Sensors for monitoring of atmospheric corrosion

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Outline

- Commercial sensors for monitoring of atmospheric corrosion
- Principle of Electrical resistance sensors (ER sensors
- Application of ER sensors
  - Monitoring under field conditions
  - Accelerated corrosion tests
  - Cultural heritage
- Conclusions

Atmospheric Corrosion Sensors

Techniques to determine the atmospheric corrosion rate in the laboratory include:

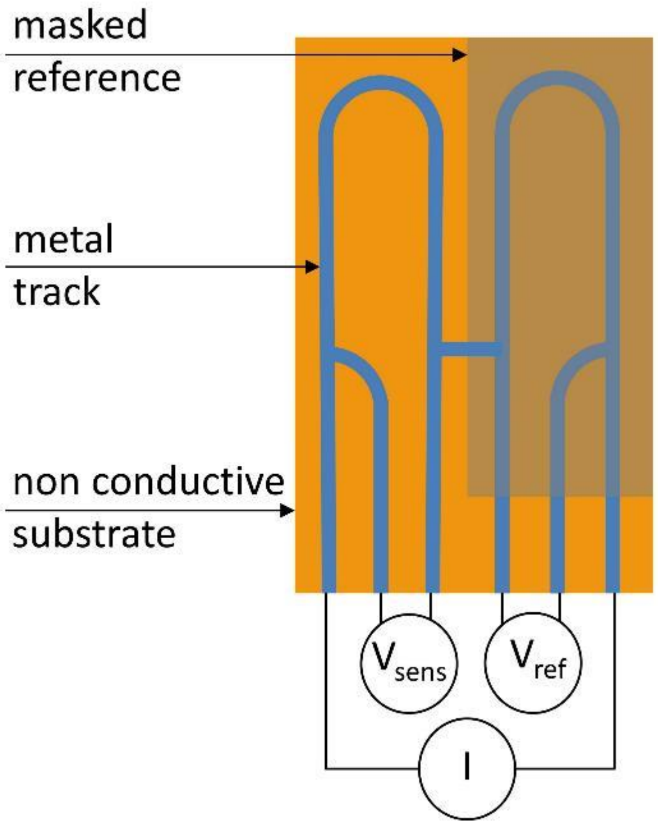
- Electrochemical techniques like impedance spectroscopy
- Quartz crystal microbalance
- Electrical resistance measurements
- Optical techniques and ultrasonic techniques (US)
- Weight loss measurements.

However, many of them are limited for field studies and monitoring of the corrosion rate under real environmental conditions.

Commercial corrosion sensors

Technique	Nb of suppliers	Drawback
Electrical resistance	4	Sensitive to temperature. Limited or no possibility for local corrosion. Limited to some ref materials
QCM	2	Sensitive to temperature, moisture and dirt. Limited to some ref materials. Not suitable for harsh env.
ACM (atmospheric corrosion monitor)	1	Unclear data interpretation (rainfall). Presence of electyrolyte req.
EIS/ACM	1	Same as ACM

Electrical resistance technique



$$CD = t_{init}\left(\frac{R_{ref,init}}{R_{sens,init}} - \frac{R_{ref}}{R_{sens}}\right)$$ Corrosion depth

t_{init}	Initial reference track thickness
R_{sens}	Resistance of the sensor track
R_{ref}	Resistance of the reference track
$R_{sens,init}$, $R_{ref,\ init}$	Initial resistance

- \+ Simple principle → Easy interpretation
- \+ Sensitivity → Immediate response
- \+ Mechanically non-vulnerable
- \+ Unaffected by humidity and dust

- \- Sensitive to temperature variation
- \- Impossible to distinguish between uniform and localized attack

Versions of AirCorr logger

AirCorr I: *Indoor version with an exchangeable sensor*

AirCorr I Plus: *Indoor version with temperature and RH sensors, 2 exchangeable corrosion sensors, LCD showing actual corrosivity*

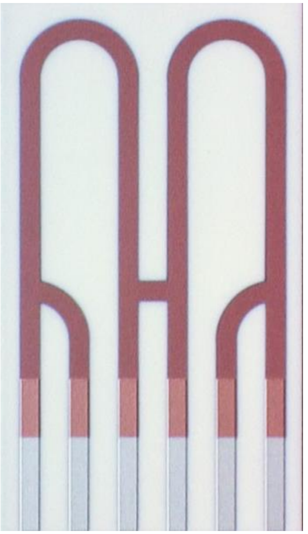
AirCorr O: *Watertight outdoor version*

Small | Light | Battery driven (autonomy 3–5 years) | Non-contact data reading | Optional GPRS access

AIRCORR sensors

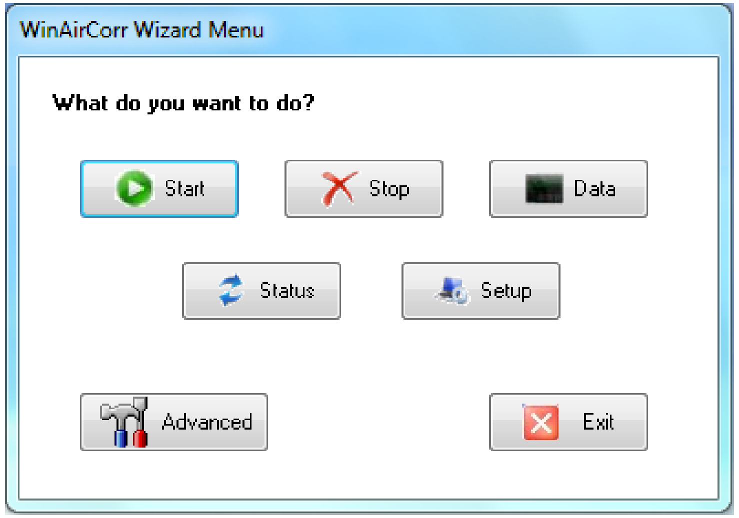
- **Wide range available**: From ultra sensitive sensors for low-corrosive environments to robust ones

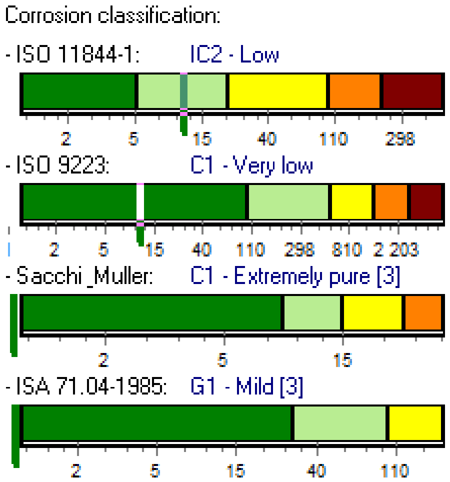
Material	Indoor, high sensitivity	Indoor, long lifetime	Outdoor, high sensitivity	Outdoor, long lifetime
Copper	100 nm	500 nm	5 µm	12 µm
Silver	50 nm	500 nm		–
Lead	400 nm	25 µm		
Iron/steel	800 nm	25 µm		250 µm
Zinc	–	25 µm		50 µm
Tin	–	10 µm		
Bronze	400 nm		5 µm	
Brass	–	10 µm		



