M5Framatome cladding high temperature oxidation behavior during simulated LOCA transients

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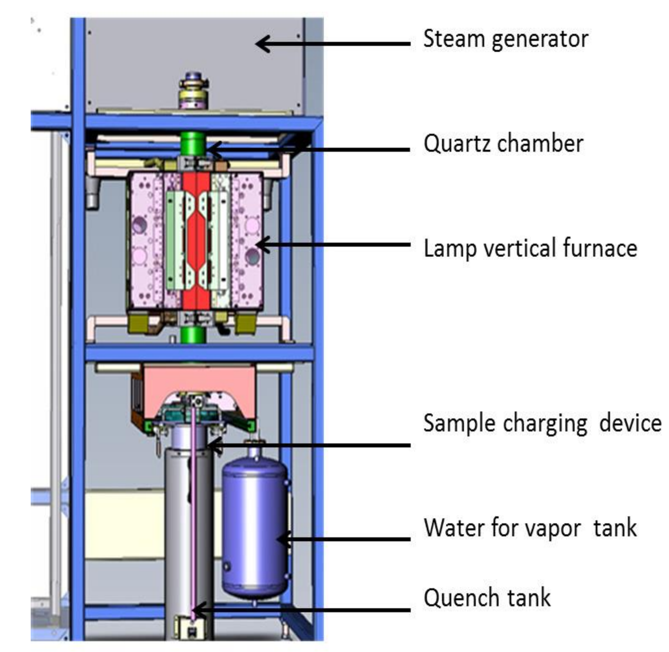
1. Context

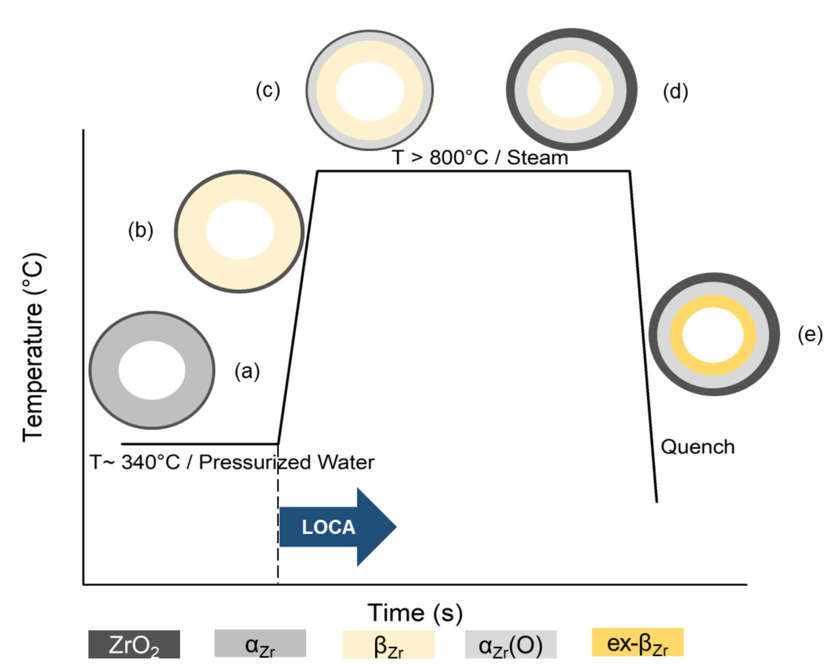
Demonstrating the acceptable cladding oxidation behavior in LOCA conditions is critical for the fuel vendor and its customers. Key to this is the accurate characterization of the cladding's resistance to breakaway oxidation, which can lead to rapid hydrogen pick-up and loss of ductility. Framatome has developed a dedicated facility at its Paimboeuf plant in order to perform one- and two-sided oxidation tests in steam, with a tight monitoring (temperature, steam flow) .

Protective oxide and a low hydrogen pick-up were observed. These tests confirmed the excellent performance of M5$_{Framatome}$ cladding and the absence of breakaway oxidation in LOCA relevant conditions, as already showed by V. Garat (TopFuel 2016).



