Performance Evaluation of CPCs Using Corrosion Sensors – Laboratory and Field Studies

Marta A. Jakab

Southwest Research Institute

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
04 FEB 2009		**00-00-2009 to 00-00-2009**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Performance Evaluation of CPCs Using Corrosion Sensors - Laboratory and Field Studies	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Southwest Research Institute,6220 Culebra Rd.,San Antonio,TX,78238-5166**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
2009 U.S. Army Corrosion Summit, 3-5 Feb, Clearwater Beach, FL

14. ABSTRACT

15. SUBJECT TERMS

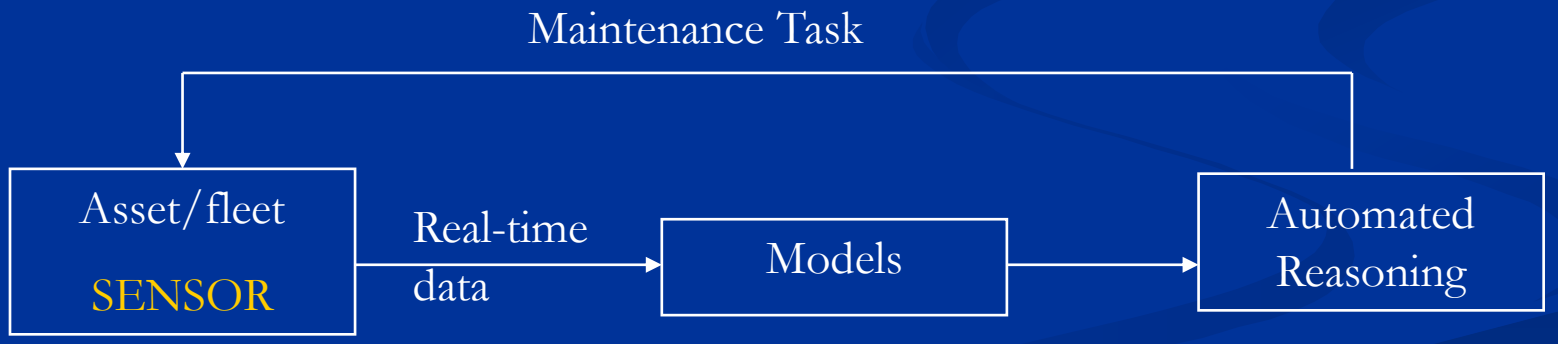
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**30**	

Outline

- Introduction
- Laboratory Evaluations
- Field Evaluations
- Summary

Condition Based Maintenance

- Goal: reduce inspection cost, while maximizing safety and readiness – optimize maintenance intervals
- Uses real-time data to prioritize and optimize maintenance resources



Motes Based Technology

- Based on miniature computer platform (motes) containing TinyOS2 operating system.
- Advantages:

  - localized control at each sensor

  - external triggers can be used to activate sensors (e.g., environmental change, signal from other motes or from control hub)

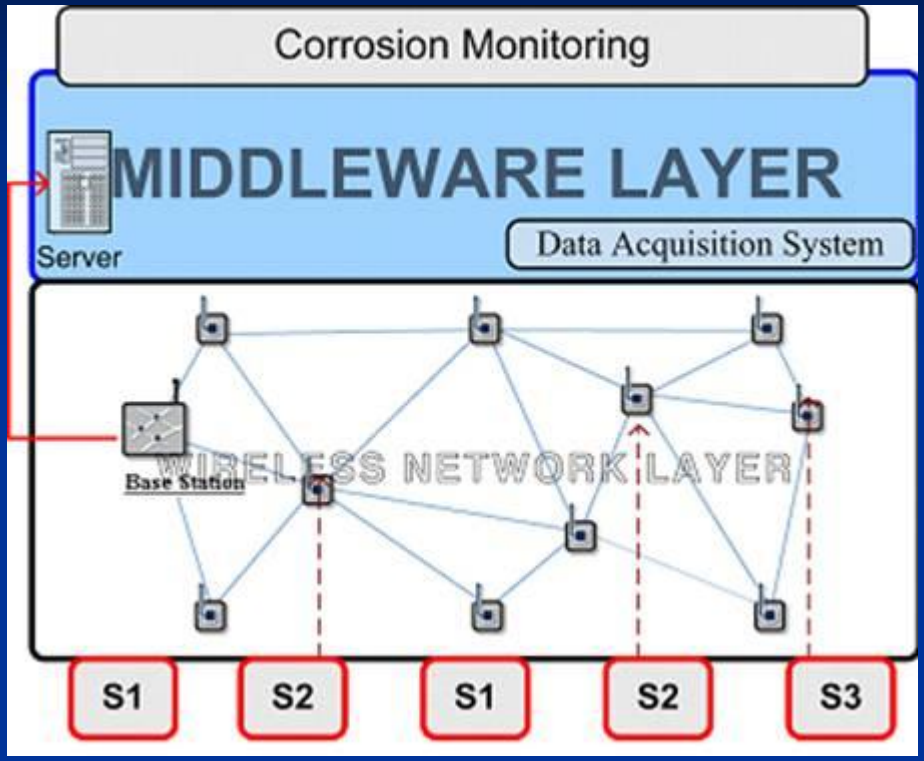
  - on-board data storage

  - on-board communications

  - motes network can optimize data transmission, i.e., allows intelligent distributed sensor network

  - automated data acquisition

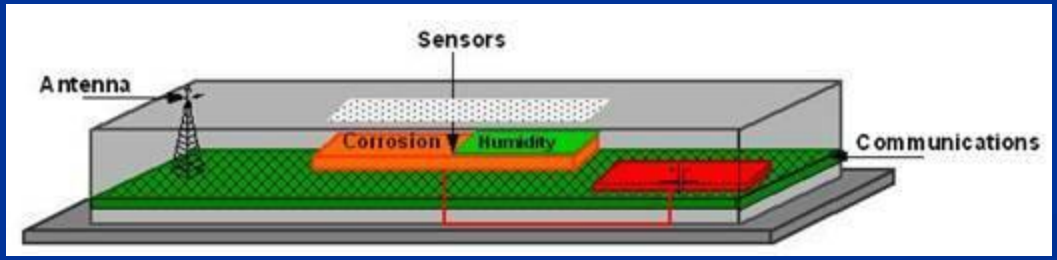
Data Transmission



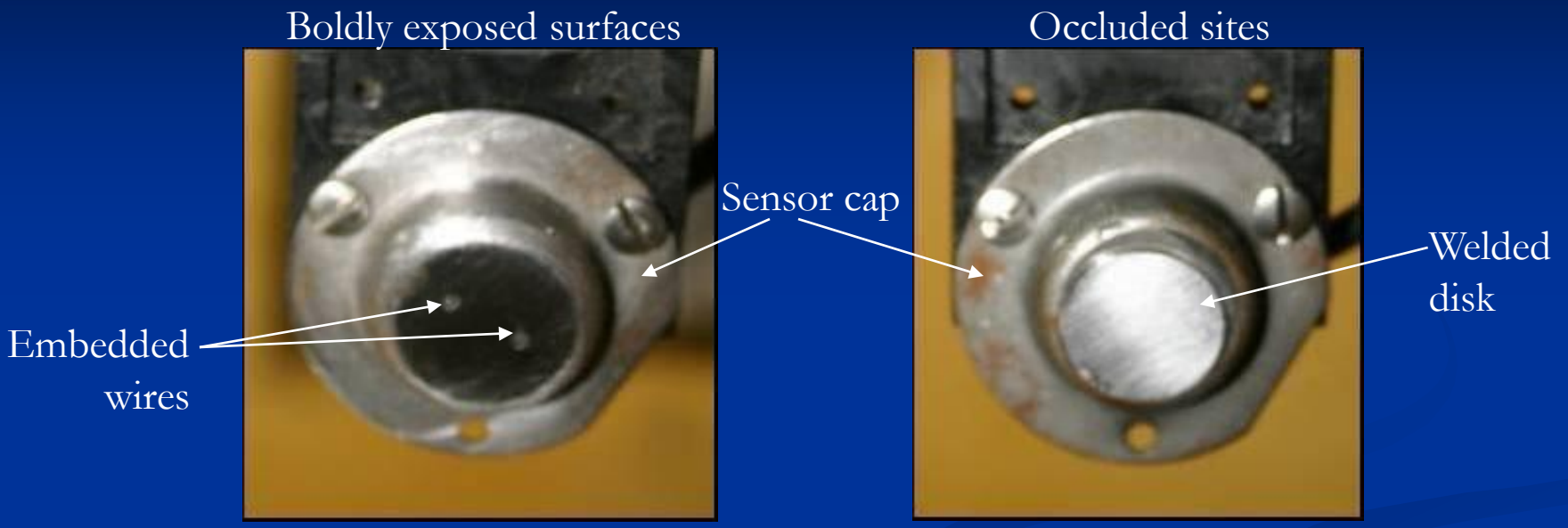
Base station connected to web portal through data network