WinAirCorr software

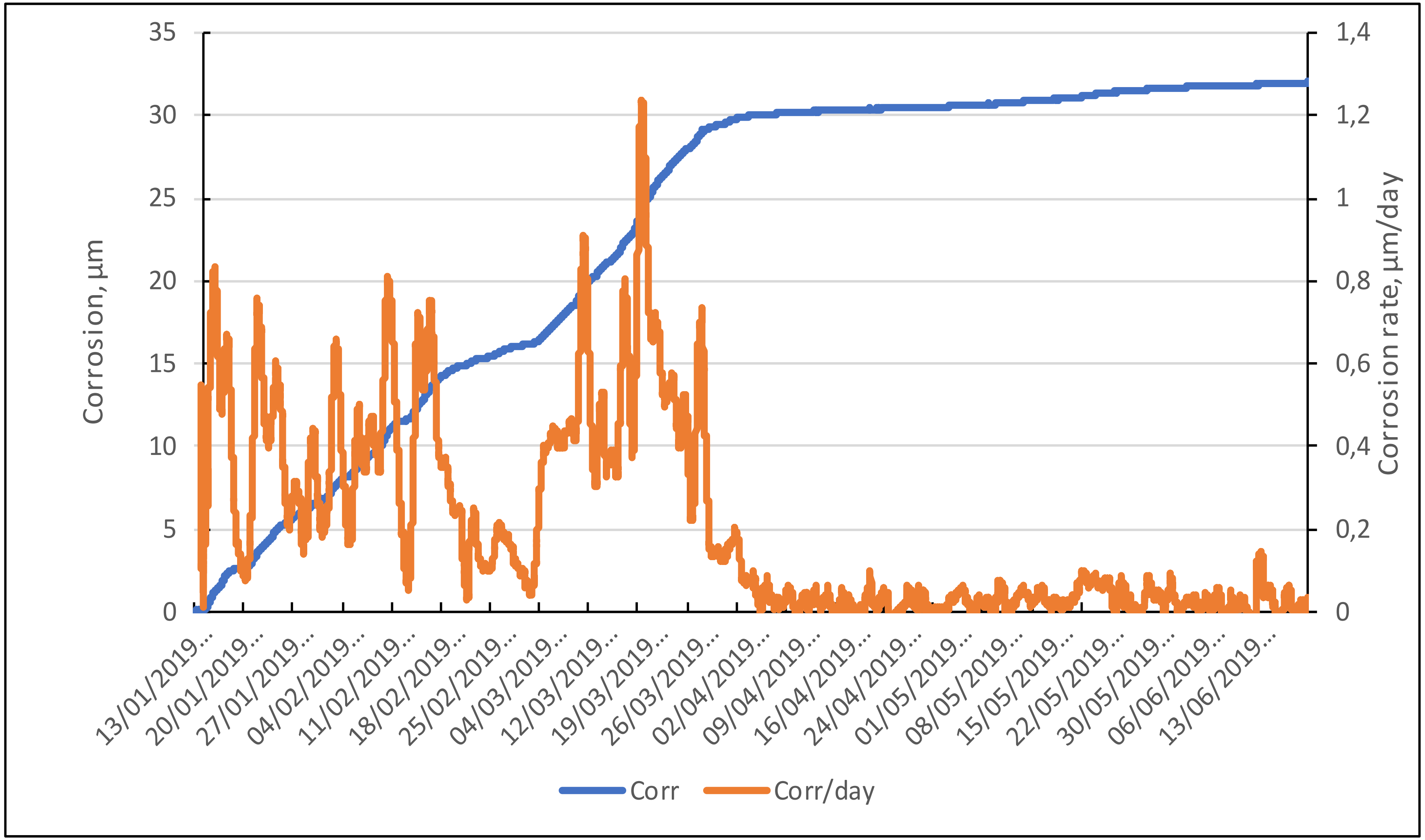
- **User-friendly WinAirCorr software**
  - Easy handling with help of wizards
  - Data interpretation, filtering
  - Air corrosivity classification following standards and recommendations



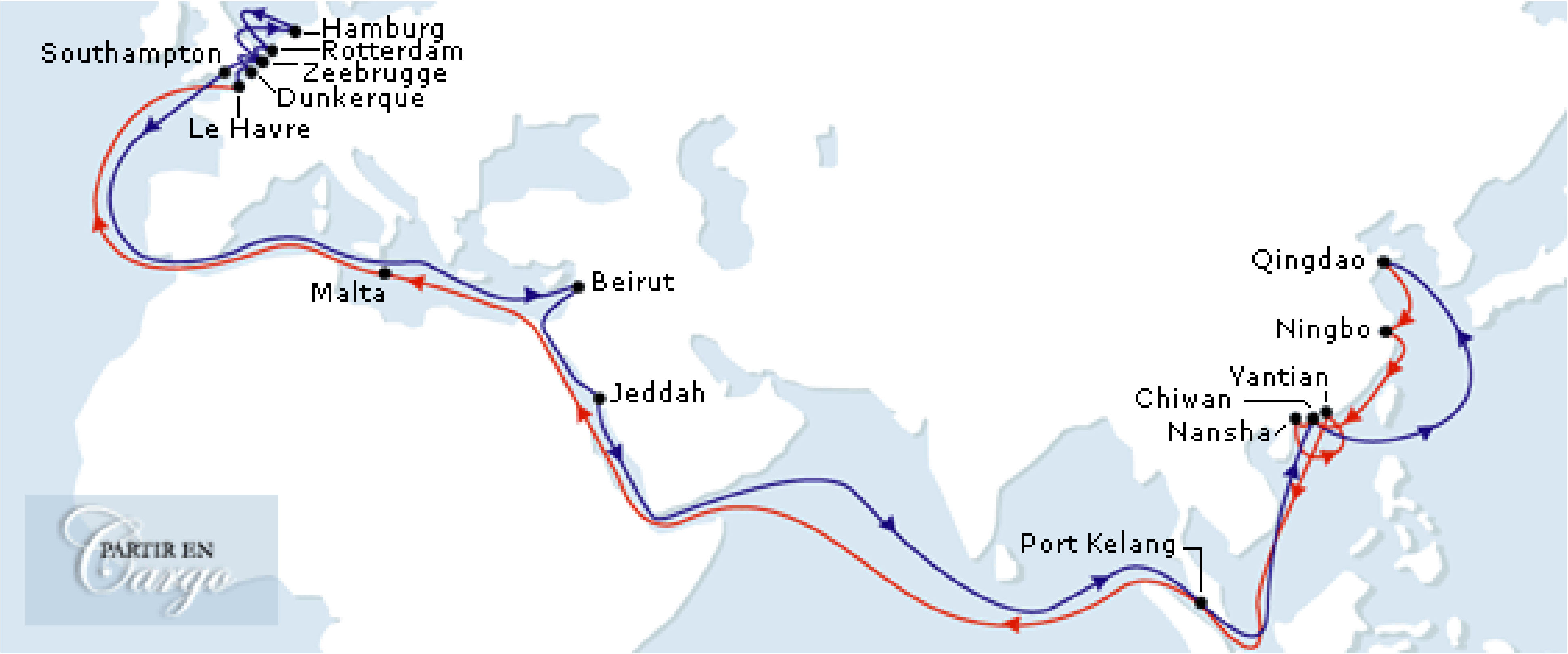


- **Exposure on trucks**

Atmospheric corrosion sensor Fe
Mobile exposure 2019-01-13 – 2019-06-13



Container carrier



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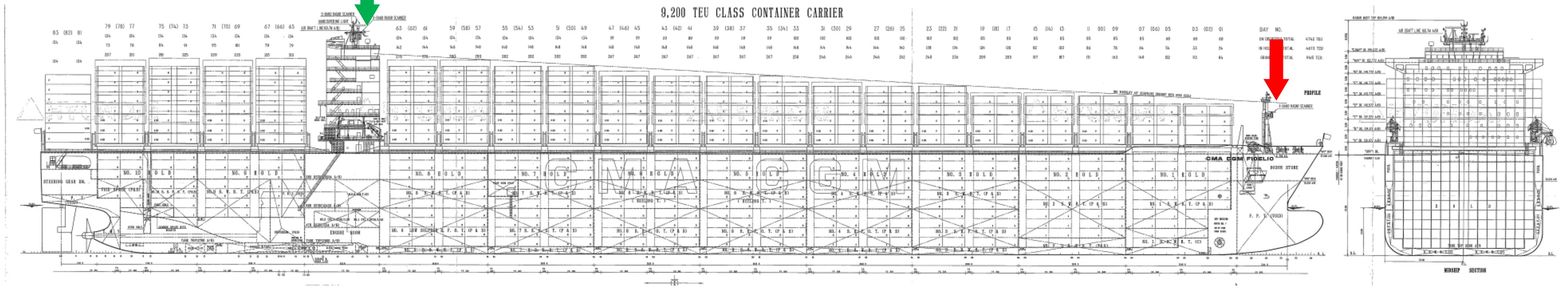
Localisation 2: Pont G

