

# **Impact of Atmospherically Deposited Solid Contaminants on Materials of Interest for the Interim and Long Term Storage of High Level Nuclear Waste**

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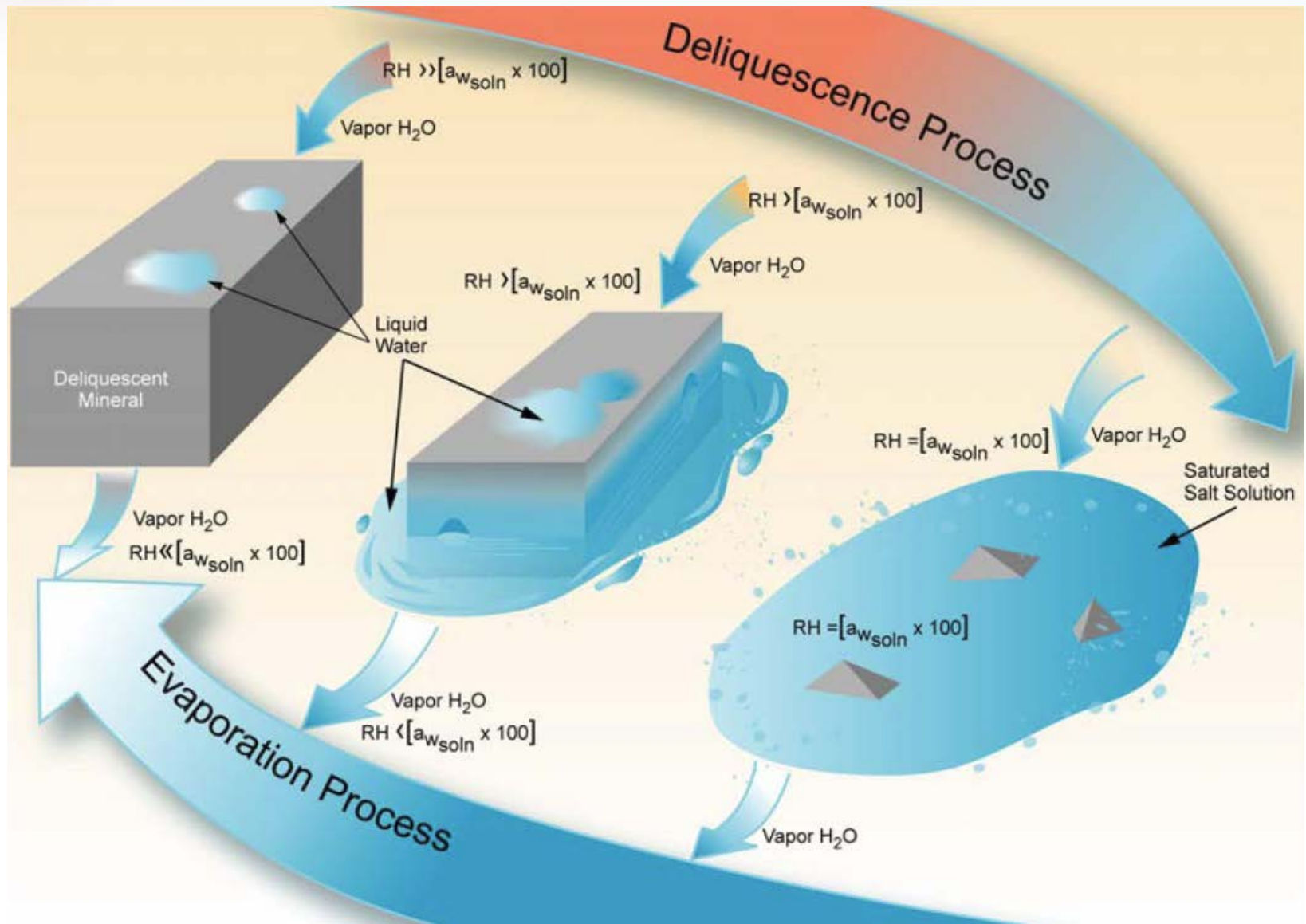
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# Motivation for This Work

