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From electrochemical behaviour to biotribocorrosion of metal alloys dedicated to joint prostheses

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A. Impergre, Ana-Maria Trunfio-Sfarghiu, Christelle C. Der Loughian, Benoît Ter-Ovanessian, Aline Bel-Brunon, et al.. From electrochemical behaviour to biotribocorrosion of metal alloys dedicated to joint prostheses. 4th International Conference on BioTribology, Sep 2018, Montréal, Canada. hal-02526010

HAL Id: hal-02526010

<https://hal.science/hal-02526010>

Submitted on 31 Mar 2020

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Introduction

Total Ankle Replacement (TAR)

- High rate of reoperation :
 - 20% after 5y¹⁻²
 - 10-30% after 10y (sometimes 50%)³⁻⁵

The mobile-bearing Buechel-Pappas TAR. Metallic tibial and talus components and a UHMWPE bearing.

Body's response:

- Inflammation
- Cystic osteolysis
- Pseudotumors
- Aseptic loosening

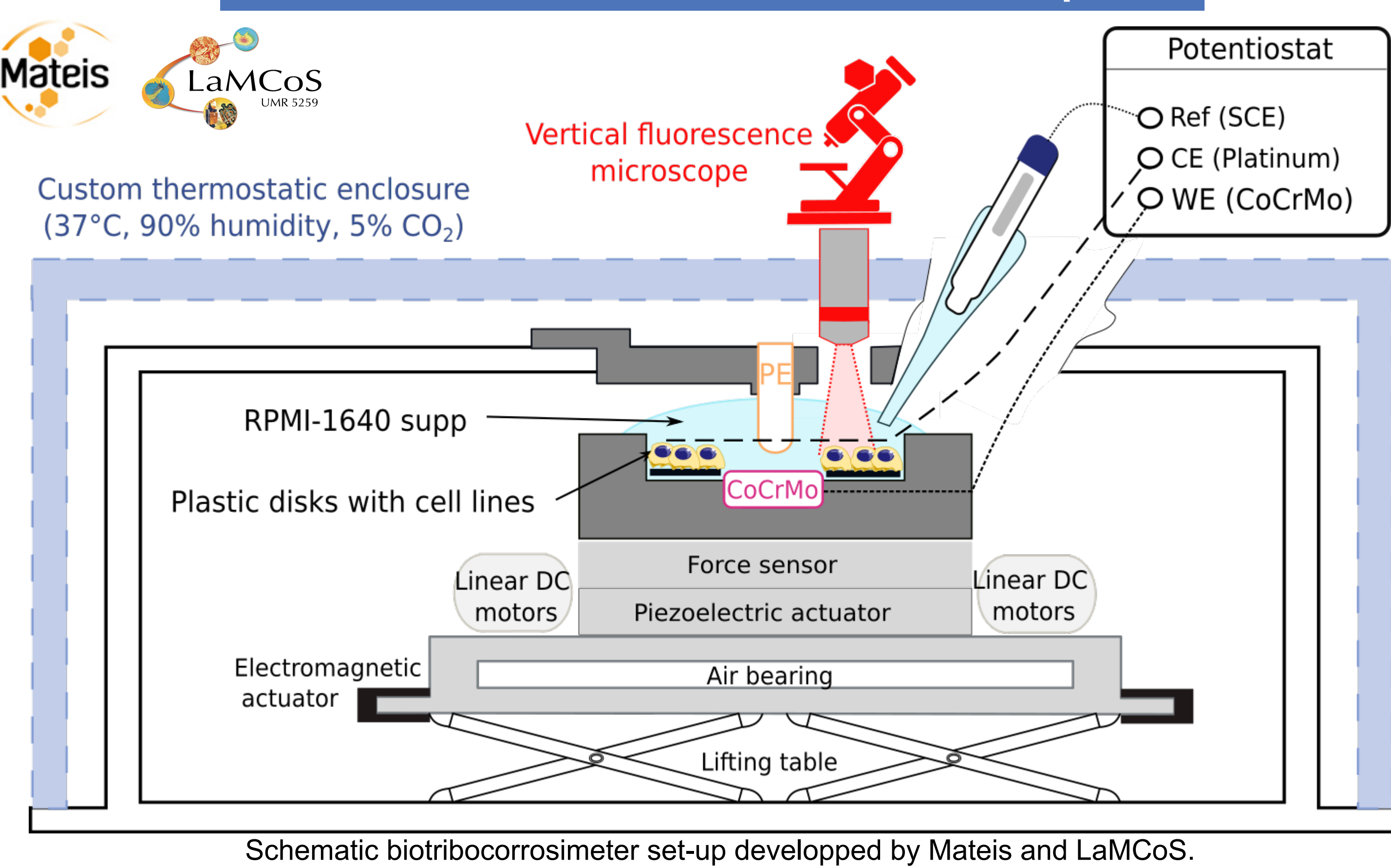
Causes:

- Metal ions release⁶
- Metallic and polymeric micro/nanoparticles⁷⁻⁸
- But the entangle of mechanisms remain unclear**

▶ Differences between in-vivo and in-vitro conditions
▶ Tribocorrosion test method need to be adapted to match cell culture conditions

Develop a custom Biotribocorrosion test rig taking into account the biological, mechanical and chemical factors
Understand the role of synergistic interaction of wear and corrosion in the case of CoCrMo/PE implants

Biotribocorrosion set-up



Experimental conditions

UHMW-PE pin
Standard double mobility prosthesis inserts (HDM248, TORNIER)

CoCrMo disk
(Biodur® CCM®, Carpenter) ASTM-F1537-11 ISO 5832-12:2007

Mechanical contact, force and displacements applied

Cell culture medium : RPMI-1640 + 10% Fetal bovin serum + 1% Antibiotics

Murine macrophages RAW 264.7
Human osteoblasts hFOB 1.19
Cell seeding density : 5.10⁴ cells/cm²

Fluo. marker: intracellular pH (pHrodo™ Red AM, Thermofisher)

Biotribocorrosion sequence

Electrochemical meas. :
Evolution of open circuit potential E_{OCP} and voltage drops.

Biological meas. :
Visualization of living cells and acidification: specific sensor of endocytic (ions) and phagocytic (debris) internalization.

Surface and debris analysis (SEM, IFM)

Mechanical sequence : Init : Initialization phase, CSR : Compression Stress Relaxation, Rh : Rheology, Slid : Sliding phases. V_{slid} : 0.5-2 mm/s)

Init CSR Rh Slid. Init

F(N)

