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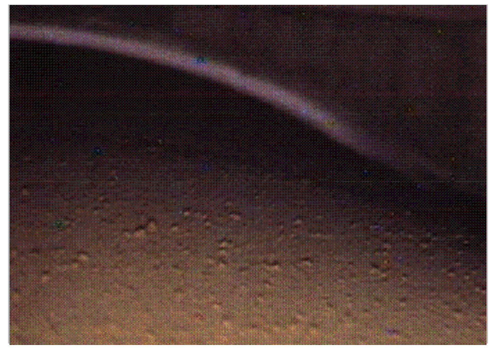

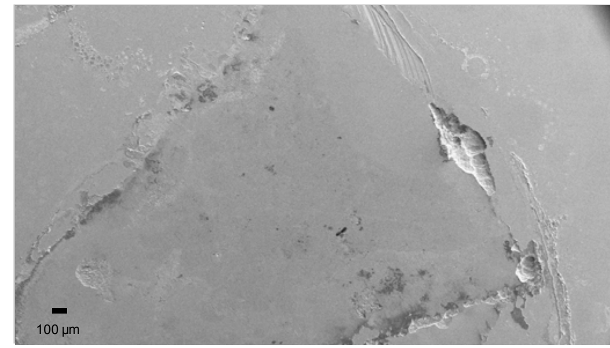

Sandia National Laboratories: Research Evaluating the Long-Term Performance of SNF Interim Storage Containers

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SNL/BAM Meeting, 26-27 September 2013, Berlin

Work performed by David Enos, Charles Bryan, and Kirsten Norman

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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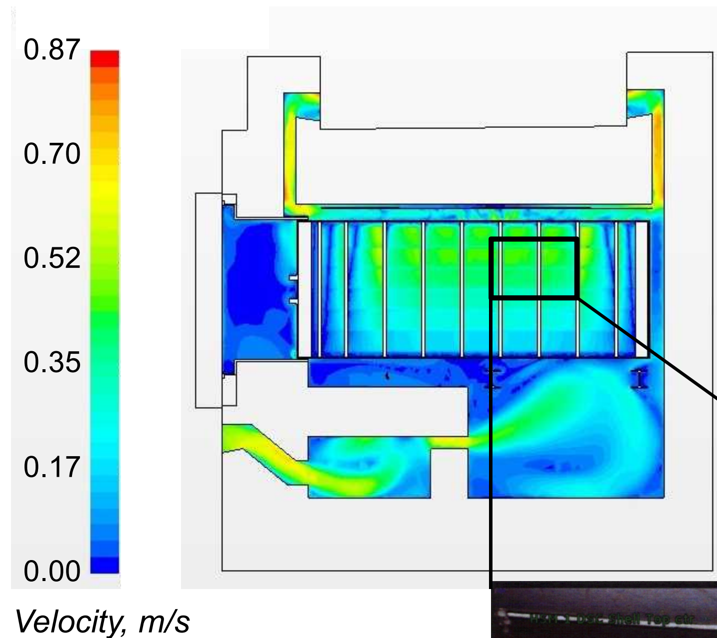
Performance of SNF Interim Storage Containers

Sandia National Laboratories

<u>Background:</u> The United States currently does not have a disposal pathway for SNF. Dry storage casks currently in use may be required to perform their function for decades beyond their original design criteria. Localized corrosion, especially SCC, of welded stainless steel (304L) casks is considered most important potential failure mechanism.

- SCC requires:
  - Chemically aggressive environment—the presence of an aqueous, chloride-rich fluid
    - SNF containers are generally stored in overpacks, limiting the effects of weather
    - However, passive ventilation draws large volumes of outside air through the overpacks; dust and aerosols are deposited on the cask surfaces
    - As packages cool, deliquescence of salts in the dust generates aqueous, potentially corrosive solutions.
  - Susceptible material—chloride-induced SCC of 304L stainless steel is well known
    - High residual stresses in heat-affected zones near welds (no stress mitigation during manufacturing)
    - Metal sensitization in heat-affected zones



Airflow through a NUHOMS horizontal storage module (PNNL 2012, Figure 7.3)

