Long-term corrosion performance of T91 ferritic/martensitic steel at 400 °C in flowing Pb-Bi eutectic with ~10^{-7} mass% dissolved oxygen

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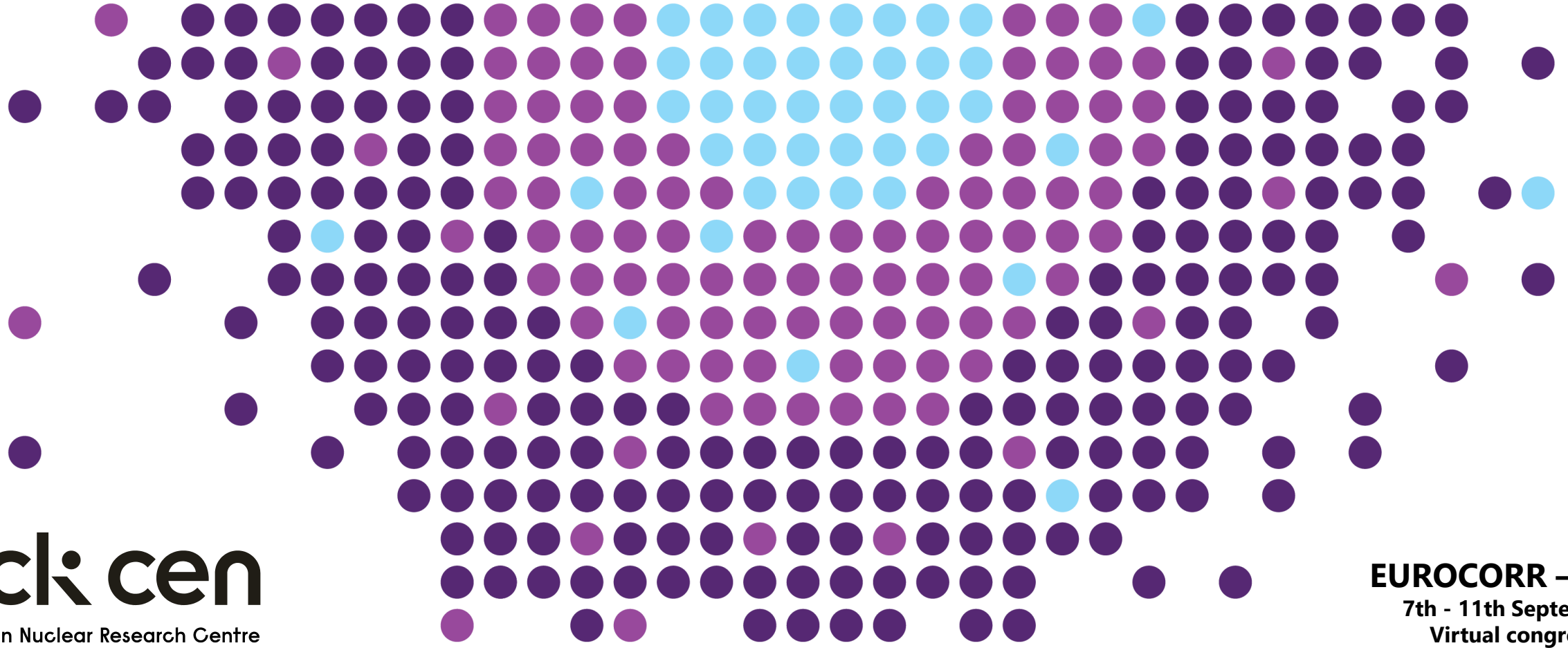

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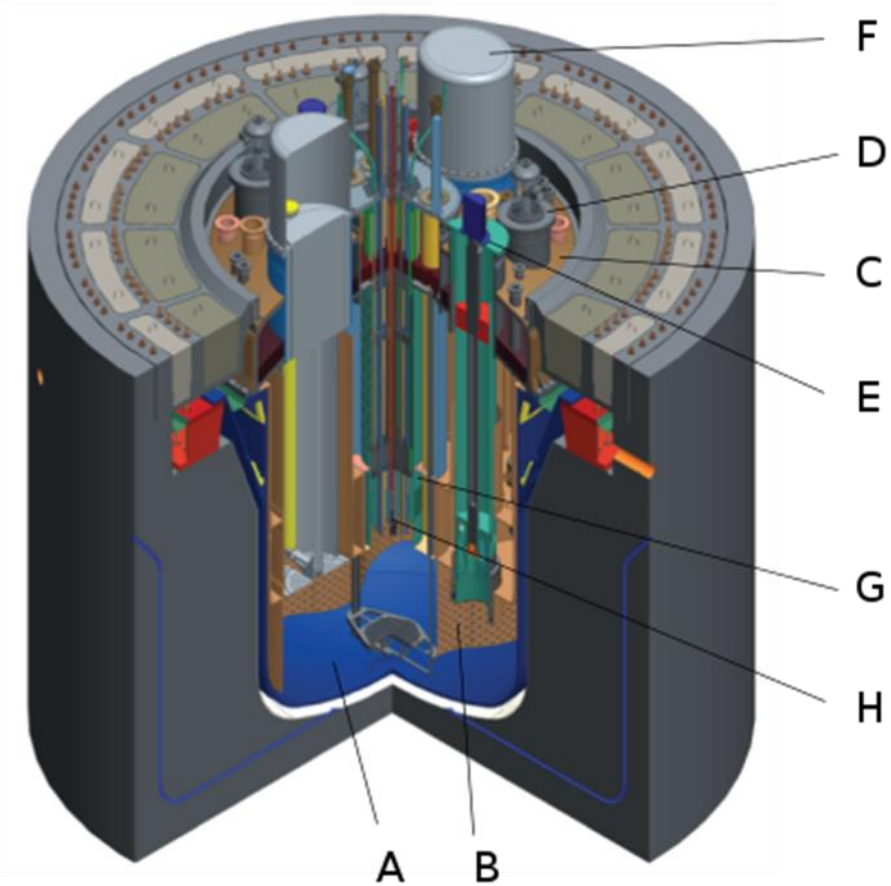
MYRRHA -

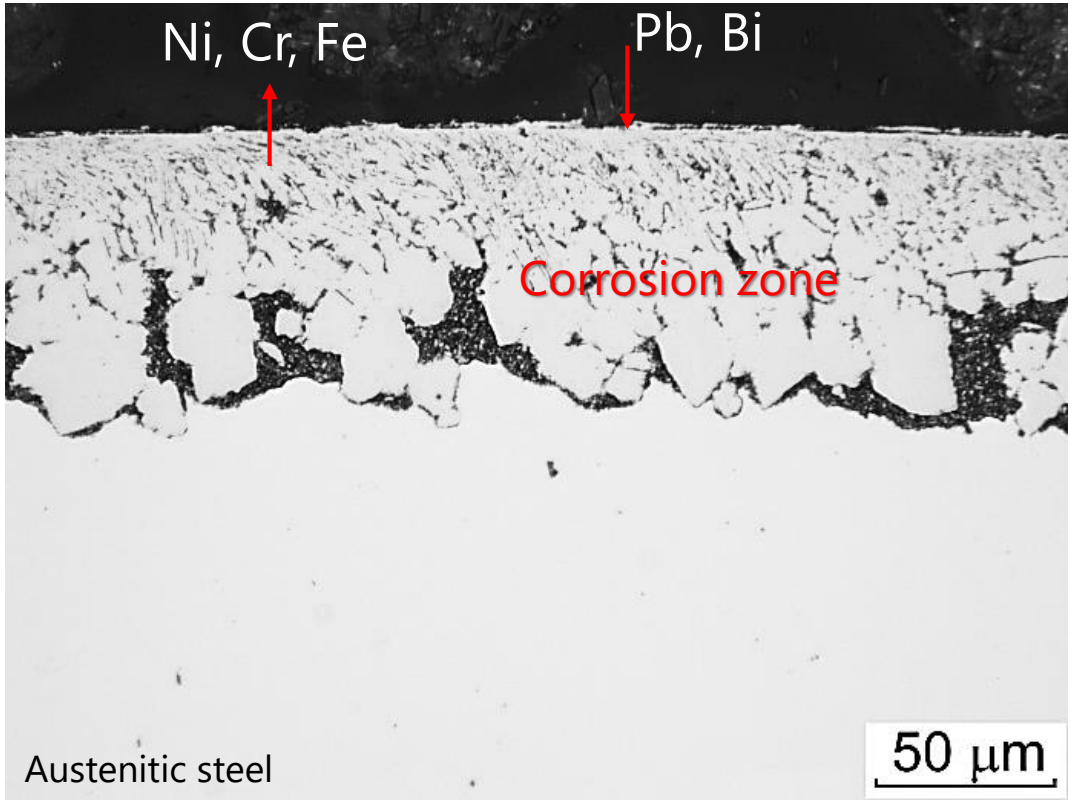
Multi-purpose h**Y**brid **R**esearch **R**eactor for **H**igh-tech **A**pplications