Localisation 1 : Brise Lame



Location

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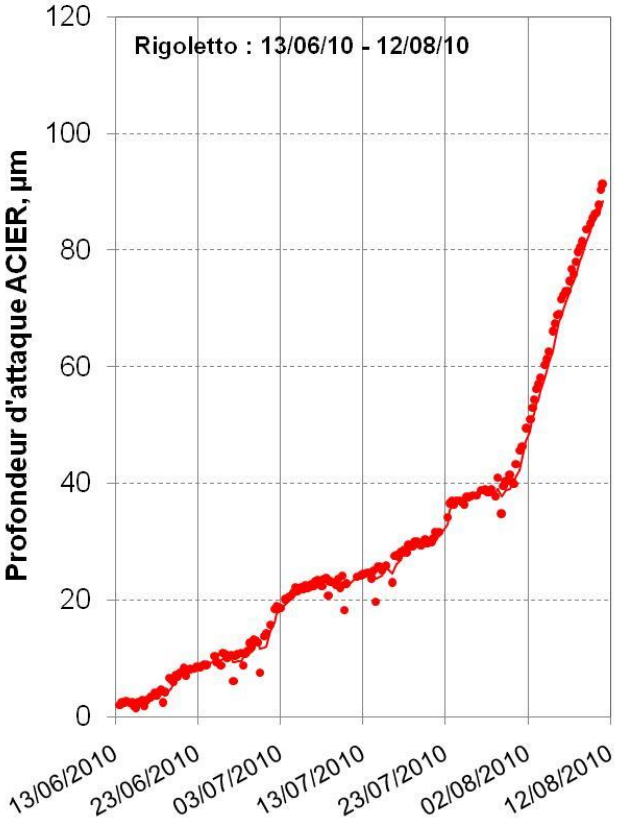
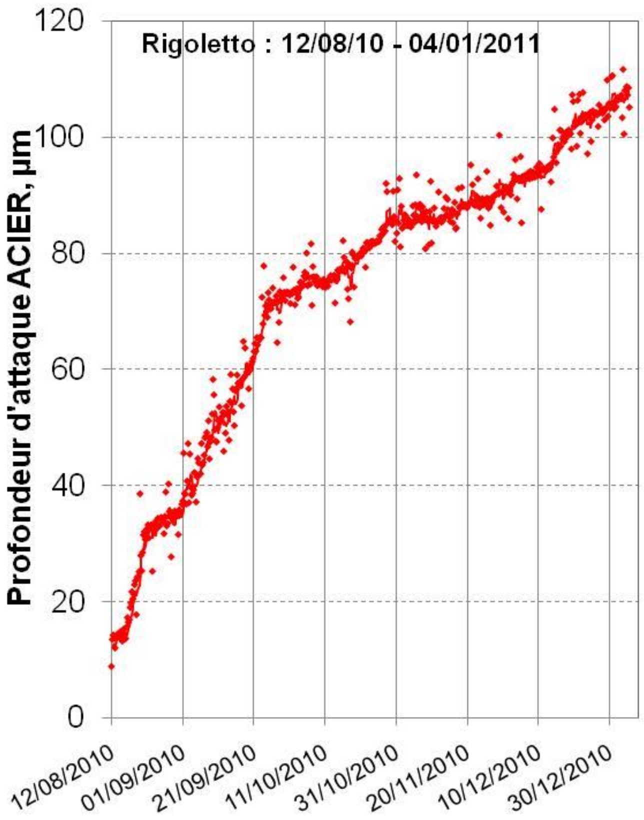
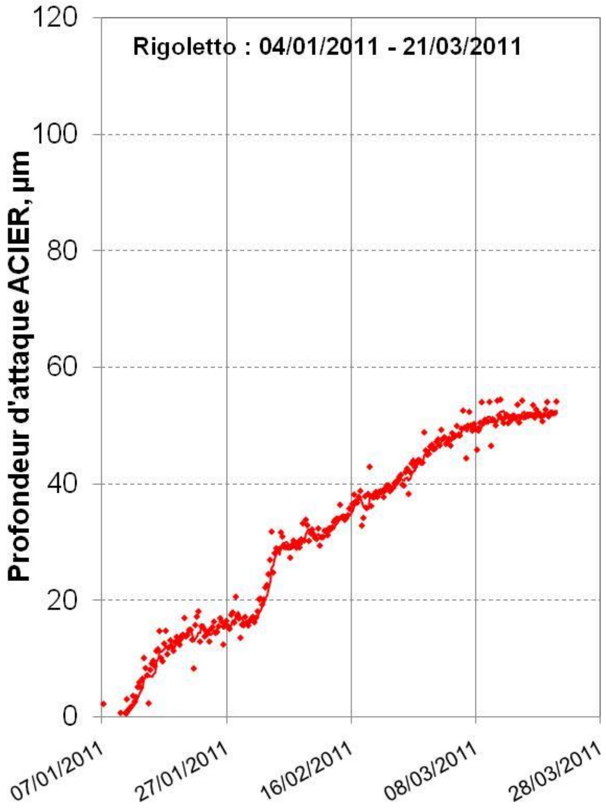
STEEL