Dust on a storage container surface, Calvert Cliffs

Sandia's Role: Evaluating Corrosion of SNF Interim Storage Containers

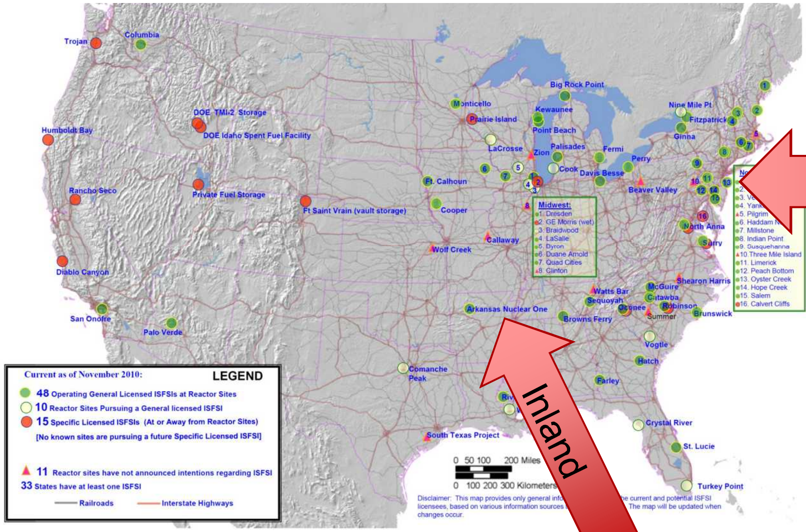
DOE Used Fuel Disposition Program

- Evaluate the chemical environments resulting from dust deliquescence on the storage container surfaces
  - Composition of deliquescent brines; use geochemical modeling and experimental tests to evaluate processes affecting the composition of deposited salts and deliquesced brines.
  - Analysis of dust samples collected from in-use interim storage containers (in collaboration with EPRI)
- Assess likelihood of container failure by localized corrosion mechanisms
  - Evaluate the importance of limited reactant (deposited salts) on the extent of corrosion.
  - Experimental testing with representative welds to assess probability of through-going SCC.

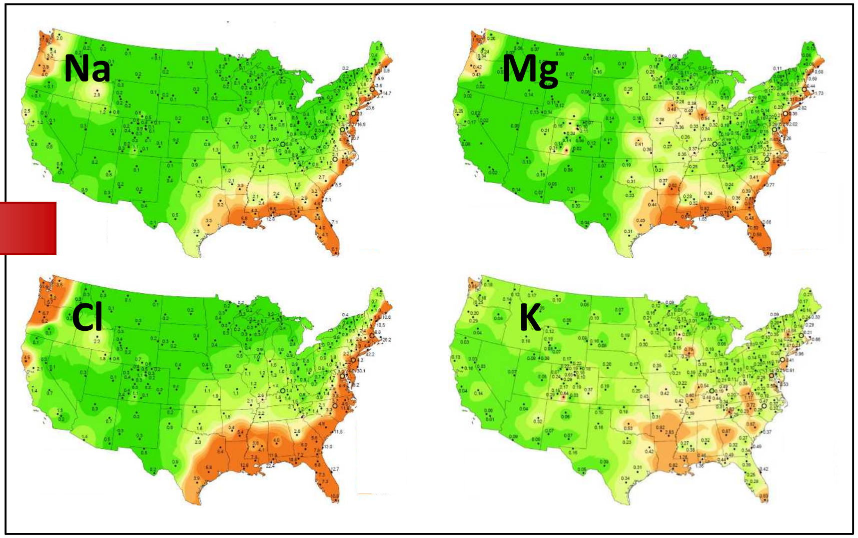
Chemical Environments:

Expected salts vary with location

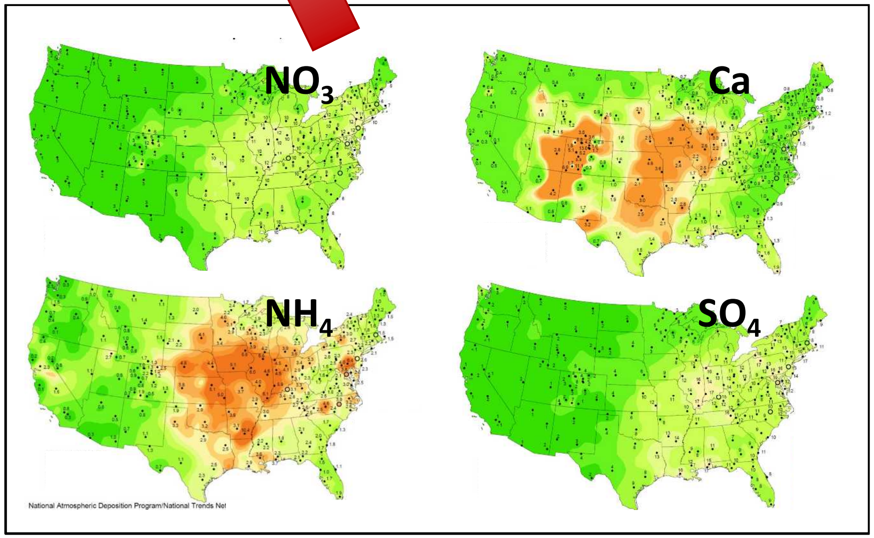
U.S. ISFSI sites



Source: U.S. NRC website



Source: U.S. National Airfall Deposition Program (NADP) wet deposition maps



Chemical Environments:

SCC experimental work may not have been done under representative conditions

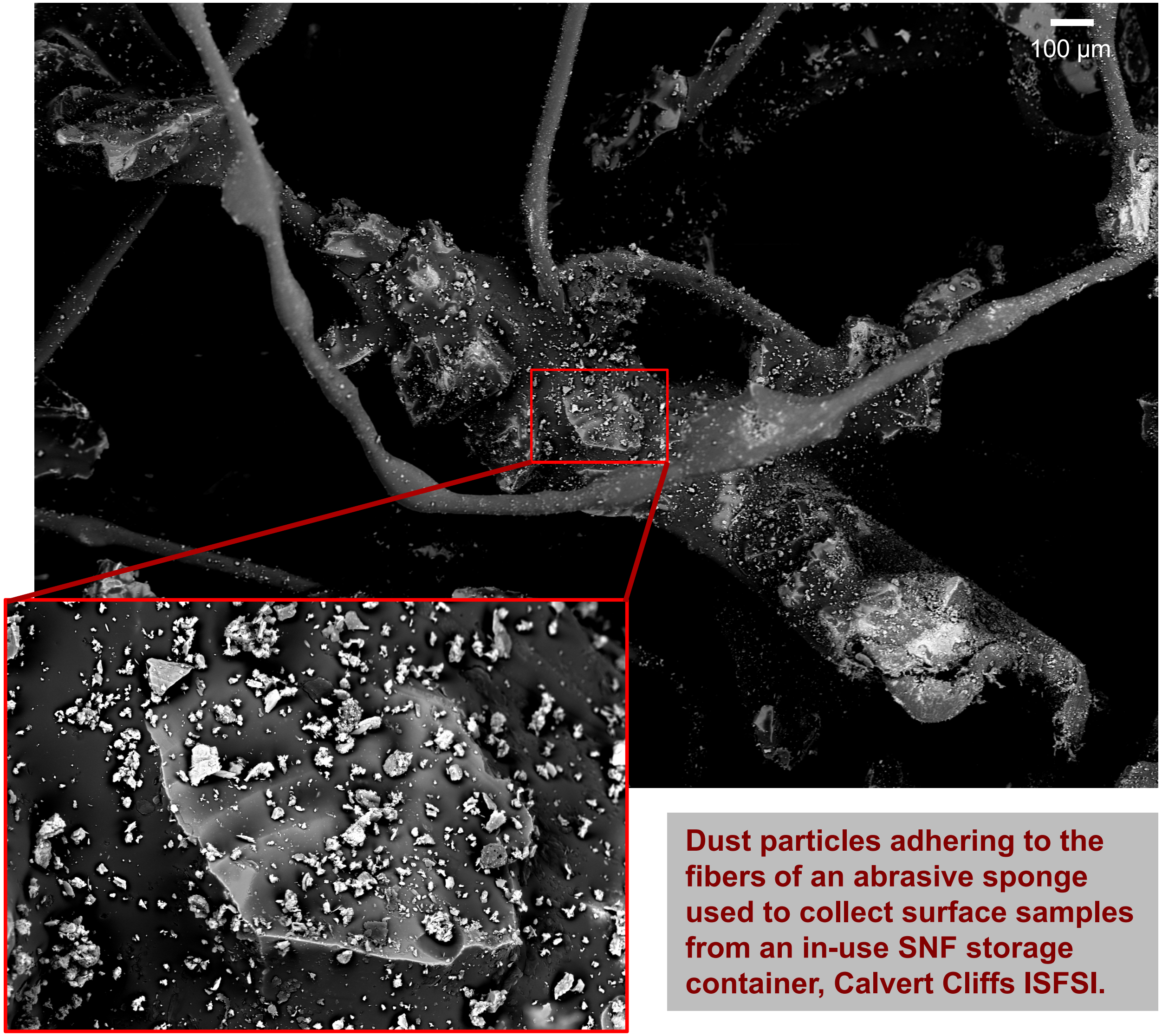
- For near-marine environments, *published experimental* work with sea salts suggests that SCC will likely occur.
  - Sea salts deliquesce at low relative humidities
  - Deliquescent brines are chloride-rich and corrosive; SCC has been observed in many experimental tests under conditions nominally relevant to storage
- However, experimental conditions *may not have been representative*:
  - Use of *synthetic sea salts* to simulate near-marine environments may be unrealistic
    - Salts deposited on the cask surface will not be sea salts, but will include ammonium, nitrate and other species from inland air.
    - Deposited salts will be modified by reactions with atmospheric gases and degassing.
    - Reactions with other dust components may mitigate/enhance corrosivity of deliquesced brines.
  - Limited air flow and *use of clean air streams* in experiments may minimize important atmospheric exchange reactions

