SAND2014-19367C

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Fuel Cycle Technologies

Understanding the Surface Environment and its Impact on the Extended Performance of Interim Storage Containers for Spent Nuclear Fuel

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2014 ANS Winter Meeting
November 10th, 2014

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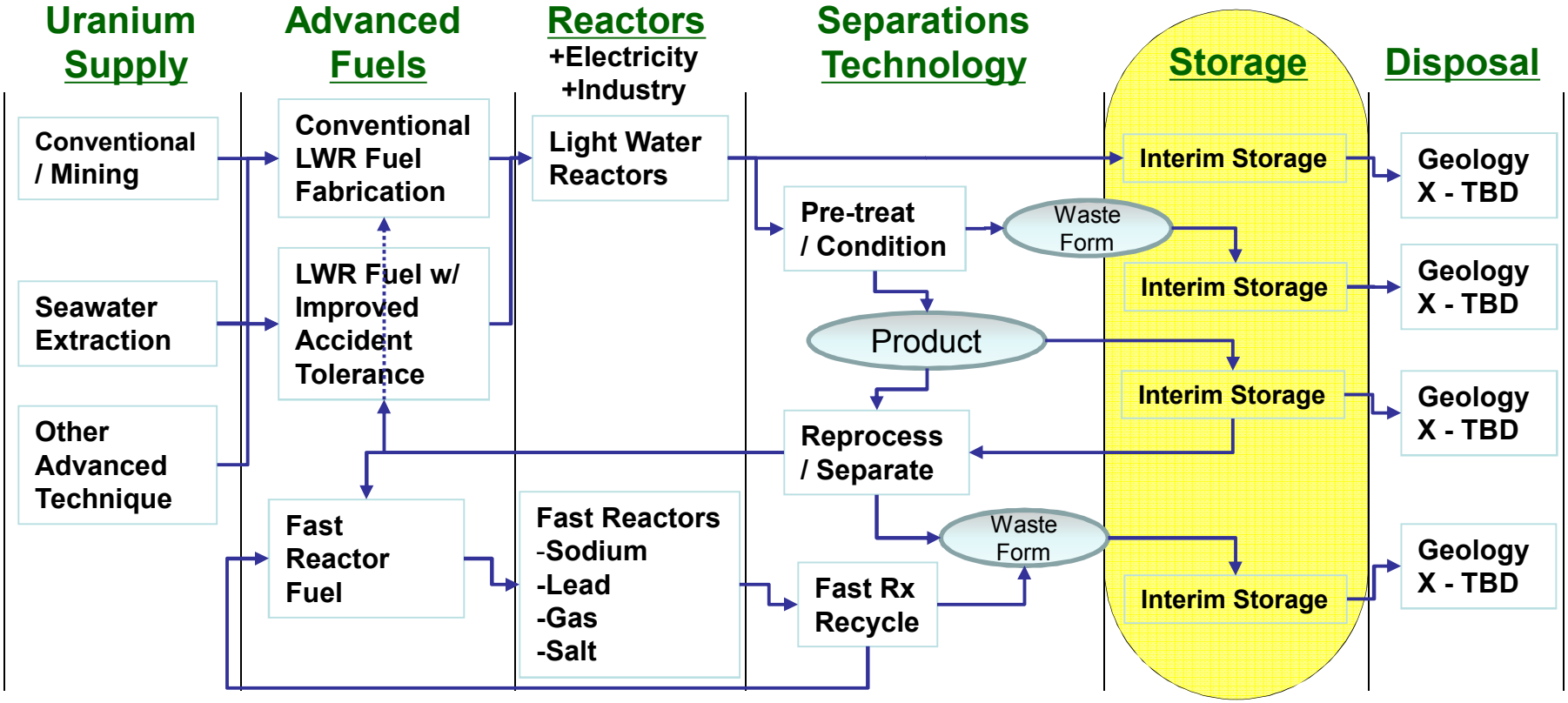
Fuel Cycle as a System



- Optimized System: We want the best performance for each step in harmony with other parts of the system
- Near-Term/Long-Term Balance: Seek near-term applications while maintaining the long-term objective of a sustainable fuel cycle