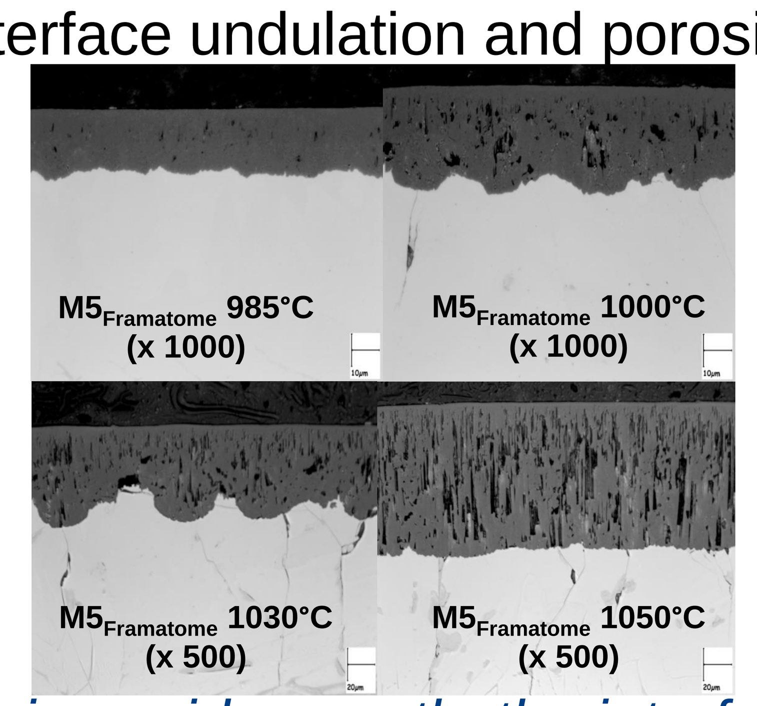
2. Experiments & results

Two-sided steam oxidation of M5$_{Framatome}$ claddings for 5000 s at 800 -1050°C in Paimboeuf facility.



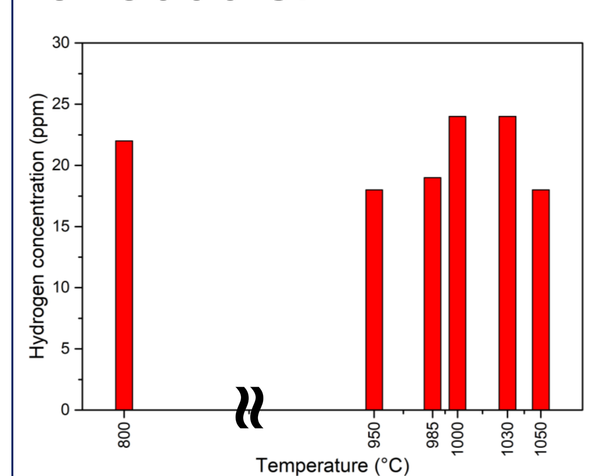
Optical microscopy of the samples

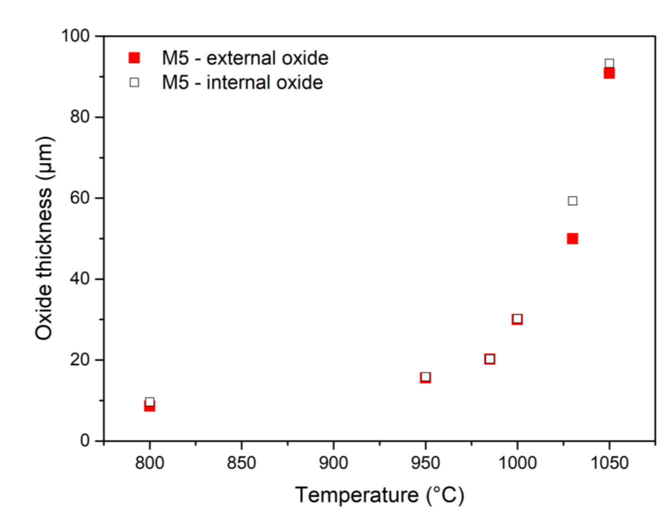
- Interface undulation and porosity.

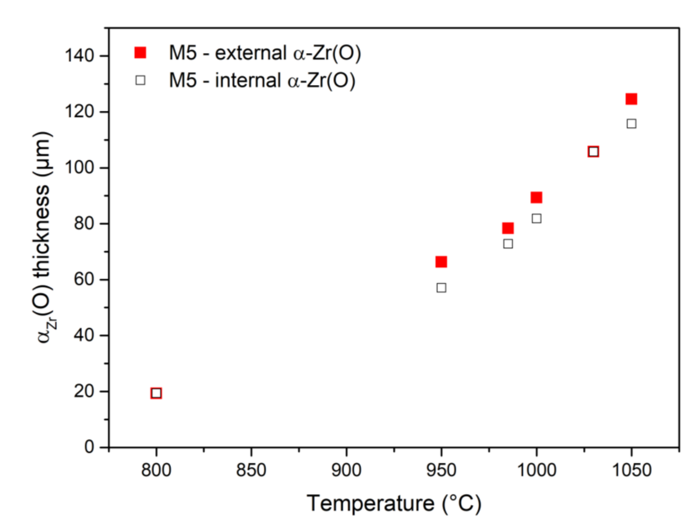


During oxide growth, the interface undulation reaches a maximum at 1030°C then decreases, with no sign of breakaway by 5000 s.

Oxide and α-Zr(O) thicknesses and hydrogen pick-up after steam oxidation for 5000 s.