A. Reactor vessel
B. Diaphragm
C. Reactor Cover
D. Primary Heat Exchanger
E. Primary Pump
F. In-Vessel Fuel Handling Machine
G. Core Barrel
H. Reactor core

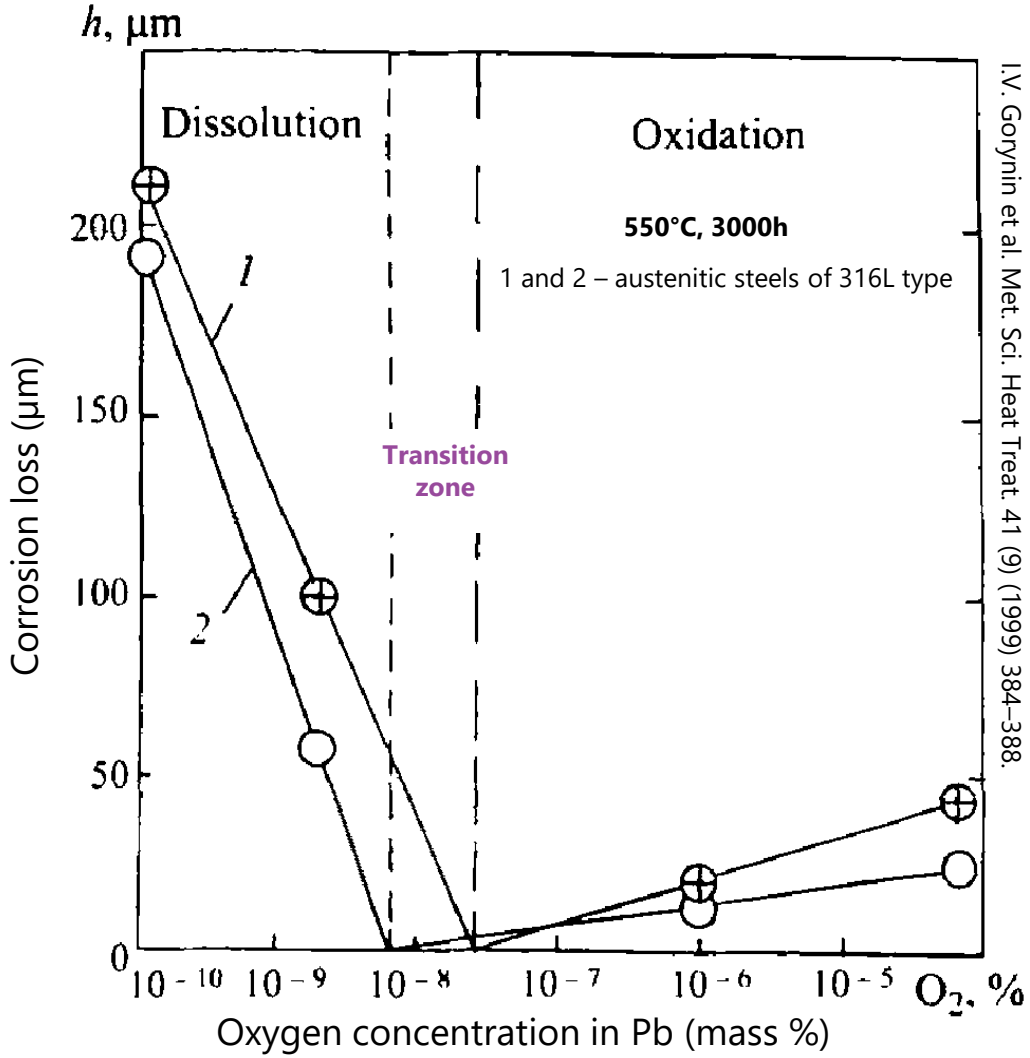
Pb-Bi eutectic – spallation target and coolant

Corrosion



Pure Pb-Bi de-alloys intensively steels at high temperatures

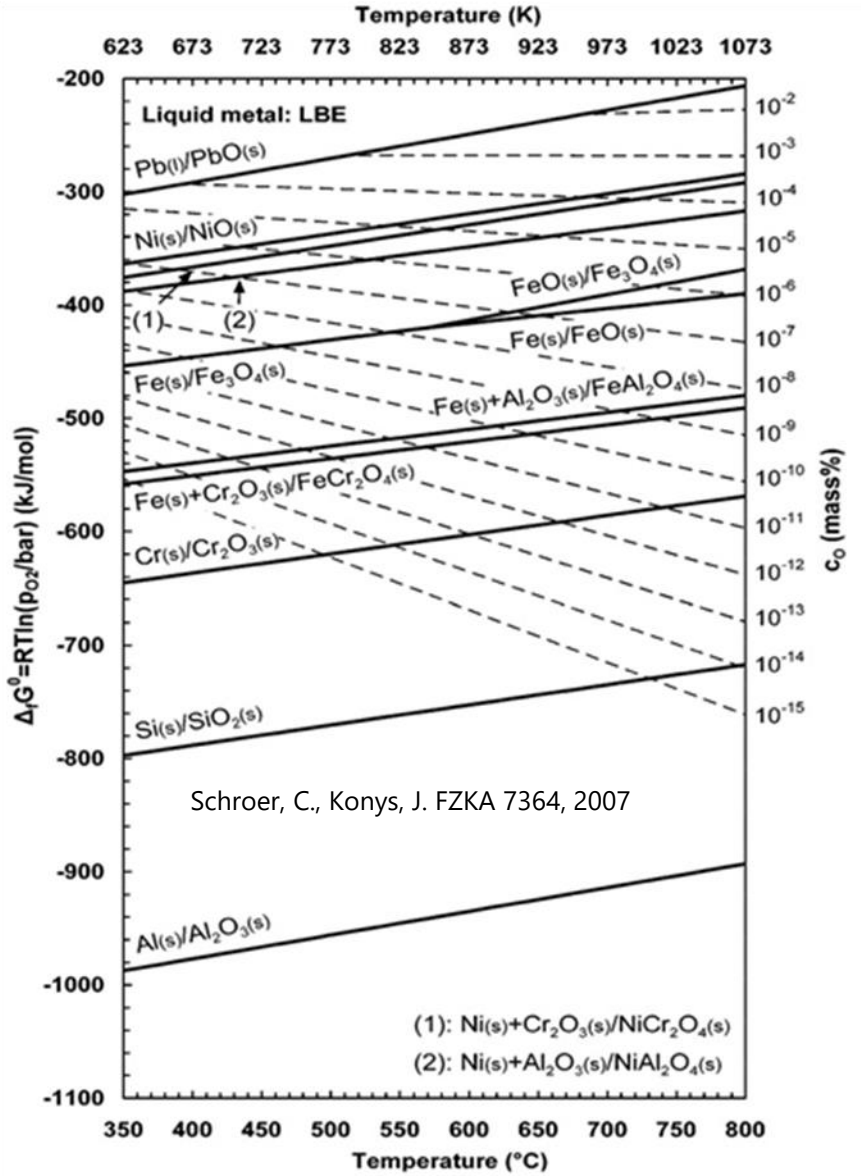
Corrosion mitigation approach



I.V. Gorynin et al. Met. Sci. Heat Treat. 41 (9) (1999) 384–388.