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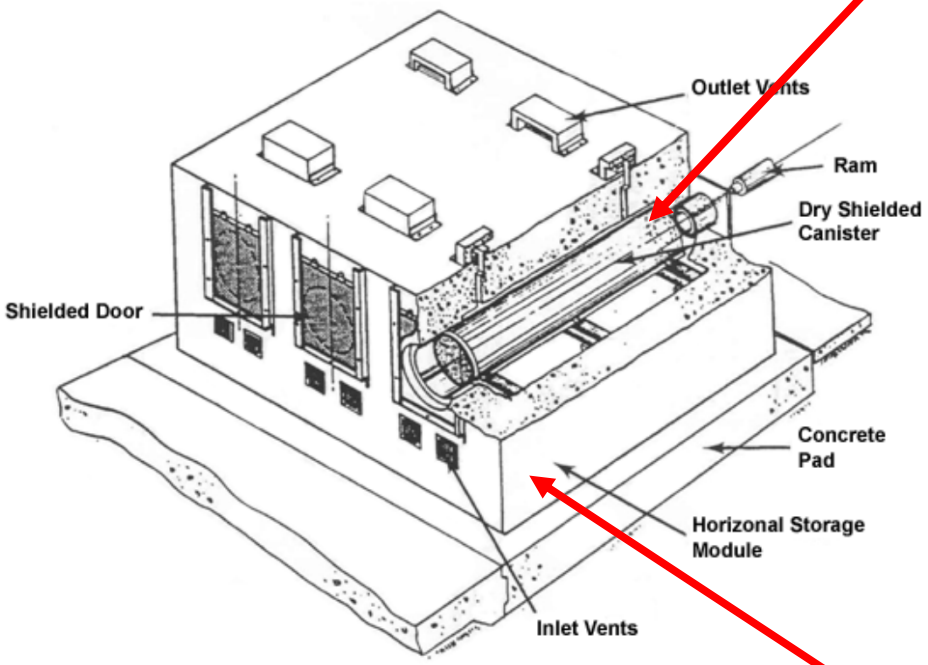
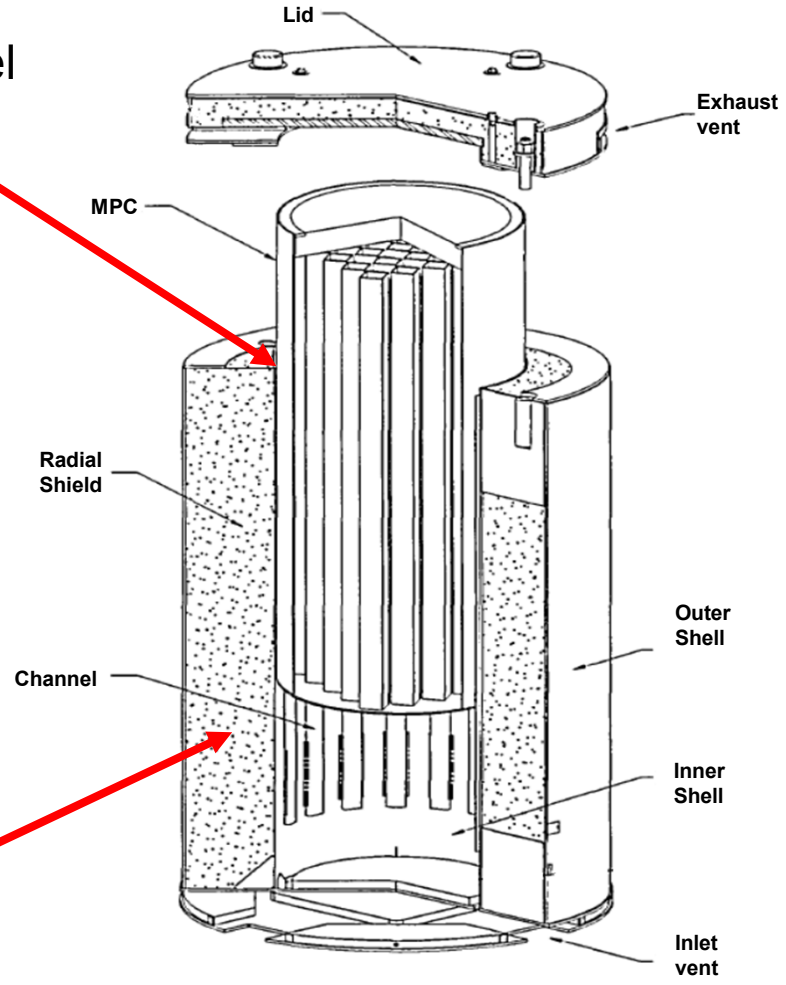
Interim Storage Systems (Welded)

Stainless Steel (304)





Concrete

Horizontal (e.g., Areva TN)

Vertical (e.g., Holtec)

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Degradation mechanism of concern: Stress Corrosion Cracking (SCC)

- **Stress corrosion cracking requires three things**
  - Aggressive environment
  - Susceptible material
  - Stress (applied or residual)

- **<u>Questions that need to be answered</u>:**

1. Will a chloride bearing environment form on the surface of the containers?
2. Is the material of construction for fielded interim storage containers susceptible?
3. Is there a sufficiently large tensile stress to support crack initiation and propagation in fielded interim storage containers?

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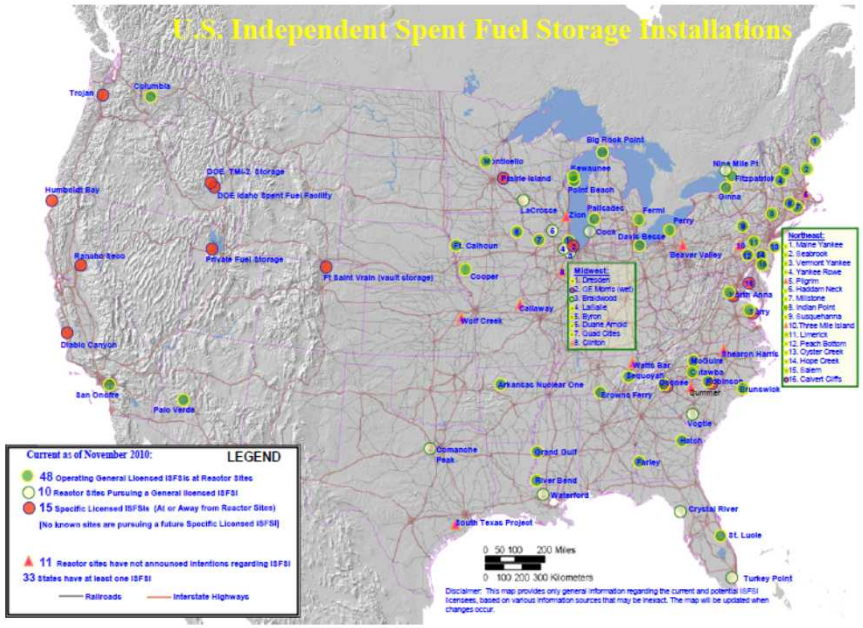
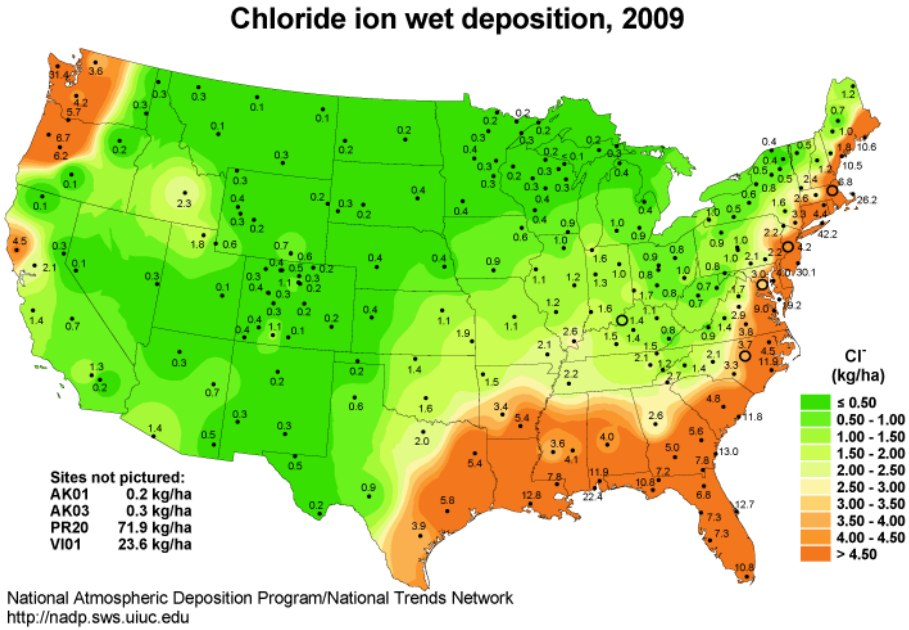
Where are ISFSIs located?