2 months

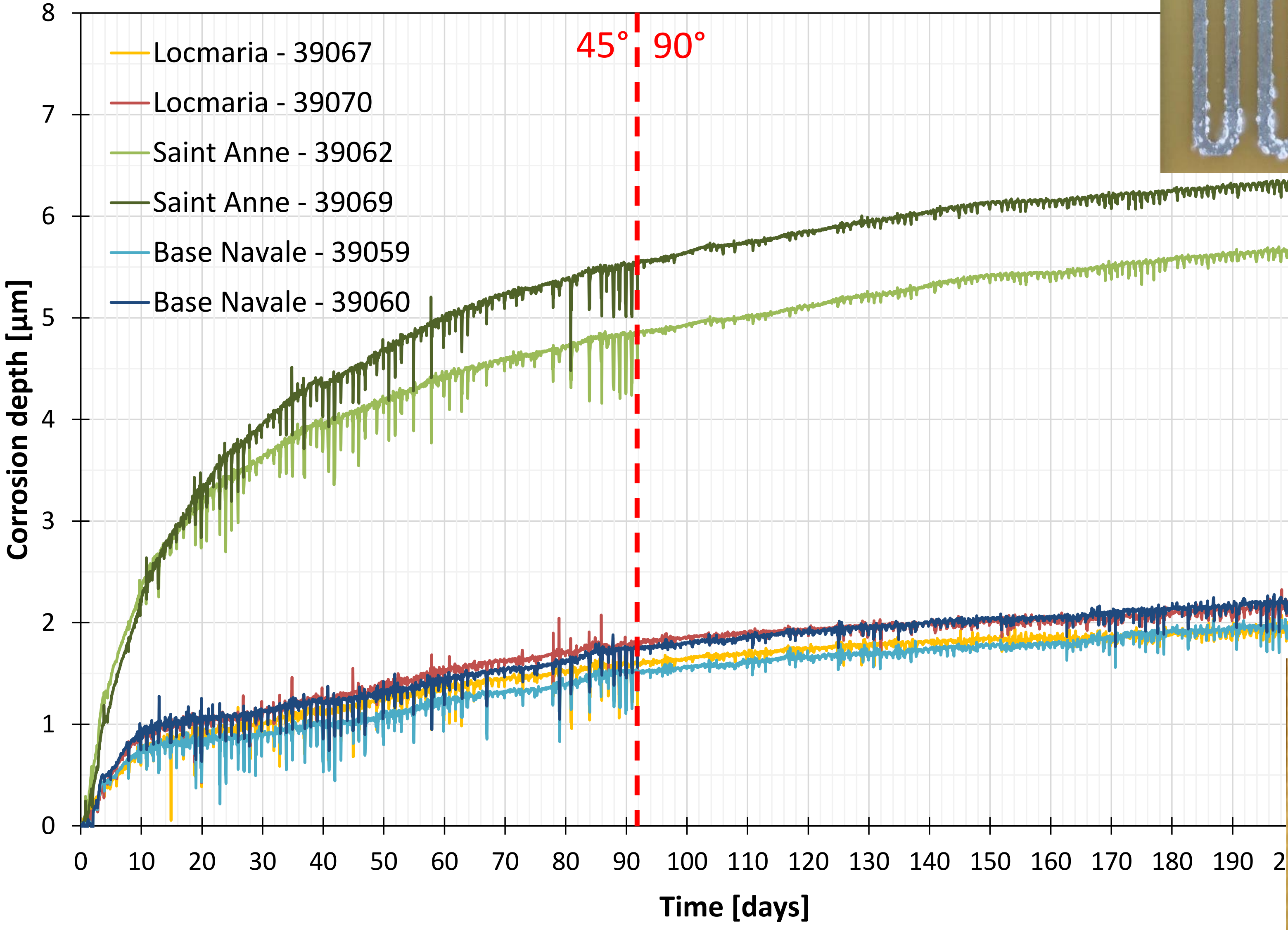


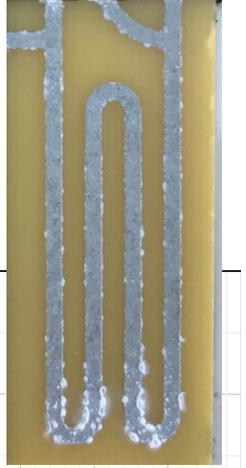
4.5 months

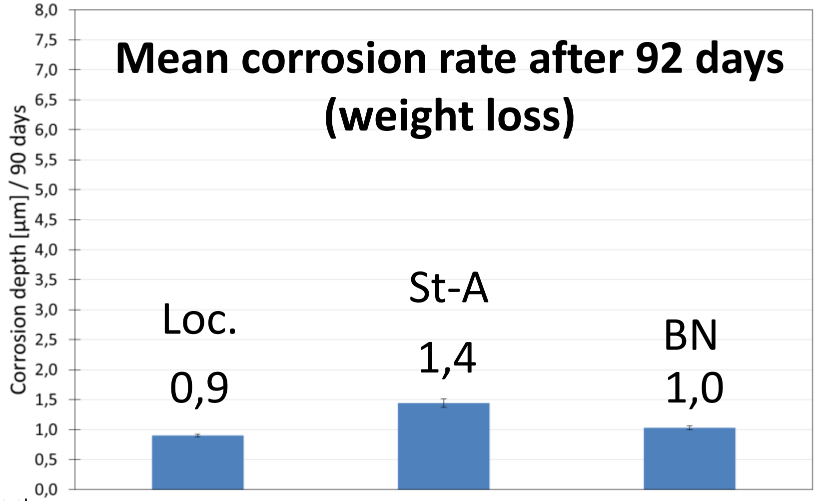


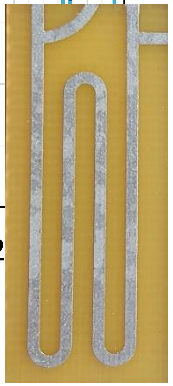
2 months

Exposure at 3 different field sites





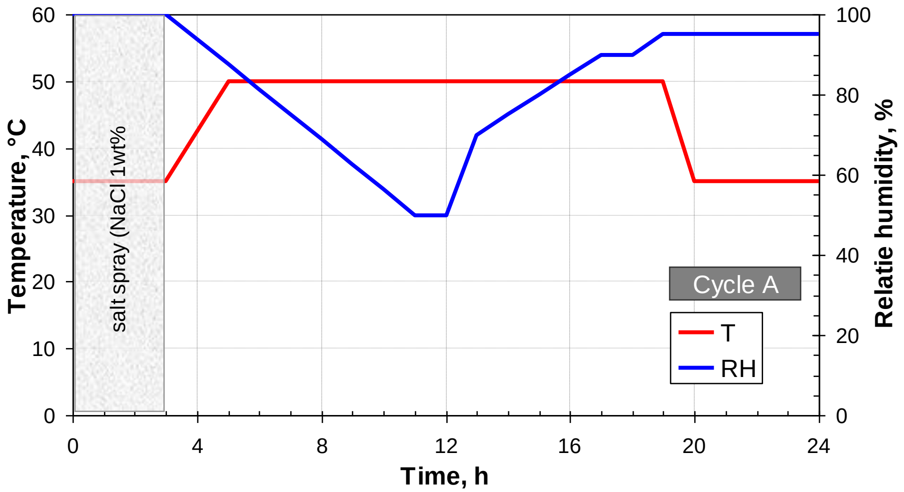


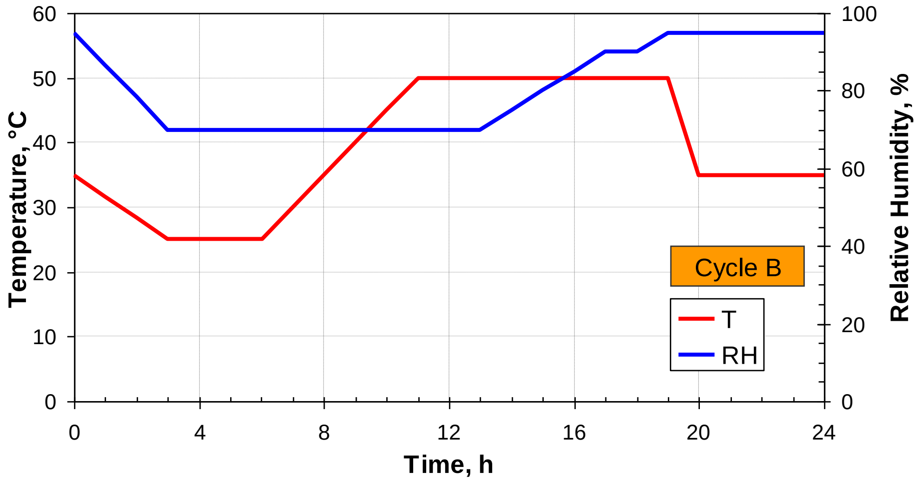


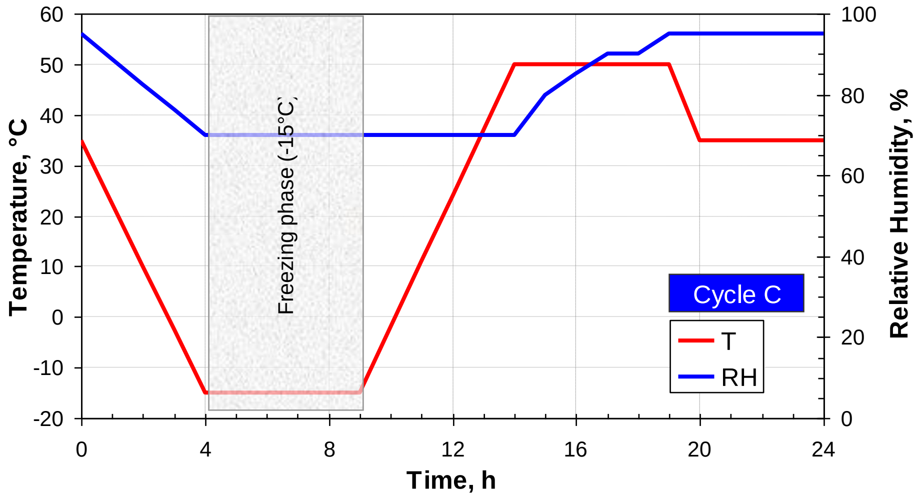
Mean corrosion sensors after 92 days

Saint-Anne ~5 µm
Base Navale ~ 1,6 µm
Locmaria ~ 1.6 µm

ACCELERATED CORROSION TEST





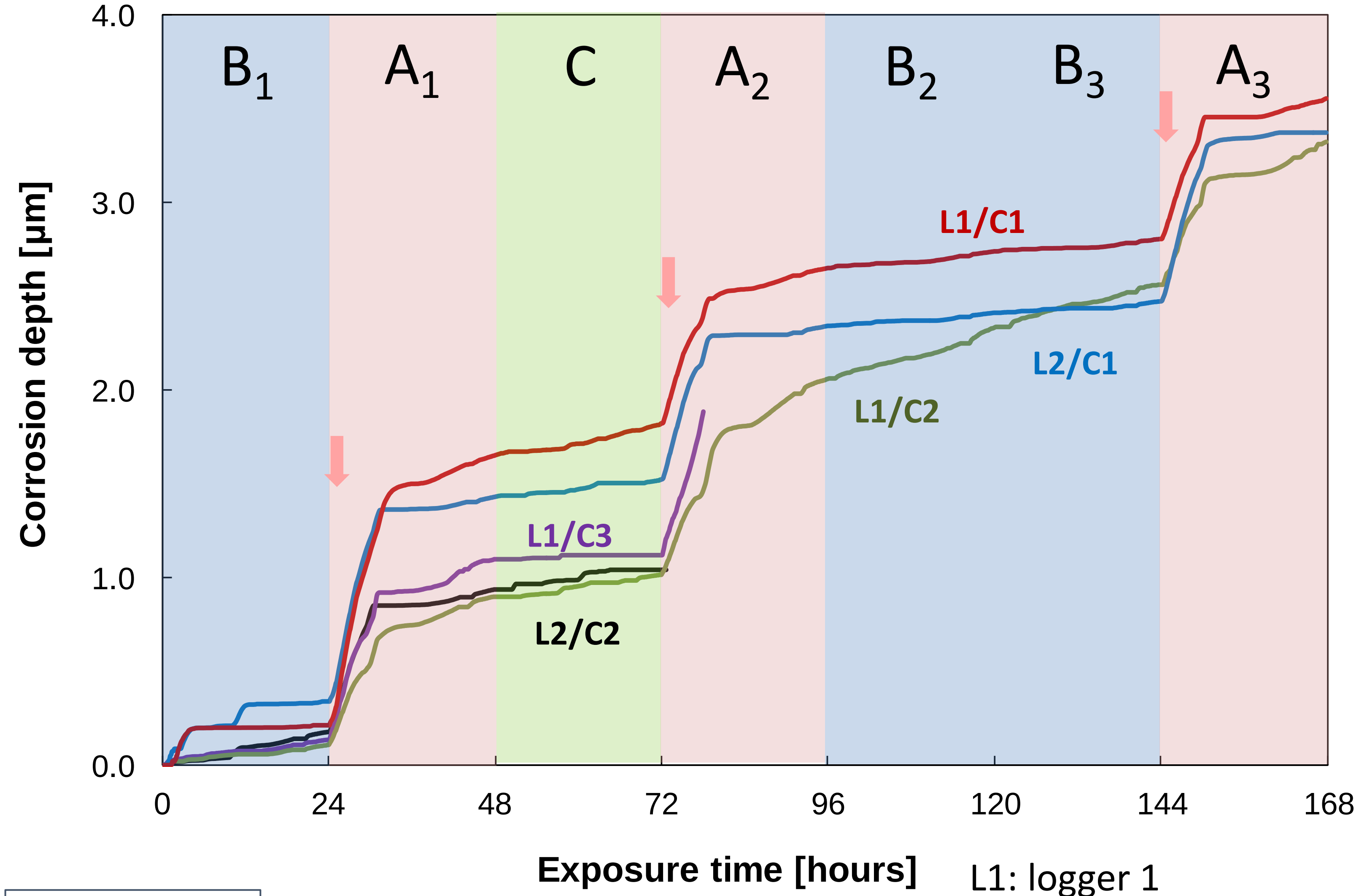


N-VDA test

A–B–A–C–A–B–B
