Mega Rust 2017: Naval Corrosion Conference

Delivering for Success

Newport News, Virginia, USA
20 - 22 June 2017

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PEO CARRIERS

IN-SERVICE AIRCRAFT CARRIERS

Aircraft Carrier Perspective: Life Cycle Management

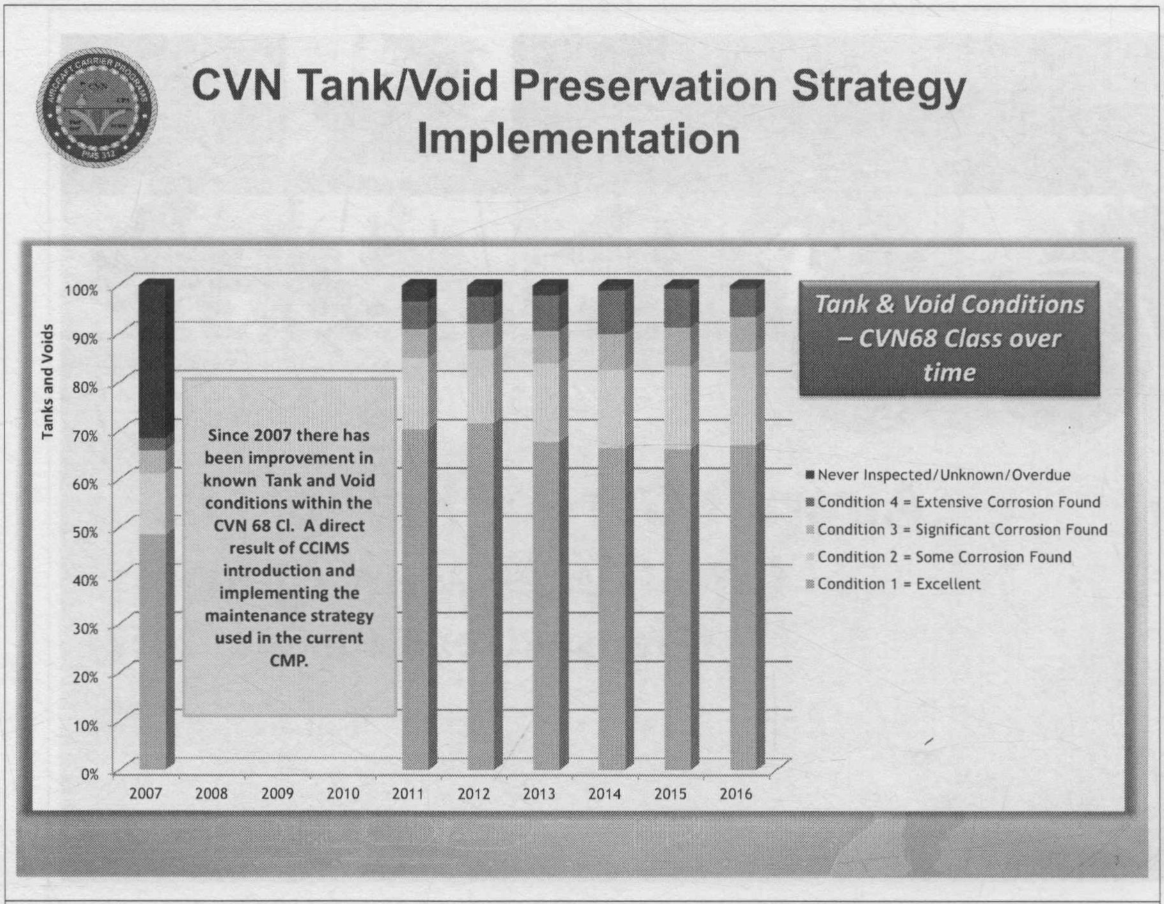
(Prepared for MegaRust 2017)

