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Materials Aging and Degradation

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Research Expertise/Experience

- Primary Areas of Expertise
  - Corrosion science and more broadly, the environmental impact on materials.
  - Metallurgy

- Extensive experience in
  - Aqueous and atmospheric corrosion of structural materials
  - Atmospheric corrosion of microelectronic devices
  - High temperature materials degradation
  - Aging effects on materials and their long term impact on material performance.

Research Interests

- Aging behavior of materials and its impact on long term performance
  - Atmospheric corrosion and stress corrosion cracking of interim storage systems for spent nuclear fuel
    - Material Behavior
    - Environmental Evolution
  - Atmospheric corrosion of microelectronic devices and the associated degradation in device function
  - Development of meaningful accelerated test methods to assess aging behavior of materials
- Assessment of new material performance and qualification for long term use in high consequence systems
  - Material replacement (e.g., Cr(VI) elimination)
  - Development of meaningful accelerated test methods to benchmark new systems relative to legacy materials

Understanding the Risk of Chloride Induced Stress Corrosion Cracking of Interim Storage Containers for the Dry Storage of Spent Nuclear Fuel

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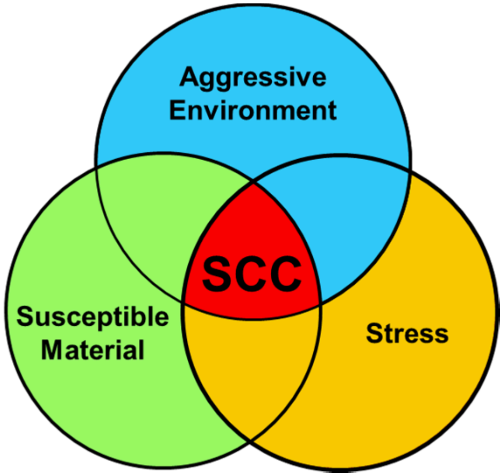
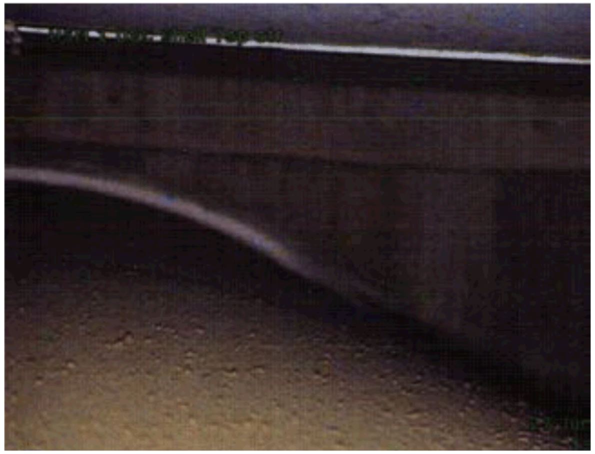
- Determine the nature of the residual stress state associated with the container and associated welds for a representative interim storage container.
- Establish environmental conditions that need to be considered for evaluation of the SCC risk for used nuclear fuel interim storage containers
- Evaluate localized corrosion performance of container materials under relevant environmental conditions
- Explore conditions that lead up to SCC crack initiation, the following crack growth, and long term cracking behavior to feed predictive model aimed at assessing risk of SCC as a function of geographic location.





What is the Surface Environment on Fielded Dry Storage Containers?

