



Corrosion and decommissioning

D. Feron, F Legendre, Marion Le Flem, Stéphane Gossé, Pierre Laghoutaris

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CORROSION & DECOMMISSIONING

Damien Féron, Fabrice Legendre, Marion Le Flem, Stéphane Gossé, Pierre Laghoutaris

Den-Service de la corrosion et du comportement des matériaux dans leur environnement (SCCME), CEA, Université de Paris-Saclay, Gif-sur-Yvette, France

NUPP 2018 - 2nd International Conference on Nuclear Power Plants: Structures, Risk & Decommissioning

Croydon, London, UK / 11-12 June 2018

Introduction / background

Thermodynamics (corium)

ATTILHA setup

Database

Material behavior & irradiation

Experimentation

Carbon & Stainless steels

Long term issues

Atmospheric corrosion



Chooz

Nuclear facility life cycle

- ❑ Siting of nuclear facility
- ❑ **Design of nuclear facility**
- ❑ **Construction & commissioning**
- ❑ **Operation, management & maintenance**
- ❑ **Severe accident management**
- ❑ **Decommissioning of nuclear installations**
- **Nuclear waste management**



Bold type: corrosion issues

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Decommissioning of nuclear reactors

- ❑ 110 commercial power reactors, 48 prototypes and over 250 research reactors have been retired from operation.
- ❑ About 17 of these had full decommissioning.
- ❑ 12 reactors closed following an accident/incident, including 8 (partial) core melts:
 - TMI (USA-1979)
 - Chernobyl (Ukraine – 1986)
 - Fukushima Daiichi (Japan, 2011)
- **Corrosion issues**
 - During the dismantling when it is not immediate
 - Specific issues after core melt
 - Nuclear waste interim & geological storages

Importance of corrosion management during decommissioning

- Structural materials have been chosen for reactor standard operation, investigated for their behavior during accidents, but not for decommissioning conditions while they still have functions (mechanical, tightness,...)
- Long term issues (deferred dismantling)
- After core melt:
 - knowledge of the corium interactions, fuel debris and fission products (physico-chemical status) & behaviour
 - corrosion & radiations
 - behavior of key components after accident conditions

⇒ Development of fundamental knowledge

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Subjects related to decommissioning investigated at the CEA “Corrosion Service”

Thermodynamics (corium)

Experimental facilities

Database

Material behavior & irradiation

Experimentations *and radiolysis calculations*

Carbon steels & Stainless steels

Long term issues

Atmospheric corrosion / *Microbial Influenced corrosion*

Corrosion modelling & simulation

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HIGH TEMPERATURE THERMODYNAMIC TOOLS FOR THE INVESTIGATION OF CORIUM BEHAVIOR

Experimental setup

Thermodynamic modeling

FROM RESEARCH TO INDUSTRY

cea den In-vessel & Ex-vessel Core Melts

Issue: core melt configurations

In-vessel corium Interactions:

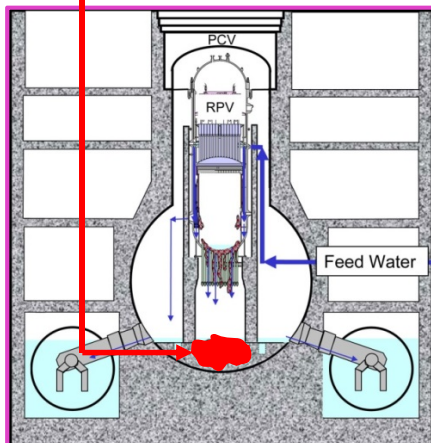
MOx + Zircaloy + stainless steel + Inconel + B₄C + Fission Products

“Prototypic” in-vessel corium system: U-Zr-Fe-O

The **Molten Corium Concrete Interaction** starts:

- The components of the concrete (CaO, SiO₂, Al₂O₃, MgO, H₂O, CO₂) are added to the already complex in-vessel system (U-Zr-O-Fe)
- As a first approximation the **Fe-U-Zr-Al-Ca-Si-O** system is representative of an ex-vessel corium

Fukushima



A better thermodynamic description of the in & ex-vessel corium sub-systems is needed to improve the thermal and thermo-hydraulics codes accuracy

Need of exp. data at very high temperatures
1500°C ≤ T ≤ 3200°C

Development of a specific exp. setup

Advanced Temperature and Thermodynamics Investigation by a Laser Heating Approach