Joel Korzun
Carrier Planning Activity, PMS312C

Expectation

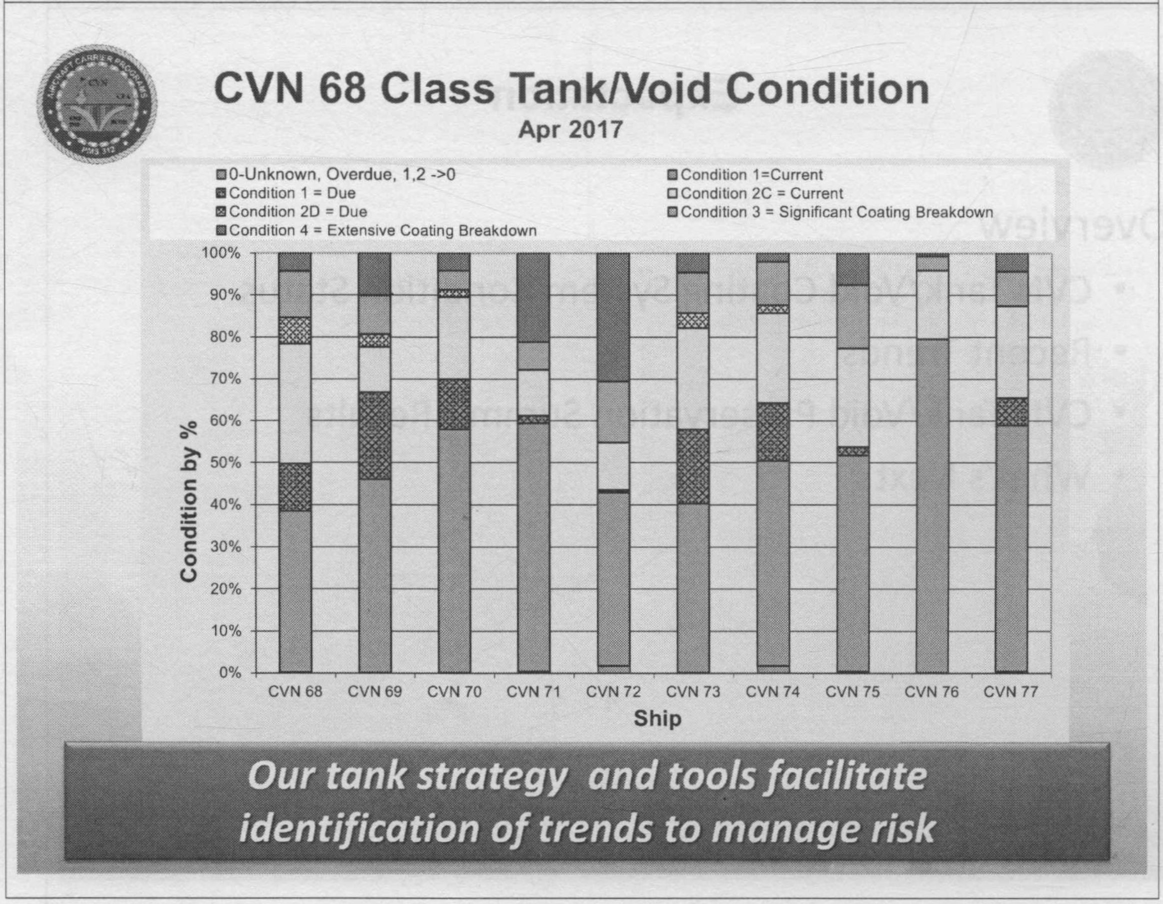
Overview

- CVN Tank/Void Coating System Condition Status
- Recent Trends
- CVN Tank/Void Preservation Summit Results
- What's Next



CVN Tank/Void Preservation Strategy Implementation

Since 2007 there has been improvement in known Tank and Void conditions within the CVN 68 Cl. A direct result of CCIMS introduction and implementing the maintenance strategy used in the current CMP.



CVN 68 Class Tank/Void Condition

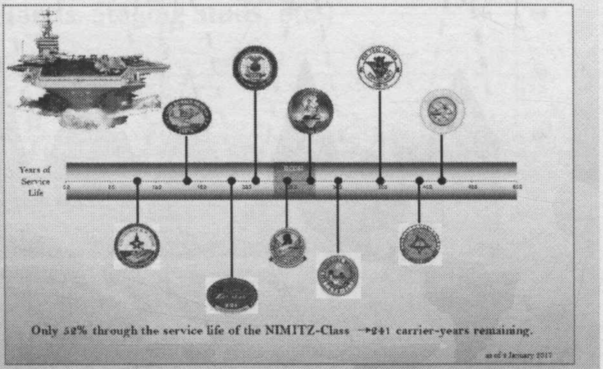
Apr 2017

Our tank strategy and tools facilitate identification of trends to manage risk

CVN Recent Trends

- Recent trends show we are not executing preservations at the rate anticipated under our strategy
- Legacy coatings installed during new construction and not being replaced fast enough
  - 2011 Coating age – 15.8 yrs
  - 2017 Coating age – 19.1 yrs

10 hulls –500 total carrier-years, serving over 84 years, from 1975 until 2059



Only 52% through the service life of the NIMITZ-Class →241 carrier-years remaining.

as of 1 January 2017

We must align Requirements & Throughput

CVN Tank/Void Preservation Summit Results

Constraints

- Resources
  - Shared personnel across CONUS
  - Port Loading
- Contracts
  - Turnaround and Flexibility
- Locational
  - Limited work/laydown area
    - Grouping compartments for preservation improve productivity
  - Environmental/Permitting
  - Water temperature