- **Many interim storage sites are located in marine environments where significant deposition of marine aerosols is anticipated**





National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

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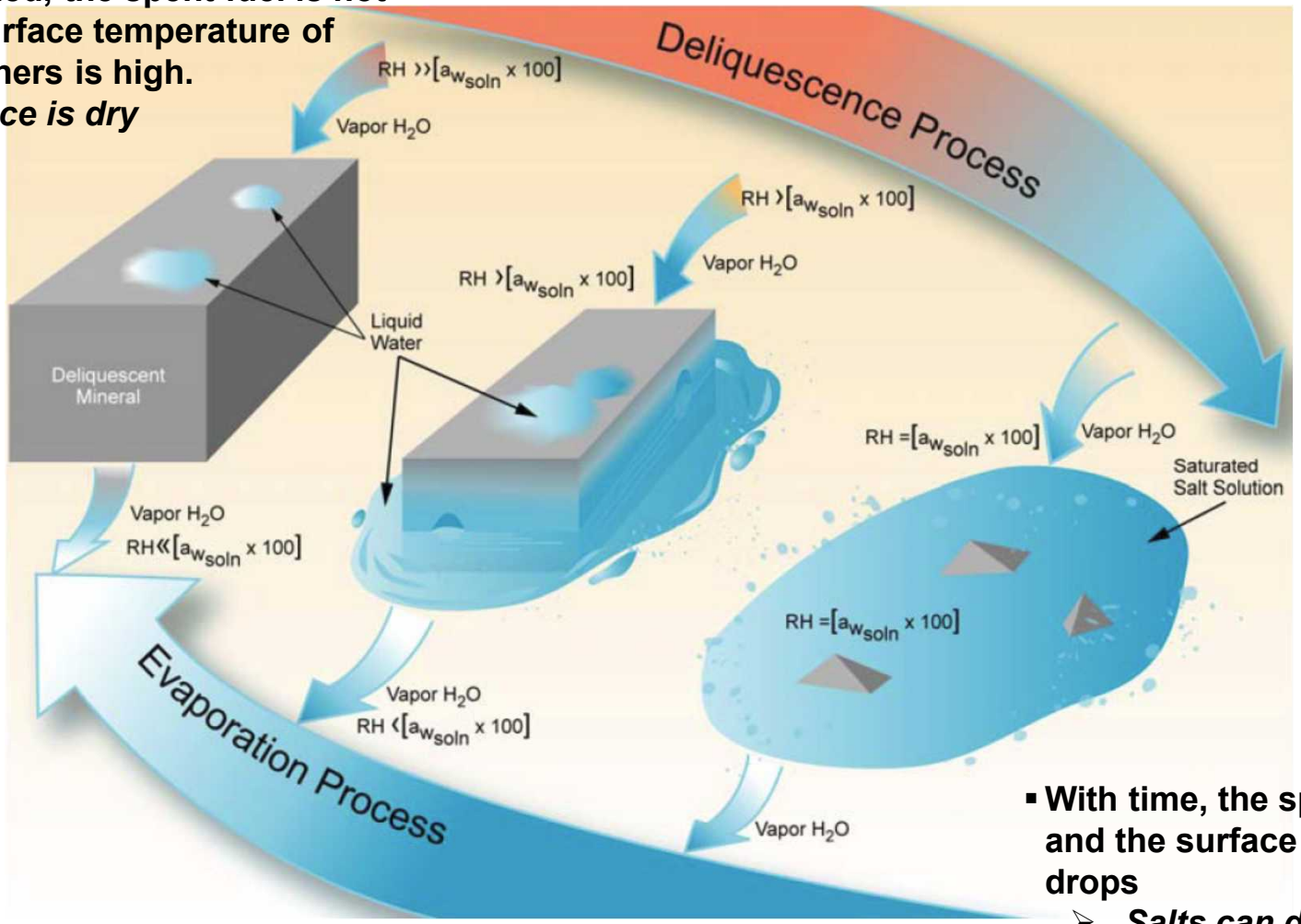
Development of an Aggressive Environment

- When loaded, the spent fuel is hot and the surface temperature of the containers is high.
  - ***Surface is dry***



- With time, the spent fuel cools and the surface temperature drops
  - ***<u>Salts can deliquesce</u>***

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Is there anything on the surface of fielded containers?