There are insufficient data to assess the environment produced by deliquescence on the SNF dry storage casks, or the corrosivity of that environment. There is a critical need for a field sampling program to evaluate dust and salt compositions on storage canister surfaces. Such a program has recently been initiated by EPRI.

Chemical Environment

Sampling of dust on in-service storage canisters

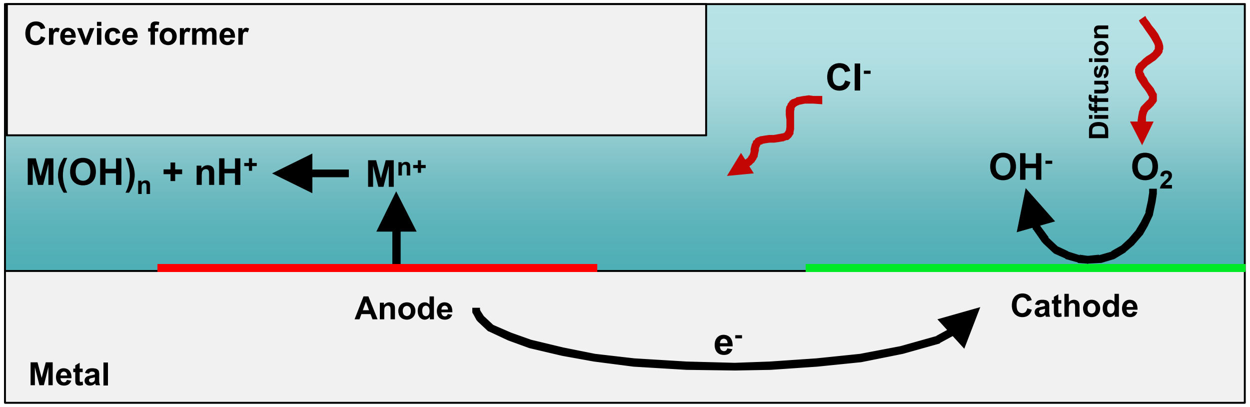
- Joint program with the Electrical Power Research Institute (EPRI) and SNL.
- Analysis of samples from Calvert Cliffs ISFSI is ongoing; two other sites, Hope Creek and Diablo Canyon, will be sampled in FY14.
- EPRI collects dust samples, Sandia characterizes the samples via wet chemistry, XRF, XRD, SEM EDS, GC-MS, and other methods.



Dust particles adhering to the fibers of an abrasive sponge used to collect surface samples from an in-use SNF storage container, Calvert Cliffs ISFSI.

Corrosion Experimental Work

Is Crevice Corrosion a Valid Failure Mechanism?