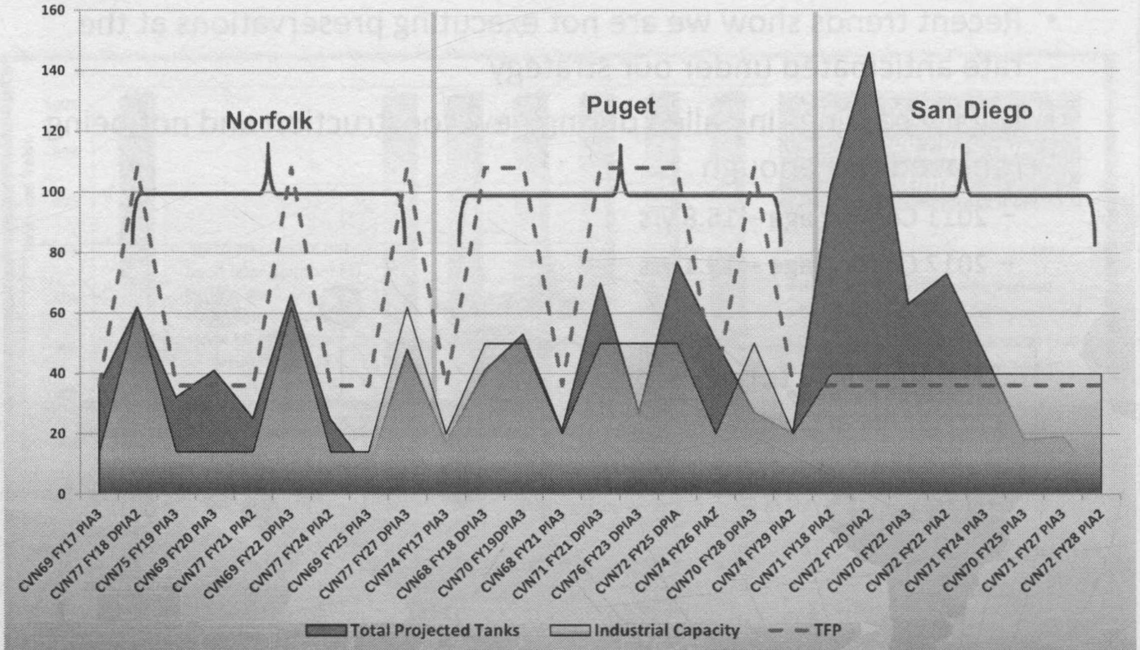
Industrial Capacity

Region	PIA	DPIA
TFP 36 month	36	108
Norfolk	14 (12/2)	62 (50/12)
Puget	20 (10/10)	50 (30/20)
San Diego	25-40	-

Note: (contractor/Public SY) total for that avail type.

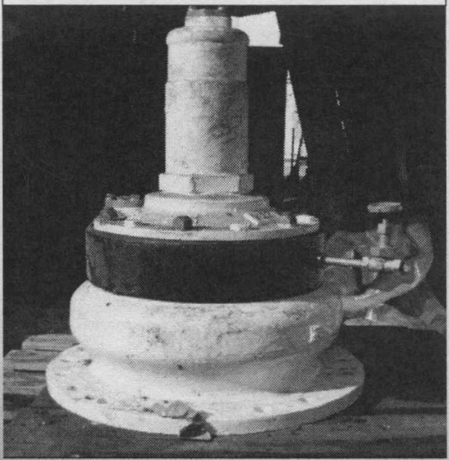
Tank Preservations by Availability

(SRA and RCOH excluded)

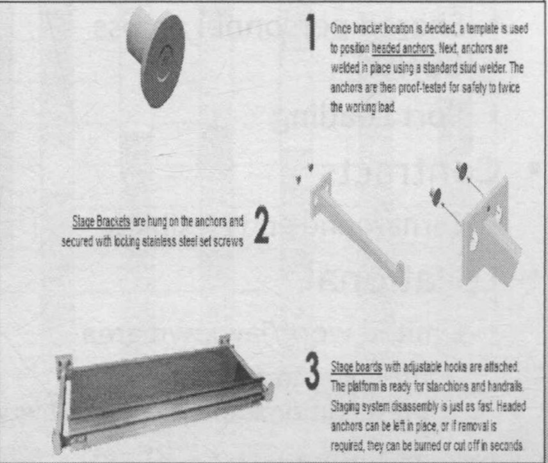


Constraint Mitigation

- ✓ Use a Belly Band for hull valves instead of cofferdam – (obtaining double valve protection)



- ✓ Shoot studs in lieu of welding padeyes for plenum preservation in only 2 minutes using the new system



1 Once bracket location is decided, a template is used to position headed anchors. Next, anchors are welded in place using a standard stud welder. The anchors are then proof-tested for safety to twice the working load.