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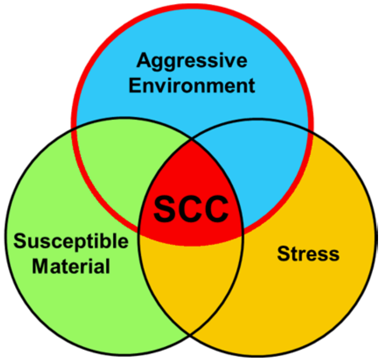
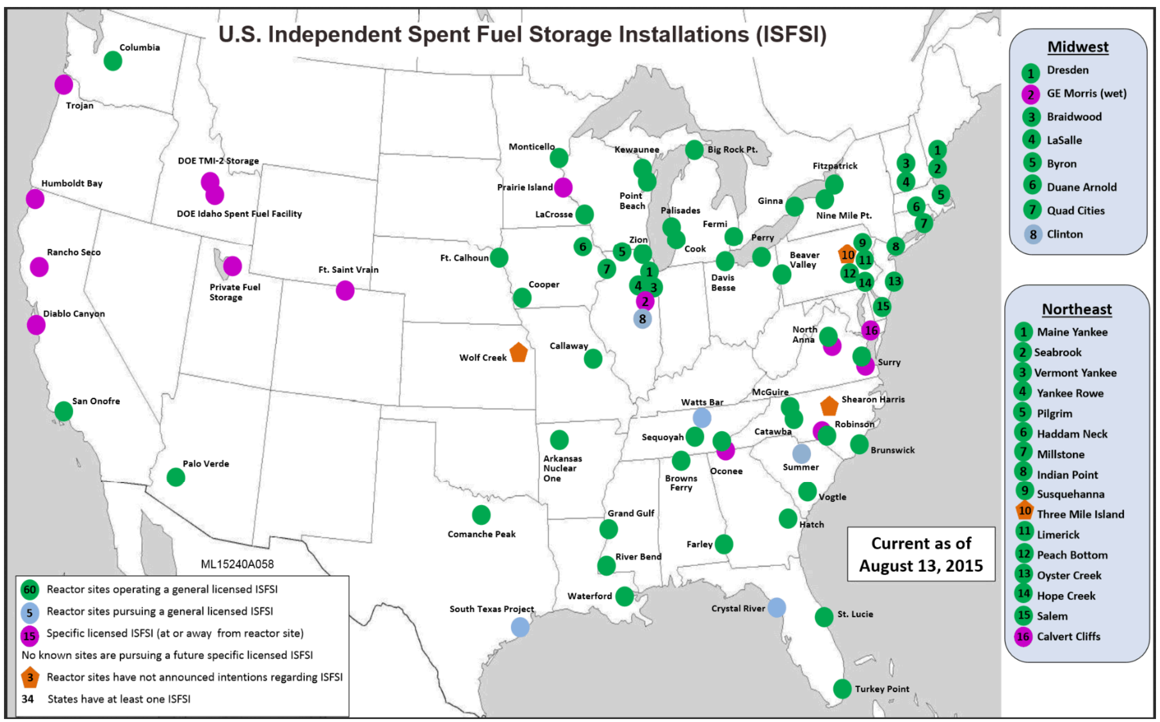
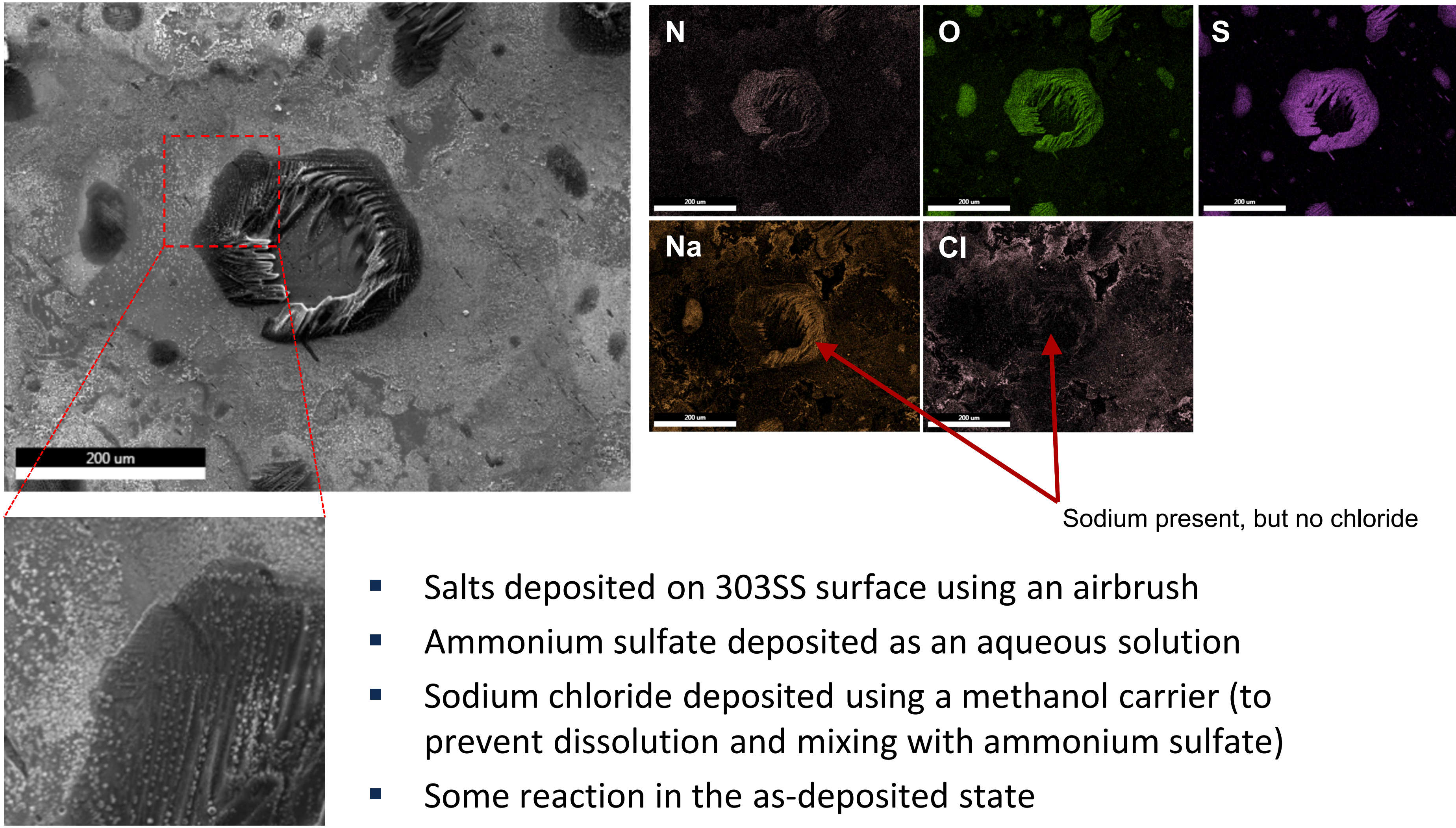