In-situ oxygen addition into Pb-Bi

Thermodynamic



Schroer, C., Konys, J. FZKA 7364, 2007

- Pb-Bi dissolves and transports oxygen
- Si, Cr, Fe form stable oxides in Pb-Bi[O]

❑ General aim

Corrosion performance of steels under MYRRHA conditions

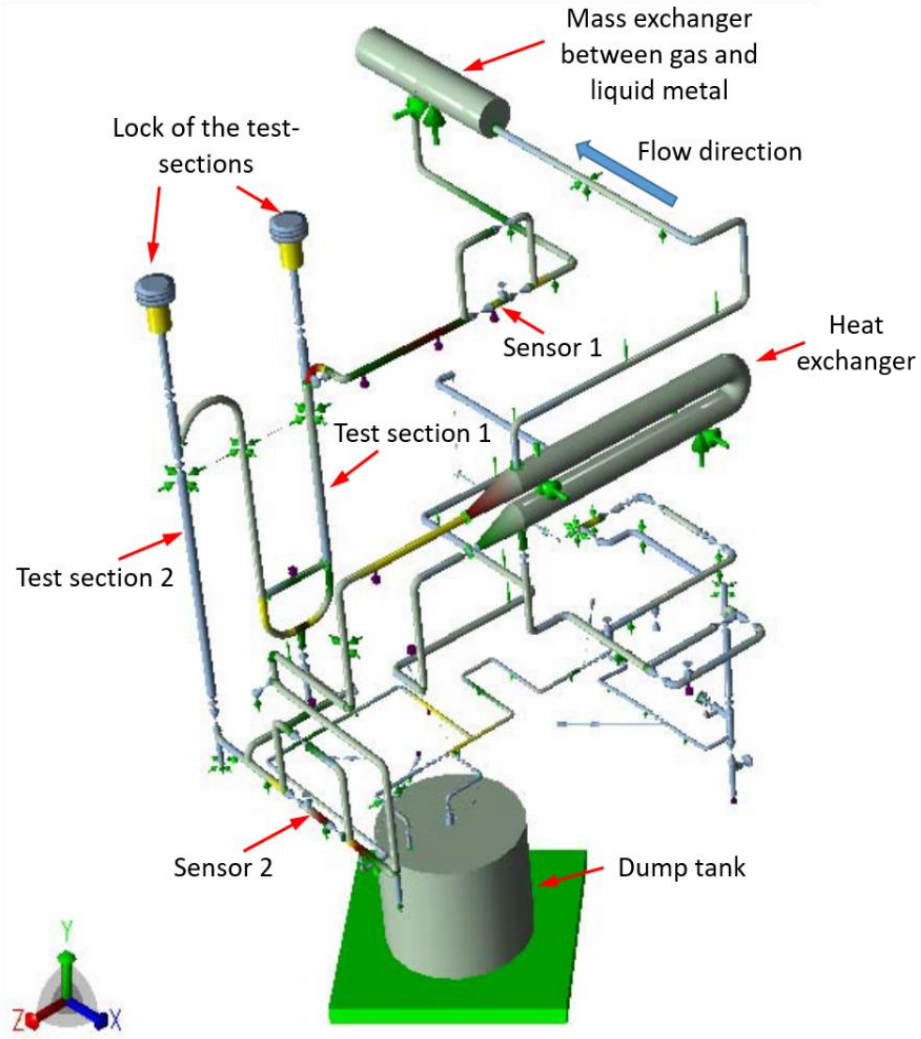
❑ Main task

Optimum parameters to minimize corrosion

❑ Current activity

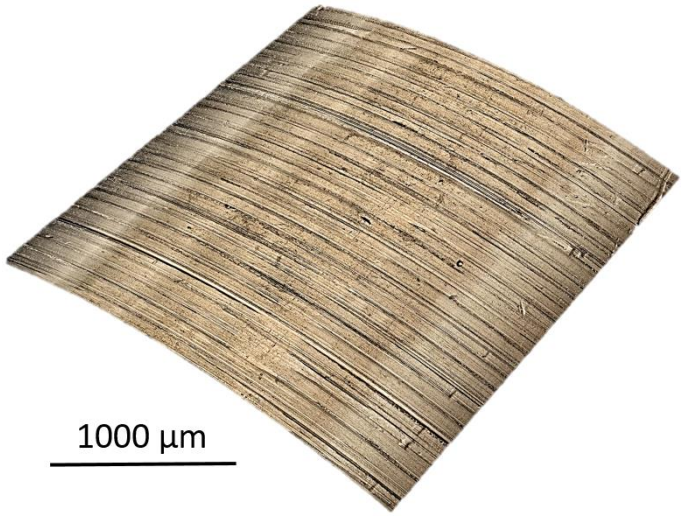
Reliable quantitative data on corrosion of steels

CRAFT forced-convection Pb-Bi loop



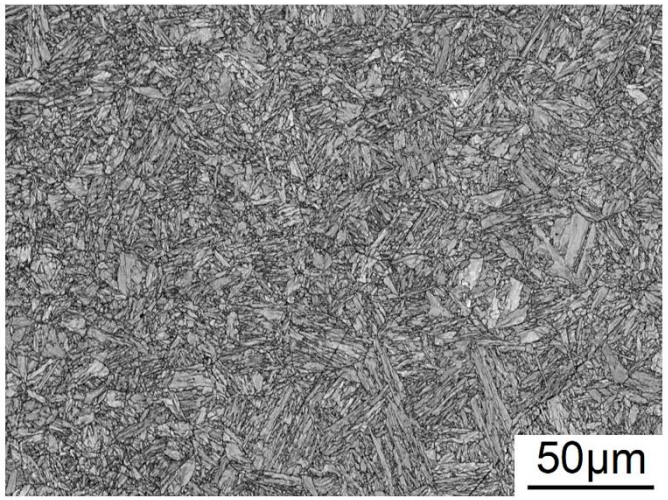
Corrosion **R**esearch for **A**dvanced **F**ast reactor **T**echnologies

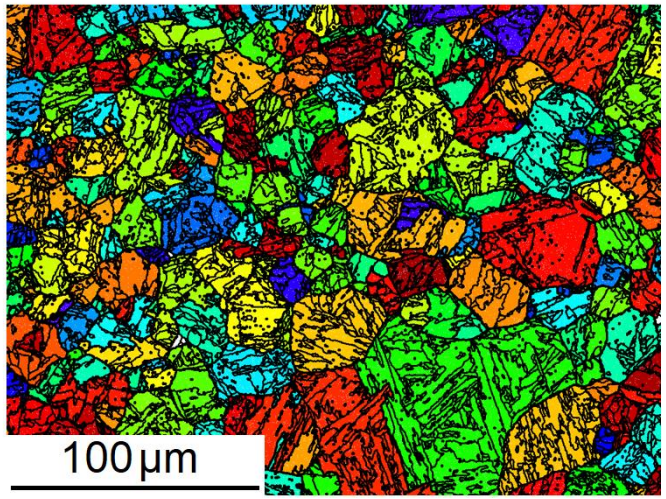
Fe-9Cr ferritic-martensitic steel T91



Cylindrical samples:
- Ø8 × 35 mm

Surface finishing:
- fine turning
- spiral grooves:
  - width 80 µm
  - depth 0.9 µm.