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

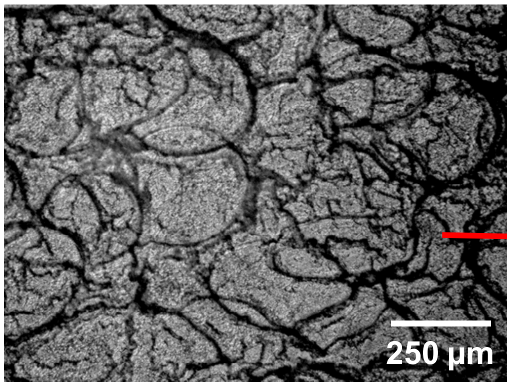
- Available active surface area outside of a potential crevice limits the ability for crevice corrosion to initiate and/or propagate.
  - Relocation of cathode inside crevice does not allow maintenance of the critical crevice solution (Turnbull, NPL; Kelly et al., UVA)
  - Limitation of cathodic capacity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

Corrosion Experimental Work

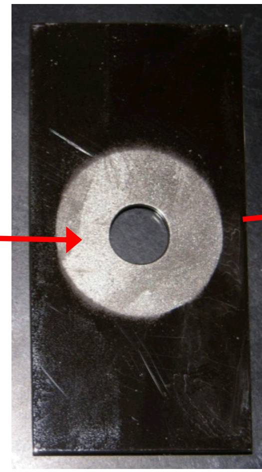
Dust Deliquescence Testing: Crevice Corrosion Initiation Studies

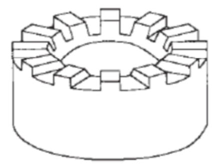
- Crevice corrosion initiated readily on 304L stainless steel

Crevice former and salt on mirror-polished coupon surface



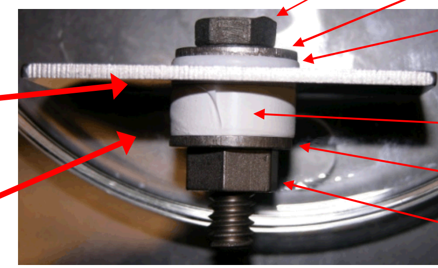
Deposited salt (120 µg/cm^2)





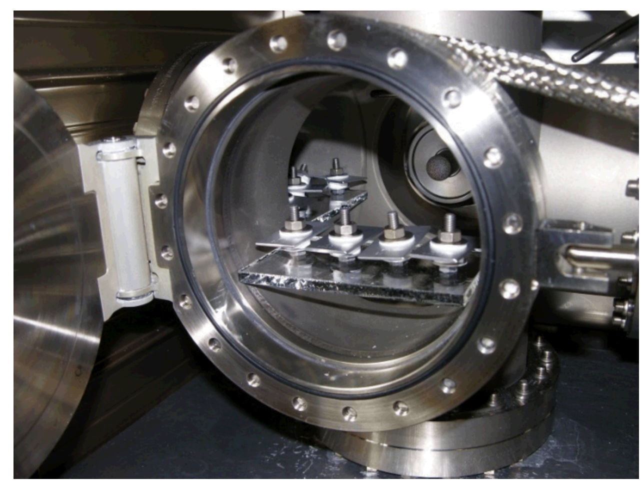
Crevice former

Assembled test assembly



Titanium Bolt
Titanium washer
PTFE washer
Coupon
Crevice former
Titanium washer
Titanium nut

(All titanium hardware electrically isolated from the sample)

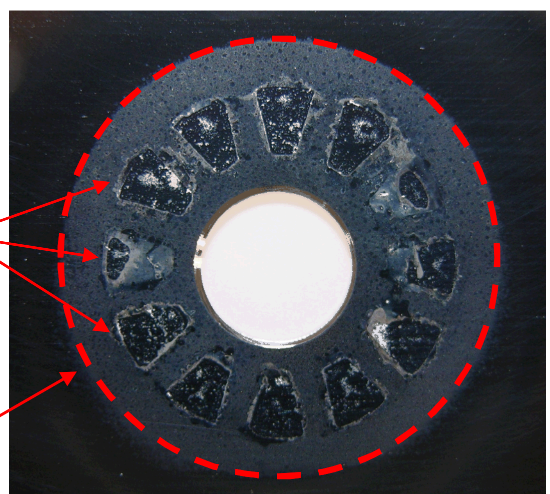


Controlled temperature/humidity chamber

Crevice corrosion initiated at the edges of the crevice former teeth.