ATTILHA: Development of a setup for high solid/liquid transitions

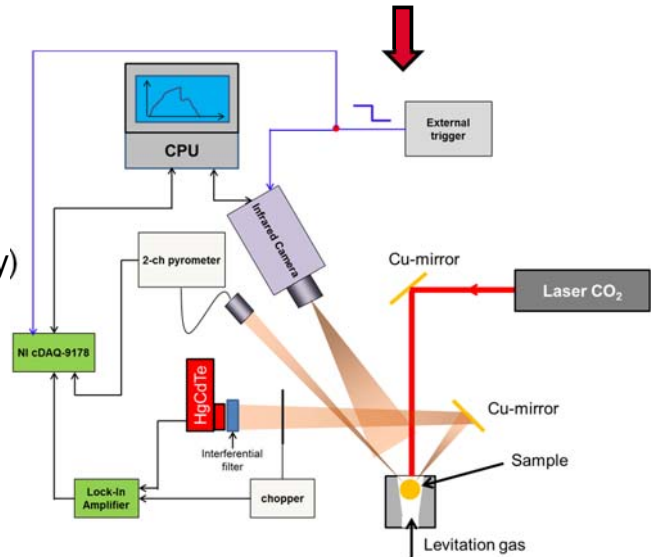
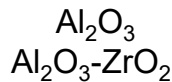
2 different ATTILHA configurations: **Contactless** → Aerodynamic levitation
Containerless

Acquisition of data on corium systems

- Phase diagram data (liquidus, solidus)
- Thermo-radiative properties (IR emissivity)

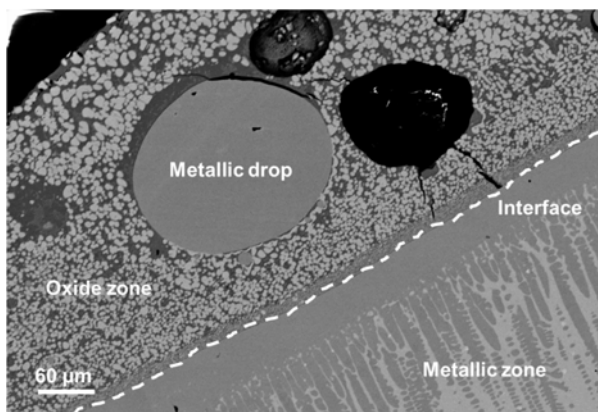


All the instruments are synchronized
Validation on transitions in oxide systems



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Miscibility gap in the Fe-Zr-O system



New result

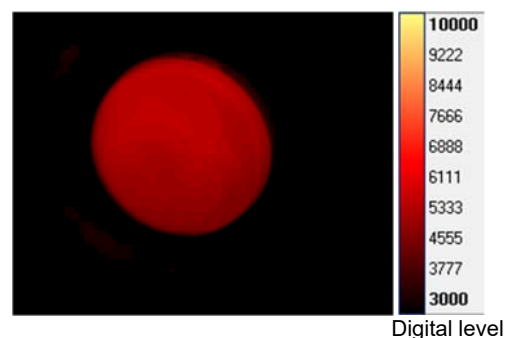
Starting composition: $\text{Fe}_{0.85}\text{Zr}_{0.15}$

↓
Levitation gas: He

Composition moved into the ternary Fe-Zr-O system

tie-line: $\text{Fe}_{0.97}\text{O}_{0.03}$ – $\text{Fe}_{0.05}\text{Zr}_{0.32}\text{O}_{0.63}$

Infrared camera footage



Real speed 200 Hz
Video player 12.5 Hz

Observation of dynamic phenomena:

→ **Formation of 2 liquids in-situ**

Estimation of the emissivity ratio between the two liquids

→ $\epsilon_{\text{oxide}} \sim 2\epsilon_{\text{metal}}$

MATERIAL BEHAVIOR & IRRADIATION

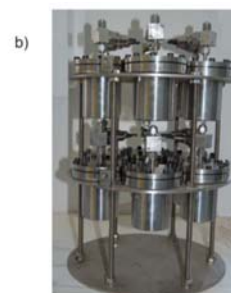
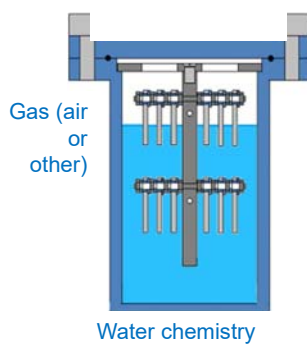
- EXPERIMENTATION