Different settings

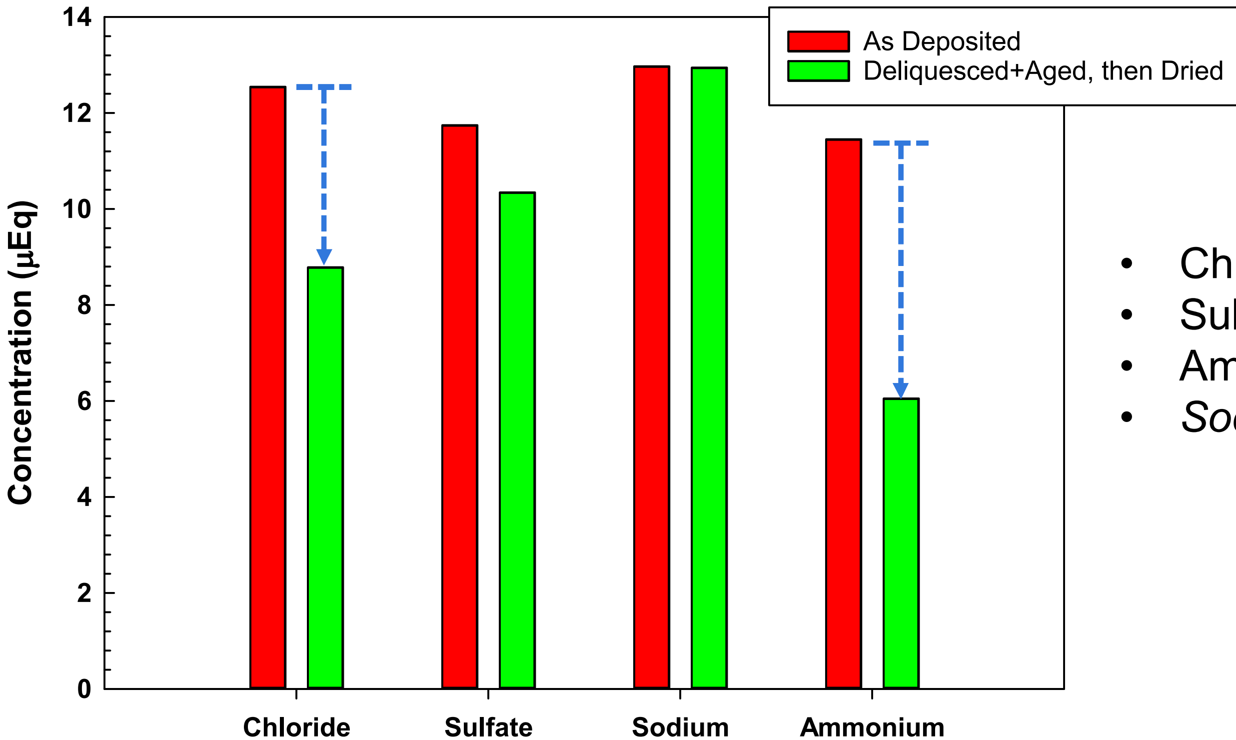
- **Range of weather conditions**
  - Dewpoint
  - Temperature
- **Varying salt assemblages**
  - Coastal (marine salt aerosols)
  - Inland (ammonium, sulfate, and nitrate-rich aerosols; possible road salts, cooling tower emissions)
  - Salt assemblages control DRH and RH_L
- **Temperature range of interest**
  - Determined by RH_L and AH