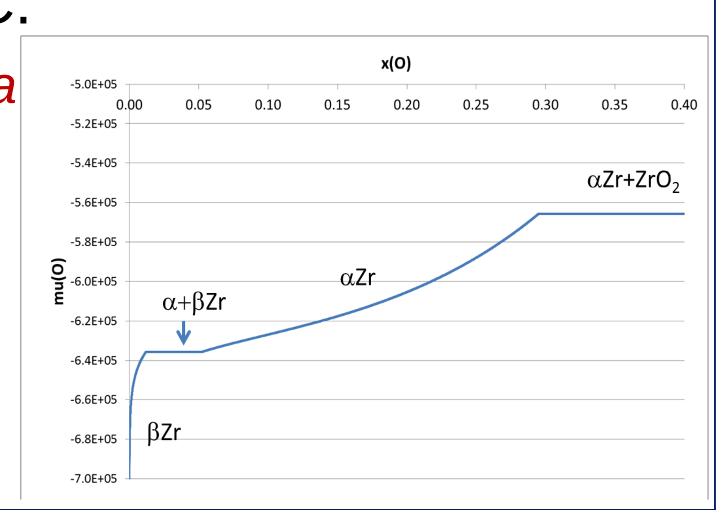


M5$_{Framatome}$ cladding exhibits low hydrogen uptake for all tested temperatures.

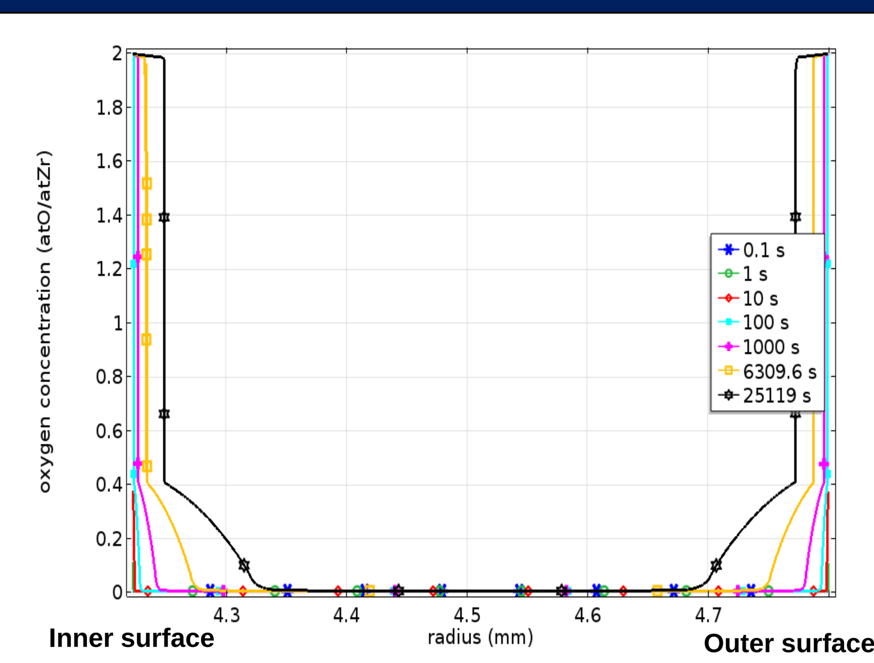
3. Diffusion modeling

Fick's equations were implemented in 1D-axisymmetry (whole cladding thickness) and coupled with in-house thermodynamic database. Diffusion coefficient of oxygen was fit to reproduce experimental data at 1000°C.

Oxygen chemical potential as a function of Oxygen fraction.

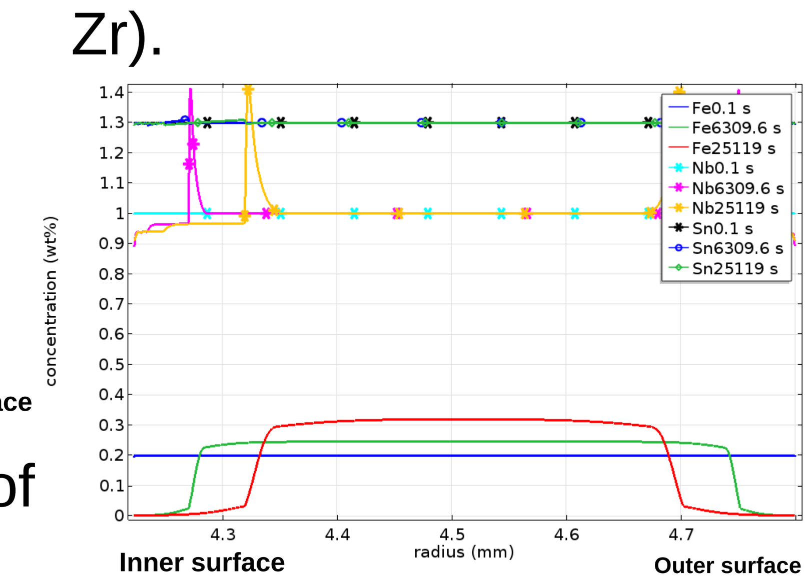


Demonstrates that the approximation of a dilute solid solution should not be assumed



Oxygen diffusion as a function of time during 1000 °C oxidation.

Diffusion of Nb, Fe, (and Sn) (independently) in the three phases (oxide, α-Zr(O), β-Zr).



4. Conclusion & Perspectives

- M5$_{Framatome}$ cladding does not show breakaway oxidation in these tests.
- Finite element modeling showed that iron is significantly pushed in the β-Zr phase, while Sn profile is almost flat and Nb migrates from oxide and α-Zr(O) towards β-Zr.

Future steps : To include strong coupling between the chemical potential of the various alloying elements (phase stabilization) and computations of stress and strains in the various phases.

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