- CARBON & STAINLESS STEELS

CORROSION & IRRADIATION

Experimental facility: CASIMIR

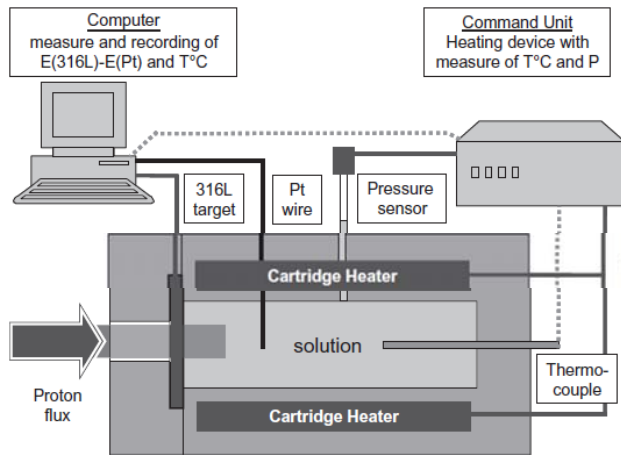
Irradiation gamma performed in the POSEIODON pond, at CEA-Saclay



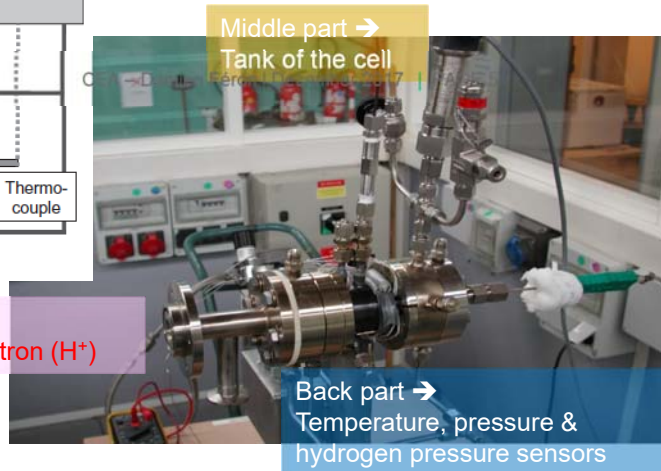
S. Perrin & al., LTC2016, Toronto, 2016



High temperature and high pressure electrochemical cell



Temperature → 300 (°C)
Pressure → 90 (bar)
Hydrogen pressure → 400 (mbar)
Free potential → E_{316L} vs. Platinum (V)

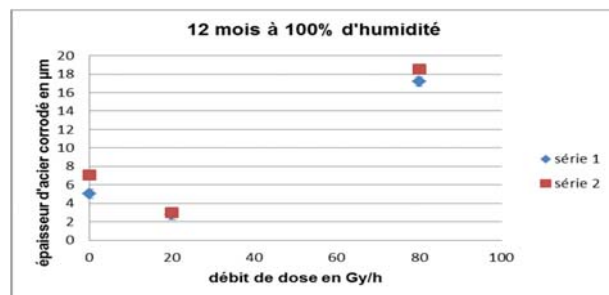
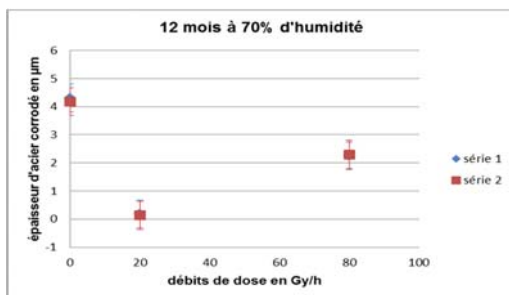


Brevet n° 08 56970
du 15.10.2008, CEA (DEN & DSM)-LSI

ATMOSPHERIC CORROSION OF CARBON STEEL

Corrosion of carbon steel (A37) in a closed humid atmosphere

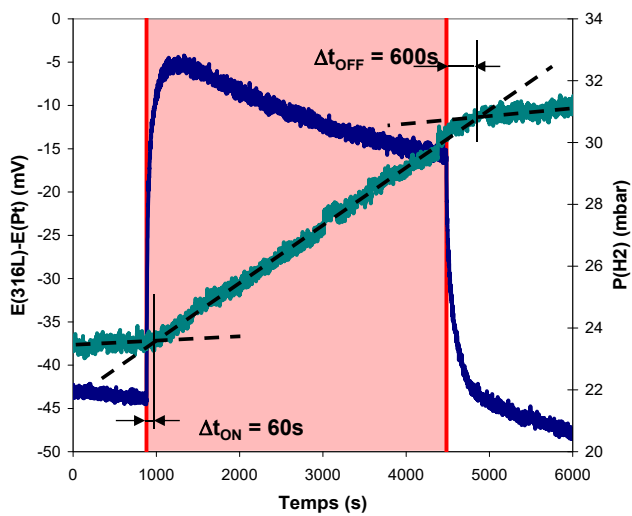
Influence of the humidity at temperature 80°C,
and of irradiation gamma (20 & 80 Gy.h⁻¹)