Data routed to base station through reader network

Autonomous sensors – data collection at programmed intervals



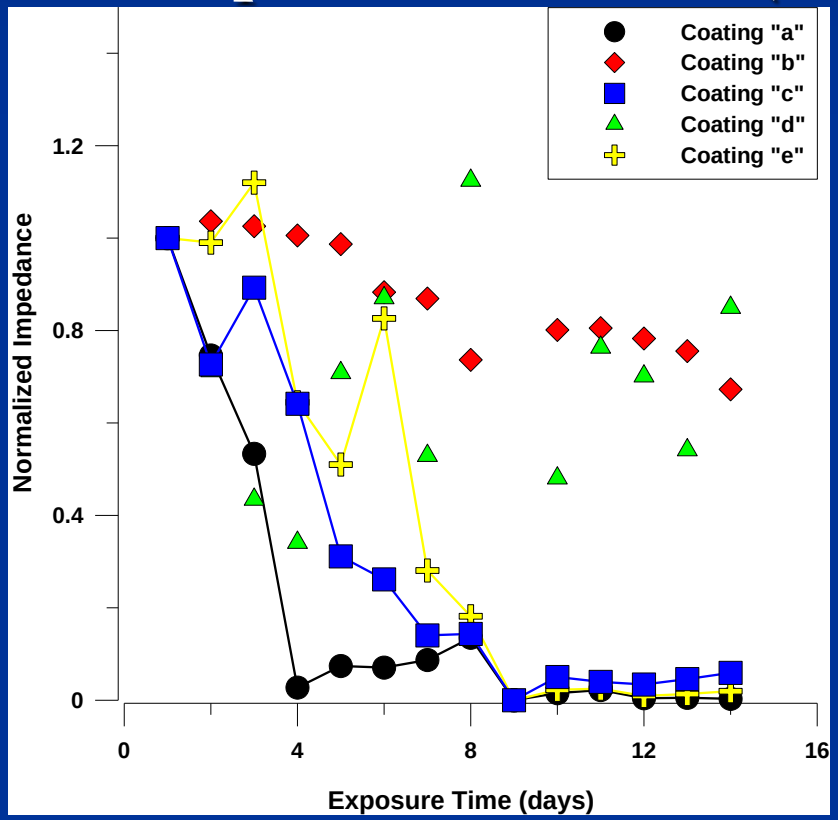
Coating Degradation Sensor (CDS)

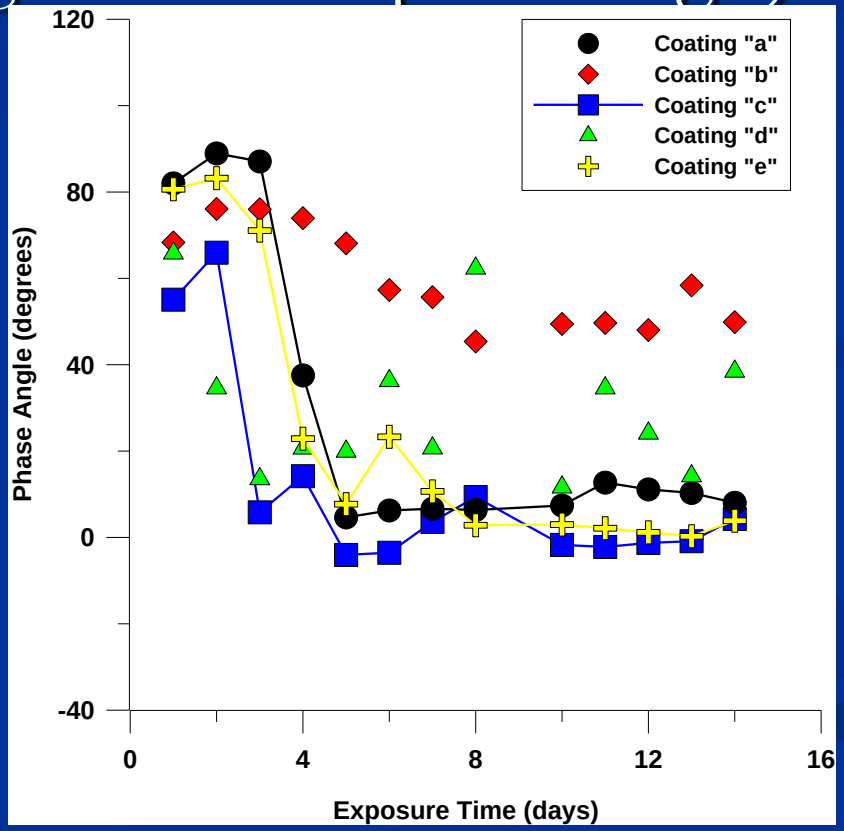


- Based on EIS
- Changes in impedance magnitude and phase angle values correlate with coating degradation
- Measurement at single frequency
- Rapid data acquisition and analysis

CDS Operation Principle

- Coating degradation is indicated by a drop in impedance values (magnitude and phase angle)





J. Dante, K. Price, A. Sabata and B. Sabata, "Embedded Coating Degradation Sensors for Monitoring Performance of Temporary Coatings", CORROSION 2007, Paper No. 07387.

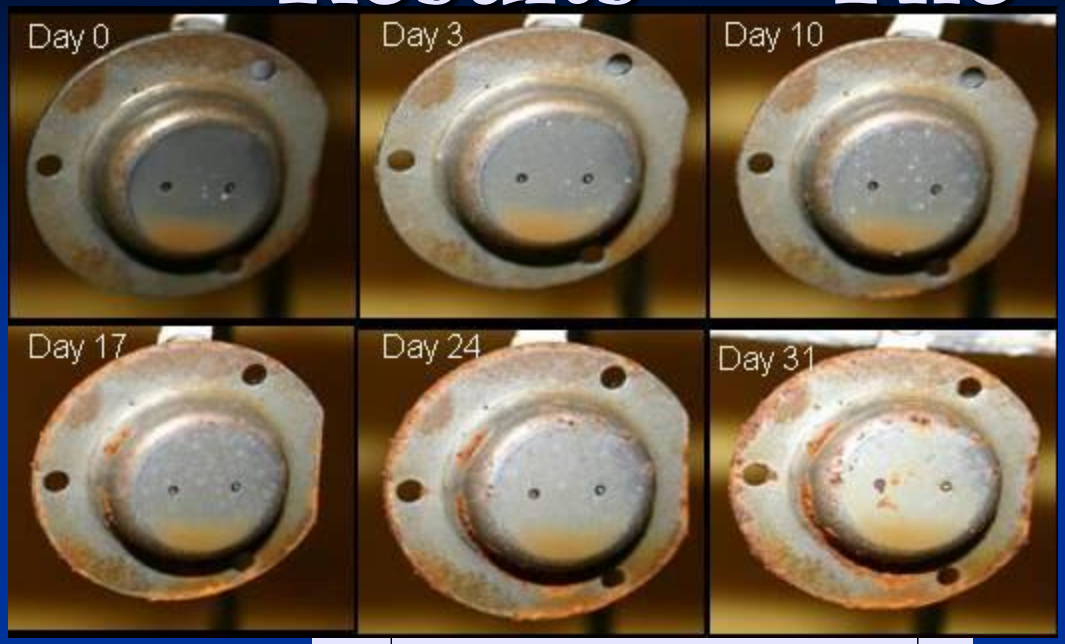
Laboratory Tests

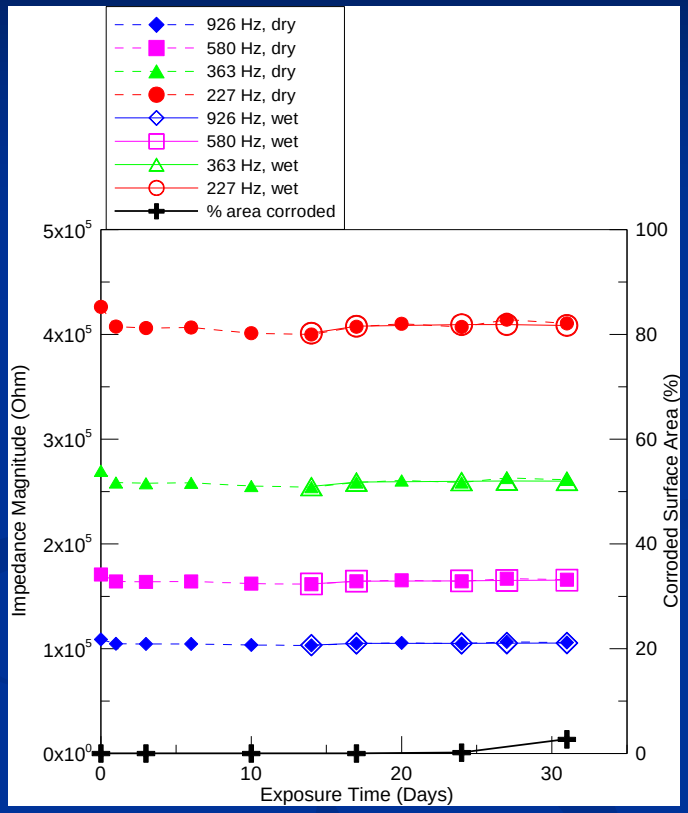
- Performed in Accelerated Exposure Testing (AET) chamber for 31 days
- Temperature: 30 °C
- Relative Humidity: 6 hrs @ 50 % and 6 hrs @ 90 %
- Salt spray: 15 sec every other day
- Salt solution composition: 0.9 wt% NaCl + 0.1 wt% $CaCl_2$ + 0.25 wt% $NaHCO_3$