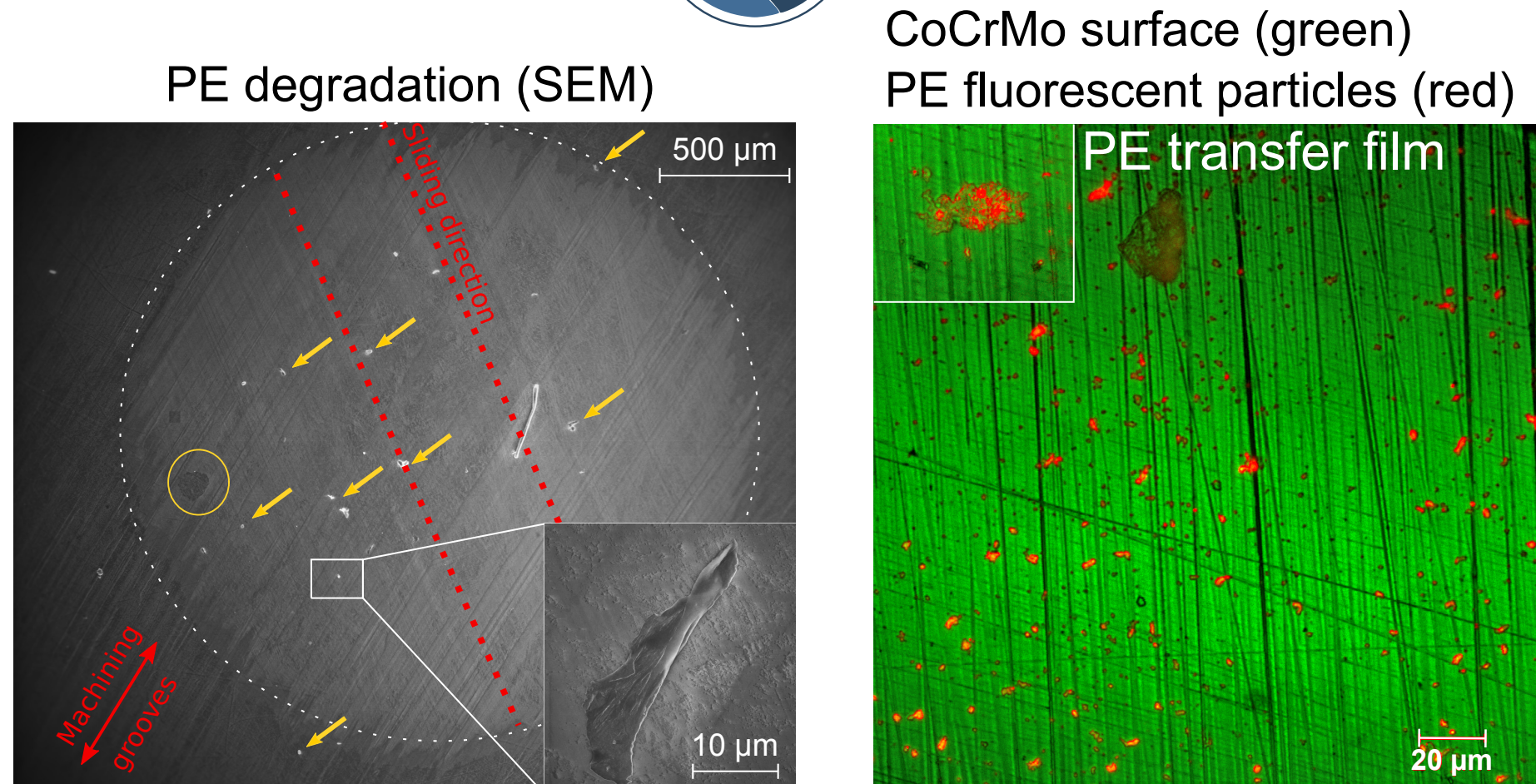
Dx (mm)

Dz (µm)