Thermal treatment:
- normalization 1050 °C/15 min
- tempering at 750 °C/45 min

Microstructure: tempered martensite
- precipitates:
  - $M_{23}C_6$ (M – Cr, Fe, Mo)
  - MX (M – V, Nb and X - C, N)

Microstructure reconstructed by ARPGE program:
- grain size ~20 µm - ASTM No 8.0 (E112–13).

Results

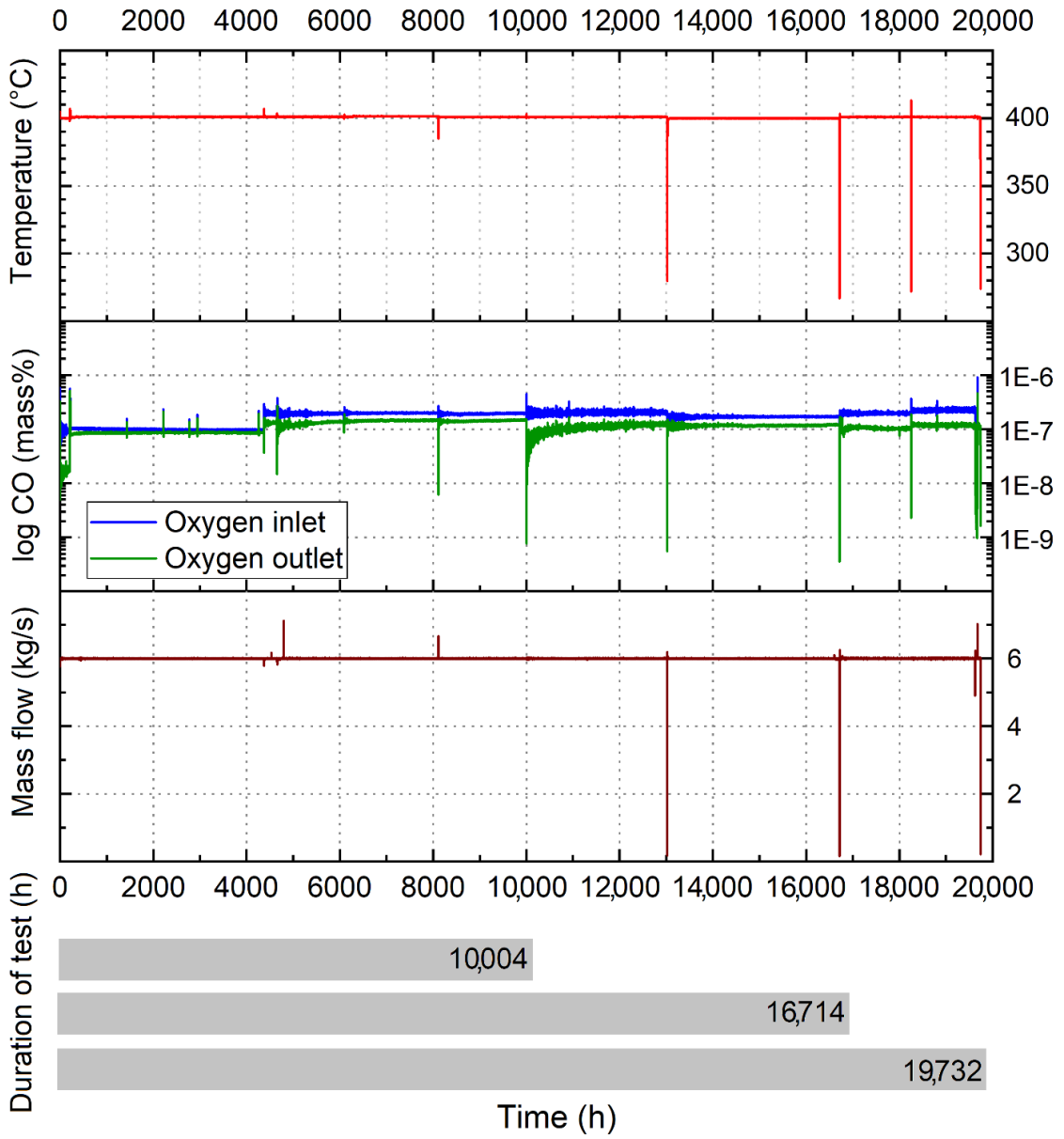
Test parameters