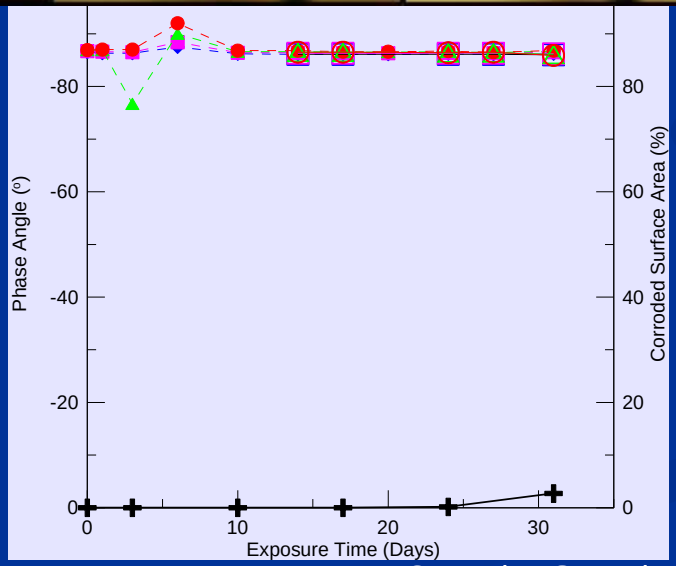
Electrochemical Impedance Tests

- Full impedance spectra measured at days 0, 3, 10, 17, 24 and 31
- Frequency range: 0.05 – 10^5 Hz
- AC amplitude: 20 mV and 200 mV
- DC bias: 0 mV
- Impedance Magnitude and Phase Angle were determined at 227, 363, 580 and 926 Hz

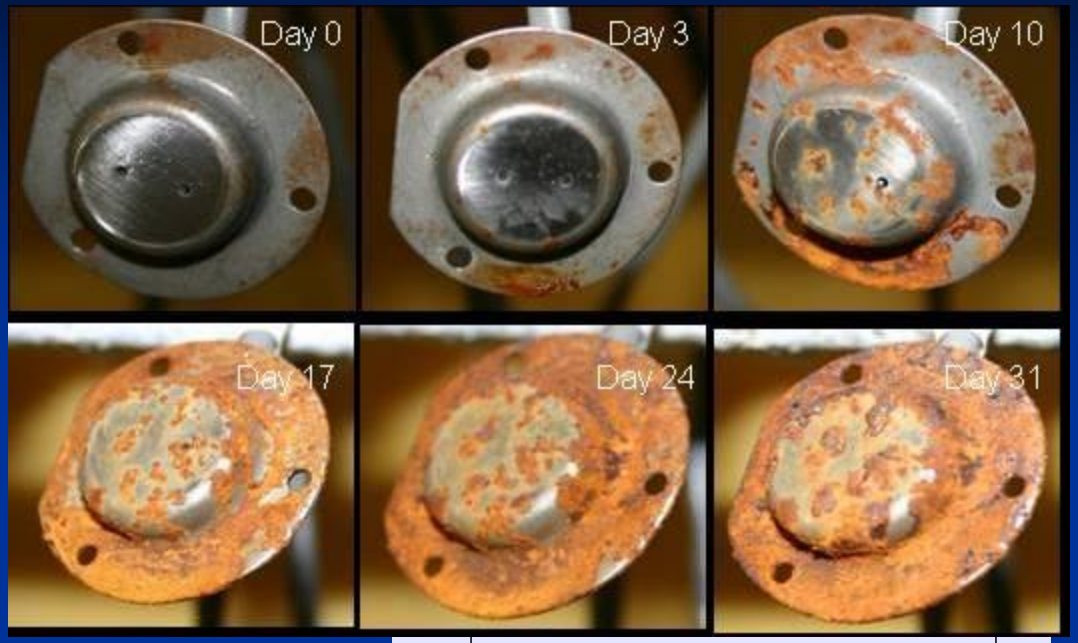
Results – "The Good"

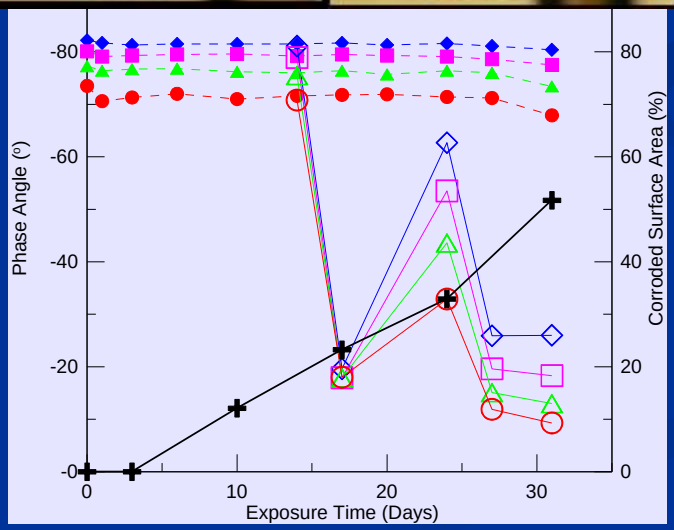


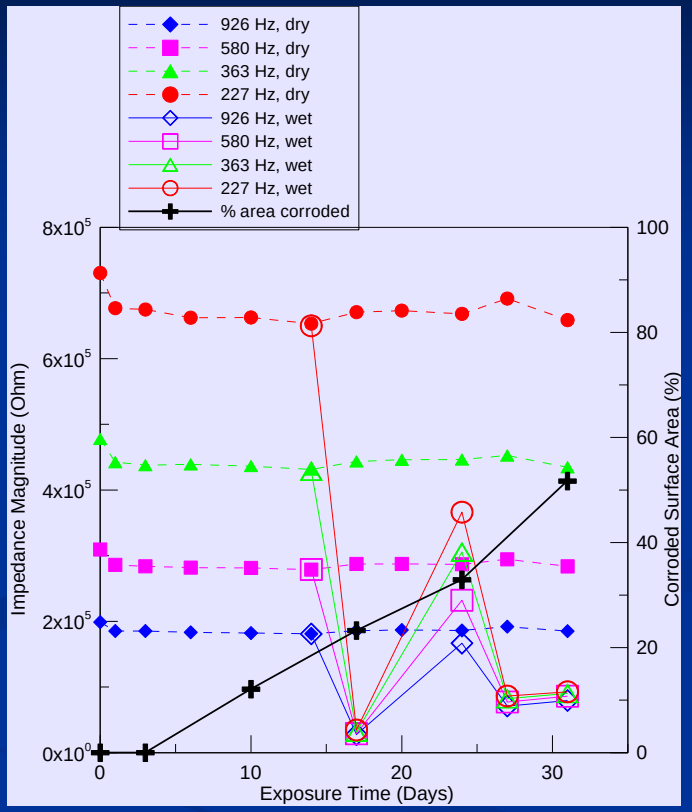




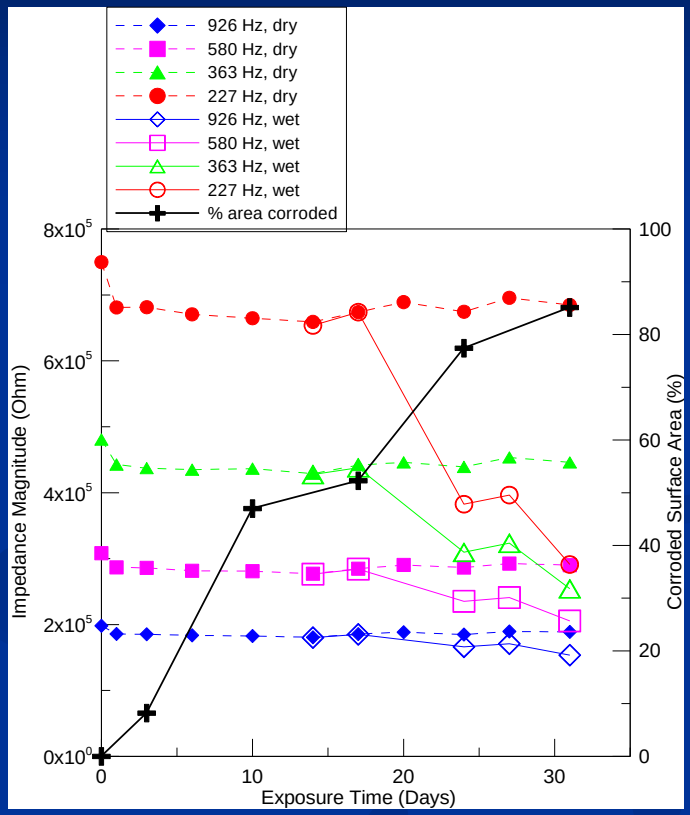
Results – "The Bad"