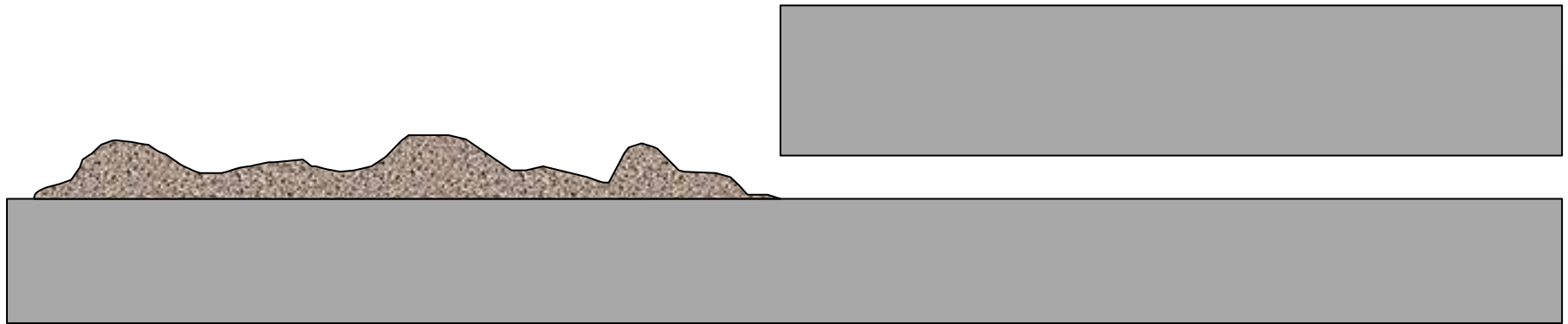
- Long Term Disposal: Numerous groups suggested that salts in dust could deliquesce and create a corrosive environment.
- Interim Storage: Analyses of the gaps in the storage of used nuclear fuel by DOE, EPRI, NRC, and the NWTRB have all identified environmental degradation of the storage system in one form or another as a key research area
  - Corrosion of metallic seals high priority in most analyses
  - SCC of weldments consistently a high priority (literature supports this as an issue)