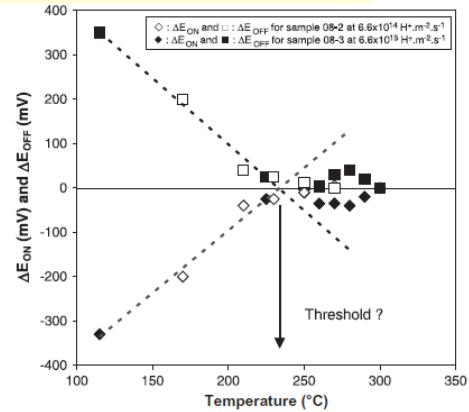
S. Perrin & al., LTC2016, Toronto, 2016

Generalized corrosion, but not uniform
Lower corrosion rate at 70% HR than at 100% HR, with or without irradiation
Higher corrosion rate at 100% HR and 80 Gy.h⁻¹

Effects of radiolysis on the electrochemical behaviour of stainless steels



Potential and hydrogen partial pressure evolution at 300°C, proton flux = $6.6 \times 10^{11} \text{ H}^+ \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$



- PWR water chemistry (300°C) /316L
- in situ measurement of the radiolytic production of H_2
- Importance of the temperature

B. Muzeau & al., JNM 419 (2011) 241–247

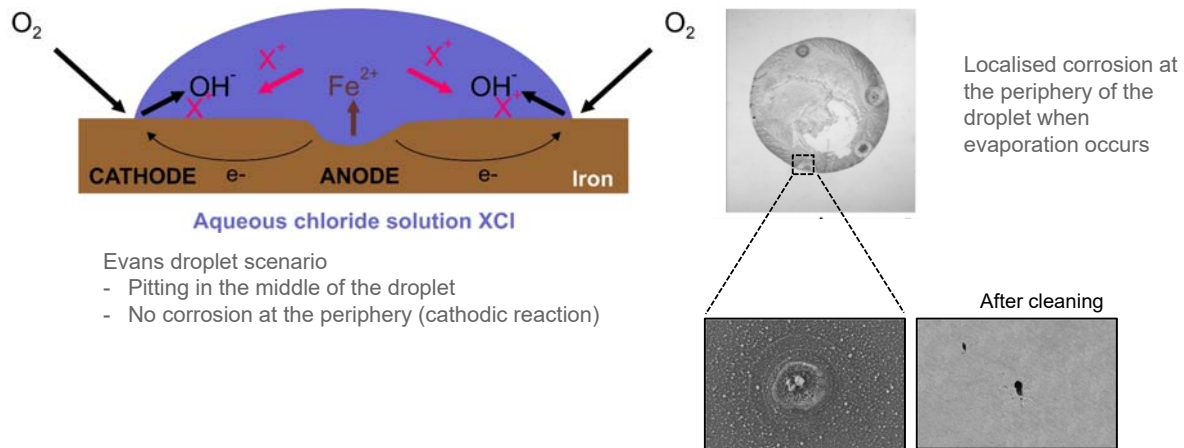
LONG TERM ISSUES

- ATMOSPHERIC CORROSION
- MICROBIAL CORROSION
- CORROSION MODELLING & SIMULATION

Phenomena: outdoor and indoor atmospheric corrosion, including closed atmospheres.

Applications: deferred dismantling, interim storage, first period of geological disposal.

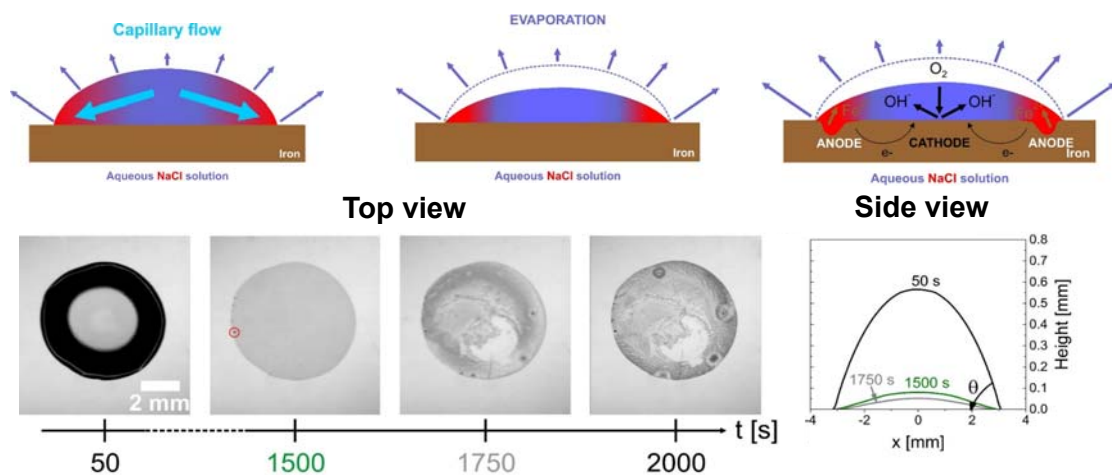
Observations: shape of localised corrosions not in accordance with the well-known “Evans” droplet