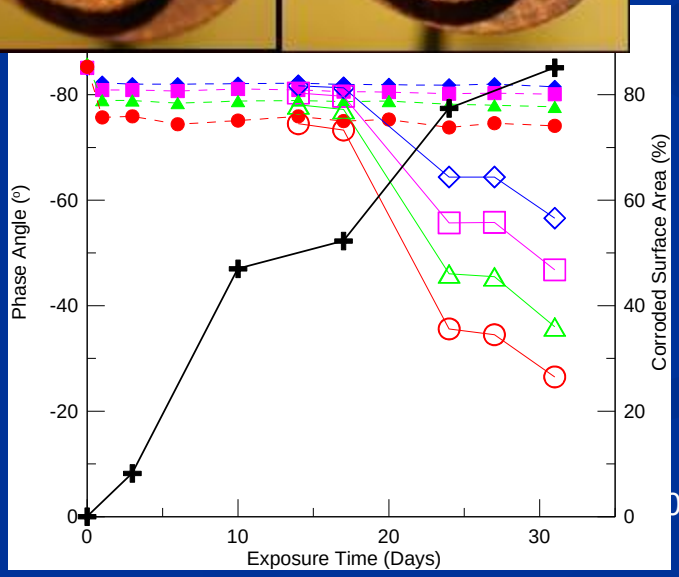






Results – "The Ugly"





Results - Summary

CPC	Threshold % area corroded	Recovery during wet part of cycle	Recovery during dry part of cycle	First visual sign of corrosion	Sensor signal indicating corrosion
CPC A	60 %	No	Yes	3 days	~18 days
CPC B	5 %	No	No	17 days	17 days
CPC C	> 2 %	No	Yes	31 days	31+ days
CPC D	20 %	Some	Yes	3 days	< 14 days
CPC E	40 %	Some	Yes	3 days	17 days
CPC F	20 %	Some	Yes	10 days	17 days
CPC G – 2 pins	20 %	No	Yes	10 days	< 14 days
CPC G – 4 pins	20 %	No	No	2 days	5 days

Ranking of CPCs – Visual and Impedance

- Visual:

  CPC A < CPC D< CPC E < CPC F < CPC B < CPC C

- Impedance (sensor output):

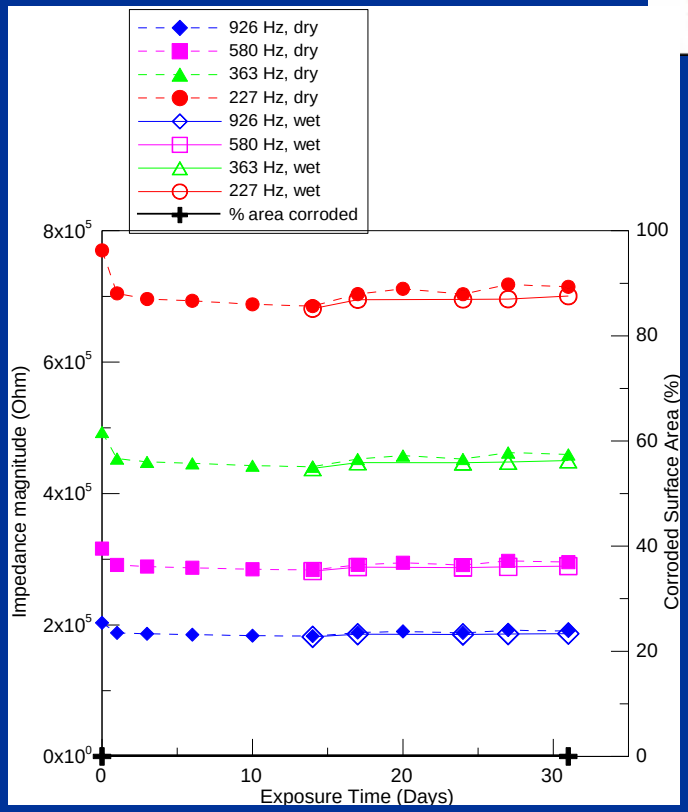
CPC D < CPC E / CPC F / CPC B < CPC A < CPC C

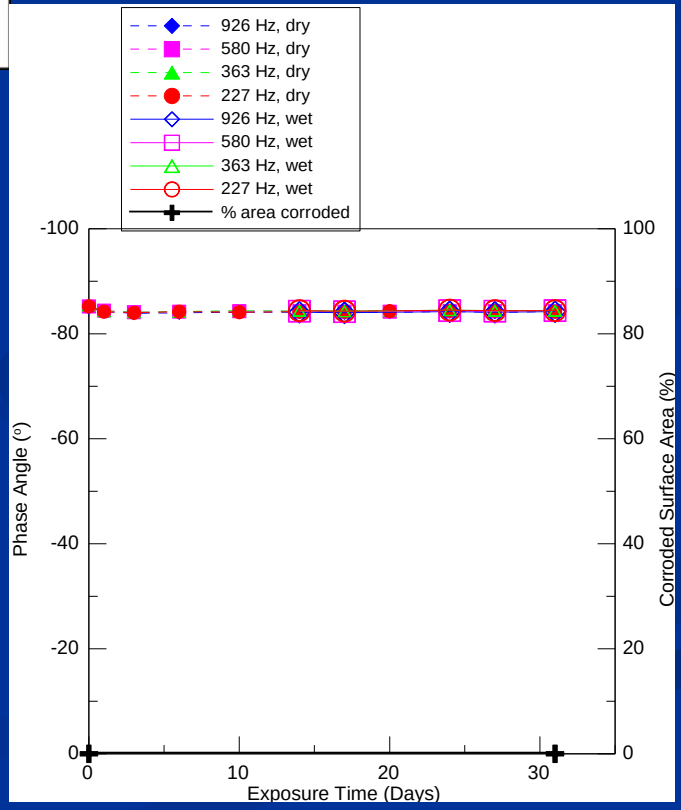
Formation of rust layer that is impermeable to moisture??

Depth of corrosion damage is also important!

Occluded Sites

Treatment with CPC prior to exposure





Field Studies

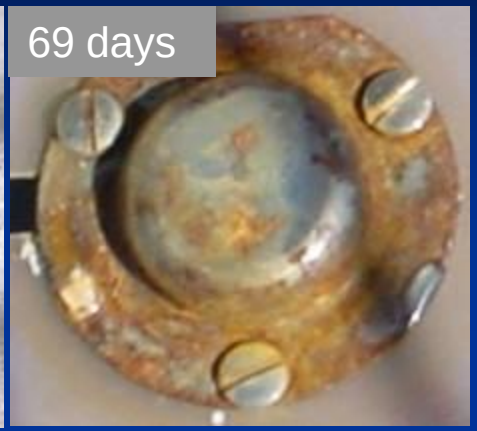
- Sensors exposed to coastal environment at Daytona Beach, FL for 149 days.
- Sensor package acquired and wirelessly transmitted relative humidity, temperature and impedance data to a web portal.
- EIS parameters:

  Frequency: 1000 Hz

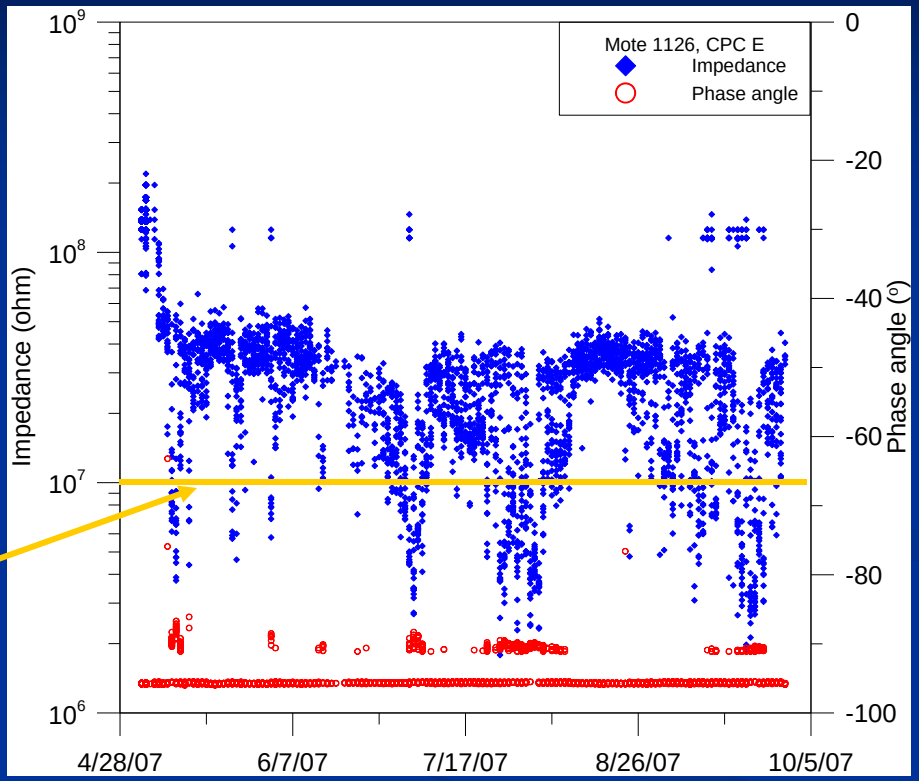
  AC amplitude: 200 mV

  Measurement interval: once every hour

Results – The "Bad"

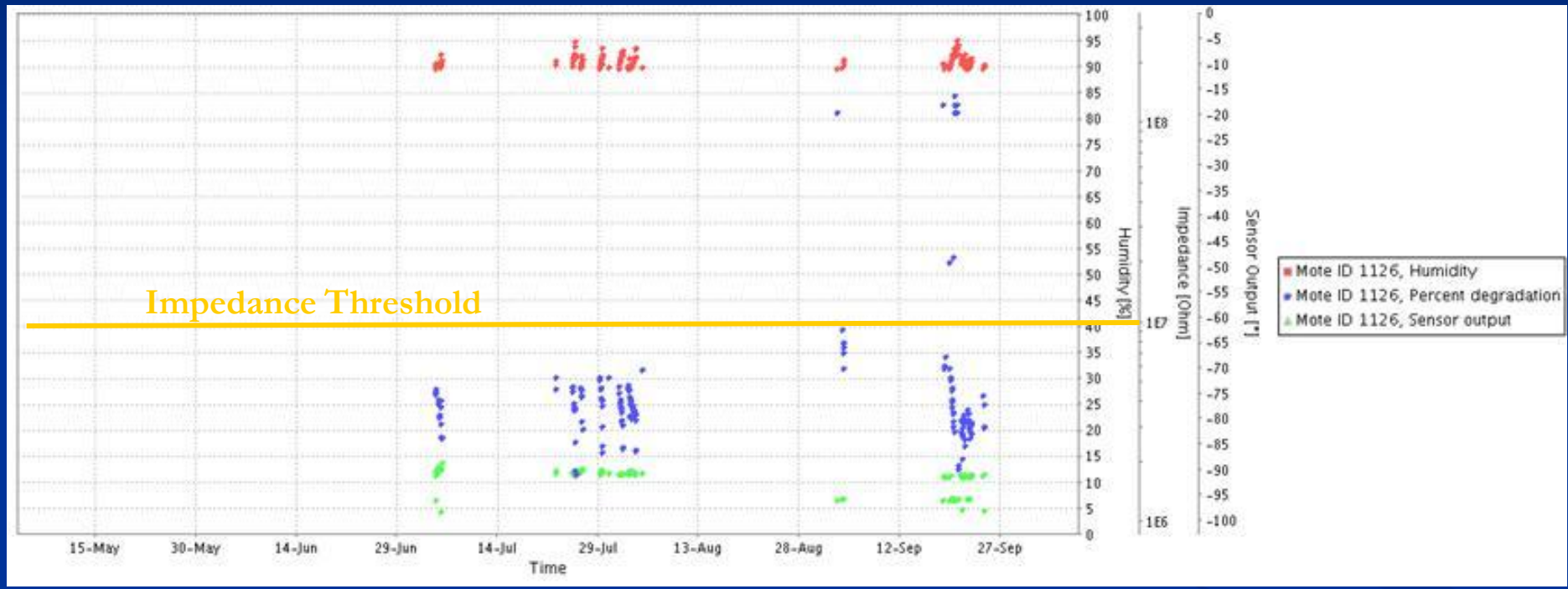


Impedance threshold



- Initial drop in impedance is due to water uptake.
- Coating failure: drop of impedance below 10^7 Ω.
- Recovery: during low RH periods, sensor surface dries out.
- Phase angle changes follow impedance magnitude trends.

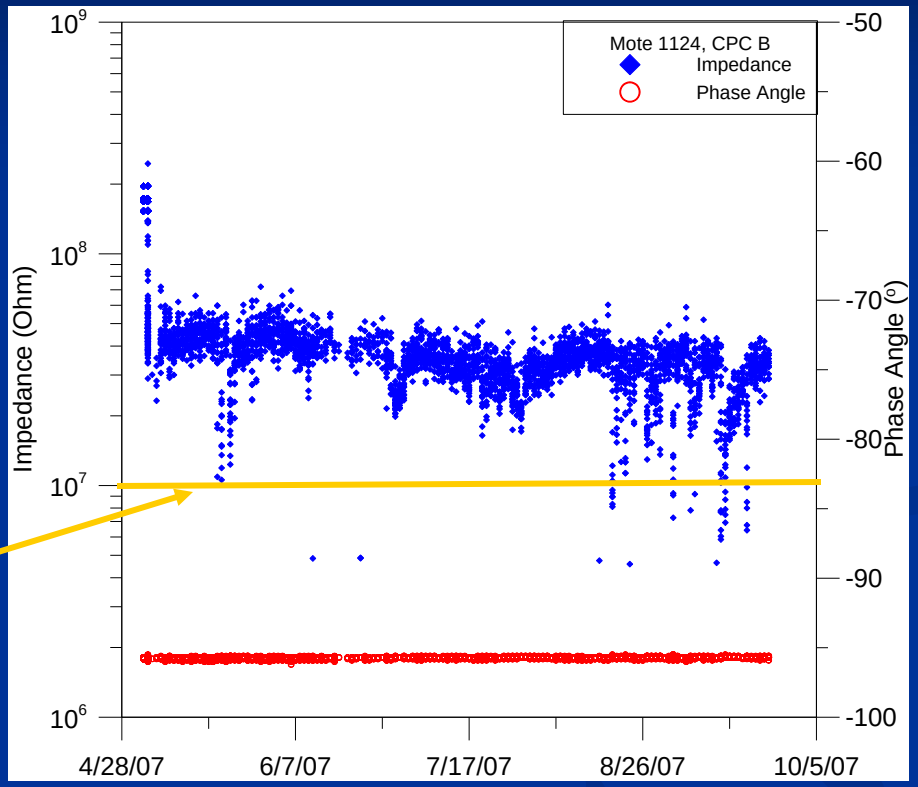
Sensor Output, RH: 80-100 %



- Most significant changes.
- Water condensation + salt deposits – high conductivity medium for corrosion.

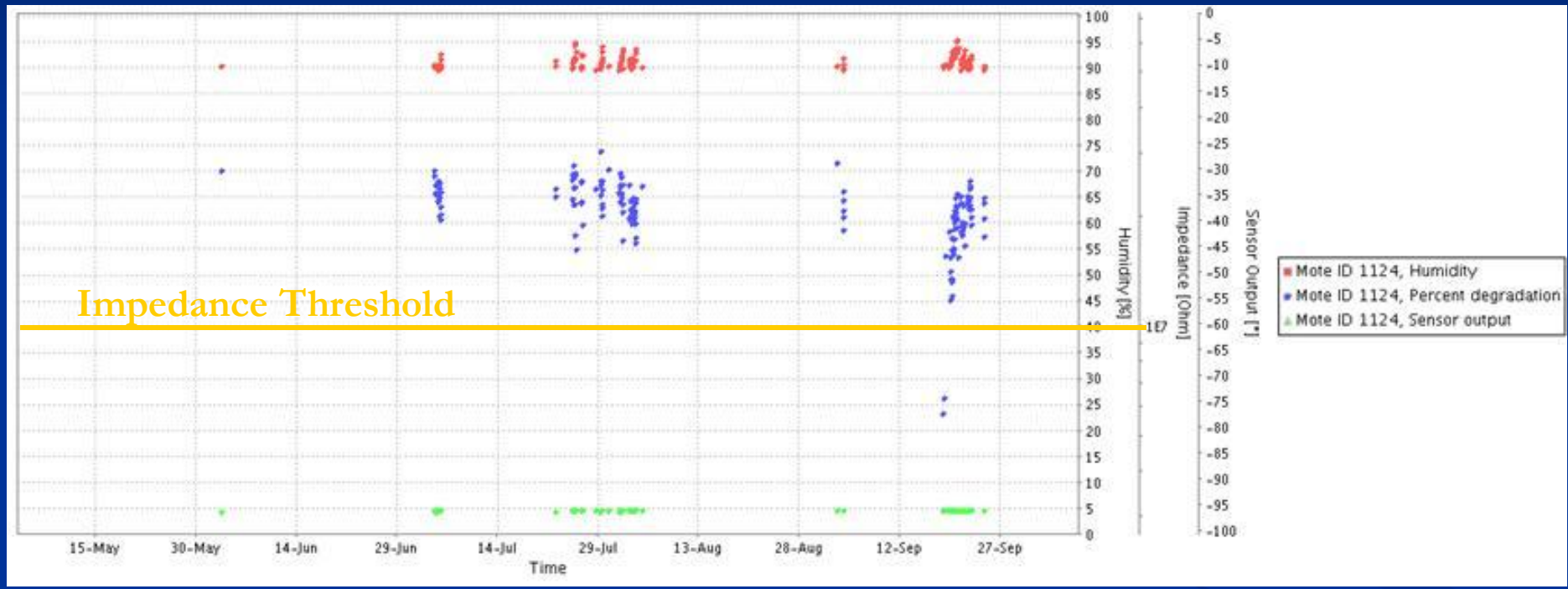
Results – "The Good"