- **EPRI has driven an effort to view and sample the dust on the surface of the containers at several ISFSI sites**
  - Calvert Cliffs (with support from Areva TN)
  - Hope Creek (with support from Holtec)
  - Diablo Canyon (with support from Holtec)

Images from July 27, 2012 supplemental information letter submitted from CENG to the NRC (Adams document no. ML12212A216)

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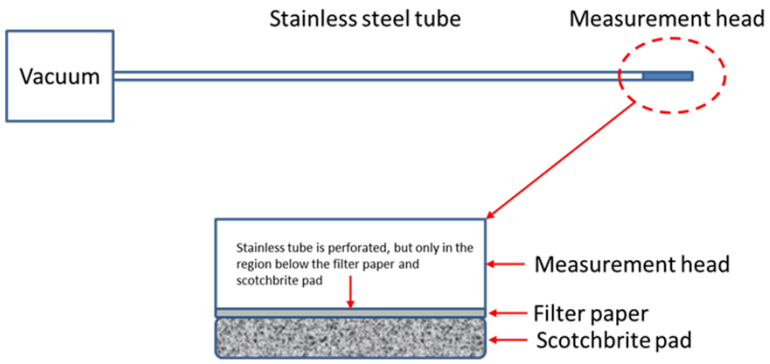
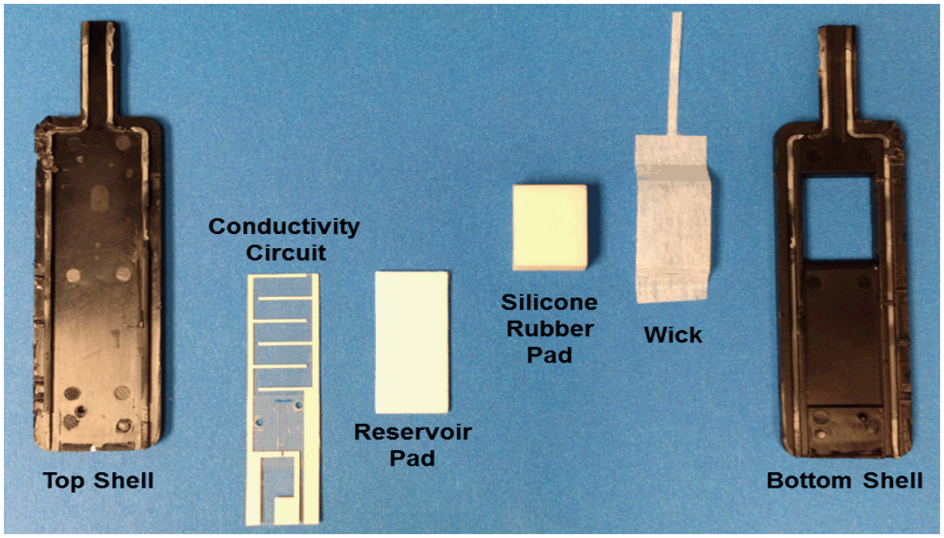
Both wet and dry sampling techniques were employed

- Similar procedures were used at all three utilities
- Dry sampling was accomplished via an abrasive pad rubbed on the container surface
- Wet sampling was performed using a device known as the SaltSmart





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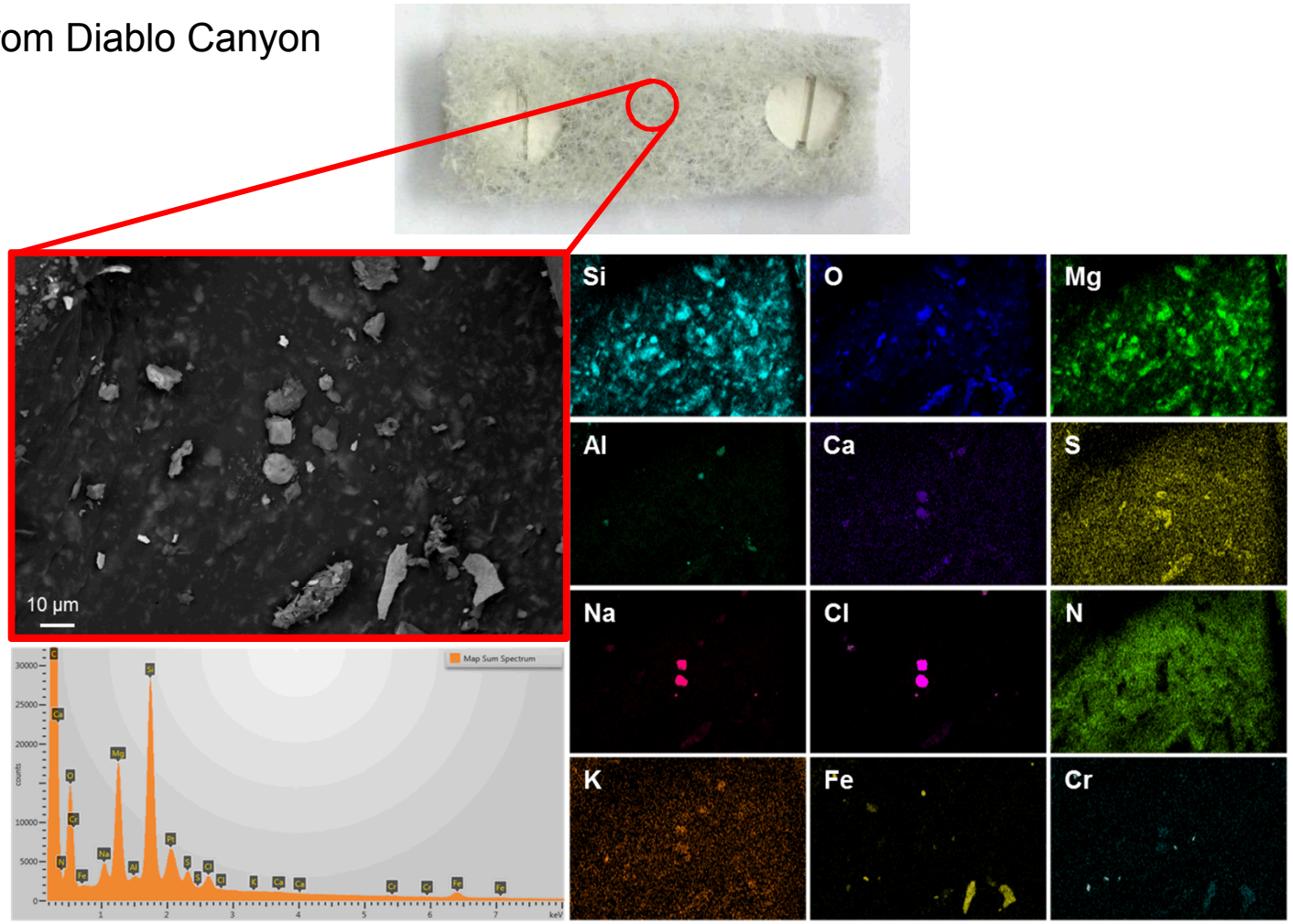
Typical Dry Sample Results