# Atmospheric Corrosion Processes

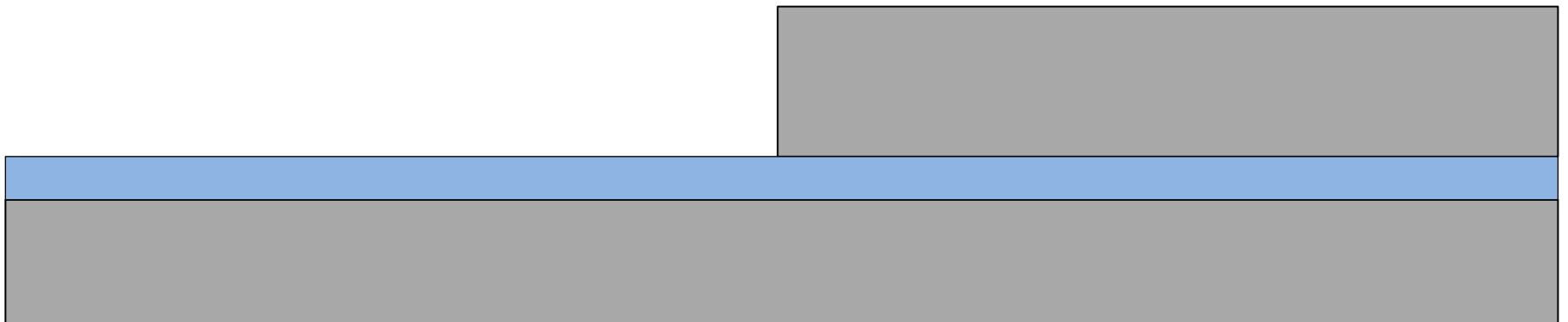




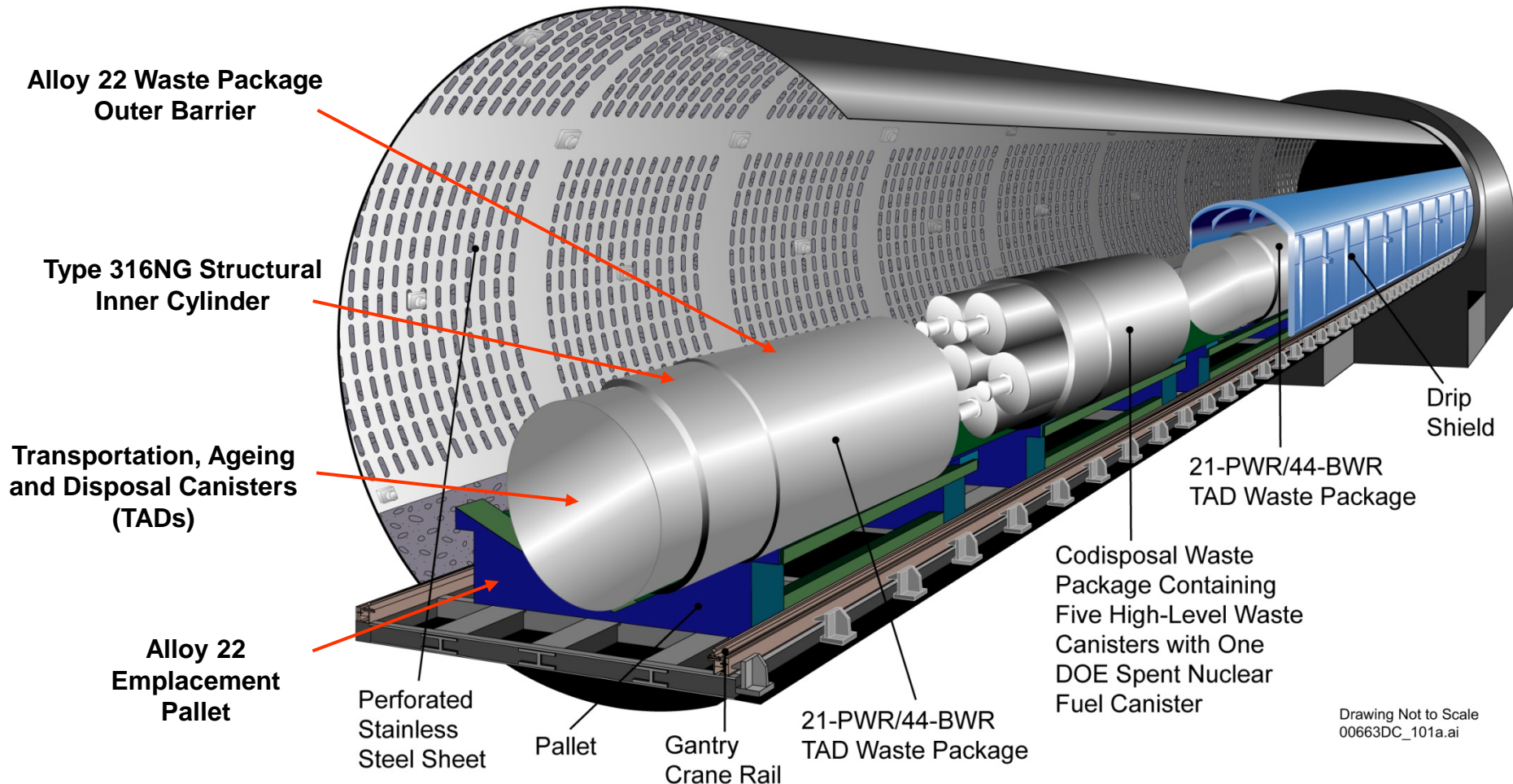
# Schematic of Crevice



High dewpoint environment



# Long Term Disposal

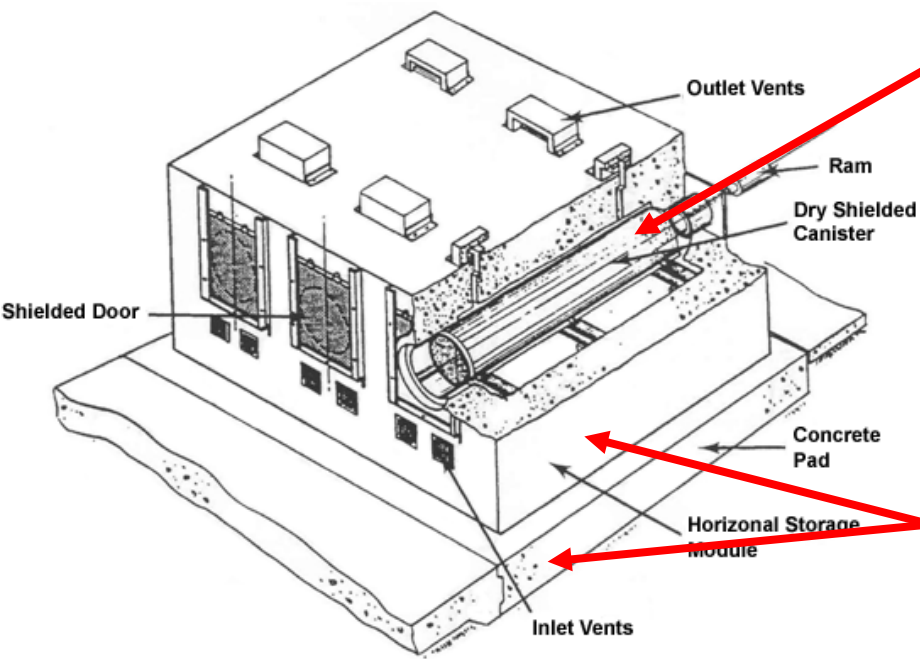