Impedance threshold



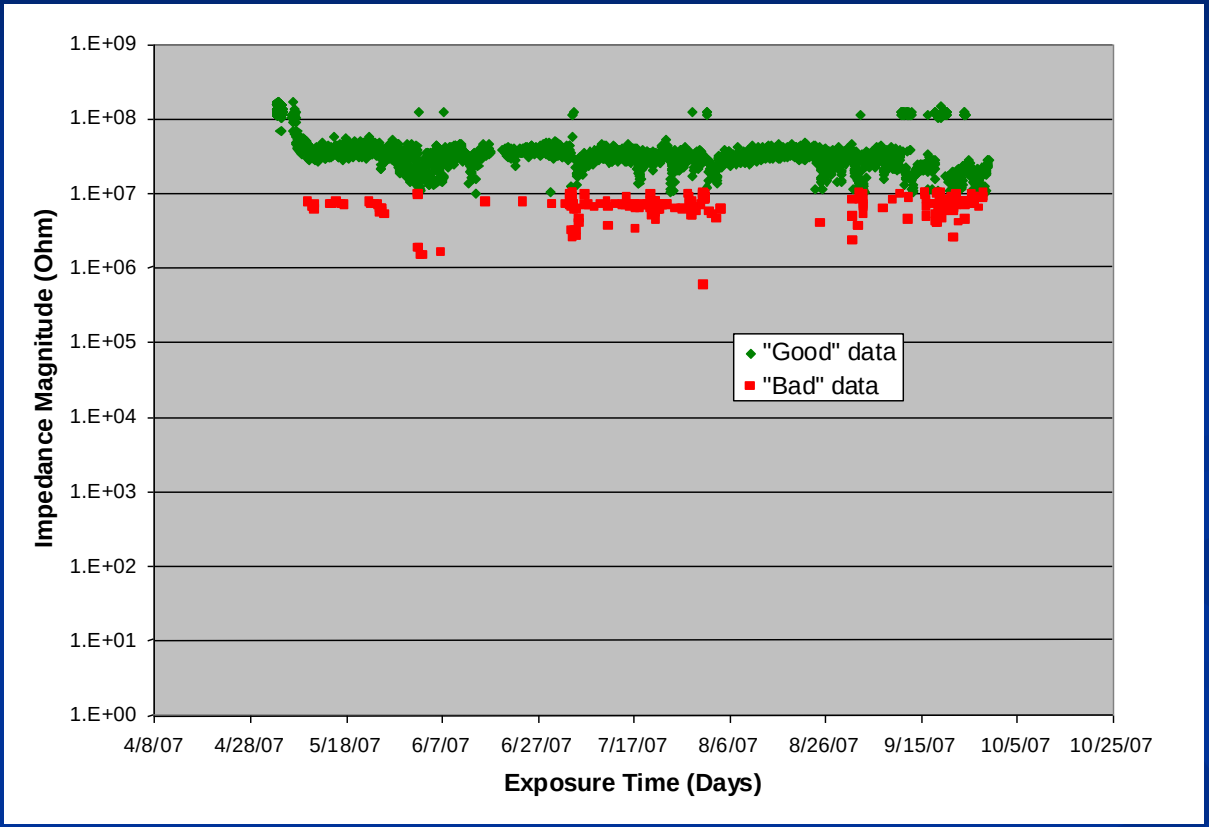
- Initial drop in impedance is due to water uptake.
- No corrosion is observed on treated top surface.
- No significant drop of impedance below threshold.
- No change of phase angle.

Sensor Output, RH: 80-100 %



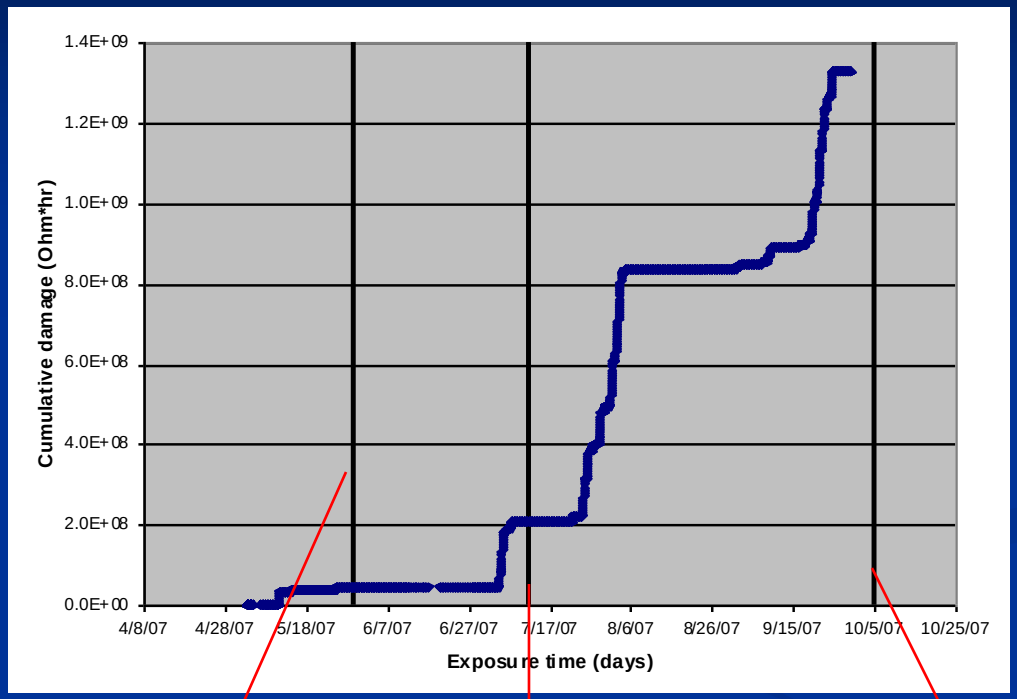
- No drop below impedance threshold for up to 110 days.
- No change in phase angle.
- This CPC provides excellent corrosion protection even under high humidity conditions.

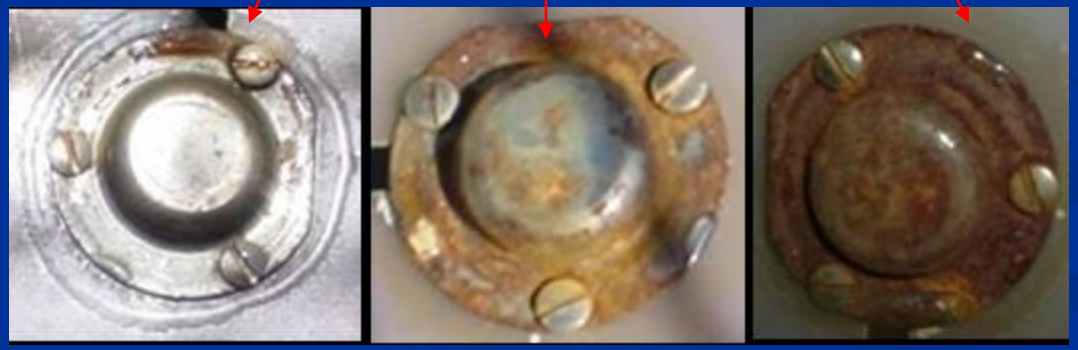
Cumulative Damage Analysis



$$Cumulative\ Damage = \int_0^t \left| 10^7 - Impedance\ Magnitude_{if\ I<10^7\ \Omega} \right| dt$$