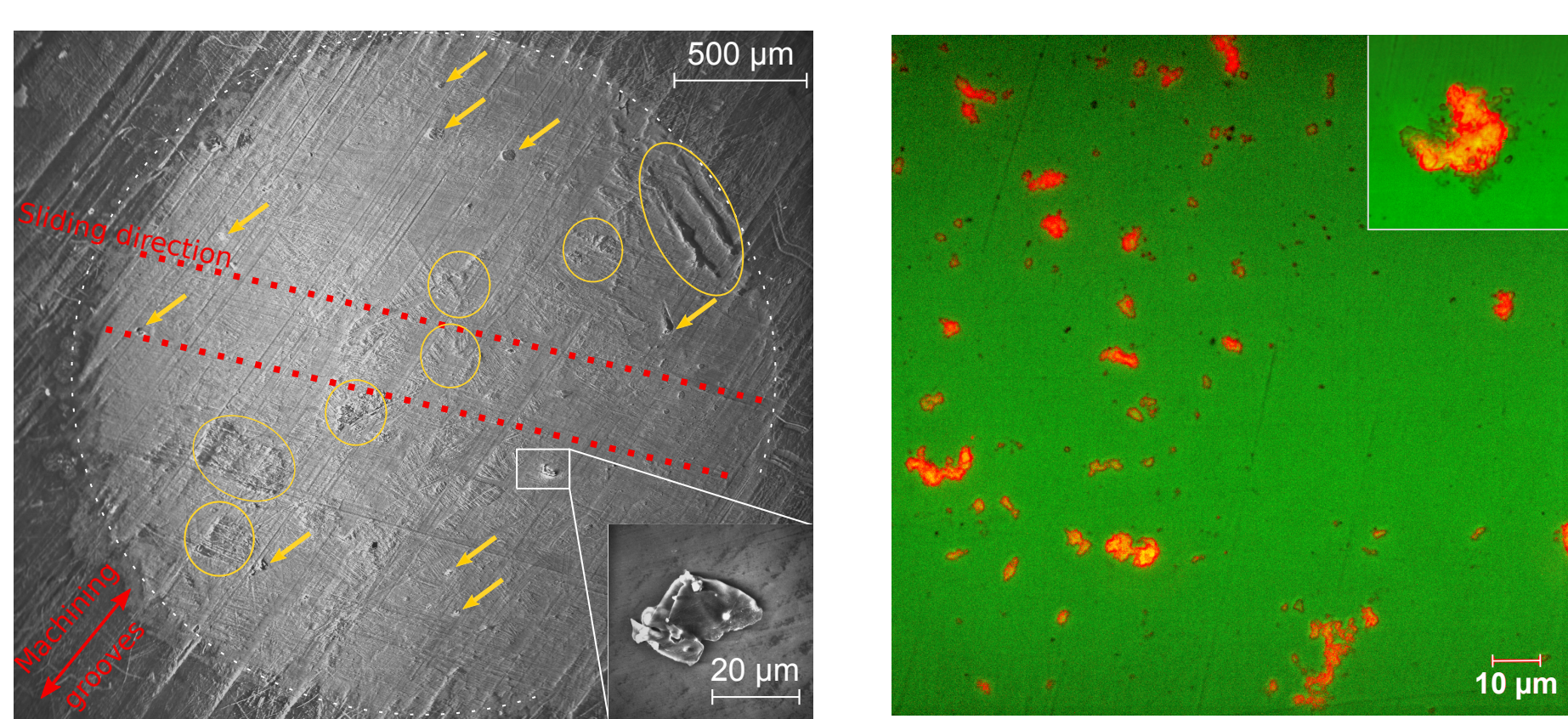
Results

Test N°	CoCrMo surface	V _{sliding} (mm/s)	Cell line
1	SiC 1200	0.5	Macrophages
2	Mirror polishing	2	Osteoblasts