or B–A–C–A–B–B–A.

Duration: 6 weeks

RESULTS / Zn sensor



Zn 25µm

L1: logger 1
L2: logger 2
C1, C2, C3: 1st, 2nd & 3rd cycle

RESULTS / Zn sensor

Change in corrosion depth, µm

Logger/ Cycle	Sub-cycle[1]							
	B_1	A_1	C	A_2	B_2	B_3	A_3	Full cycle
L1/C1	0.2	+1.4	+0.2	+0.8	+0.1	+0.1	+0.8	=3.6
L2/C1	0.3	+1.1	+0.1	+0.8	+0.1	+0.1	+0.9	=3.4
L1/C2	0.1	+0.8	+0.1	+1.0	+0.3	+0.2	+0.8	=3.3

Average change in corrosion depth ~ 3.5 µm/week

Metal loss on coupons ~ 16.3 ± 2.4 µm/6 weeks

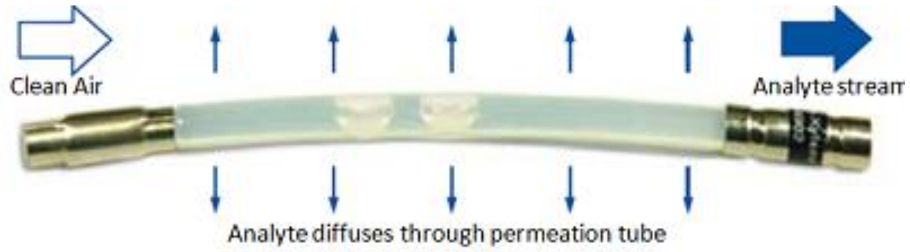
→ 2.7 µm/week (if linear rate)