Cumulative Damage Analysis





Results - Summary

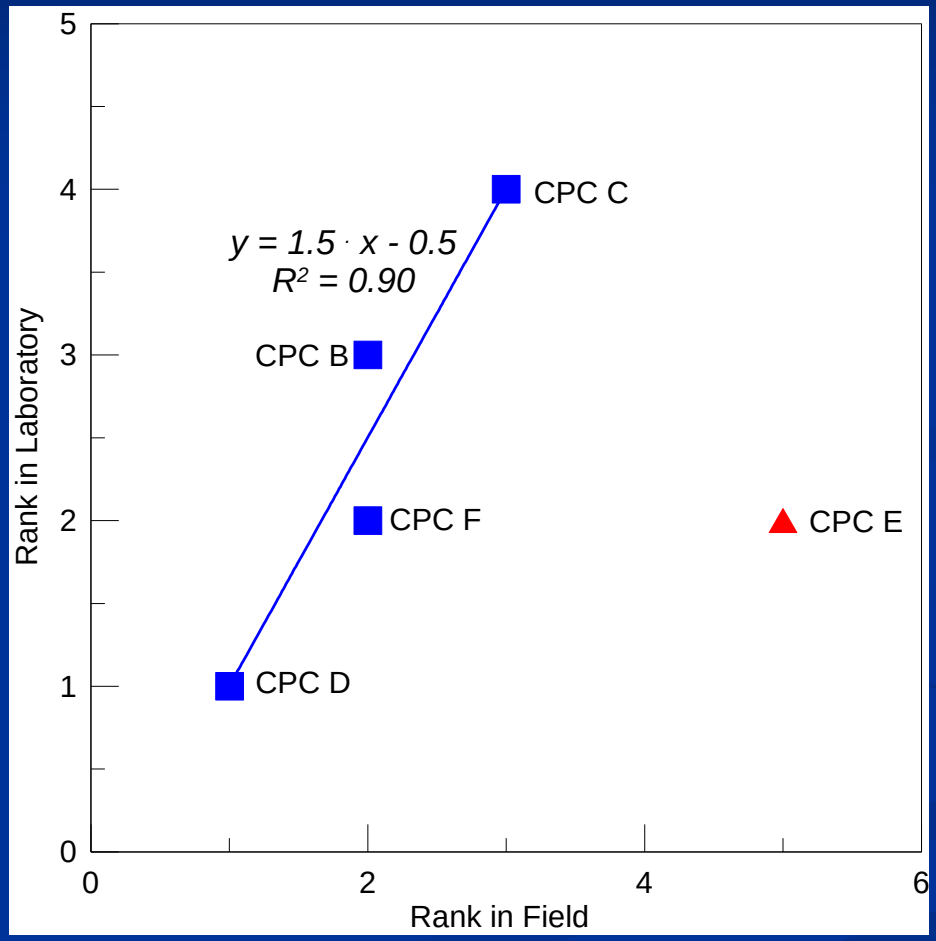
Ranking based on cumulative damage:

CPC D < CPC F < CPC B < CPC C < CPC E

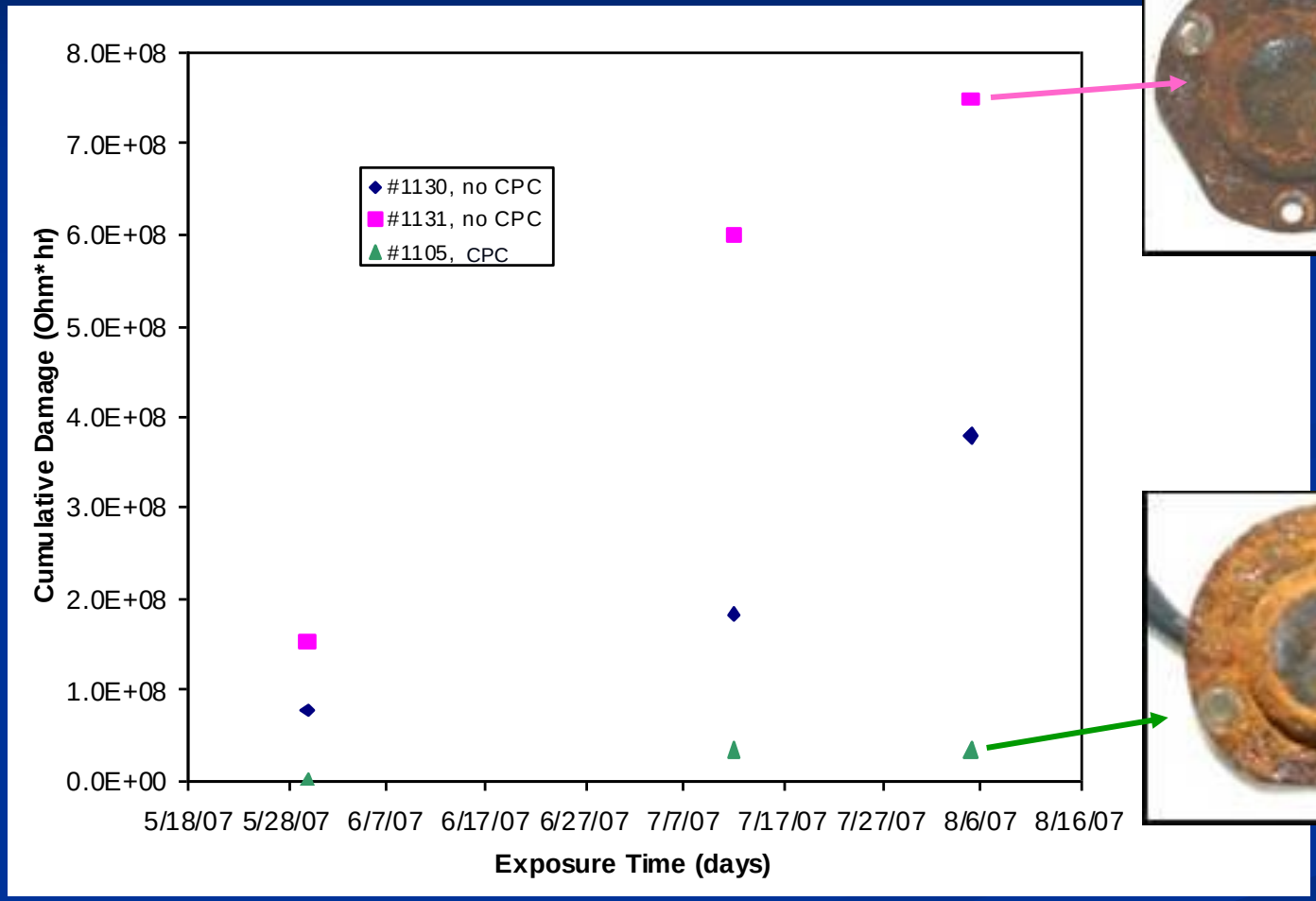
Ranking based on visual observations:

CPC D = CPC B < CPC F < CPC C < CPC E

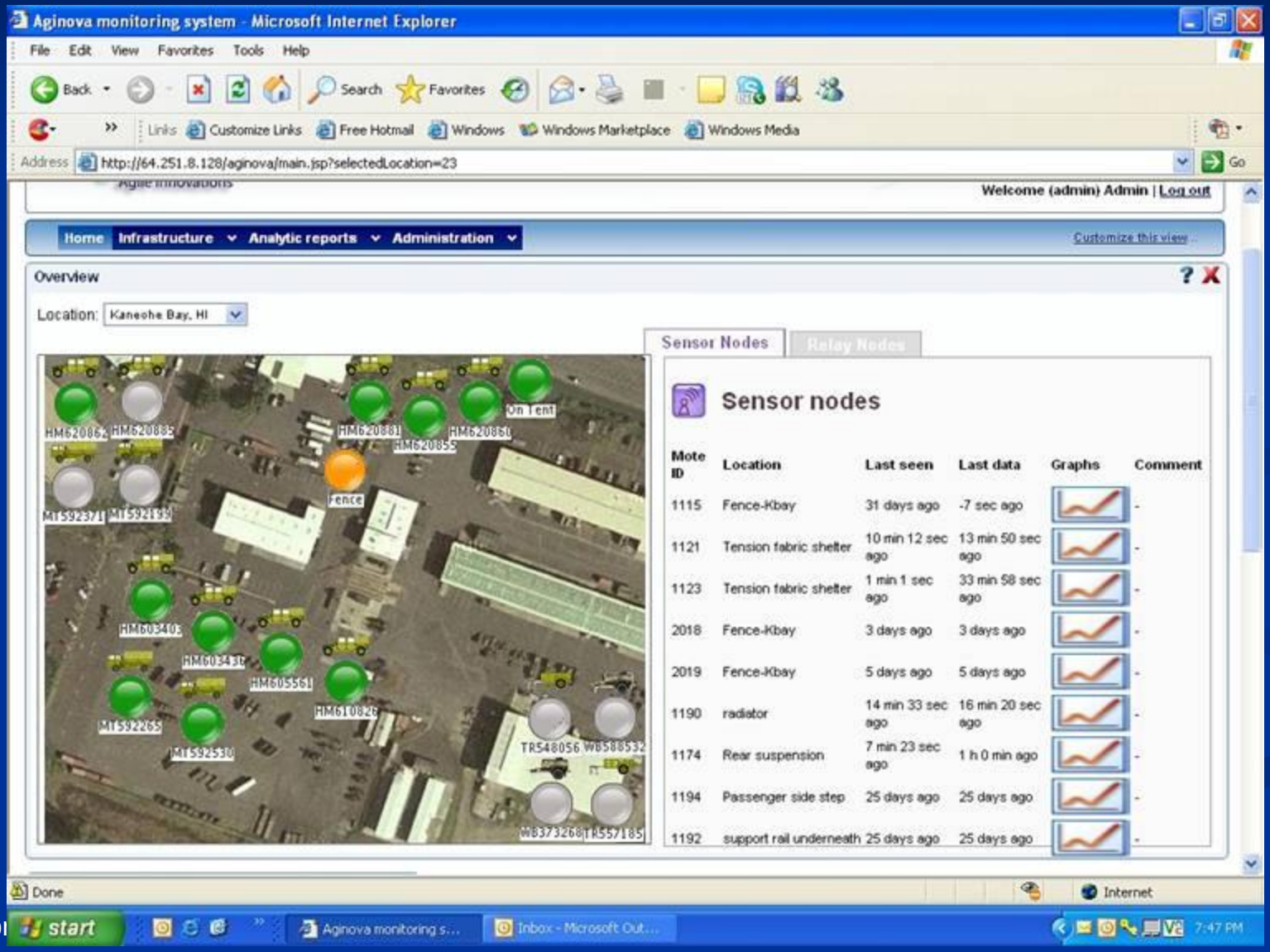
Performance Ranking of CPCs: Cyclic lab test vs. Daytona Beach field test