Tribology

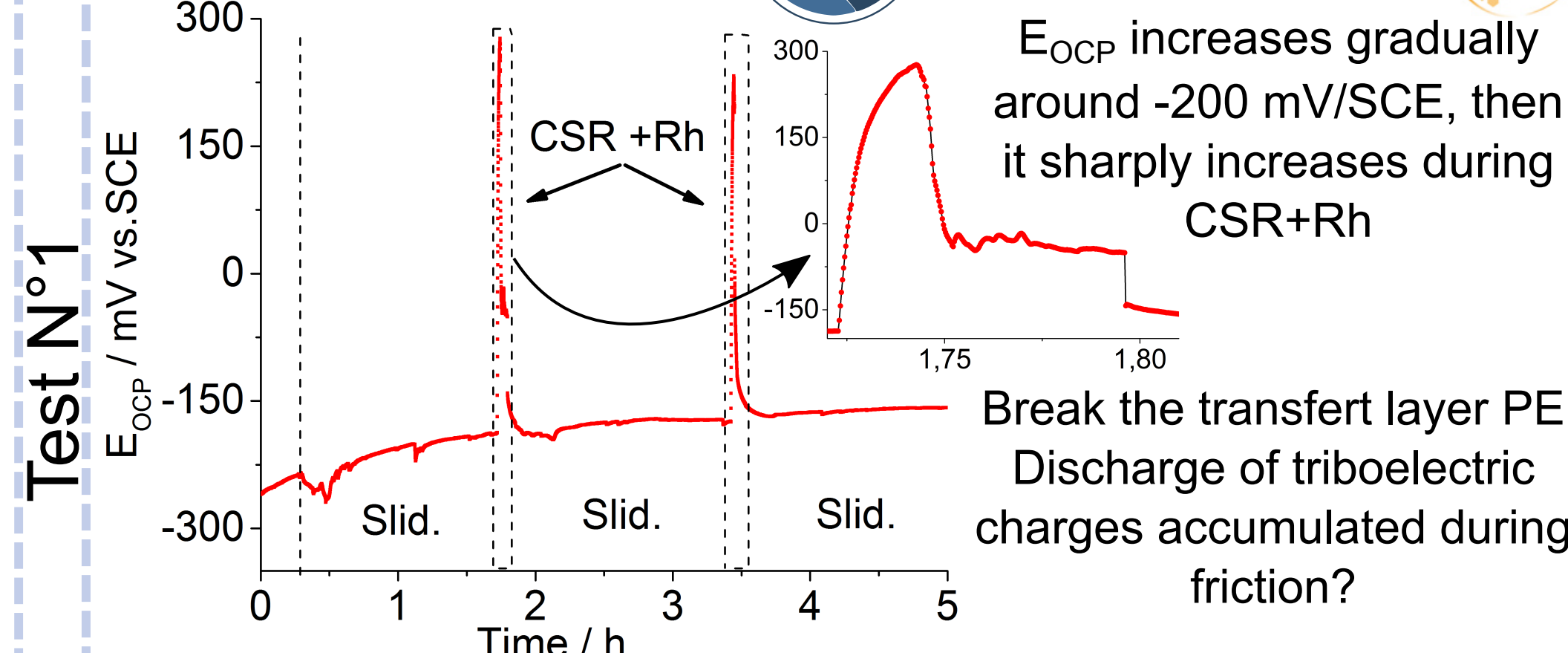


Numerous and round particles ejected out of the contact due to rough rugosity of CoCrMo. PE layer adherent and pulled. Adhesive wear