Example from Diablo Canyon



From: C.R. Bryan, D.G. Enos "Analysis of Dust Samples Collected from Spent Nuclear Fuel Interim Storage Containers at Hope Creek, Delaware and Diablo Canyon, California", SAND2014-16383, July, 2014

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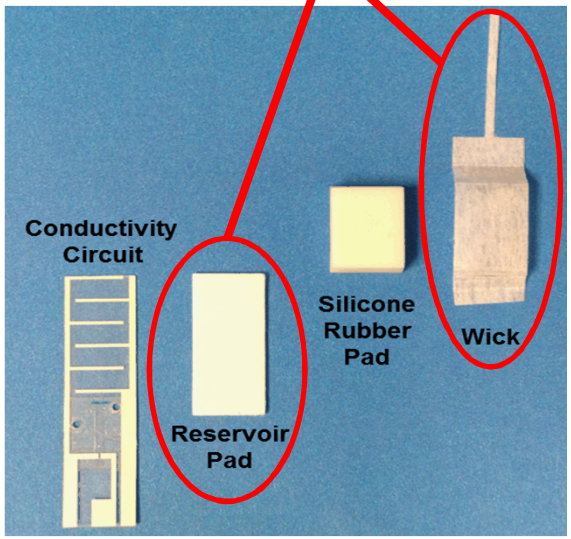
Typical Wet Sample Results

- **Solutions extracted from SaltSmart reservoir pads**
- **Complicating factors**
  - Extraction efficiency in the field
  - Temperature effects
  - Pad to container contact patch variation



Example from Hope Creek

Sample #	Location	Depth, ft	Temp., °F	Cl^-, mg/m^2
144-008	Side	13	93.2	3
144-009	Side	7.5	116.5	2.9
144-010	Side	1	133.9	3.9
144-013	Top	0	138	14
144-014	Top	0	141.2	60
144-003	G.S.	—	—	1.6
144-004	G.S.	—	—	2.5
145-006	Side	13	70.6	7.3
145-007	Side	7.5	100.8	7.1
145-014	Side	1	130.3	4.1
145-013	Top	0	174.1	7.5
145-002	G.S.	—	—	2.2
145-011	Blank	—	—	2.5

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Is Localized Corrosion of Interim Storage Components a Legitimate Concern?

- Requirements for crevice corrosion or pitting
- Driven vs. atmospheric
- Implications of a thin electrolyte layer
- Available active surface area outside of a potential crevice limits the ability for crevice corrosion to initiate and/or propagate.
- Evolution of brine chemistry on the container surface

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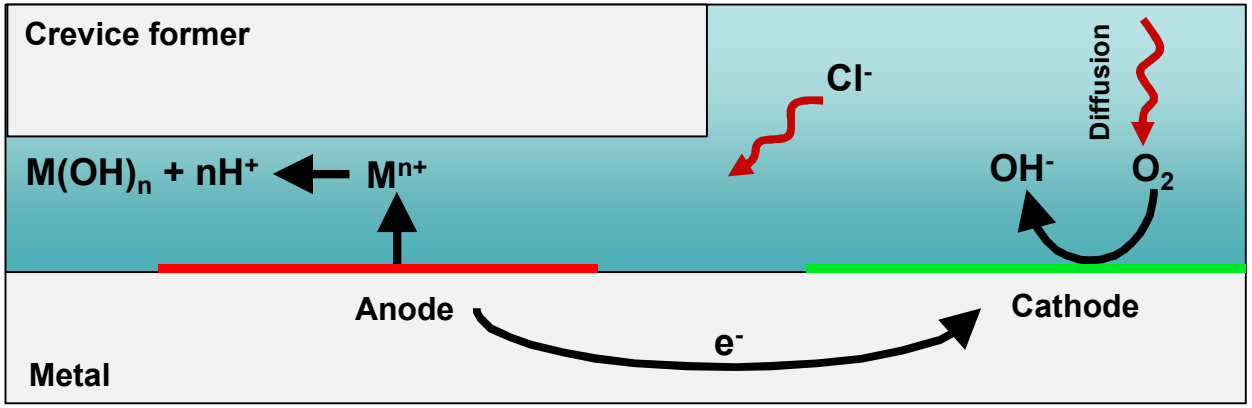
Is Localized Corrosion Possible Under Atmospheric Conditions?



