ON-GOING R&D, UPDATE AND SOME PERSPECTIVES ON CHROMIUM COATED Zr BASED CLADDINGS FOR ENHANCED ACCIDENT TOLERANT FUEL OF LWRs

(CEA-EDF-AREVA FRENCH NUCLEAR INSTITUTE)

OECD-NEA 3rd meeting of the Expert Group on ATF of LWRs

Task Force 2 session

OECD-HQ – Issy les Moulineaux

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JC. Brachet et al. (CEA),
J. Bischoff et al. (AREVA),
A. Ambard et al. (EDF).

PROSPECTIVE STUDIES AT CEA ON ENHANCED ACCIDENT TOLERANT FUEL CLADDINGS FOR LWRS

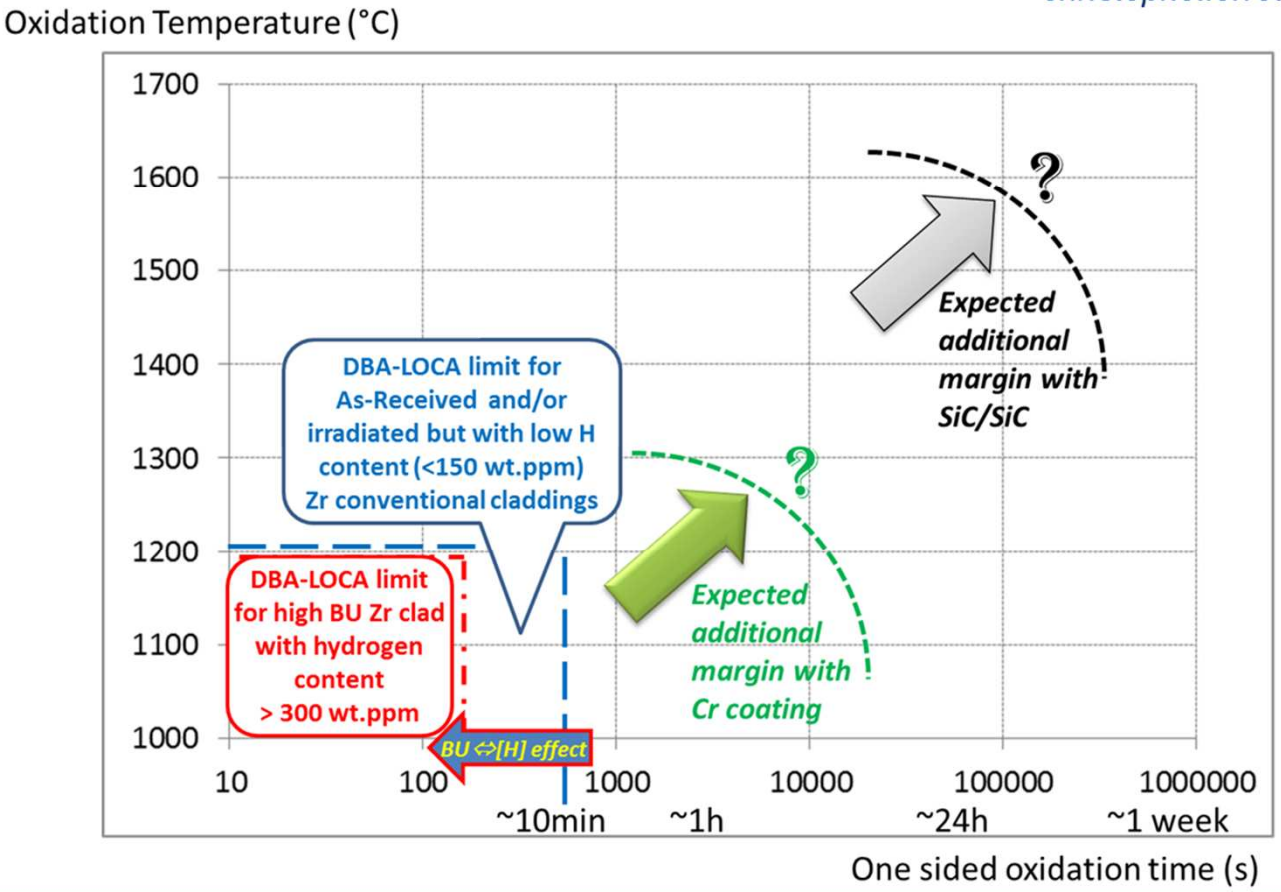
Short/mid-term R&D:

1- Optimized Cr coating on Zr clad

Break-through/long-term R&D:

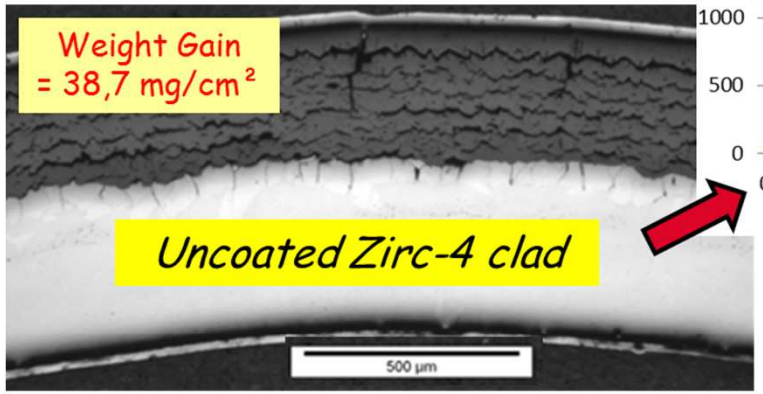
2- SiC_f/SiC + liner « sandwich-design » composite

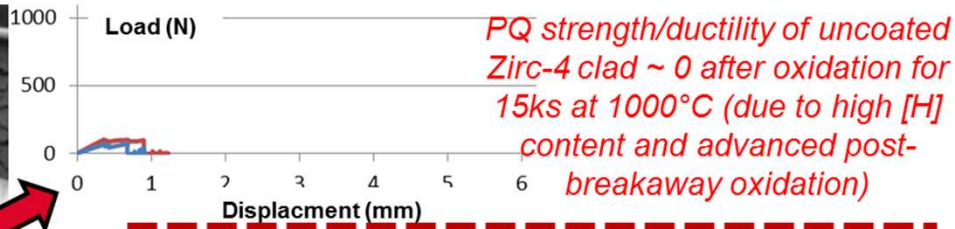
christophe.lorrette@cea.fr



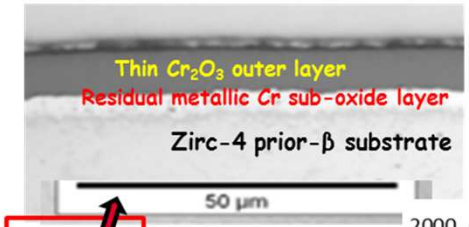
- ***Beyond DBA-LOCA oxidation times:***
  1000℃, >4h *=> "post-breakaway"*
  (150mm length Zircaloy-4 based clad segments)

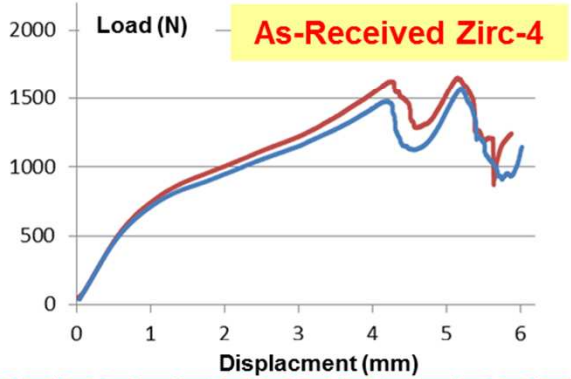
Post-Quench (PQ) Ring Compression Tests (RCT) at 20-135°C

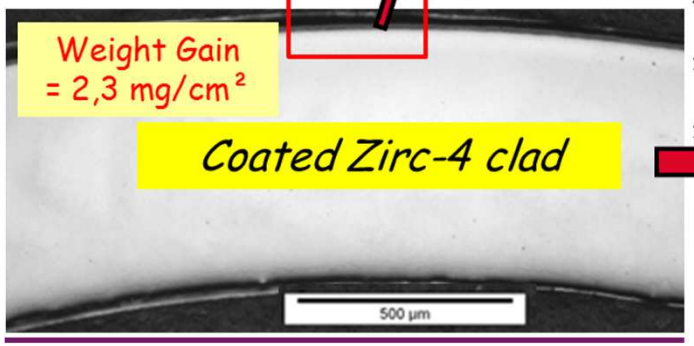


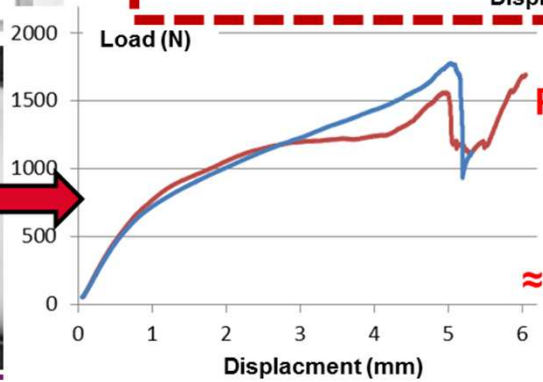


PQ strength/ductility of uncoated Zirc-4 clad ~ 0 after oxidation for 15ks at 1000°C (due to high [H] content and advanced post-breakaway oxidation)