Crevice tooth sites

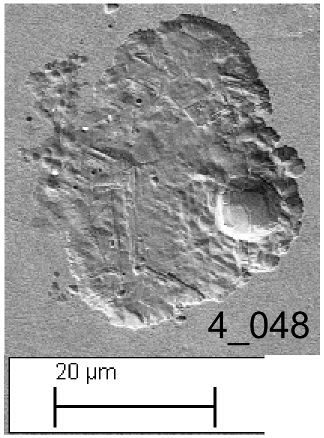
Edge of salt-deposited region

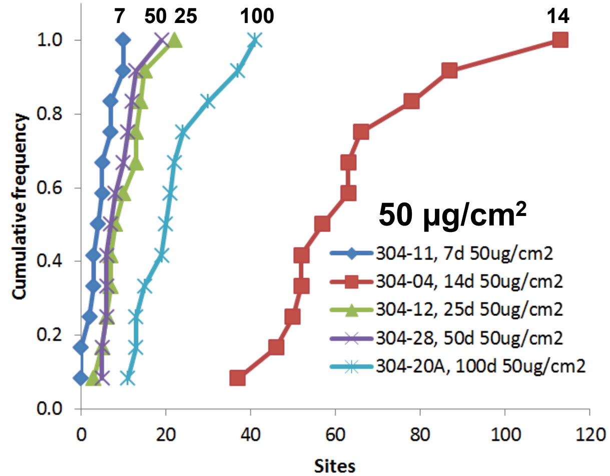


Corrosion Experimental Work

Dust Deliquescence Testing: Effect of Limited Mass of Deposited Salts

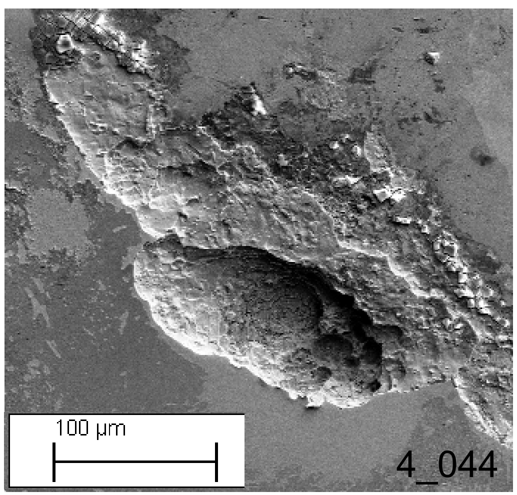
Crevice corrosion sites characterized (number, total area) vs. time and salt loading

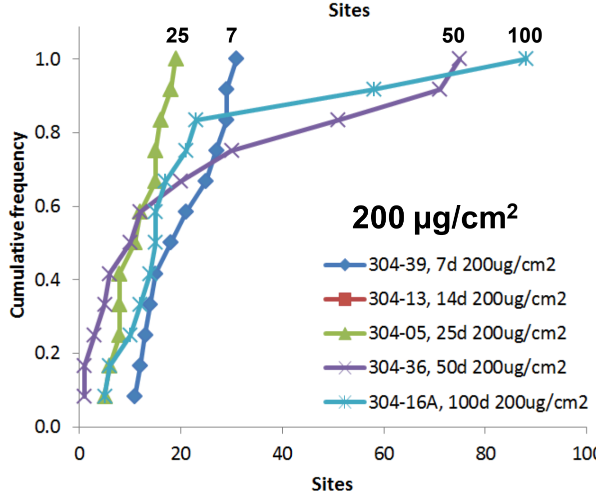


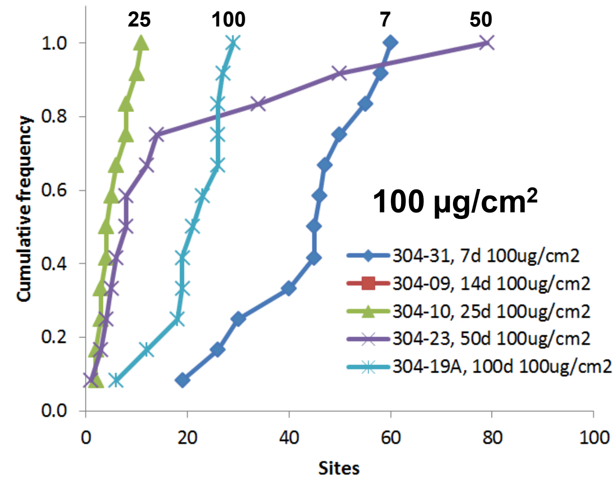


Number of Corrosion Sites vs. Loading

- No clear correlation between number of sites and salt loading
- For a fixed salt loading, the number of sites does not seem to correlate with exposure time