T= 400 °C

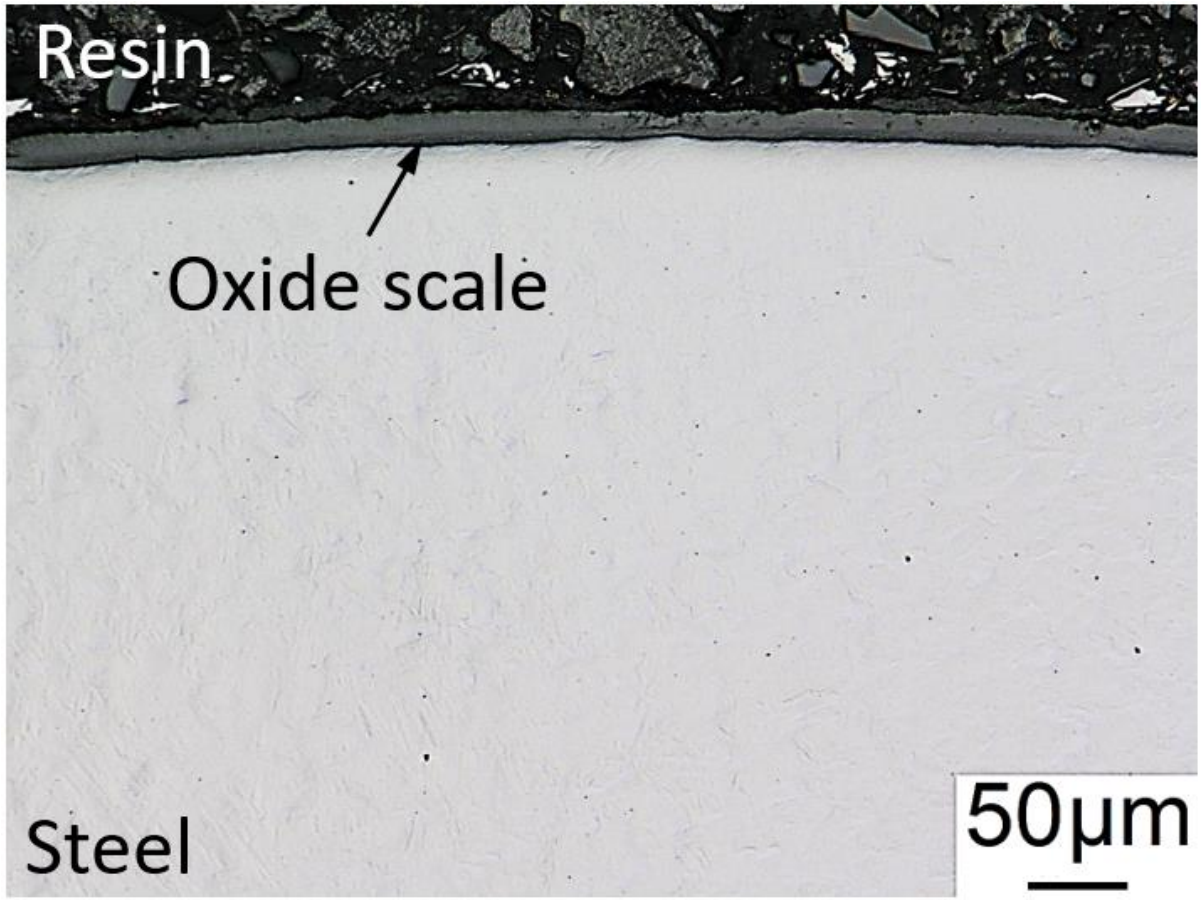
$C_{O[Pb-Bi]}$= 2×10^{-7} mass%O

Flow velocity= 2 m/s

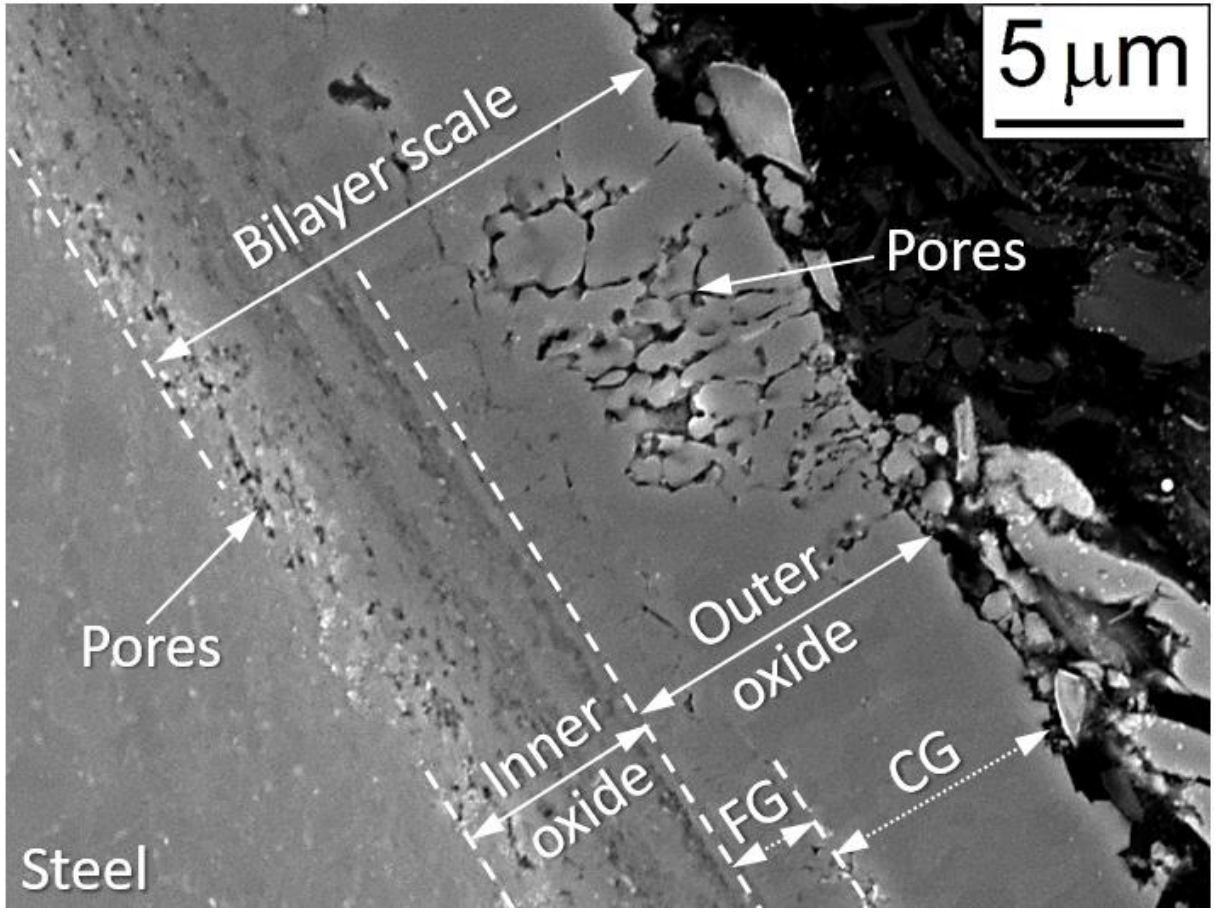
Time~ 20,000 h



General uniform oxidation



Features of oxidation

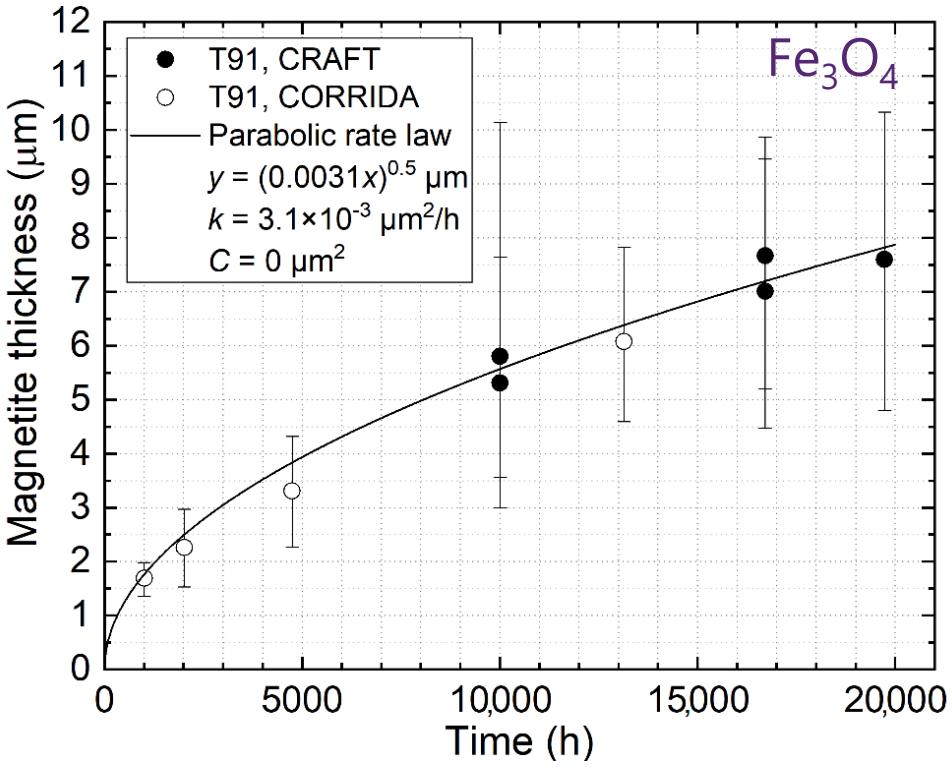


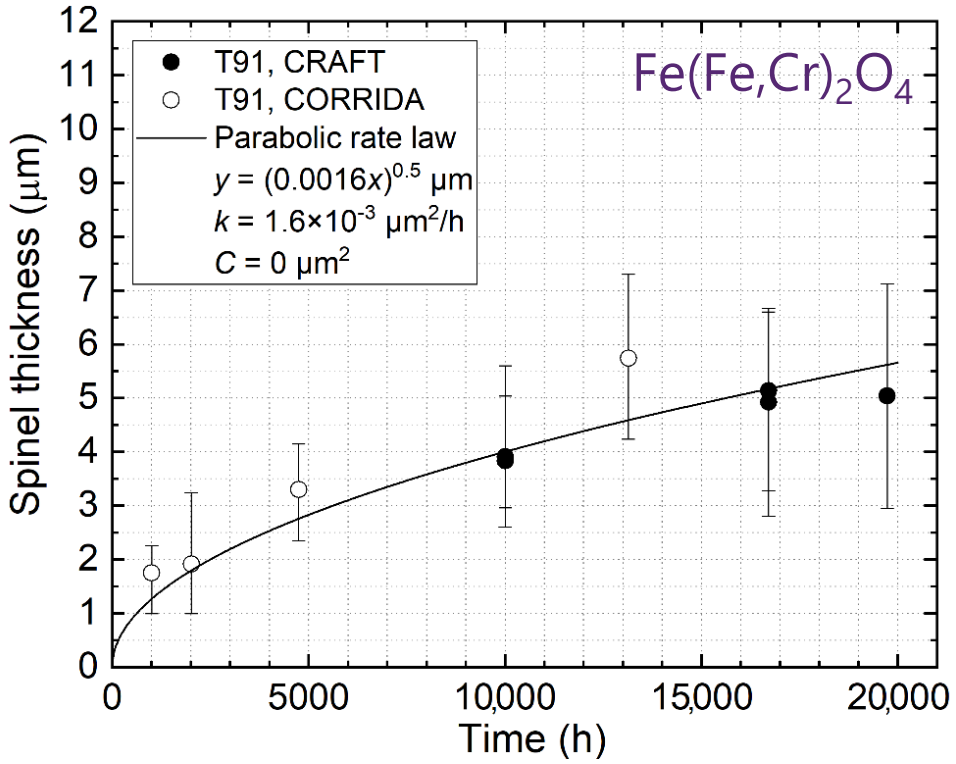
Bilayer magnetite scale: $Fe_3O_4/Fe(Fe,Cr)_2O_4$