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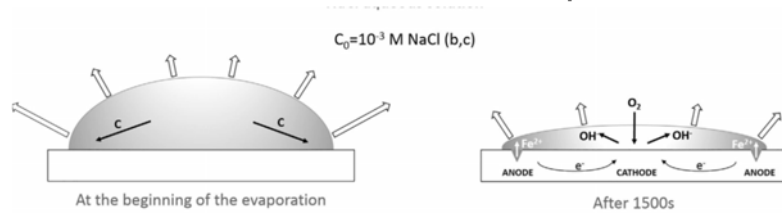
Corrosion under Evaporating Salty Sessile Droplets

Low salt concentration: $c_0 = 10^{-3} \text{M NaCl}$

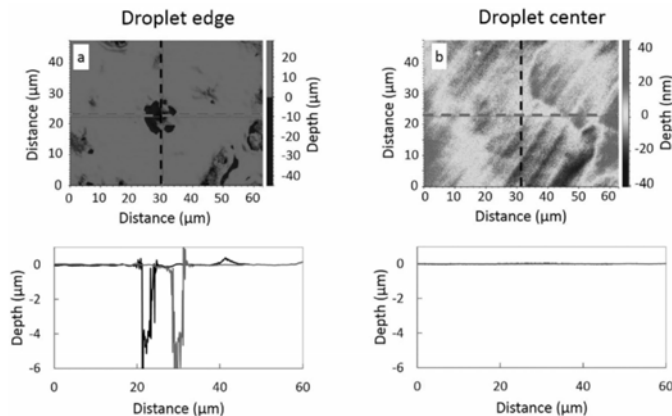


Evaporation of pinned salty sessile droplets causes **peripheral salt enrichment**
Local chloride enrichment promotes the **initiation of corrosion**

Strong correlation between evaporation process and localization of corrosion phenomena



Schematic diagram of the processes



Experimental observations on iron

Soulié, Lequien & al., Materials and Corrosion, Sept. 2017, Vol. 68 Issue 9, p927-93

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CONCLUSION

Decommissioning and corrosion

Fundamental knowledge needed in several areas

Thermodynamics

Effects of irradiation (low & high doses)

Corrosion phenomena even at low temperatures

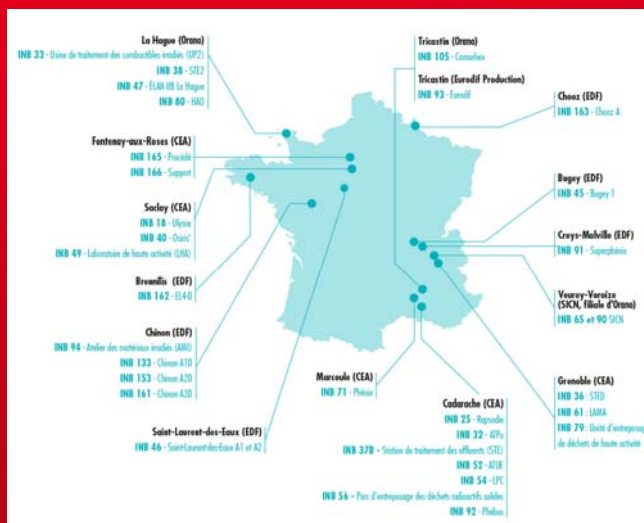
Modeling and simulation

Prediction of phases and compounds in melt core

Long term prediction & coupling of multi-corrosion issues

Protective measures

THANK YOU FOR YOUR ATTENTION



MERCI DE
VOTRE
ATTENTION



@YLMsportScience

Damien Féron / damien.feron@cea.fr
Commissariat à l'énergie atomique et aux énergies alternatives
Centre de Saclay | 91191 Gif-sur-Yvette Cedex
T. +33 (0)1 69 08 20 65 | F. +33 (0)1 69 08 15 86

Direction de l'Energie Nucléaire
Département de Physico-Chimie
Service de la Corrosion et du
Comportement des Matériaux dans
leur environnement
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