Deliquescence of a $(NH_4)_2SO_4$ and NaCl Salt Mixture



- Salts deposited on 303SS surface using an airbrush
- Ammonium sulfate deposited as an aqueous solution
- Sodium chloride deposited using a methanol carrier (to prevent dissolution and mixing with ammonium sulfate)
- Some reaction in the as-deposited state

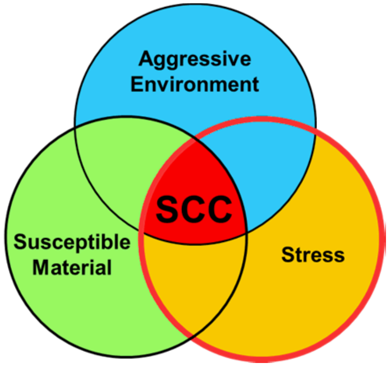
Evolution of Surface Chemistry



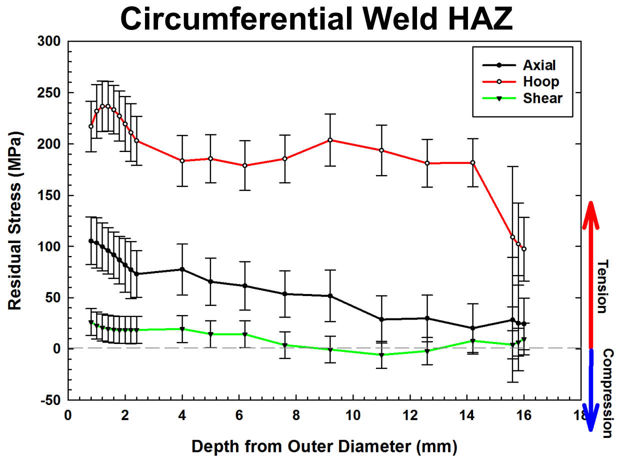
- Chloride loss
- Sulfate loss
- Ammonium loss
- *Sodium unchanged*

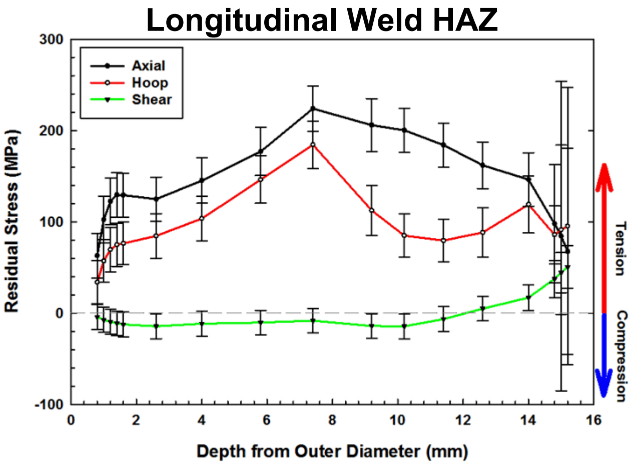
- Salts extracted from surface of control sample and deliquesced sample
- Degassing took place, as evidenced by reduction in chloride and ammonium (ammonium loss = chloride loss plus sulfate loss)
- Incidentally deposited chloride salts (e.g. road salts or cooling tower salts) will only form persistent chloride-rich brines *if the chloride deposition rate is greater than the ammonium deposition rate*.