Metal ion content builds and oxygen is depleted within crevice, resulting in local acidification and separation of anode and cathode
Driven conditions – cathode not on sample surface

- **Available active surface area outside of a potential crevice limits the ability for crevice corrosion to initiate and/or propagate.**
  - Relocation of cathode inside crevice does not allow maintenance of the critical crevice solution
    - Turnbull (NPL), Kelly et al. (UVA)
  - Limitation of cathodic capacity outside of the crevice
    - Payer, et al. (CWRU), Kelly et al. (UVA)

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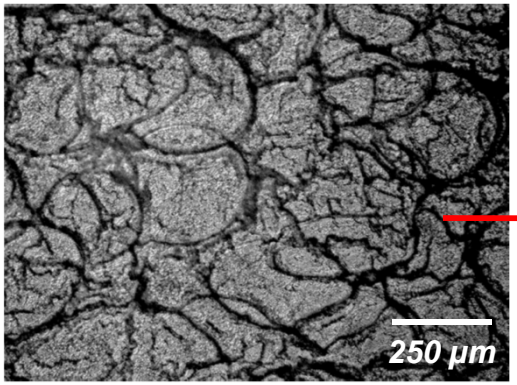
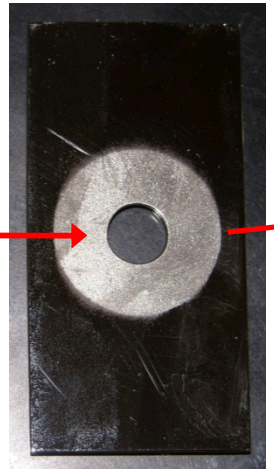
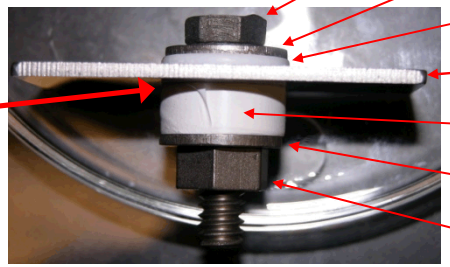
Dust Deliquescence Testing: Initiation Studies

- Crevice former and salt on one side of coupon which was polished to a mirror finish

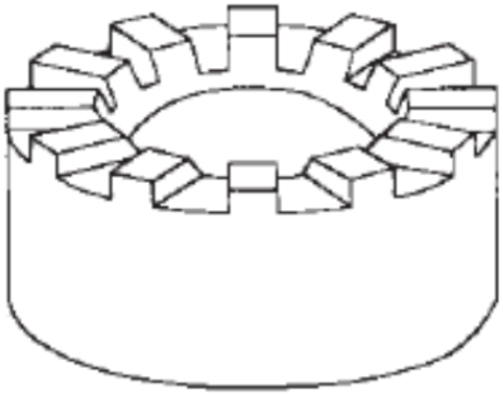


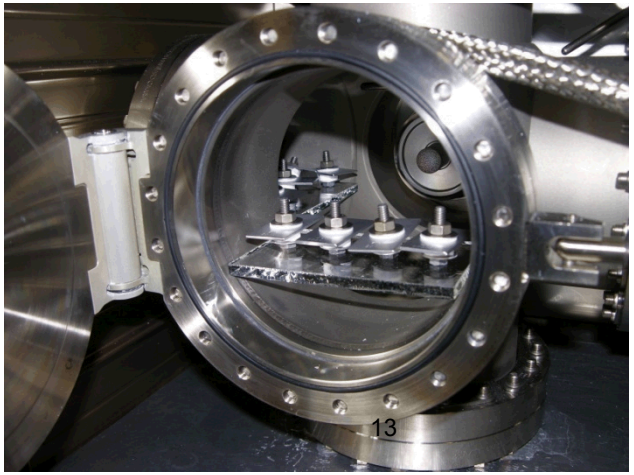
120 µg/cm²





(All titanium hardware electrically isolated from the sample)