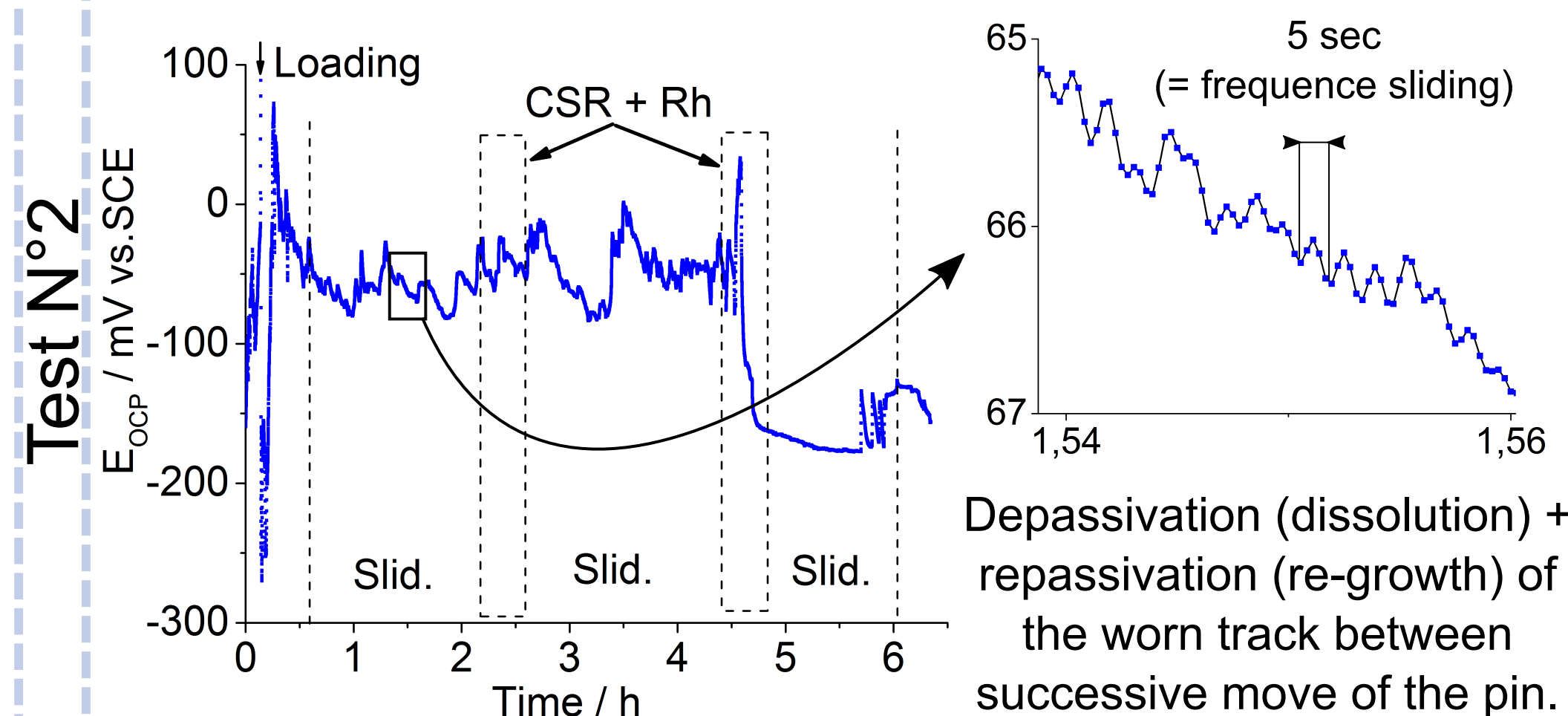
Test N°1: PE adhesive layer, adhesive wear
Test N°2 : Third-body thick, hydrodynamic
Confirmed by :
COF 1 (0.076) > COF 2 (0.054)
