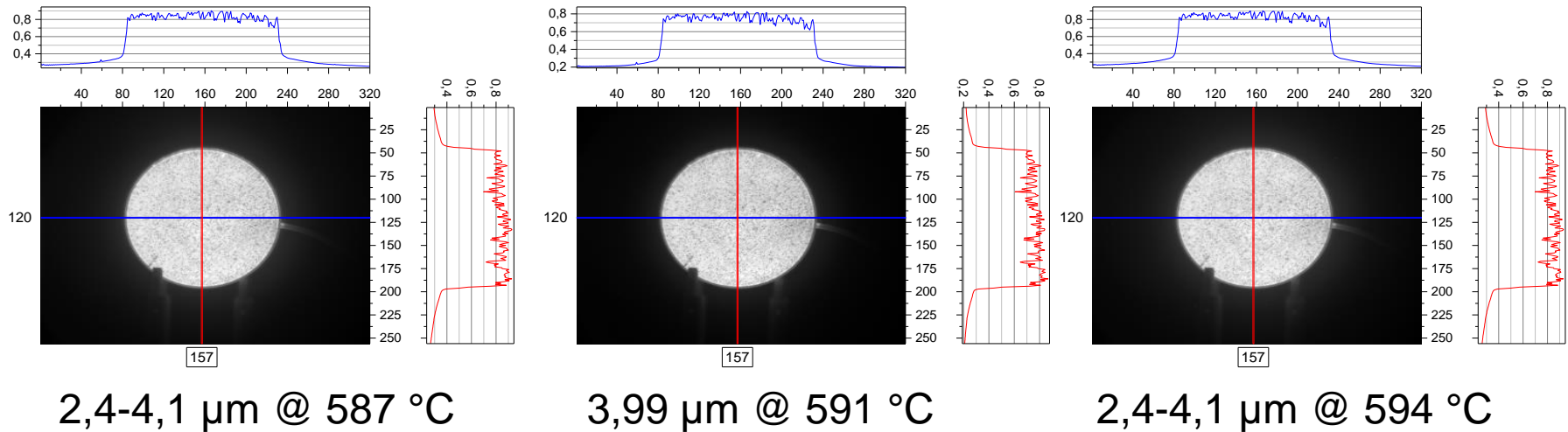
**Oxidation leads to a rise in the emissivity**

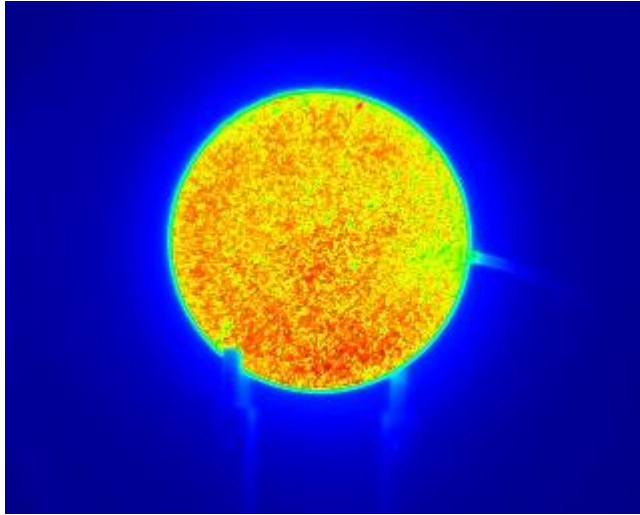
**EMISSIVITY RESULTS**  
**SPECTRAL BAND 2,4-4,1  $\mu\text{m}$**

### ■ Test procedure (15 min to limit surface-air interaction)

- 1) T=587 °C, spectral band
- 2) T=591,2 °C, monochromatic
- 3) T=593,6 °C, spectral band

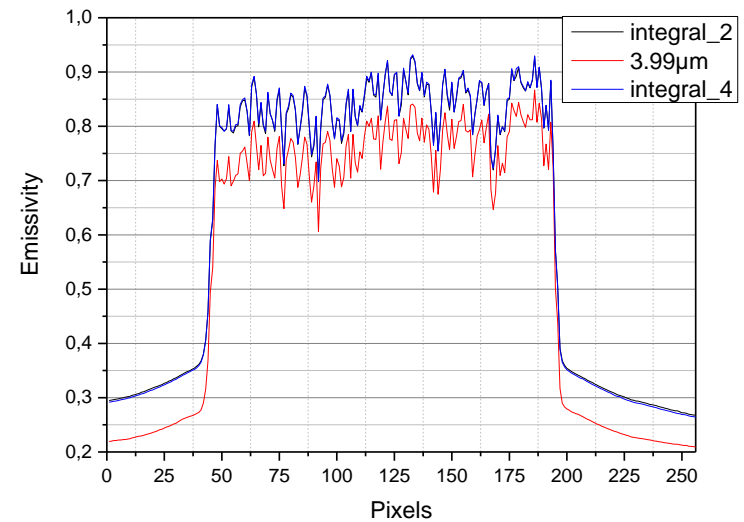
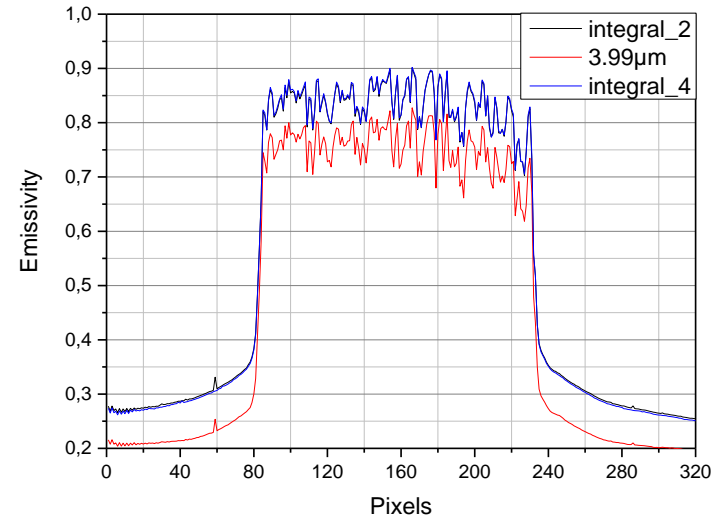
### ■ Monitoring of the stability of the radiative properties along the test





Emissivity measured in the spectral band 2,4-4,1  $\mu\text{m}$  is of the same order of magnitude of that measured at 3,99  $\mu\text{m}$ .

→ Needs to enlarge the experimental spectral band to be more representative of the real case



### A new experimental setup has been developed

- Radiative properties of ASTRID steel vessel
- Several surfaces have been investigated: coating, as-fabricated, oxidized

### Emissivity measurement under air

- $\text{Cr}_2\text{O}_3$  coating maintains a constant spectral emissivity
- Rough-rolled surface emissivity is affected by time exposure and temperature. The oxidation is not homogeneously distributed on the surface

### Emissivity measurement on steel sample under $\text{N}_2$

- Comparison between as-fabricated steel and oxidized steel →  $\epsilon(\lambda)$  increases

### Emissivity measurements on a spectral band

More representative of the real case

### Future work

- Angular dependence of emissivity
- Enlarged spectral band

All information contained in this document is to be considered as Confidential Information pursuant to the Implementing Arrangement between CEA, AREVA, JAEA, MHI and MFBR signed on August 7, 2014.

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