Kinetics of oxidation

Parabolic rate law

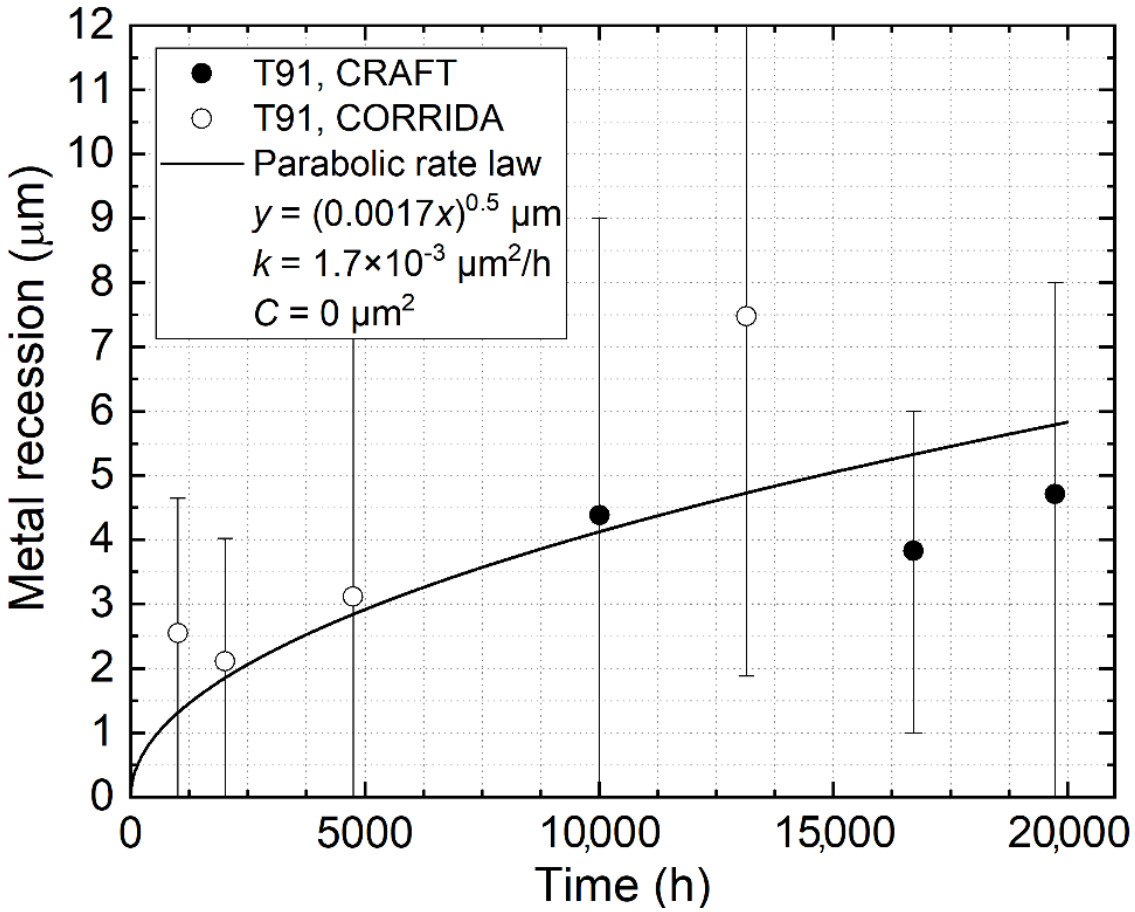
$$y^2 = k\,t + C$$





Data from CRAFT and CORRIDA loops agree well

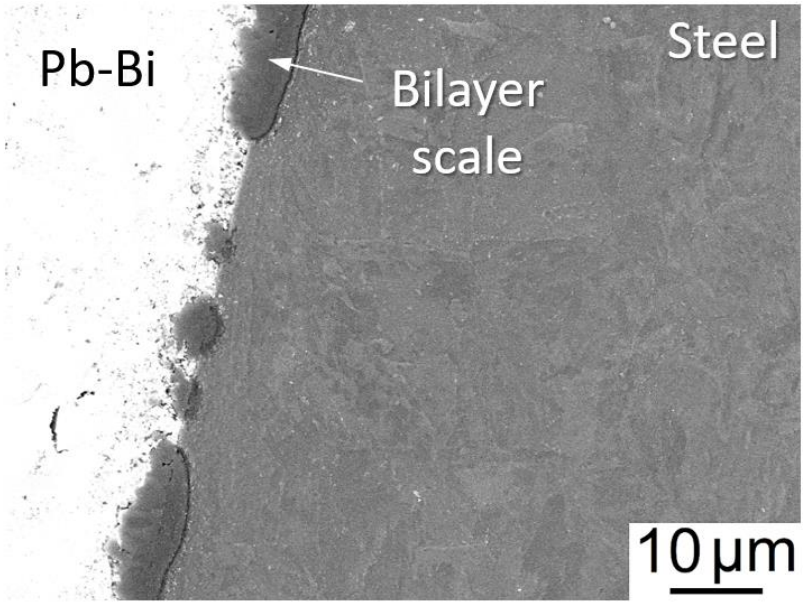
Kinetics of oxidation

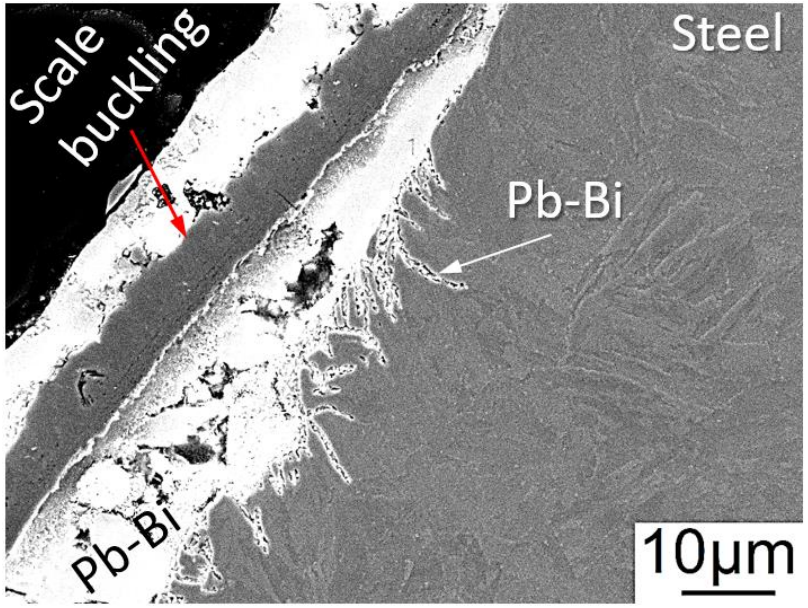


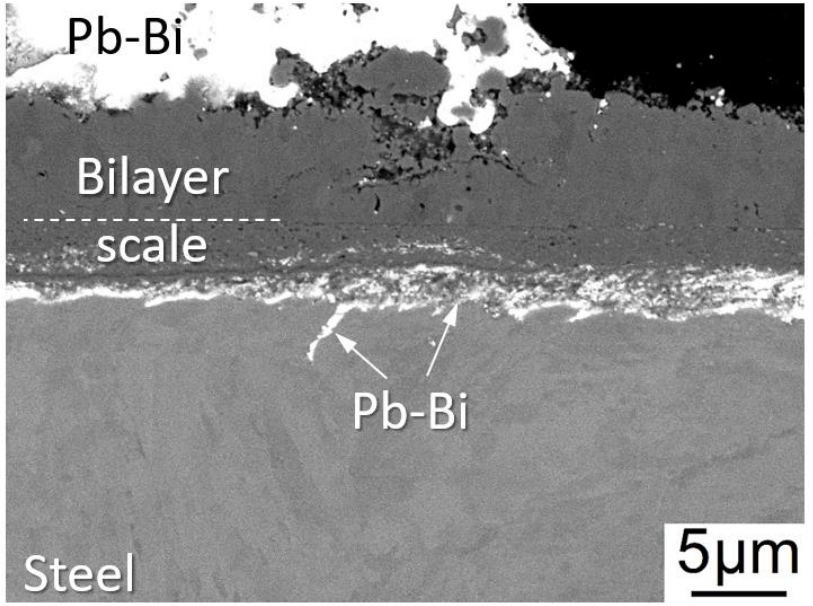
Corrosion rate ~ 4 µm/year