PQ strength/ductility of coated clad that has experienced oxidation for **15ks at 1000°C ≈ As-received conditions (!)**

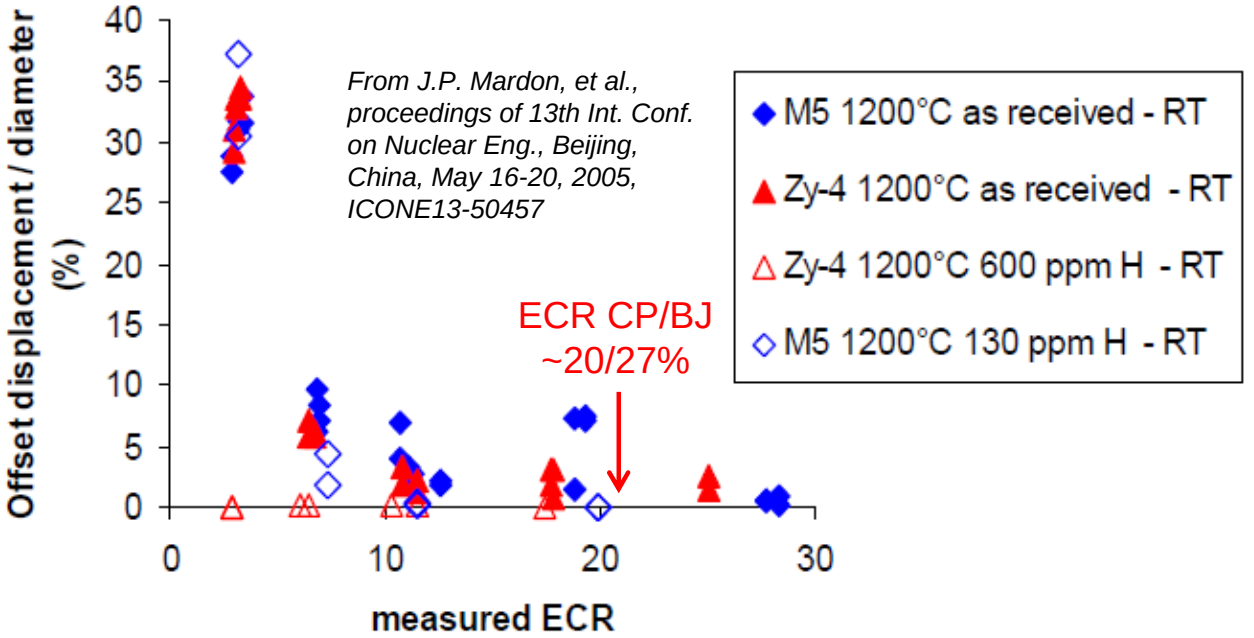
Slightly-beyond-DBA-LOCA-oxidation-time at 1200°C – 1500s :

(1) Results for uncoated Zirc-4 :

- One-sided oxidation
  ECR CP/BJ ~20/27%

⇒ Typical phase thicknesses:
~115µm for ZrO_2
and ~140µm for the α(O) layer

⇒ Post-Quenching residual ductility < 2%

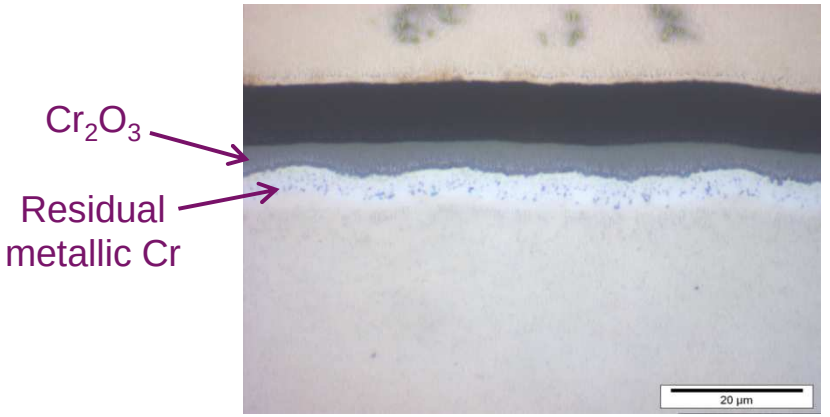


(2) Results for 6-8µm Cr coated Zirc-4:

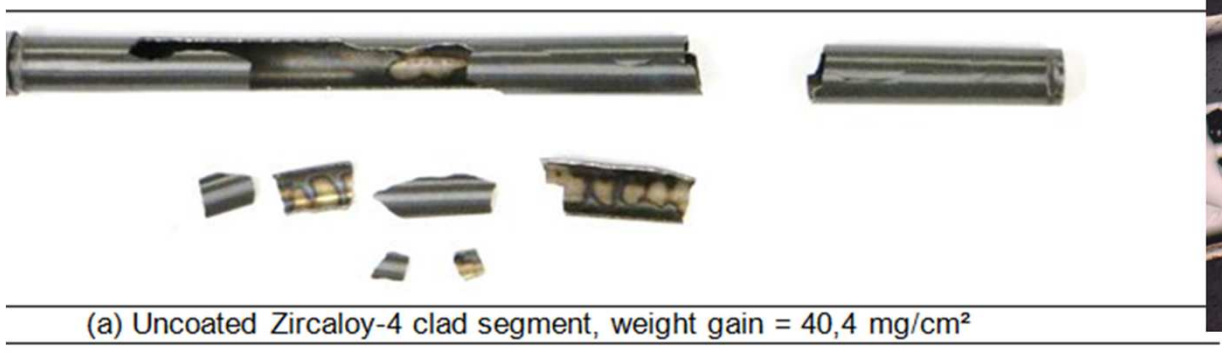
- Protective/sacrificial behavior of the coating

⇒ Negligible oxygen diffusion into Zr substrate (no ZrO_2,nor α(O) formation)

⇒ potential gain in the PQ residual ductility



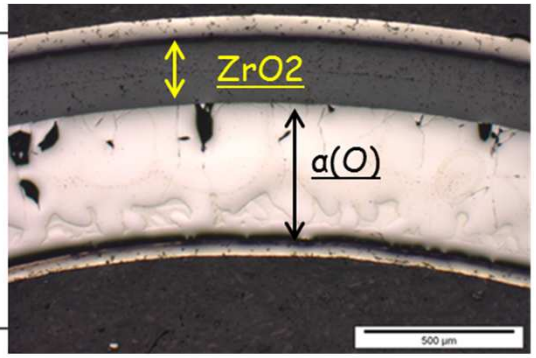
- ***More beyond DBA-LOCA oxidation times:***
  1200°C, >1h30 *(150mm length Zircaloy-4 based clad segments)*