Residual Stresses in Fielded Storage Containers



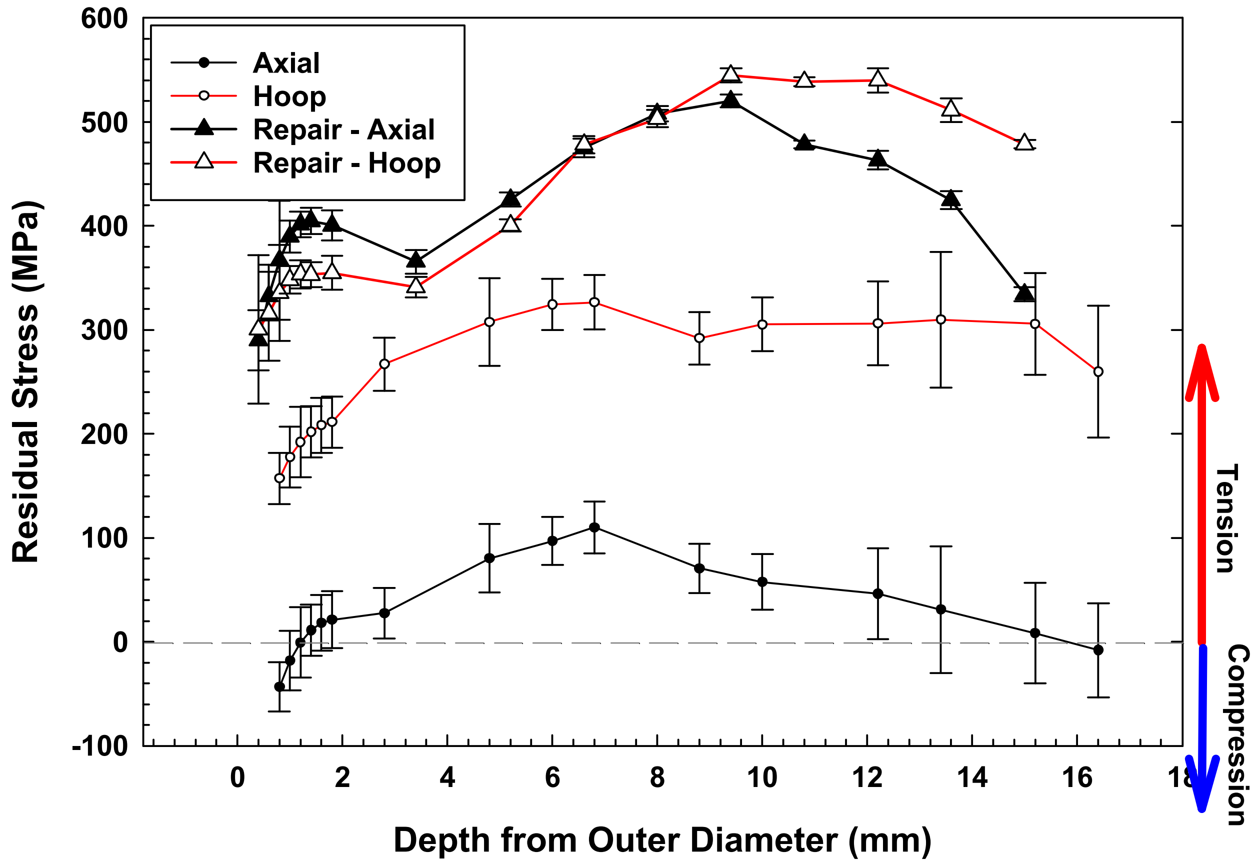
- Goal: Establish if there is sufficient through-wall tensile stresses to support SCC crack propagation
- Full-scale mockup container simulating a NUHOMS 24P container (produced at Ranor using procedures established for containers at Calvert Cliffs ISFSI)
- Series of key areas are being assessed
  - Base metal (far from welds)
  - Circumferential Weld (Centerline and HAZ)
  - Longitudinal Weld (Centerline and HAZ)
  - Weld Repair



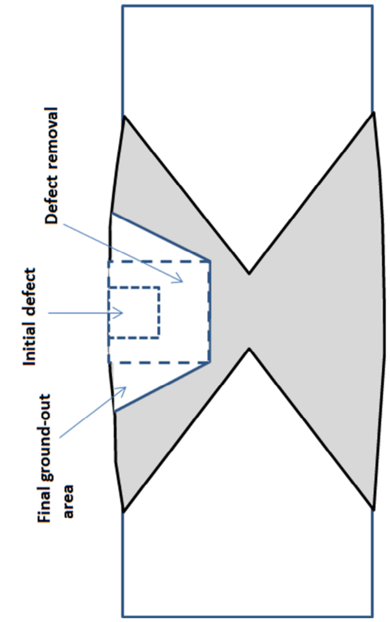


Weld Repairs Dramatically Increase Stresses

- Dramatic increase in magnitude of stresses, particularly in the axial direction, when a repair is made