Drawing Not to Scale  
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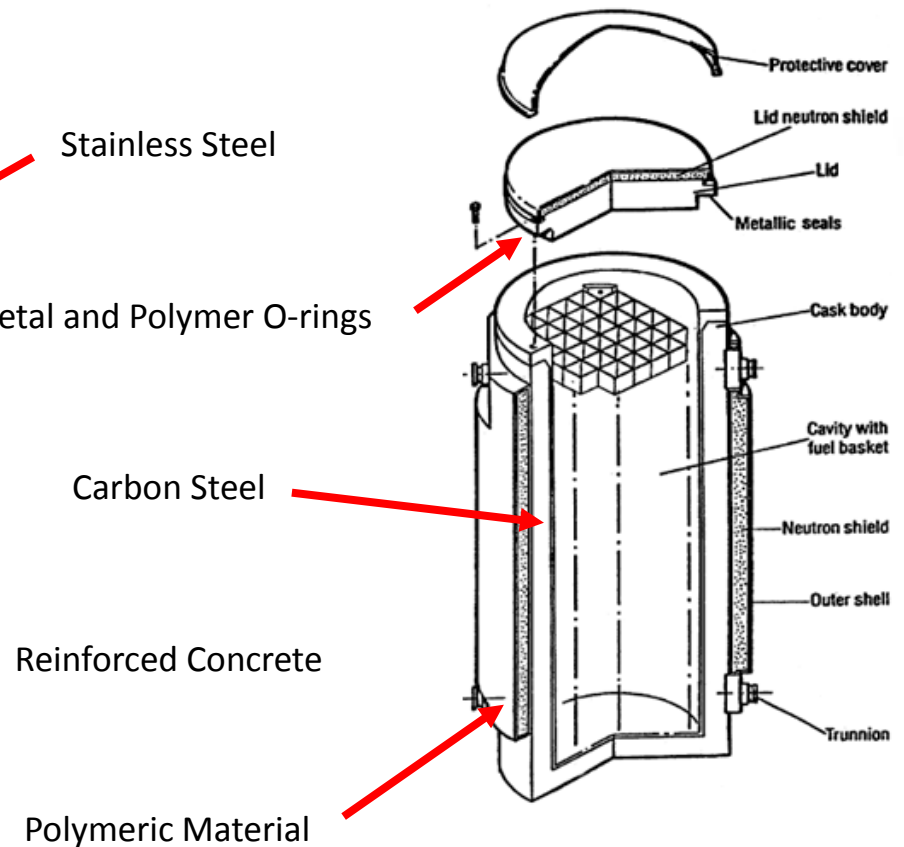


# Interim Storage Systems

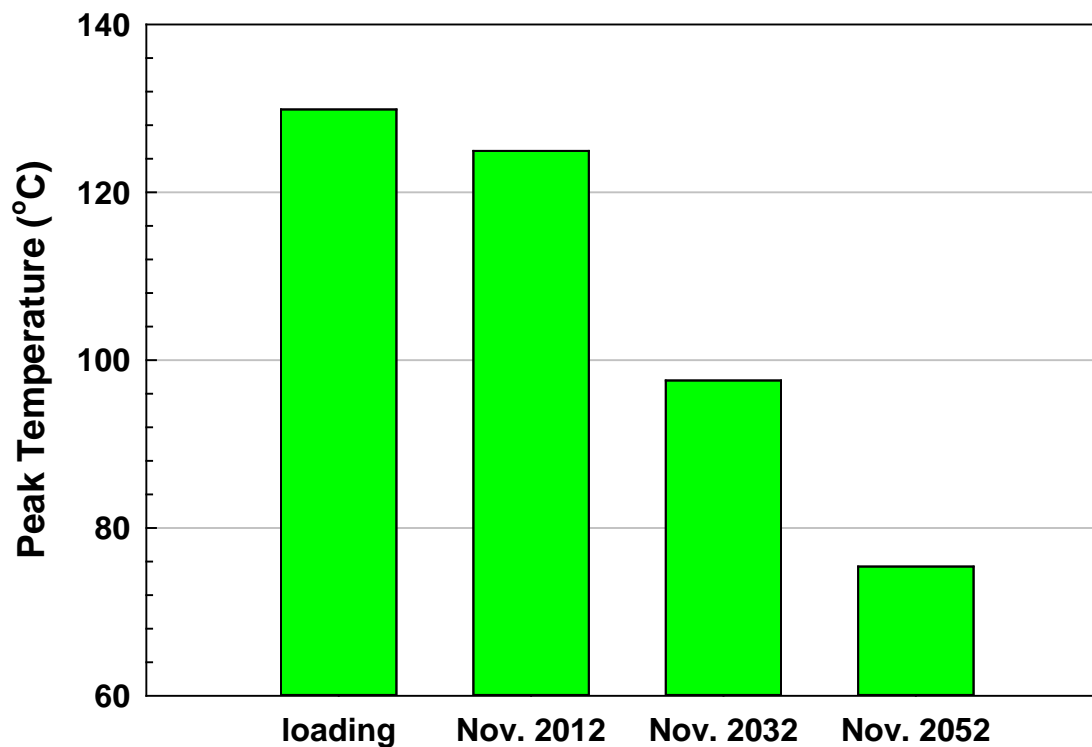
## Welded (e.g., NUHOMS)