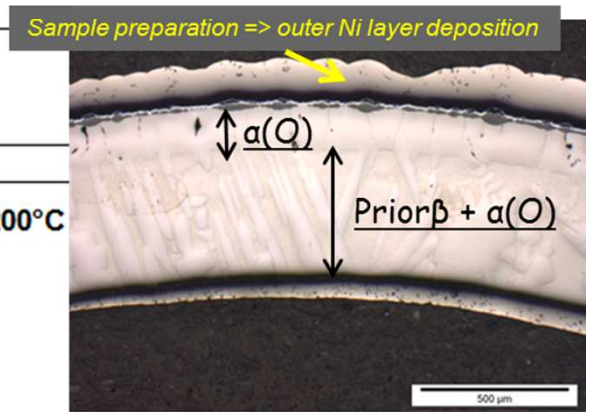


(a) Uncoated Zircaloy-4 clad segment, weight gain = 40,4 mg/cm²

(b) Coated Zircaloy-4 clad segment, weight gain = 11,4 mg/cm²

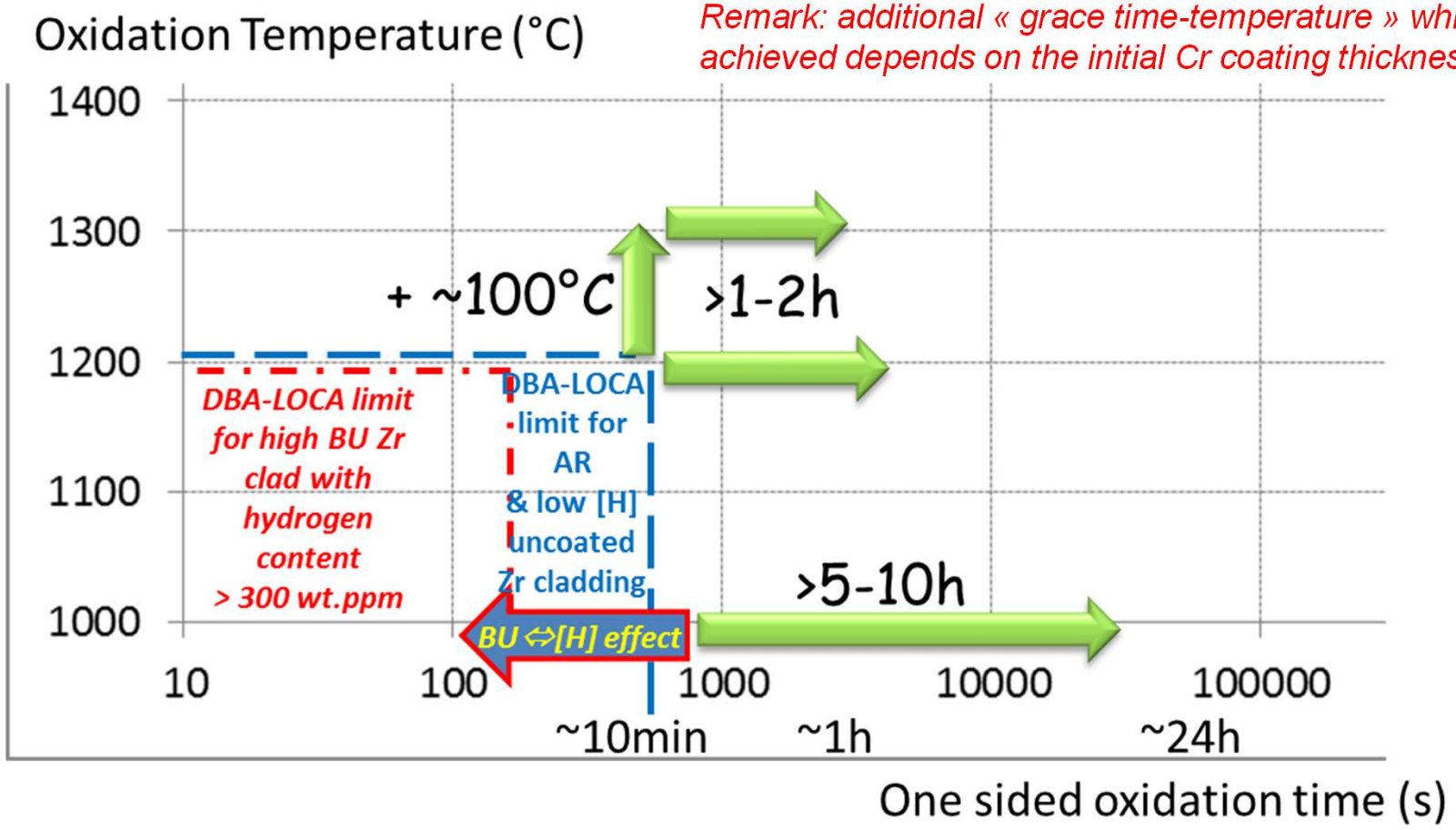
PQ Zircaloy-4 clad segments appearance after steam oxidation for 6000 s at 1200°C





Cr coatings improve the capacity of the HT oxidized cladding to maintain some residual ductility and to survive the final quenching for beyond-DBA-LOCA oxidation times at 1200°C, thus providing significant additional “grace period”:
=> 6000s is **ten times higher than the current DBA-LOCA maximum oxidation time at 1200°C** (~600s for as-received materials for one sided oxidation)

Expected additional HT steam oxydation time/temperature margins for fresh (~5-20µm thick) Cr coated Zirc-4 cladding vs. current DBA-LOCA limits



On-going

- On-going **autoclave testing** both at CEA and at AREVA (PWR pressurized water - 360℃, 100 bar – steam – 415℃)
- **Multi-scale metallurgical examinations** (XRD, SEM-EBSD, TEM observations of thin foils from FIB preparation…), micro/nano-hardness measurements…
- Additional **HT steam oxidation and post-quenching mechanical** tests
- **Transposition of deposition process to longer cladding tubes** (from 150 to 500 mm at first)
- **First irradiation performed on Cr coated Zr sheets specimen using charged particles** (Kr), thanks to CEA-Saclay "Jannus" triple-beams accelerator
  => on-going examinations (TEM, nano-hardness measurements…)

Mid/longer term Prospects

- **Ballonning/burst tests in LOCA** conditions (thanks to CEA "EDGAR" facility)
- **Other mechanical testing**: tensile, creep, internal pressure (CEA, AREVA…)
- **Longer corrosion tests** in nominal conditions (AREVA…)
- **Neutron irradiations** - Ex.: Halden, *CEA recommendations about fuel and cladding materials – including CEA Cr coated rods - to be included in the new experiments proposed for the 2015-2017 HRP, sent recently to HR board*