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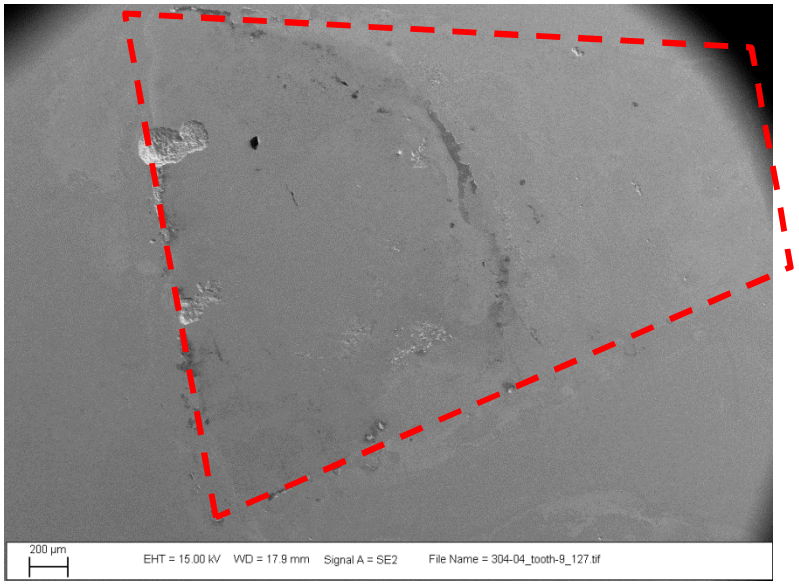
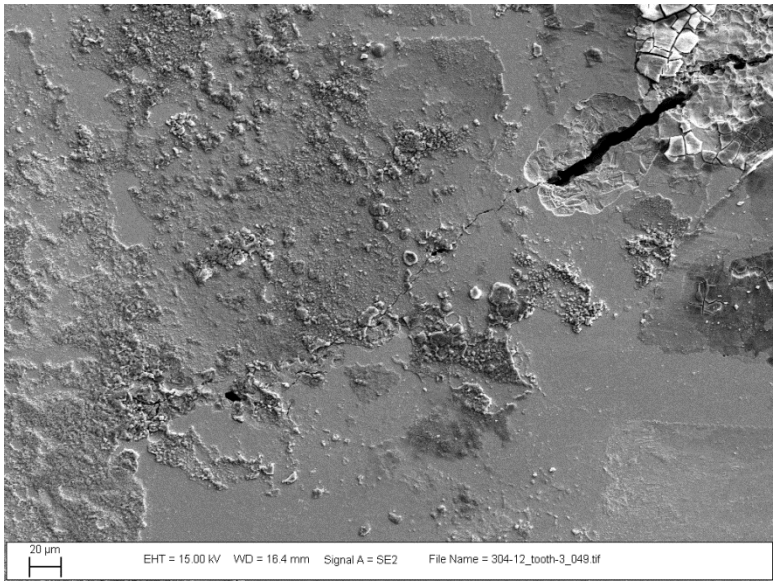
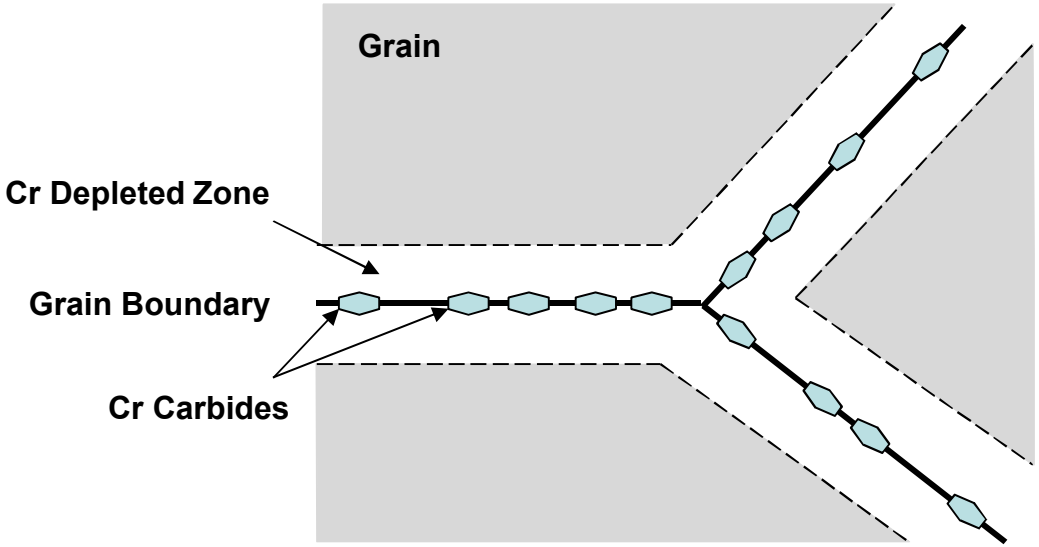
Impact of Salt Loading on 304SS at elevated temperature and humidity

- 50, 100, and 200 µg/cm^2 of a NaCl/KCl mixture
- Temperature of 100-102C, T_d of 94.5C, Exposure periods of 7, 14, 25, 50, and 100 days
- The extent of attack was characterized for 304SS and was found to correlate with the quantity of salt deposited on the metal surface prior to the experiment.
- Cracking observed at even lowest salt load





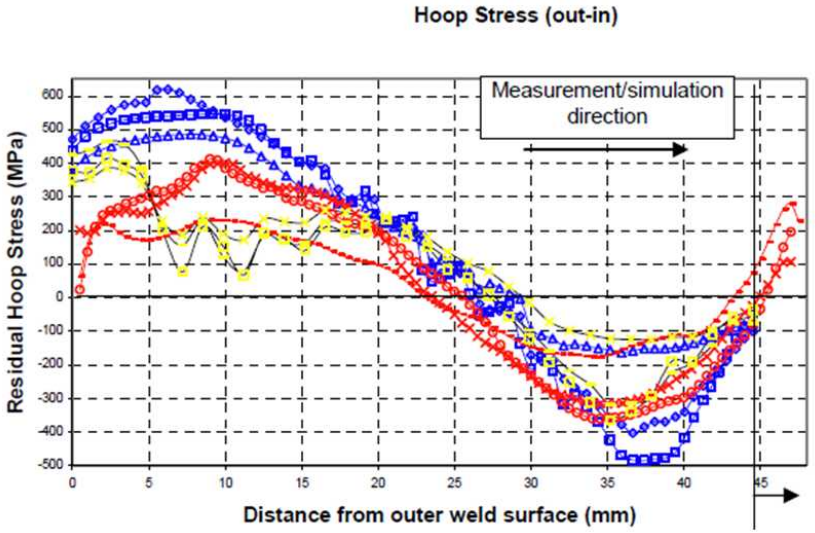
What about the weld?



- **Welding carbon bearing austenitic stainless steels such as 304 will result in sensitization**
- **Increased susceptibility to localized corrosion and SCC**
  - Active path along grain boundaries

Is there going to be sufficient stress?

- **Is there sufficient residual stress within the container wall to support propagation of a through-wall crack?**
- **Many complicating factors**
  - Weld procedure (start/stop, technique, etc.)
  - Weld repairs



K. Ogawa, et al, "Measuring and Modeling of Residual Streses in Stainless Steel Girth Welds", PVP 2008 61542, July 27-31, 2008, Chicago, IL.