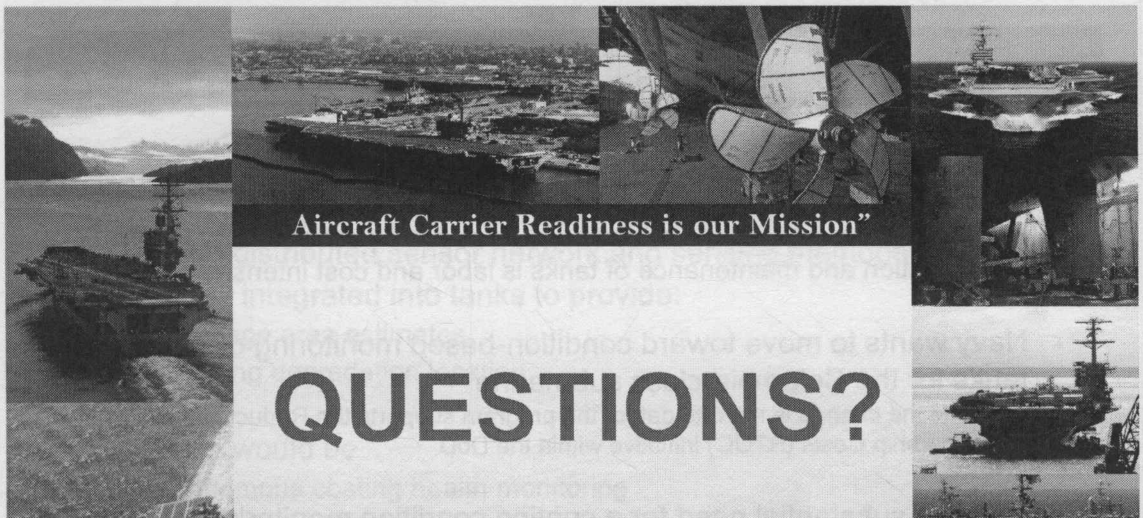
Stage Brackets are hung on the anchors and secured with locking stainless steel set screws 2

3 Stage boards with adjustable hooks are attached. The platform is ready for stanchions and handrails. Staging system disassembly is just as fast. Headed anchors can be left in place, or if removal is required, they can be burned or cut off in seconds

What's Next for CVNs

- Technical Requirements
  - Tailor CCAMM Rev 3 requirements for each Platform
  - Improve "End of Life" Plan
- Improve Capacity ("Throughput")
  - Apply Best Practices (i.e. Belly Bands, Staging Studs, etc.)
  - Utilize waterborne opportunities
  - Improve contracting process
  - Improve Forecasting & work with the other two Enterprises
  - Improve Response Time (Establish structural repair standards, etc.)
- Other
  - Transition to M&SWP 3.0

Commitment to a disciplined process is critical to stay ahead of the issues/risk



Aircraft Carrier Readiness is our Mission"

QUESTIONS?

"Aircraft Carrier Readiness is our Mission"

Low Cost Autonomous Coating Condition Monitoring System

Patrick Kramer, Kevin Farinholt, Fritz Friedersdorf

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LUNA

Mega Rust 2017 June 20-22, 2017

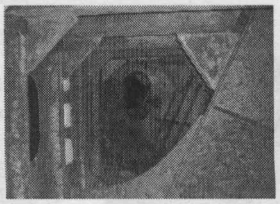
LUNA | Motivation

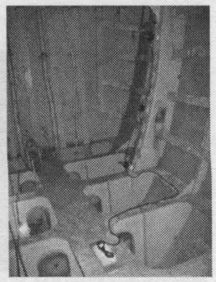
- Approximately 4,000 Navy ship tanks are inspected annually
  - Costs approach $204 million/year[1] when refurbishment and replacement are included, with ~ 50% attributed to unplanned / unnecessary work
  - Inspection and maintenance of tanks is labor and cost intensive
- Navy wants to move toward condition-based monitoring of ballast tanks for the Columbia-class submarine
  - While the change is not mandated, the program supports the Reduction in Total Ownership Costs (RTOC) initiative within the DoD
- There is substantial need for a coating condition monitoring (CCM) system to provide:
  - Improved sensitivity to coating defects
  - Direct measurement over large areas
  - Identification of defect location
  - Quantification of the severity of damage

[1] DoD, 'Corrosion Prevention and Mitigation Strategic Plan,' Corrosion Policy and Oversight Office

LUNA | Technology Need

- Current inspection requires physical access to tanks and enclosures
  - Tank entry is costly and visual inspection can be hazardous
  - Damage location is often unknown
- Currently tank condition is assessed according to the Corrosion Control Assessment and Maintenance Manual (CCAMM)
  - Visual inspection of: **Tank Tops**, **Bottoms**, **Sides,** and **T-Beams**
  - A ranking of 1-4 is assigned:
    - **P1 (Excellent)** =< 0.03% Deterioration
    - **P2 (Good)** = 0.03 – 1% Deterioration
    - **P3 (Fair)** = 1-10% Deterioration
    - **P4 (Poor)** => 10% Deterioration
  - The overall rating for a tank or enclosure corresponds to the worst performing zone[1]
    - Mandatory coating replacement depends on the extent of damage and type of compartment (CCAMM Section 4-4.5)