V_{Wear} 1 (0.019 mm³) > V_{Wear} 2 (0.009 mm³)

Electrochemistry



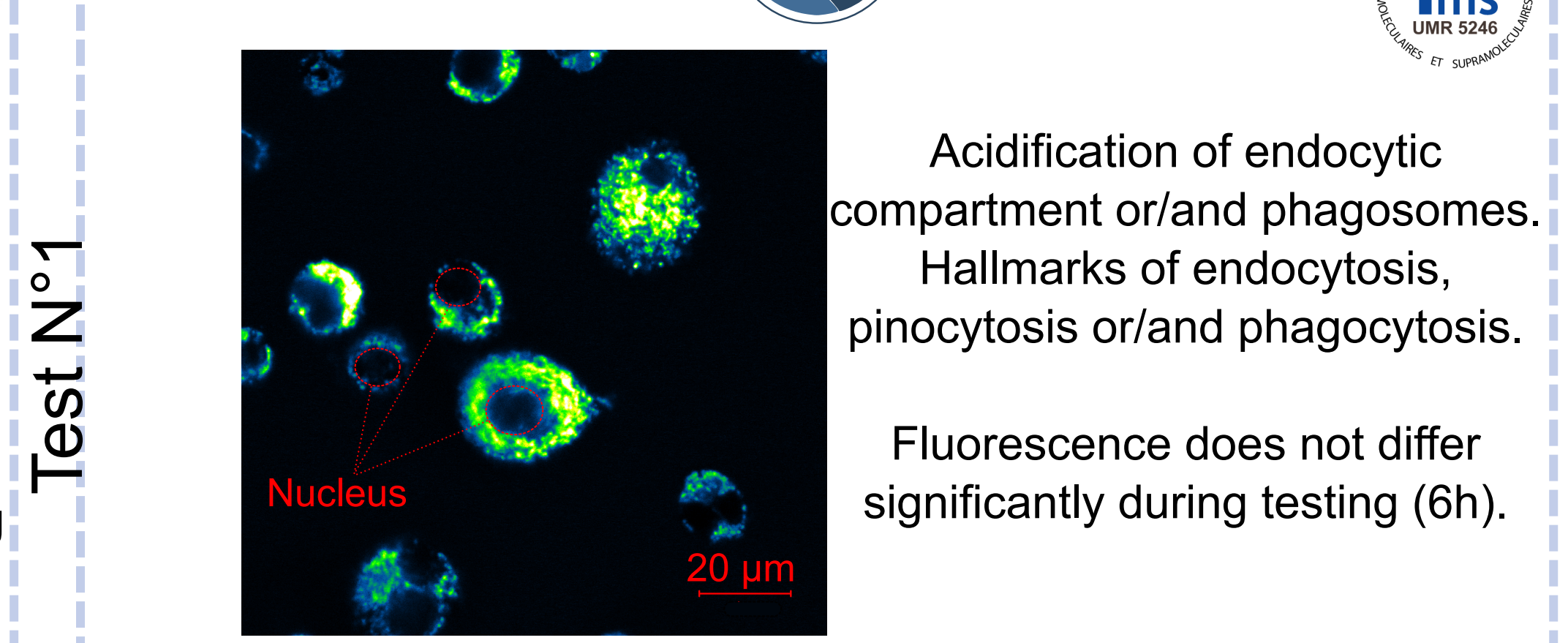
ICP-MS analysis after testing confirms no significant dissolution of CoCrMo.