Setup – Gaseous pollutants

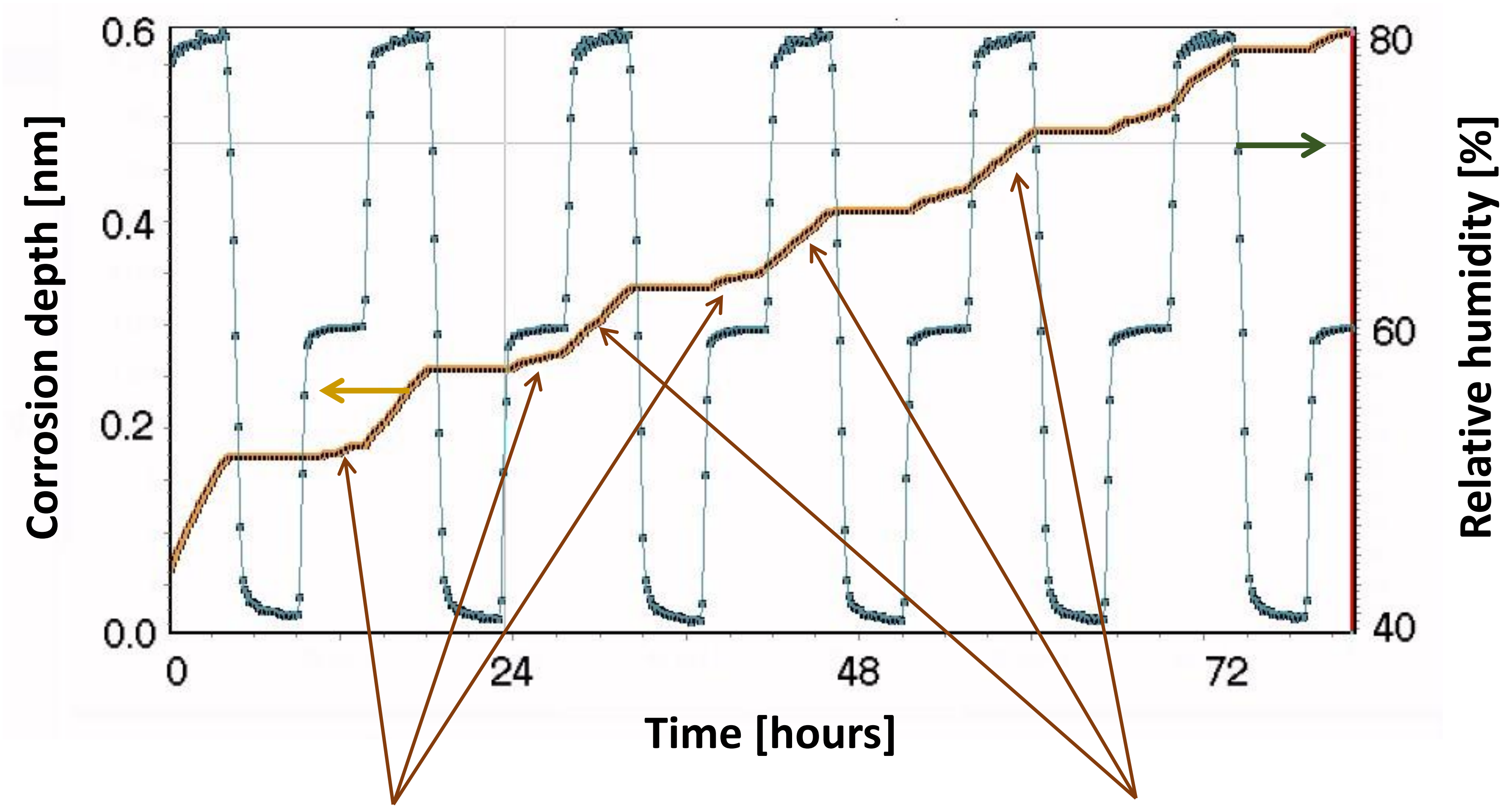
- Unique experimental setup allowing for control of T, RH and concentration of gaseous pollutant