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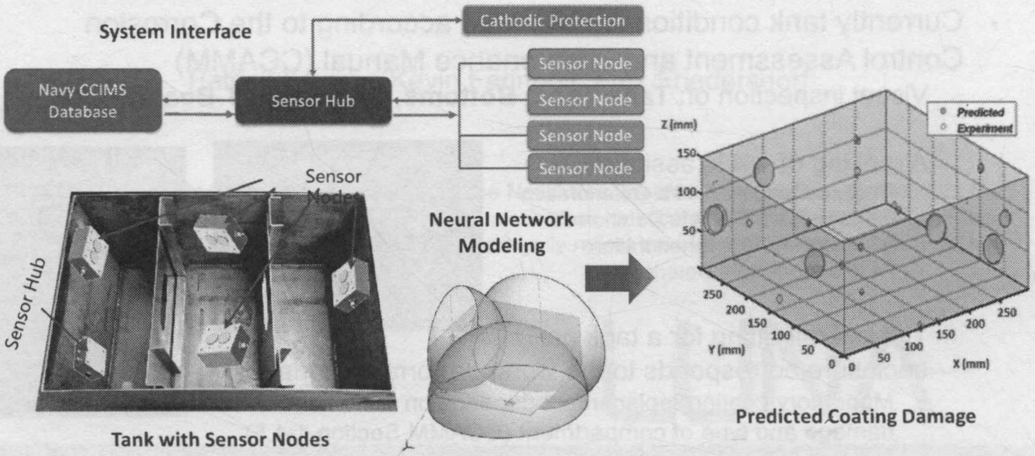
[1] DON, 'Technical Manual for Corrosion Control Assessment and Maintenance Manual (CCAMM),' T9630-AB-MMD-010, June 2015

LUNA | Goals and Objectives

- Enable condition based maintenance through corrosion monitoring
- Develop distributed sensor network and sensing methods that can be easily integrated into tanks to provide:
  - Damage area estimates
  - Coating degradation location
- Benefits would be
  - Autonomous coating health monitoring
  - Reduced labor costs and tank inspections
  - Known extent and position of damage sites

LUNA | Monitoring Technology

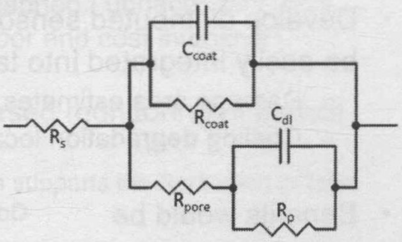
- Luna's approach uses a network of sensor nodes to monitor environmental conditions and collect Electrochemical Impedance Spectroscopy (EIS) measurements
- Neural network models are used to estimate the location and extent of coating damage within a tank or enclosure



LUNA | EIS for Coating Condition Measurements

- Electrochemical impedance spectroscopy (EIS) is an effective method for coating characterization in the laboratory
  - Low amplitude sinusoidal polarization over a range of frequencies
- Coating impedance response can be modeled as an equivalent circuit (Murray 1997)

$$Z(\omega) = \frac{V(\omega)}{I(\omega)}$$



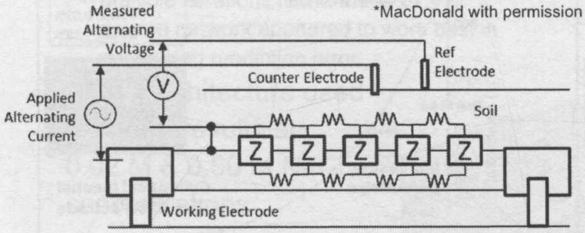
R_s = Bulk solution resistance
C_{coat} = Coating capacitance
R_{coat} = Coating resistance (normally > 10^{12} Ω)
R_{pore} = Solution resistance in coating pores
C_{dl} = Double layer capacitance of exposed substrate
R_p = Polarization resistance of exposed substrate

Equivalent circuit model for a coating

LUNA | Transmission Line Model for Large Structures

- Transmission line models can be used to model electrochemical data collected from large structures (Castaneda 2004)
  - Coating performance on pipelines modeled using neural networks
- Approach can be adapted to the present application
  - Individual circuit elements provide information on one or more of the following variables: coating defect area, defect position, activity of metal substrate