Element (ppm)	Co	Cr	Mo
Test N°1	0,29	0,01	0,01

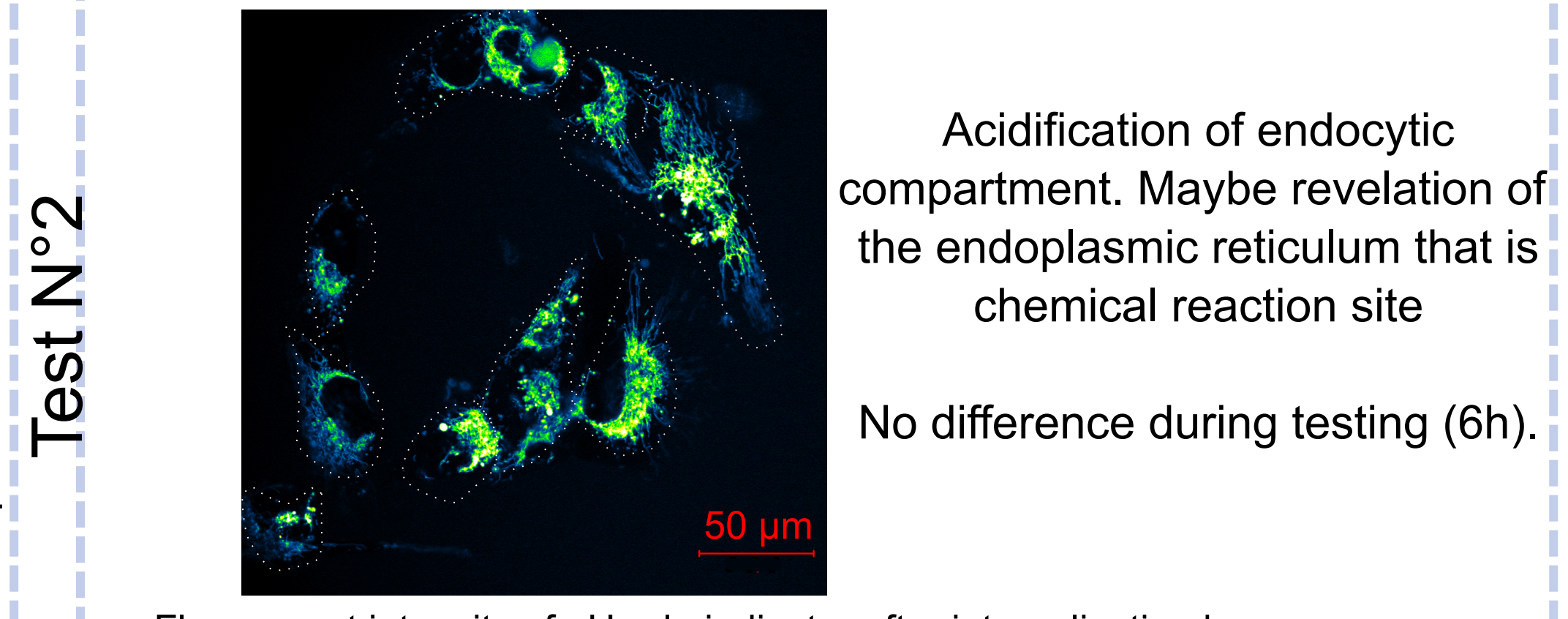


Test N°1 : Slow ionic dissolution. Low V_{slid} induces an accumulation of electrostatic charges on PE pin
Test N°2 : High V_{slid} causes dissolution and then repassivation of worn track. Ions ++

Biology



Fluorescent intensity of pHrodo indicator after internalization by living macrophages. Green intensity represents acidification (pH 4.7-5) in acidic endosomes, lysosomes and phagosomes.

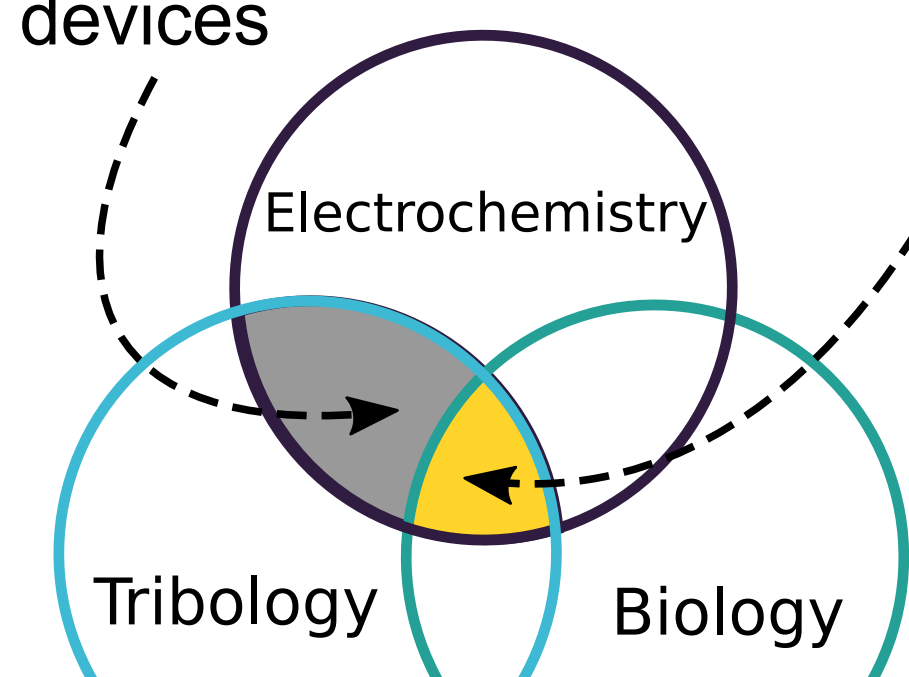


Fluorescent intensity of pHrodo indicator after internalization by living osteoblasts. Green intensity represents acidification (pH 4.7-5) in acidic endosomes and lysosomes.

Revelation of acidification: ions internalization by endocytosis, pinocytosis. Phagocytosis ?
Provide follow-up after 24, 48 hours of incubation.

Conclusion

Common tribocorrosion devices



Biotribocorrosion

Development of a biotribocorrosion apparatus to understand the synergistic effects between mechanical, chemical and physiological reactions:

- Mechanical contact identical to that of a prosthesis: PE/CoCrMo
- Direct contact of metal ions and wear debris with the cells
- Cell culture conditions fulfilled with fluorescence monitoring of living cells