- Apparatus calibrated desired concentration of

  Organic acids



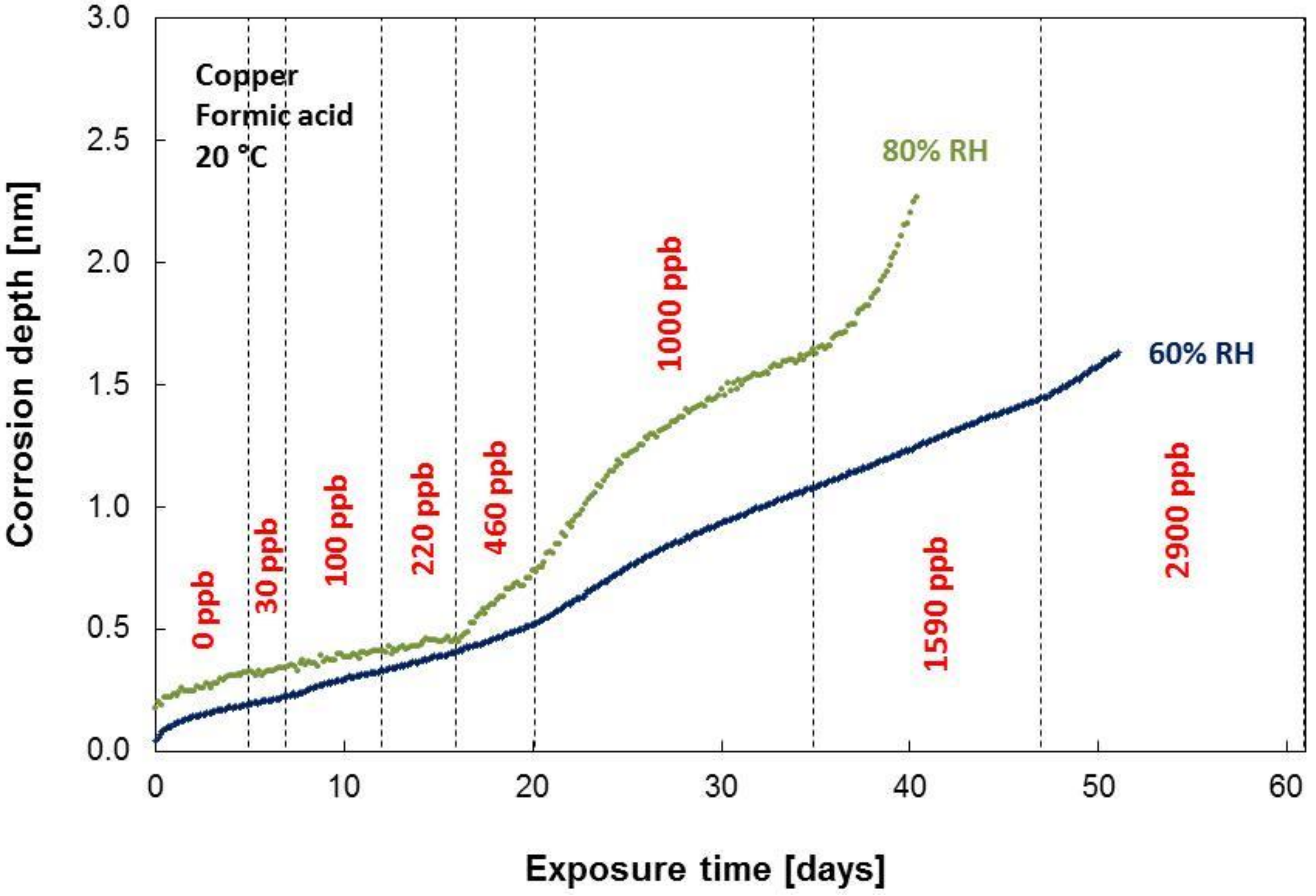
Sensitivity – Ag-50nm, air, 25 °C



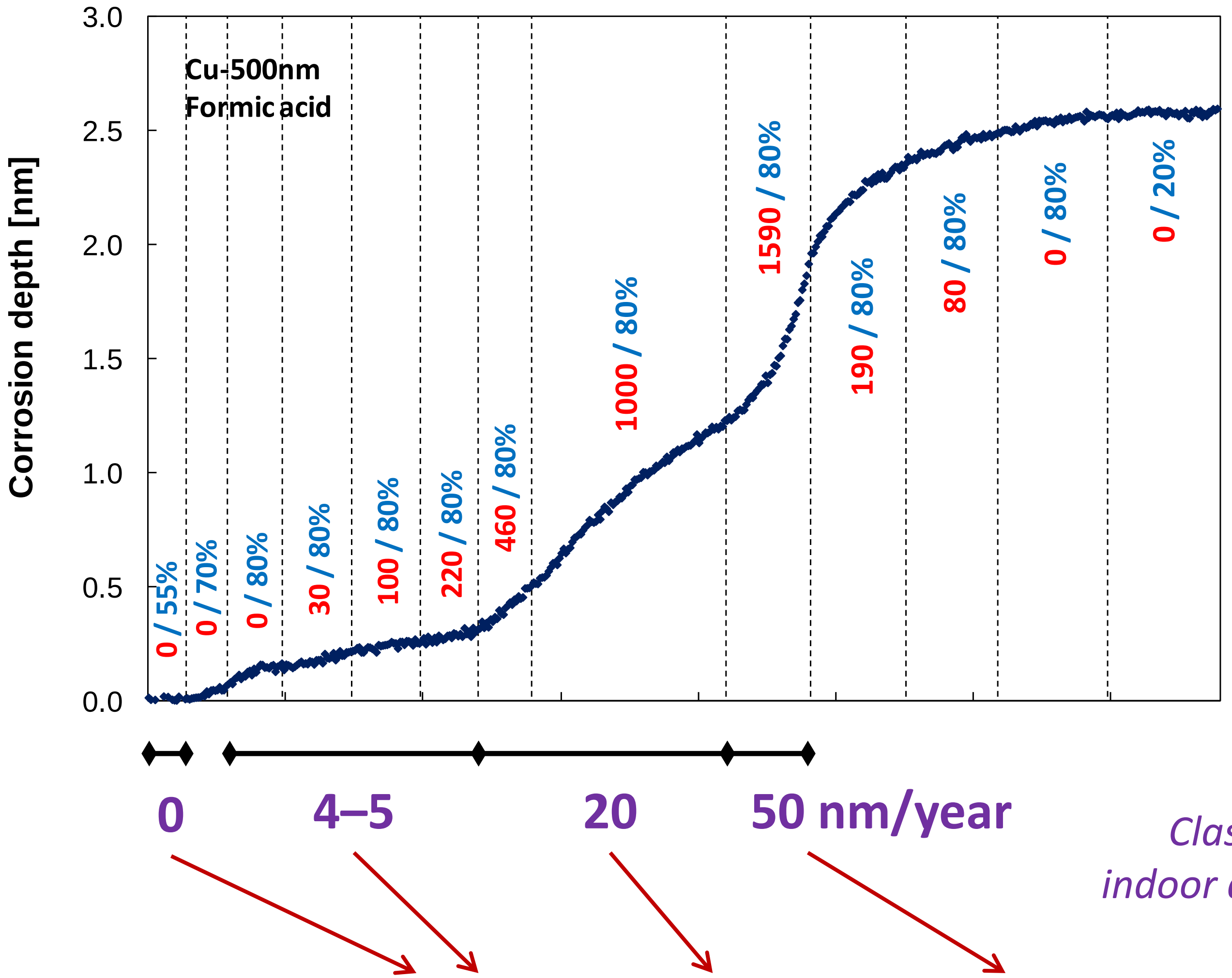
≈50 nm/year
IC2 Low (ISO 11844-1)

≈130 nm/year
IC3 Medium (ISO 11844-1)

HCOOH, Copper, 20 °C



HCOOH, Copper, 20 °C, 80 % RH



Threshold at 20°C, 80 % RH:

IC1→IC2

Between 220 and 460 ppb

IC2→IC3

Between 1000 and 1590 ppb

Classification of corrosivity of indoor atmospheres according to ISO11844-1; in nm/year

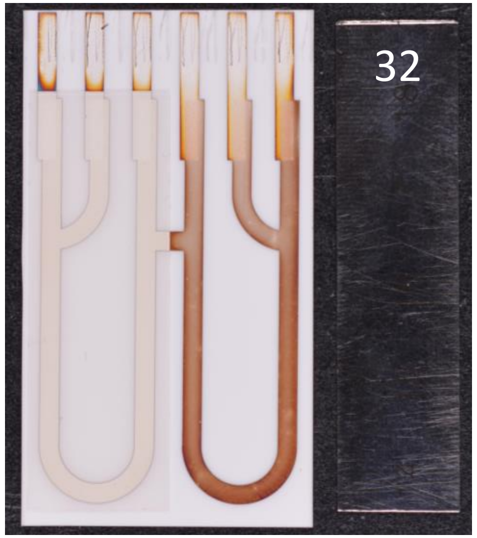
Corrosivity category	IC 1 – Very low	IC 2 – Low	IC 3 – Medium	IC 4 – High	IC 5 – Very high
Copper	≤ 5.6	≤ 22	≤ 101	≤ 224	≤ 561

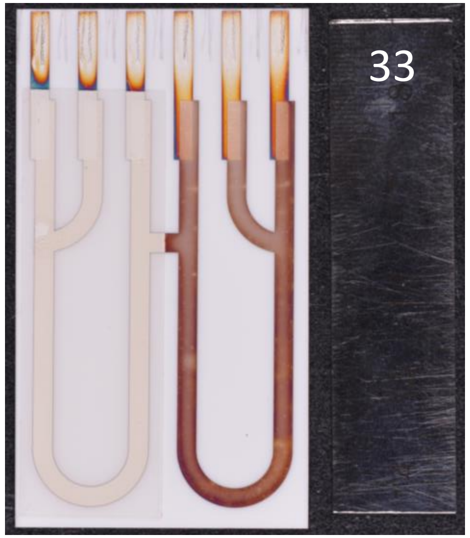
Application of ER sensors to cultural heritage

- Case studies - Indoor corrosivity class assessment (CS5 Musée Arles Antiques example)

Le chaland Arles Rhône 3 dans sa salle d'extension au Musée Départemental de l'Arles antique. (Cg13/MdAa/Chaland Arles Rhône 3/ ©RemiBenali)

RISE platform ID	Corrosion depth [nm]	Corrosion rate [nm/y]	IC class	Location
20	47	275	IC3	Anchor room
21	59	339	IC4	Ship (front)
32	46	269	IC3	Ship (back)
33	63	364	IC4	Ship (Middle)