*MacDonald with permission



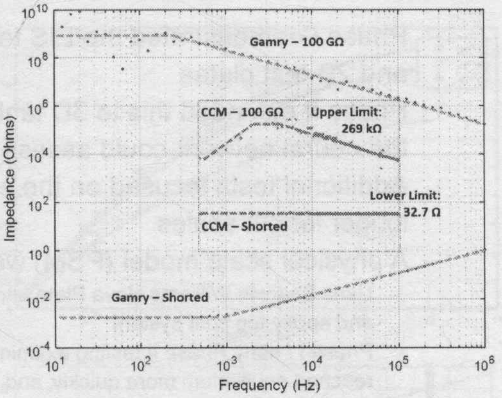
Transmission line model

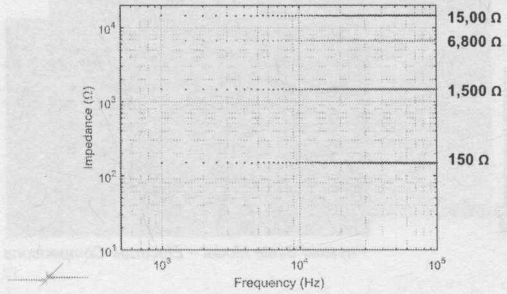
$$Z_i = \frac{Z_C Z_{NC}}{(1-\Phi)Z_C + \Phi Z_{NC}}$$

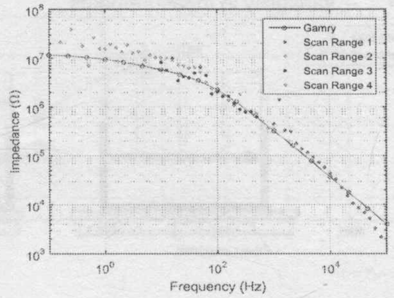
Z_i = equivalent circuit impedance
Z_c = impedance of corroding surface
Z_{NC} = Impedance of non-corroding area
Φ = coating damage surface parameter

LUNA | EIS Measurements with AD5933

- Hardware leverages developments in embedded EIS measurements
  - Extends single frequency measurements to swept frequency EIS
  - Identified range limits of CCM hardware relative to Gamry Interface 1000
- The impedance range of the AD5933 impedance-digital converter can be tuned though calibration and feedback resistors
  - Multiplexers can be used to scan over multiple impedance ranges
  - Fixed resistors have been used for validation

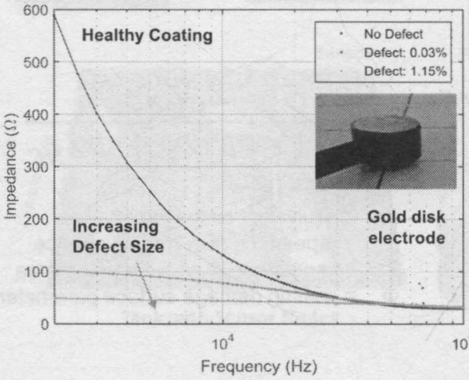


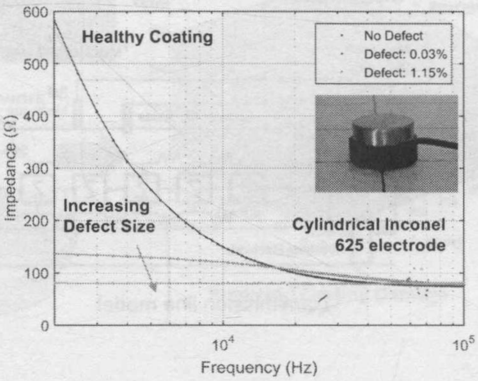




LUNA | EIS – Electrode Selection / Sensitivity to Defect Size

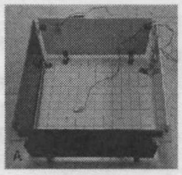
- Several electrode materials have been studied
  - Selected for corrosion resistance and effectiveness in EIS measurements
  - Gold, Inconel 625, and stainless steel electrodes examined
  - EIS trends are consistent for each of the electrode materials
- Low frequency EIS measurements are sensitive to defect size
  - Possible to detect small defect sizes (< 0.03% of tank volume) for scaled 3D electrochemical test cells
  - Scan range within the capabilities of the AD5933 impedance-digital converter



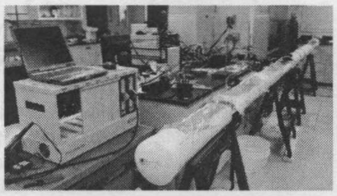


LUNA | Testing – Laboratory Setting

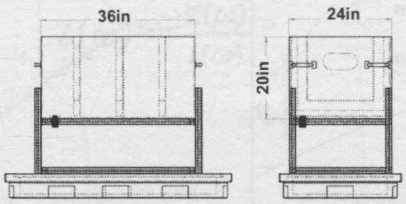
- Phase I demonstrated the EIS technique works on 1D and 2D test plates
- Phase II extended this to 3D tanks and demonstrated the neural network could assess / locate defects
- Additional tests focused on the effectiveness on longer length scales
- A physical scale model (PSM) was built for testing
  - Uses Sherwin Williams Nova Plate ultra high solids primer and epoxy top coat system
  - Phase I / early Phase II testing examined only primer - reached equilibrium more quickly, and produced less variability in measurements