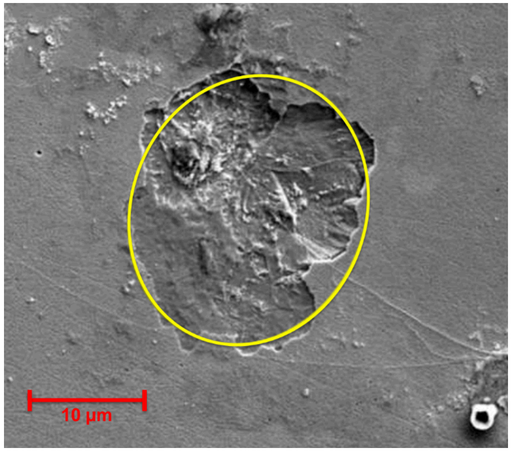




Each data point corresponds to a single crevice tooth on a single sample. Size of pit is not considered. Will look at volume of pits next to understand actual amount of attack.

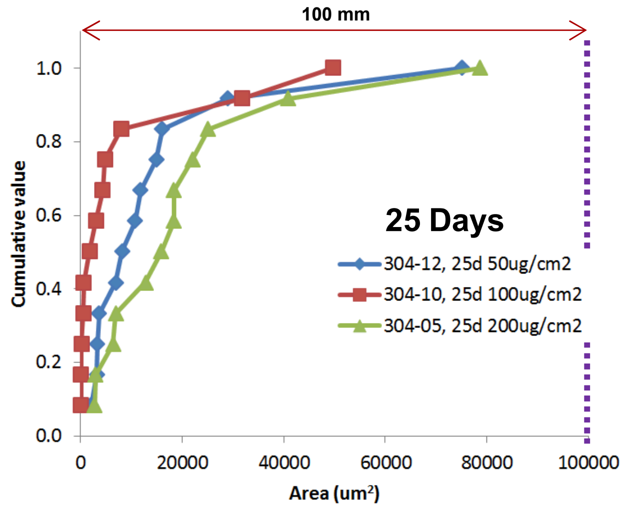
Corrosion Experimental Work

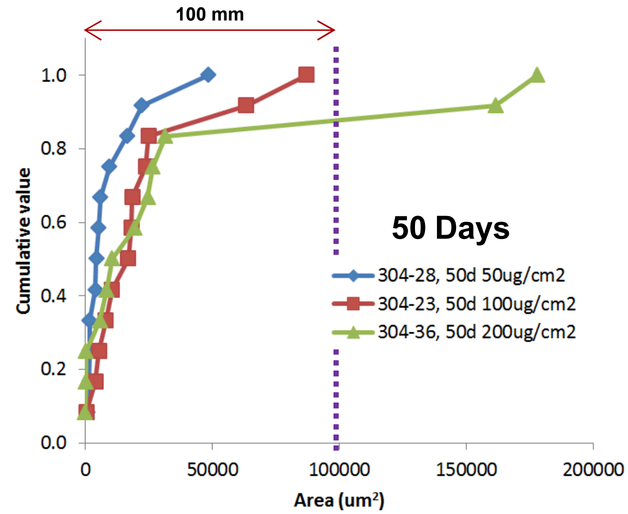
Dust Deliquescence Testing: Effect of Limited Mass of Deposited Salts, cont.