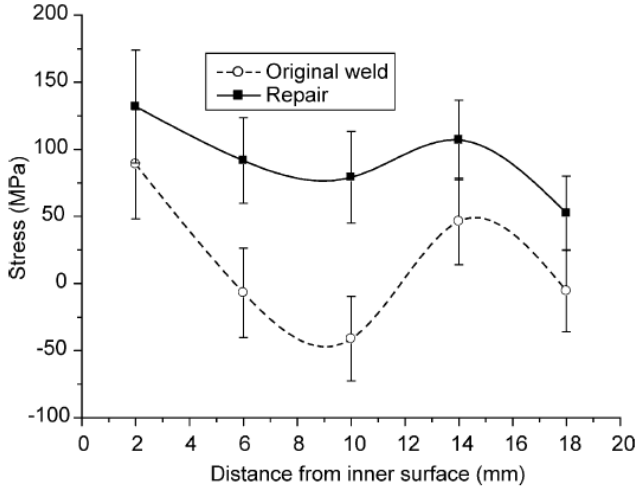


Fig. 14. Hydrostatic residual stress profile (17.5 mm from weld centre-line).

L. Edwards, et al, "Direct Measurements of the Residual Stresses near a "Boat-Shaped" repair in a 20mm Thick Stainless Steel Tube Butt Weld", International Journal of Pressure Vessels and Piping, 82 (2005), pp. 288-298

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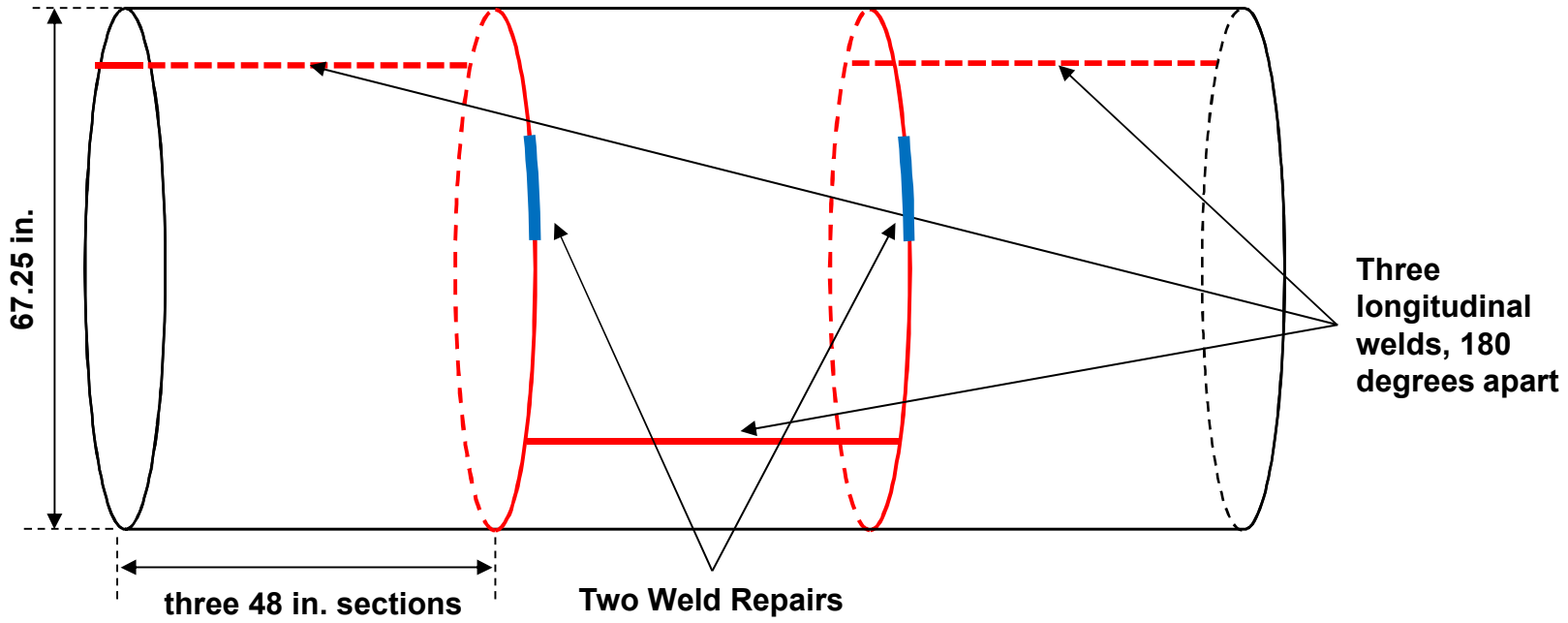
Full Scale Mock-Up Assembled to Directly Measure Residual Stresses



- **Wall material: 304 SS welded with 308 SS**
- **Wall thickness, overall diameter, weld joint geometry: standard geometry for NUHOMS 24P**
- **Welds:**
  - Full penetration and inspected per ASME B&PVC Section III, Division 1, Subsection NB (full radiographic inspection)
  - Double-V joint design, Submerged Arc welding process

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Current Plans for the Mock-Up

- **Mock up construction completed in September, 2014**
- **What are we going to measure?**
  - Weld residual stress state (deep hole drilling, neutron diffraction, contour)
  - Extent of sensitization (electrochemical)
  - Baseline electrochemical testing
  - Stress corrosion cracking susceptibility
- **What samples do we need to make?**
  - Subdividing the mock-up will impact the stress state – need to determine how much
  - Sample geometry that we need?

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Summary and Future Direction

- **Large existing fleet of storage containers made from welded 304SS, located at both marine and inland sites**
  - Material known to be susceptible to SCC
  - Chloride bearing salts likely in some locations
  - Residual stresses at welds could be significant and tensile in nature

- **Research currently focusing on**
  - Understanding potential brine chemistry on container surface
  - Quantifying residual stress state at welds and weld repairs in full scale mock-container
  - Exploring susceptibility of welded material to both localized corrosion and stress corrosion cracking initiation and propagation