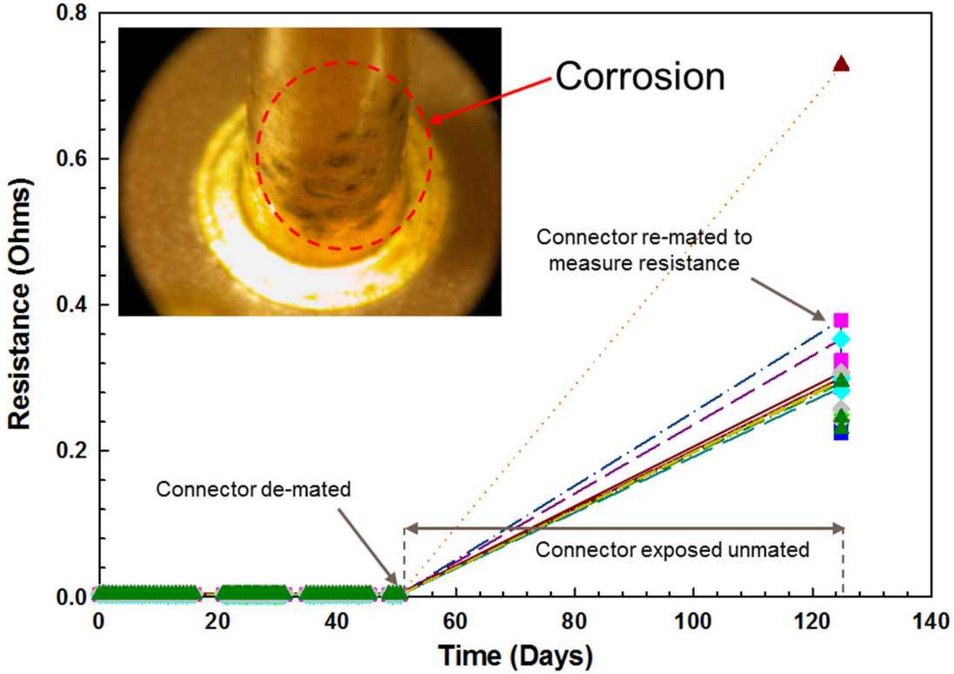


- Both axial and hoop stresses dramatically increased in weld repair



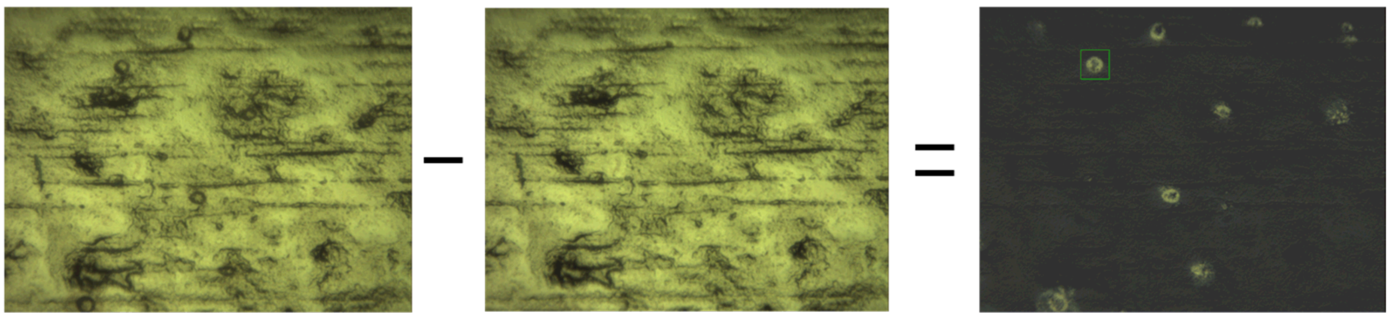
Atmospheric Corrosion of Microelectronic Devices