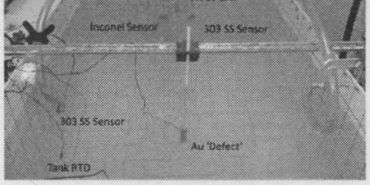


Small 3D test cell



Salinity / distance test cell – 5.5m test length

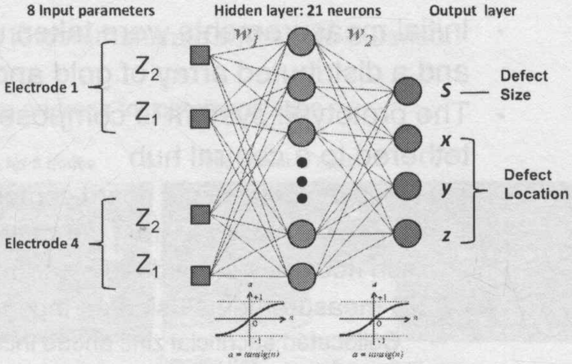


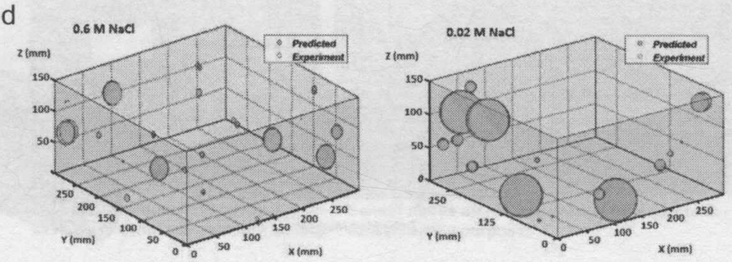


Physical Scale Model – Electrode Comparisons

LUNA | Artificial Neural Network Model

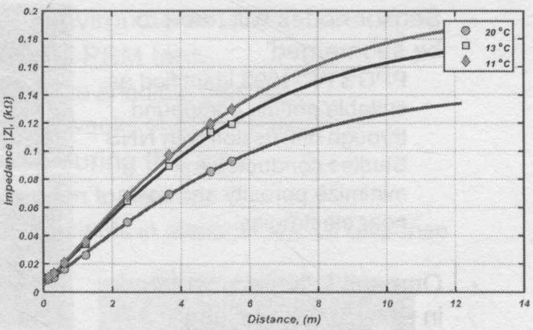
- An artificial neural network (ANN) model is used to predict defect size and location for 2D and 3D plates
- The network provides good predictions with only two input parameters for each sensor
    - Multiple iterations found that a 21 - 22 neuron network appeared to work best in minimizing prediction error
- Same architecture used to model results at 0.02 M & 0.60 M NaCl concentrations

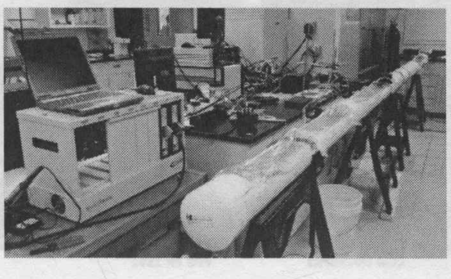


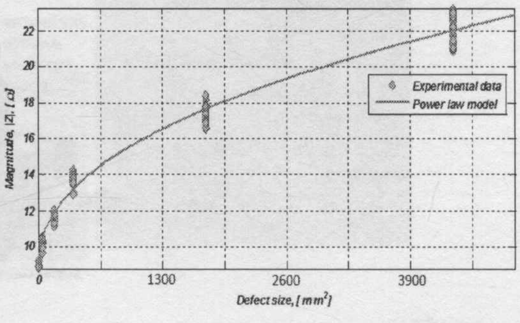


LUNA | Tank and Environmental Parameters

- Studies have also been conducted to look at the effect of several parameters:
    - Defect size and distance from electrode
    - Salt concentration and temperature
- Each parameter affects the impedance response, but can be dealt with by:
    - Developing a neural network trained on all of these conditions, or
    - Developing normalization approach to pre-scale input data

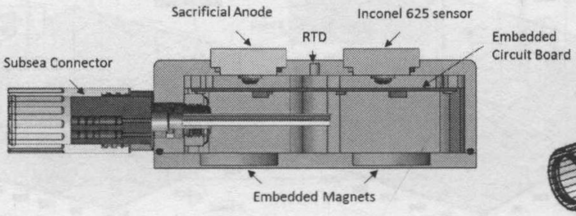


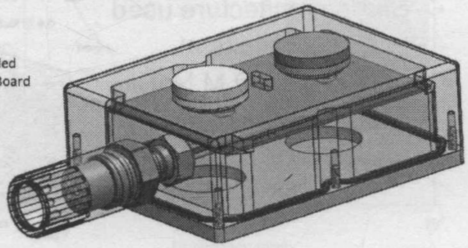




LUNA | Phase II Prototype System

- Initial measurements were taken using the Gamry Interface 1000 and a distributed array of gold and Inconel 625 electrodes
- The prototype system is composed of a network of sensor nodes tethered to a central hub
  - Hub relies on a single board computer to provide the computing resources needed to train the neural network
  - Each node has embedded electronics that allow the system to perform EIS measurements using an Inconel 625 sensor
    - Collocated sacrificial zinc anode included to provide corrosion protection
    - Embedded magnets allow the system to be mounted to tank walls