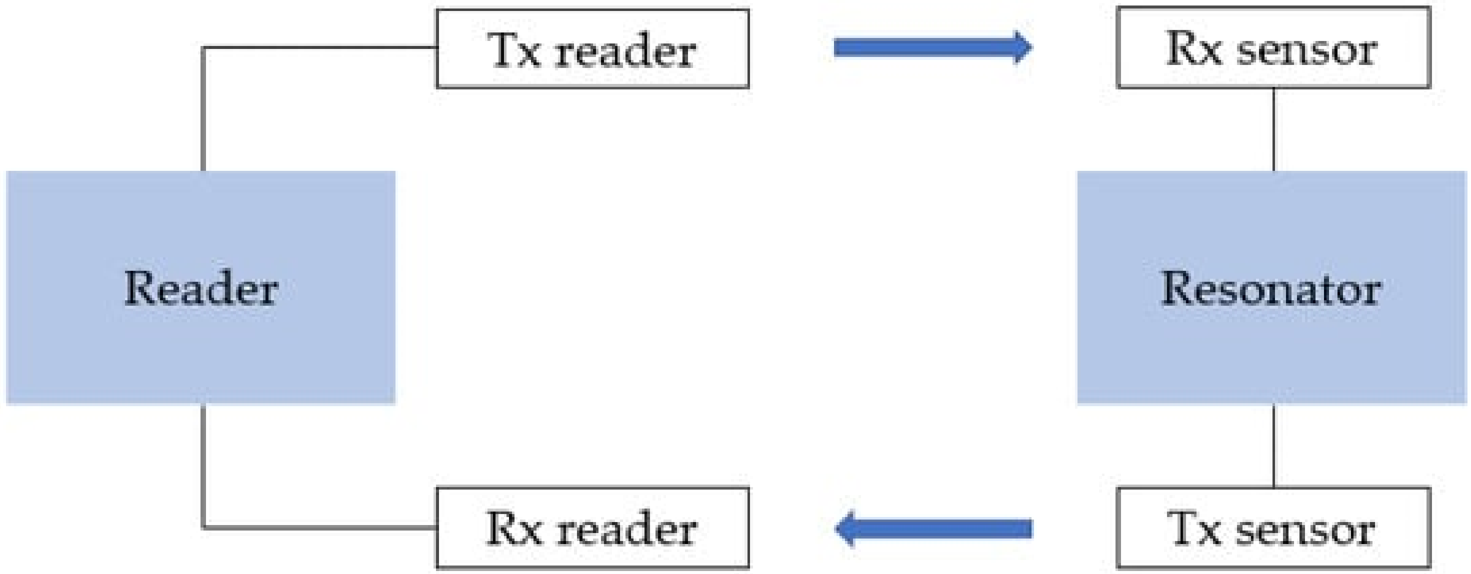


Assessment procedure

1. Reception of the corroded sensors from CS
2. Laboratory electrical resistance (ER) measurements
3. Corrosion depht calculation (ER_{ref} = $ER_{initial}$)
4. Estimation of the corrosion rate / IC class*

*exposure time estimated based on museum conservators feedbacks

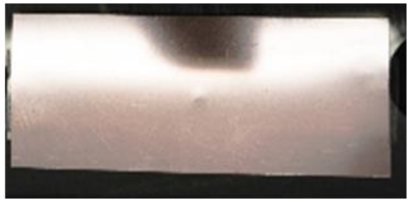
Principle of RFID corrosion sensors



Binary RFID tag for IC class determination

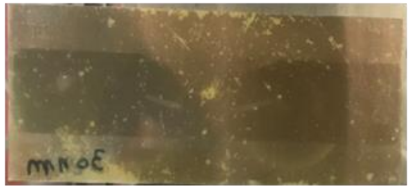
Principle: electromagnetic coupling between an RFID tag and a sensitive layer (Cu or Ag)

Commercial RFID tag



EM coupling with a sensitive element (30 nm of copper)

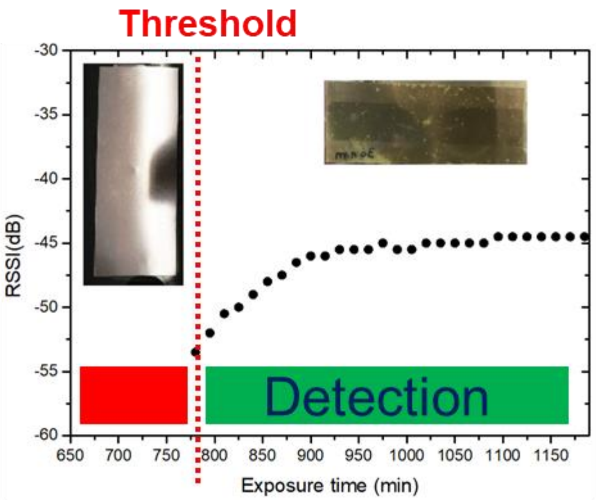
Atmospheric corrosion ⇨



After corrosion in a climatic chamber

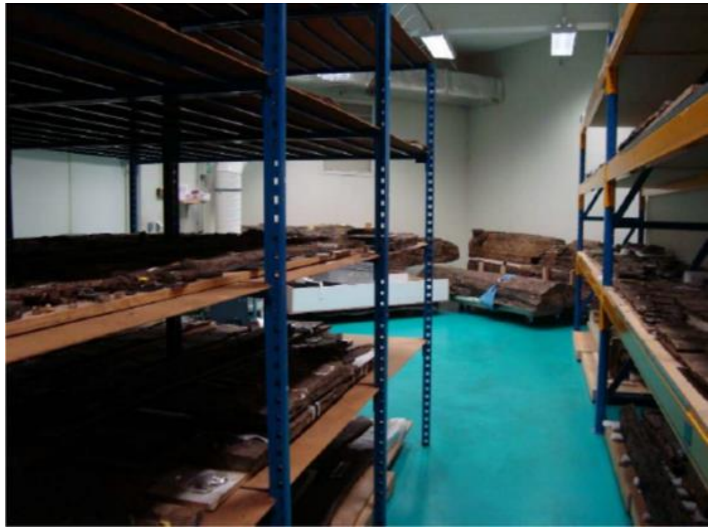
Response collected by a commercial RFID reader during laboratory exposure

Commercial RFID reader

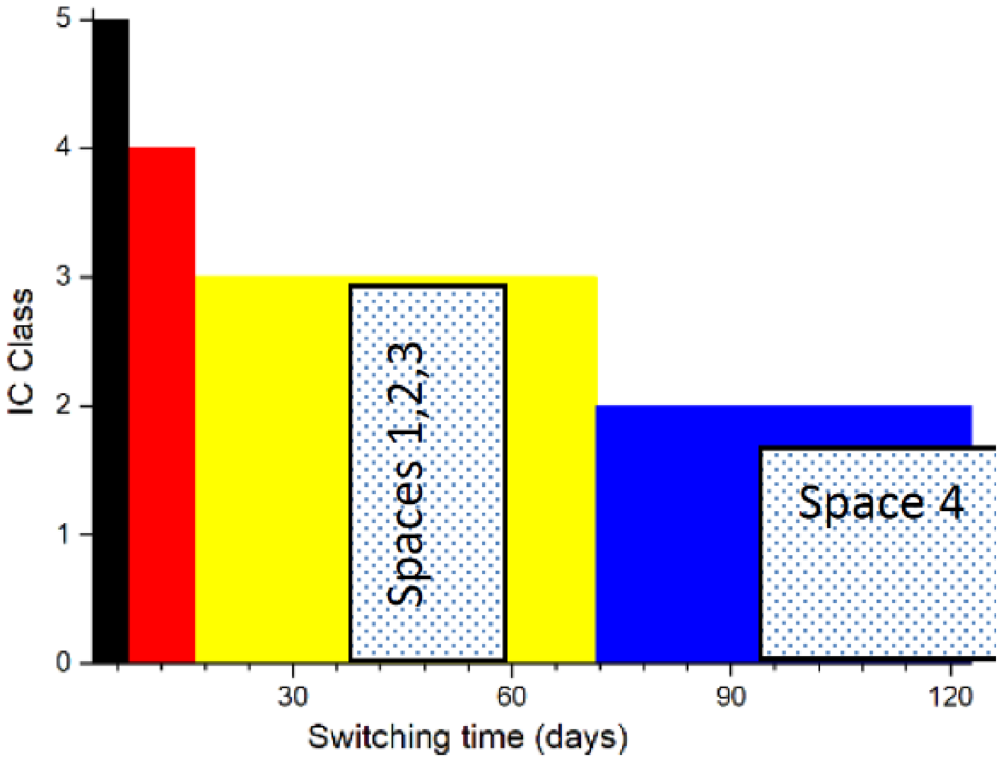


Metal (30 nm)	Metallic loss > X nm
⇩	⇩
No detection of the ID number	Detection of the ID

El Masri I et al., Development of a RFID sensitive tag dedicated to the monitoring of the environmental corrosiveness for indoor applications, *Sensors and Actuators: B. Chemical* (2020)



Location	Detection time (days)
Space 1	36
Space 2	57
Space 3	50
Space 4	>95



Conclusions

- ER well established has been widely used for monitoring the corrosion of Steel, zinc, Copper and Silver. Needs more research for other materials and « real alloys »
- RFID can be a low cost alternative (Yes/No concept)