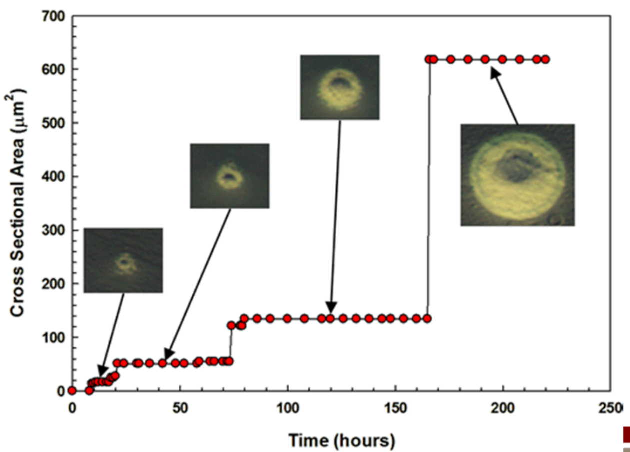
- Atmospheric corrosion, one of the primary failure mechanisms in aging microelectronic devices, is very difficult to assess without direct observation.
- Traditional electrochemical techniques can not be applied, and the ability of sensors or instrumented structures to capture the kinetics of the corrosion process on actual devices is limited.
- “Failure” can mean many things – ranging from loss of contact to an unanticipated increase in resistance

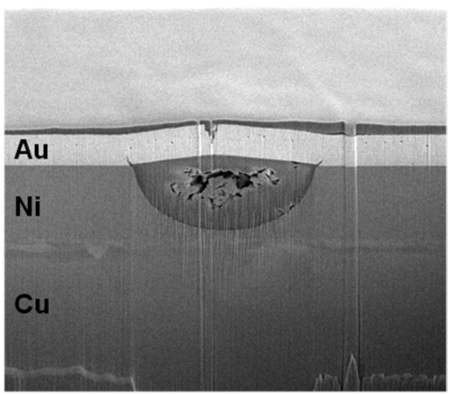


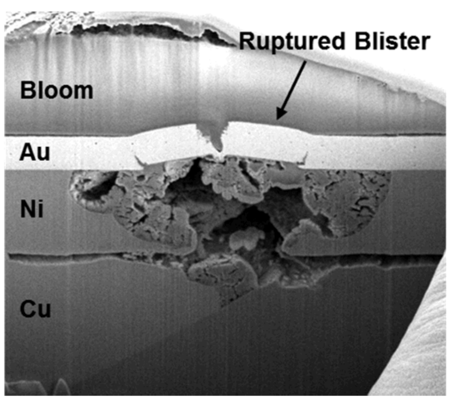
Novel Techniques for the Evaluation of Atmospheric Corrosion

- Atmospheric corrosion difficult to capture quantitatively – needed means to acquire key kinetic parameters from corrosion site growth on visually complex surfaces