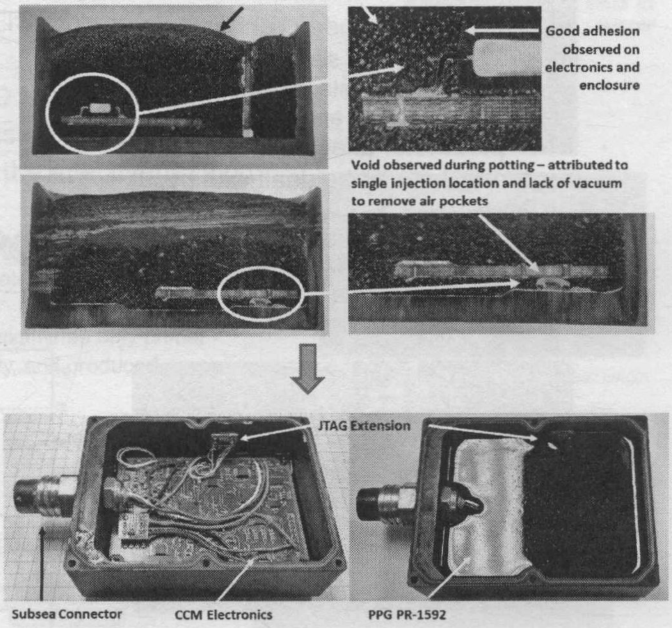




LUNA | Phase II Prototype System – Encapsulation

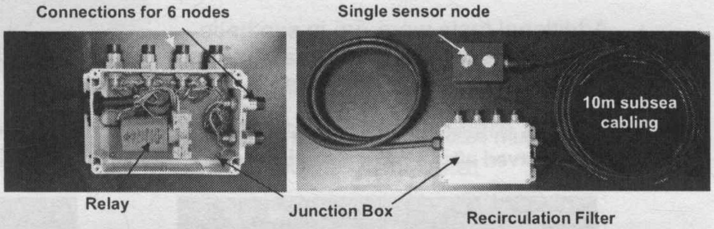
- Sensor nodes will need to be submerged
  - PPG's PR-1592 identified as suitable potting compound through discussion with NNS
  - Studies conducted to minimize porosity and voids near electronics
- One unit fully encapsulated in PR-1592 for testing
  - Subjected to sustained vibration ~ 6g
  - No adverse thermal effects were observed
  - 5 nodes remain unpotted in case modifications are needed

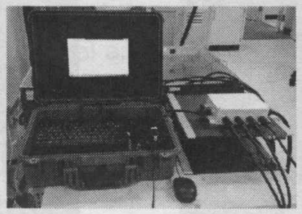
Potting compound is viscoelastic, curing under vacuum will be used to minimize porosity

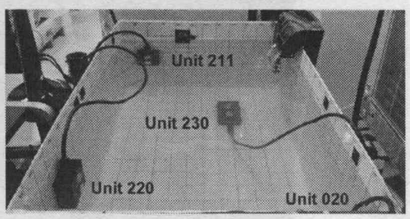


LUNA | Phase II Prototype System

- The sensor hub uses a junction box to communicate with up to 6 sensor nodes installed in the test tank.
  - Each node is prescribed with a unique address for communication
  - Nodes are connected using 10 m subsea rated cables
- Sensor hub is mounted in a protective case for relevant environment testing
  - Preliminary testing has focused on the PSM tank with scaled salt concentrations of 0.1M NaCl



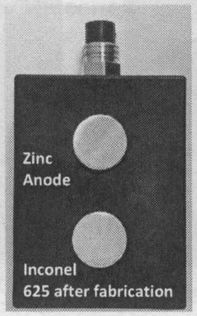

Sensor hub mounted in protective case for relevant environment testing



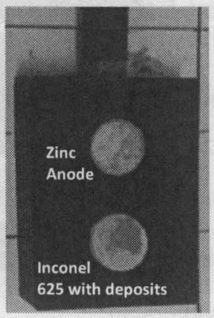
Sensor nodes distributed around PSM test tank for evaluation purposes

LUNA | Prototype Testing

- Preliminary testing aimed toward relevant environment has focused on extended submersion in salt water within the PSM tank
  - Units exposed to 3+ months in tank with passive anodic protection
  - Material deposits were observed after several weeks of submersion
- Three PSM defect studies were conducted during this time
  - Neural network prediction accuracies were seen to decline
  - Potential sources: material deposits, local transients in electrochemical response



Prior to submersion



After 2 months in PSM