Features of oxidation

- Local incomplete oxidation
- Local buckling of scale
- Penetration of Pb-Bi to the scale/steel interface





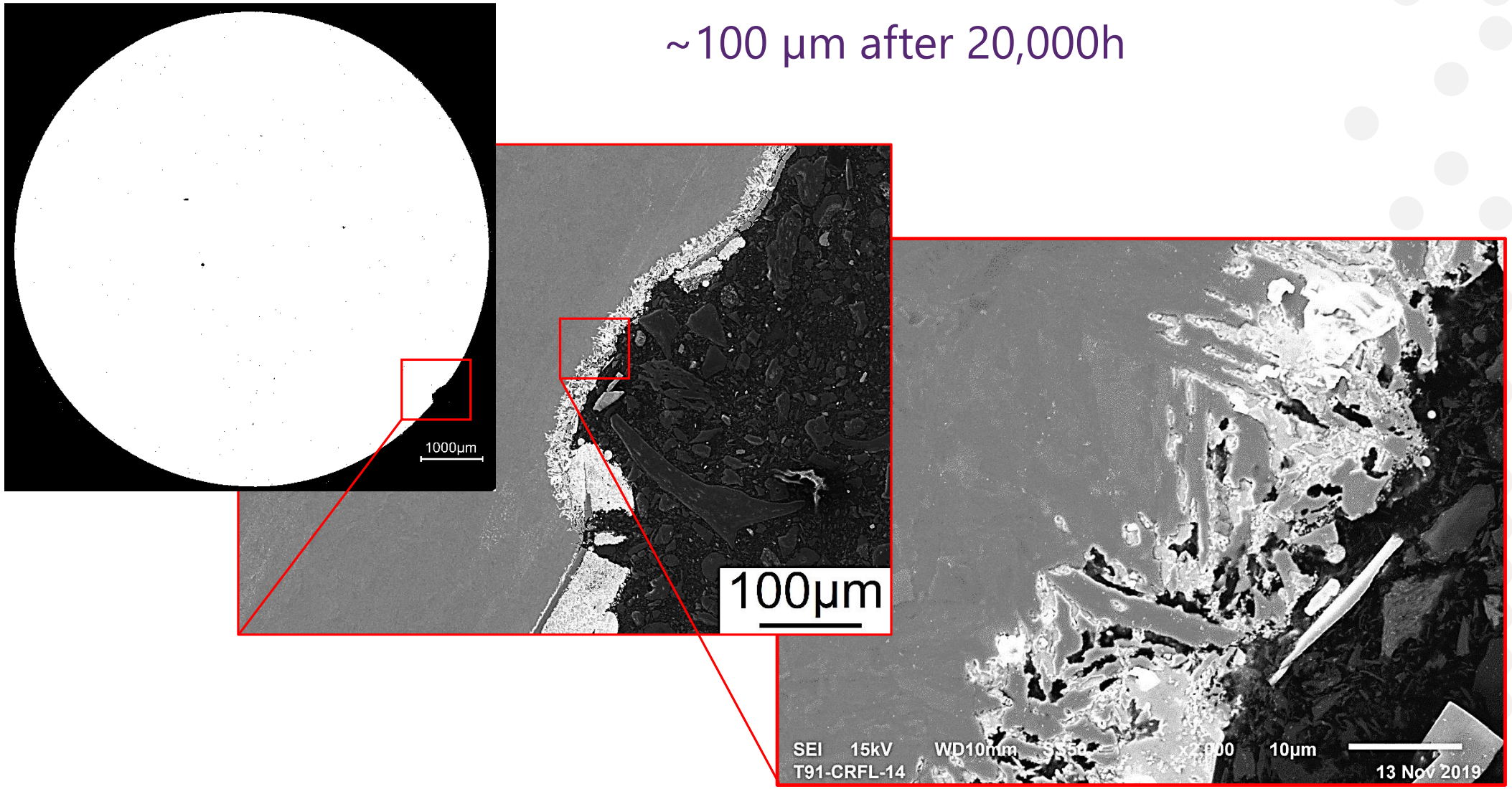


Surface examinations

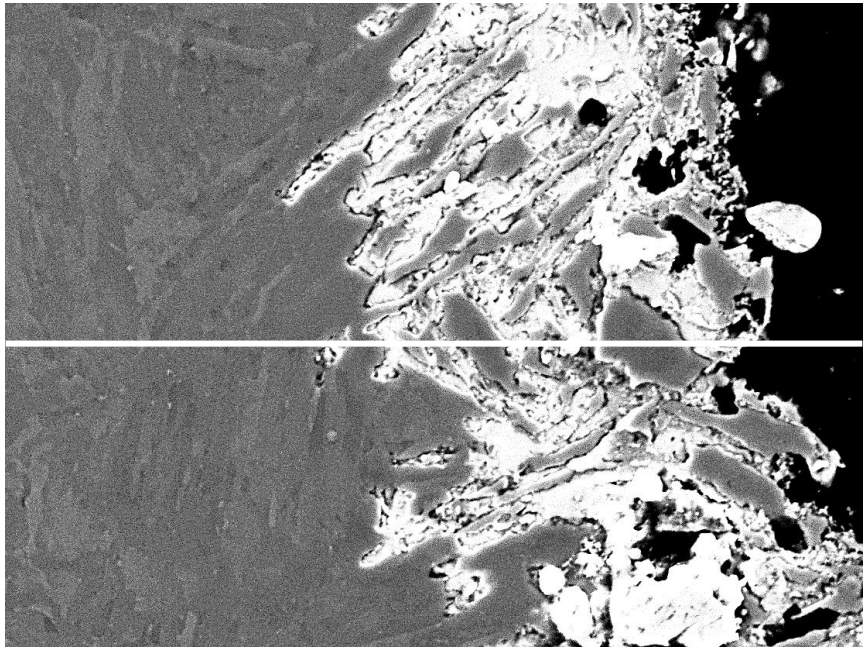
Segment of samples cleaned from Pb-Bi

Localized dissolution corrosion attack:

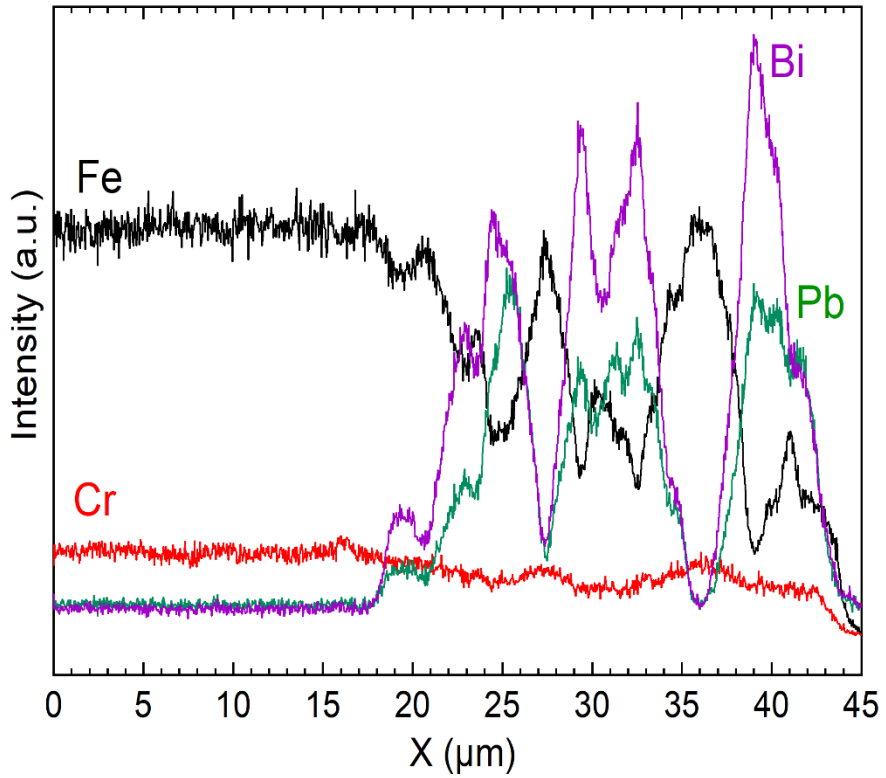
~100 µm after 20,000h



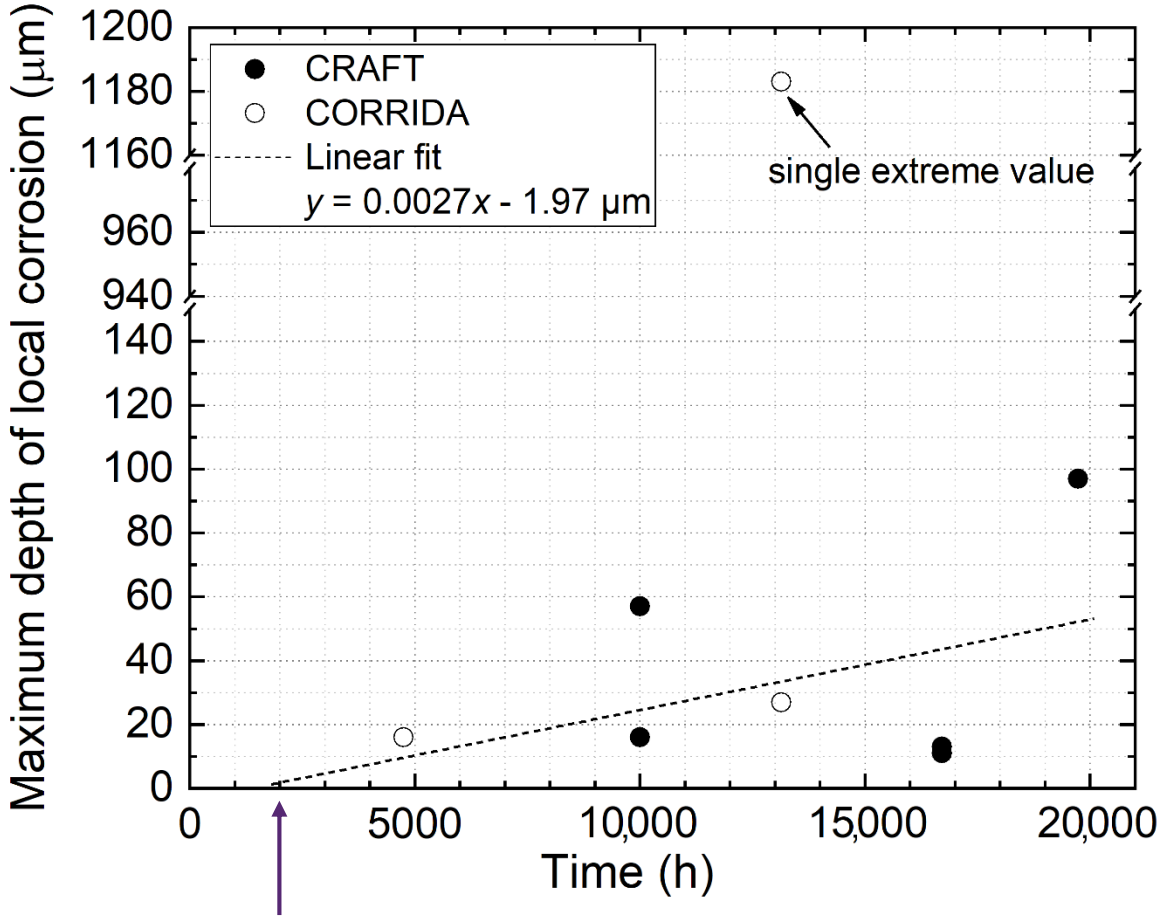
Localized dissolution corrosion attack



Non-selective dissolution



Kinetics of local dissolution



Incubation time ~ 2000 h

Corrosion rate ~ 20 µm/year

Summary

Corrosion:

- ❑ T91 steel showed major oxidation - bilayer scale Fe_3O_4 / $Fe(Fe,Cr)_2O_4$
- ❑ Corrosion rate due to oxidation ~ 4 µm/year;
- ❑ Localized dissolution corrosion rate ~ 20 µm/year;

CRAFT loop operation:

- ❑ Long-term (20,000 h) and stable operation with target parameters is achieved for the CRAFT loop in this experimental campaign;

CRAFT + CORRIDA loops:

- ❑ Complimentary data are obtained in different installations.

Concluding remarks

1. Applicability of in-situ oxygen addition to liquid Pb-Bi in order to stimulate oxidation of steel and avoid dissolution is demonstrated in this work based on the long-term test;
2. Local degradation of Fe-based oxide scale with time is an issue;
3. Improvement of the durability of oxide layers is a main challenge for further investigations.

More details in: V. Tsisar, et al. Corrosion Science 174 (2020) 108852

Thank you for your attention!

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