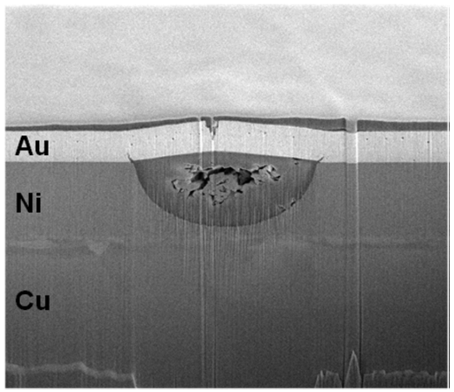


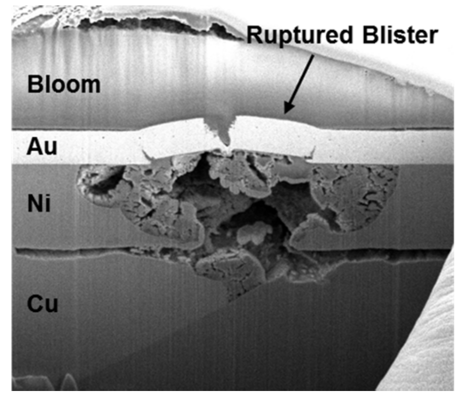


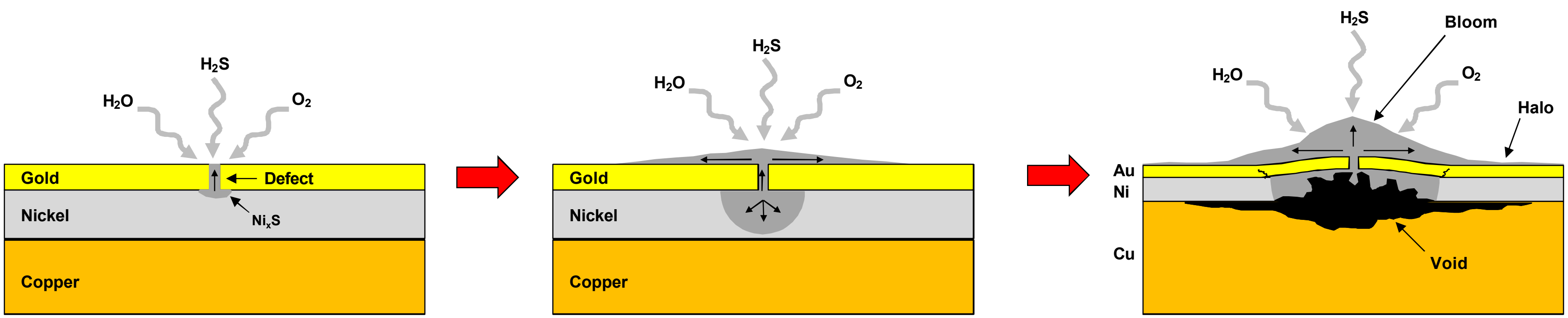




Why Is There A Multi-Stage Growth Process?







Corrosion Protection Coatings for Aluminum

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- Chromate conversion coatings have been the de facto standard for aluminum protection for decades, but ES&H issues are limiting their availability in the future
- New coatings need to be understood in terms of their long term corrosion performance and electrical properties

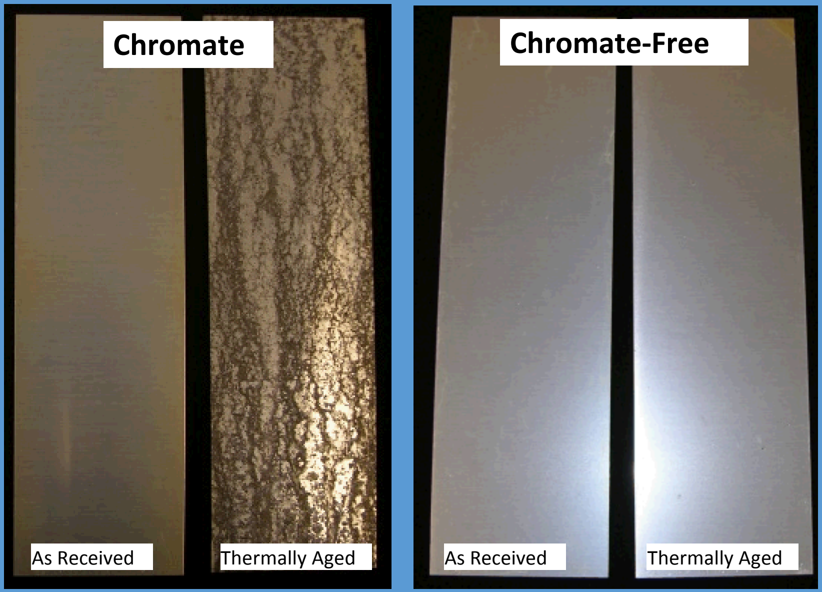
What can we get *now*?

- CHEMEON SURFACE TECHNOLOGY — **TCP-HF**
- Henkel — **Bonderite M-CR T5900**
- SurTec — **chromitAL TCP**
- LUSTER-ON PRODUCTS — **Aluminescent**
- MacDermid Enthone INDUSTRIAL SOLUTIONS — **Iridite NCP**

MIL-DTL-5541 Compliant Chemistries

Does it meet our performance requirements as we use it?

Chromate vs. chromate free coatings on AA7075 Following salt fog testing



Professional Experience and Education

- Education
  - University of Virginia, Ph.D., Materials Science and Engineering (1997)
    - Thesis: The Long Term Effects of Cathodic Protection on Corroding, Pre-Stressed Concrete Structures: Hydrogen Embrittlement of Pre-Stressing Steel
  - University of Virginia, M.S., Materials Science and Engineering (1994)
    - Thesis: The Influence of Sulfate Reducing Bacteria on Alloy 625 and a Series of Austenitic Stainless Steel Weldments
  - Rensselaer Polytechnic Institute, B.S., Materials Engineering (1991)
- Professional Experience
  - Sandia National Laboratories, 2002-present
  - 3M Corporation, 1997-2002
  - Cooperative Education (during undergraduate degree)
    - Texas Instruments, 1991
    - GE Aircraft Engines, 1990
    - Arthur D. Little, 1989
- Professional activities
  - NACE International (Research Committee, Awards Committee)
  - NACE Corrosion Journal, Associate Editor