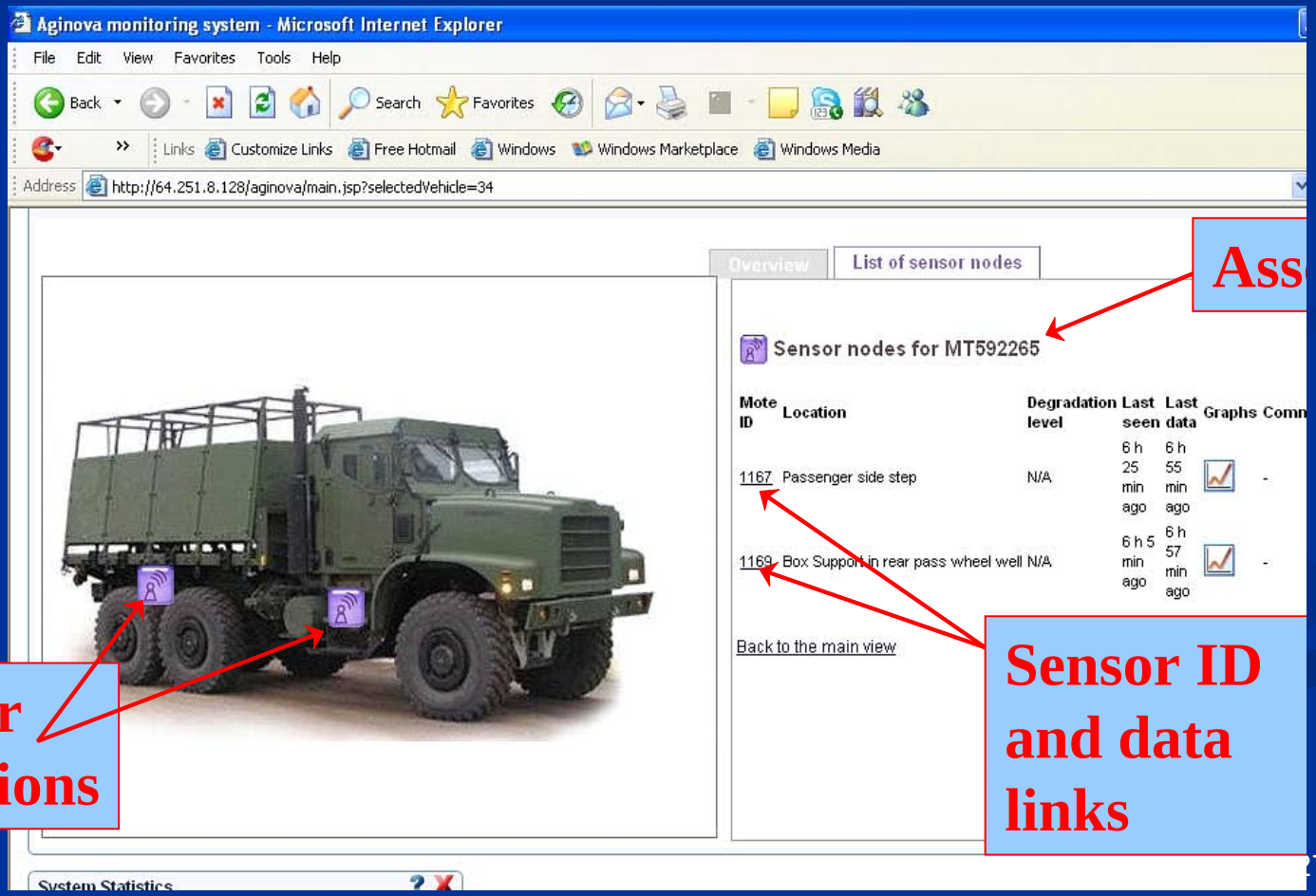
Occluded Sites



Web Portal


Aginova monitoring system - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Search Favorites
Links Customize Links Free Hotmail Windows Windows Marketplace Windows Media
Address http://64.251.8.128/aginova/main.jsp?selectedLocation=23
Go
Welcome (admin) Admin | Log out
Home Infrastructure Analytic reports Administration
Customize this view
Overview
Location: Kaneohe Bay, HI
Sensor Nodes
Relay Nodes
Sensor nodes
Mote ID
Location
Last seen
Last data
Graphs
Comment
1115 Fence-Kbay 31 days ago -7 sec ago -
1121 Tension fabric shelter 10 min 12 sec ago 13 min 50 sec ago -
1123 Tension fabric shelter 1 min 1 sec ago 33 min 58 sec ago -
2018 Fence-Kbay 3 days ago 3 days ago -
2019 Fence-Kbay 5 days ago 5 days ago -
1190 radiator 14 min 33 sec ago 16 min 20 sec ago -
1174 Rear suspension 7 min 23 sec ago 1 h 0 min ago -
1194 Passenger side step 25 days ago 25 days ago -
1192 support rail underneath 25 days ago 25 days ago -
On Tent
Fence
Done
Internet
start
Aginova monitoring s...
Inbox - Microsoft Out...
7:47 PM

Web Portal


Aginova monitoring system - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Search Favorites
Links Customize Links Free Hotmail Windows Windows Marketplace Windows Media
Address http://64.251.8.128/aginova/main.jsp?selectedVehicle=34
Overview
List of sensor nodes
Sensor nodes for MT592265
Mote ID
Location
Degradation level
Last seen
Last data
Graphs
1167 Passenger side step N/A 6 h 25 min ago 6 h 55 min ago
1169 Box Support in rear pass wheel well N/A 6 h 5 min ago 6 h 57 min ago
Back to the main view
System Statistics
Sensor Locations
Sensor ID and data links

Summary

- It was determined that impedance based coating degradation sensors can be successfully used to detect coating failure and assess the performance of CPCs in coastal environments.
- Laboratory tests showed that the changes associated with coating failure are more pronounced at lower measurement frequencies.
- The sensitivity of the sensor was found to be dependent on the performance of the CPC; better sensitivity was found in case of better performing CPCs.
- The changes in impedance parameters measured during the wet part of the exposure cycle were found to correlate well with visual observations of surface corrosion. In some cases, recovery of the impedance values during the dry part of the cycle was observed.

Summary

- No significant improvement in sensitivity was found when the number of sensor wires embedded in the surface was increased from two to four.
- Field testing of sensor packages at Daytona Beach, FL indicated that it is feasible to collect and wirelessly transmit temperature, relative humidity and impedance data using mote based sensor technology.
- A data analysis method was developed to assess the performance of CPCs based on sensor output.
- The order of performance of different CPCs determined from sensor output in the field and laboratory was found to be in agreement.

Acknowledgements

- The work reported here was sponsored by the U. S. Marine Corps Corrosion Prevention and Control (CPAC) Program Office.
- The author acknowledges the guidance provided by Mr. Matthew Koch, USMC CPAC and Mr. Hancel Porterfield.
- The author also acknowledges the technical assistance provided by Mr. Albert Faz in the laboratory tests and Mr. Bill Abbott in the field tests as well as guidance provided by Dr. Ashok Sabata.