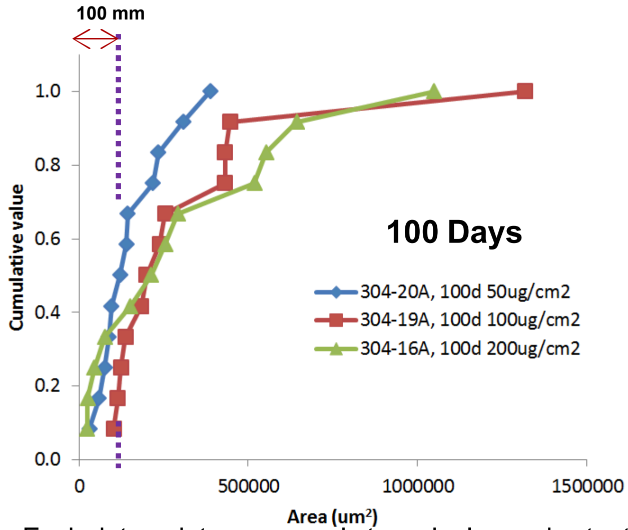


Approximating the two-dimensional area of a corrosion site.

Next step is to look at the volume to understand the large increase in corrosion between 50 and 100 days.







Each data point corresponds to a single crevice tooth on a single sample

Area of Corrosion Sites vs. Time

- Corrosion surface area increases with time, with a large increase between 50 and 100 days.
- For a given exposure time, corrosion surface area increases with mass loading

Corrosion Experimental Work

Dust Deliquescence Testing: Effect of Limited Mass of Deposited Salts, cont.

Was stifling observed?

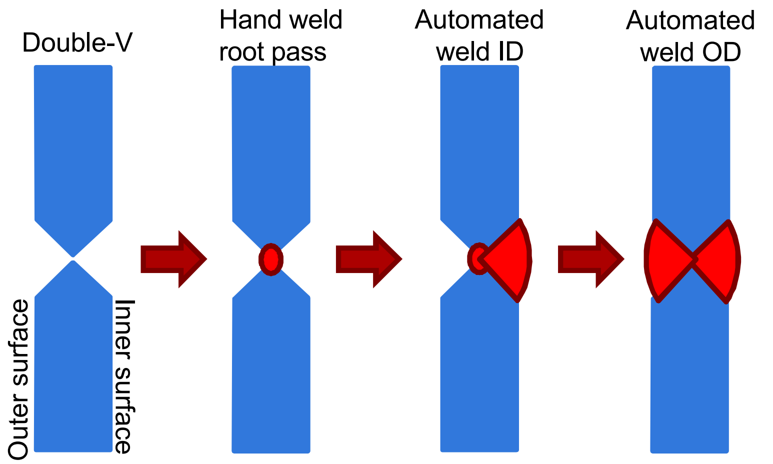
- Number density of sites suggests that there is continuous nucleation
  - No meaningful trend in the number of sites as mass loading increases.
- Surface area is more indicative of the extent of attack
  - Sites can combine as they grow. 2-D approximation of surface area is more indicative of the degree of attack than the number of pits.
  - Extent of attack increases with time at a given mass loading
  - Significant increase in area from 50 to 100 days
- The data have limitations
  - Different samples were used for each time interval
  - Data collection is time consuming. Need more data on corrosion site characteristics. Will look at volume so we can determine how much corrosion has taken place.

Corrosion Experimental Work

Failure of Interim Storage Containers by SCC

SCC of 304L SS weld heat-affected zones is well known. Several studies have shown that SCC can occur under dust deliquescence conditions.

- Sandia work will focus on:
  - Use of more representative environments than previous tests (e.g., dust/salt compositions, air flow rates)
  - Testing with samples generated using welds representative of SNF storage containers (double V). Capture residual stresses/ stress distributions accurately by matching materials and weld techniques/geometries used by the nuclear industry. Will SCC stifle due to compressive regions in the center of the plates?



Summary

Sandia is working with the DOE, EPRI, and others to assess the long-term performance of spent nuclear fuel interim storage containers. Sandia's corrosion work focuses on:

- Developing a better understanding of the chemical environment on the surface of the storage containers:
  - Theoretical assessments (thermodynamic modeling) and experimental evaluation of salt assemblies
  - Collaborating with EPRI to sample and analyze dust and salts on in-service interim storage containers.
- SCC testing using representative weld samples to determine the likelihood of SCC, and of through-penetration.
  - Use representative environmental conditions (salt loading, salt assemblages, air flow)
  - Assess potential for failure by SCC. Will SCC stifle prior to penetration due to:
    - Limited salt loading?
    - Geometry of *in situ* residual stress fields?