## Bolted (e.g., TN-32)

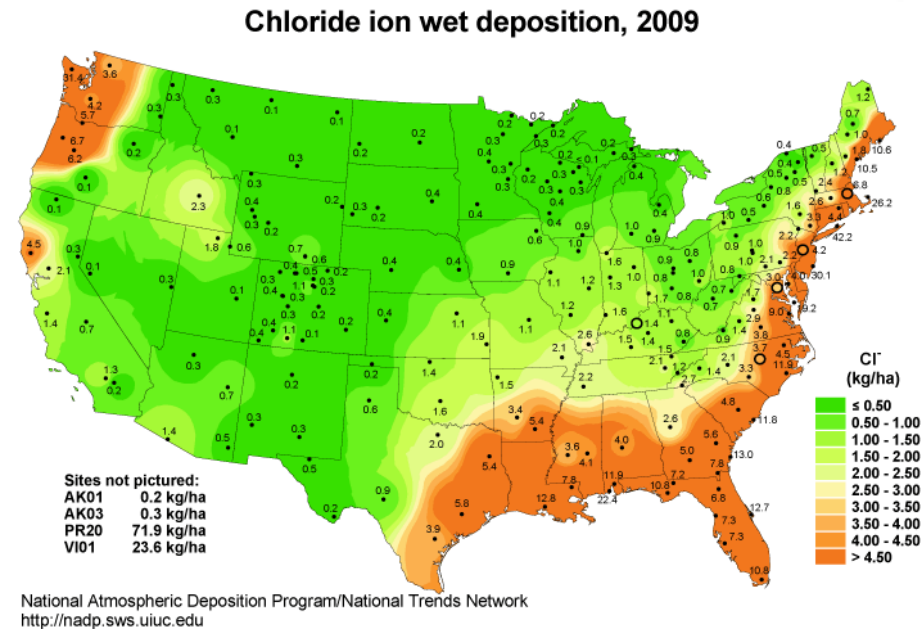
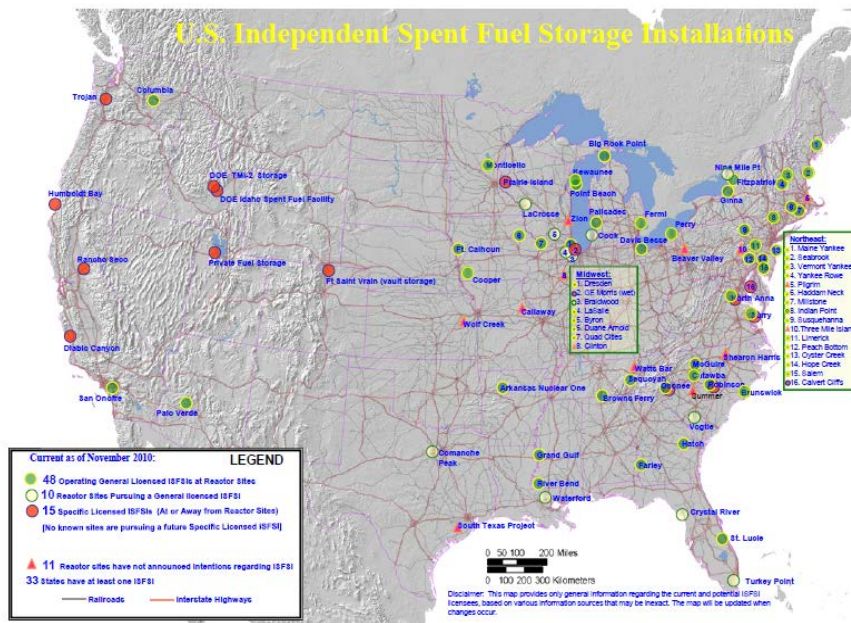


# Peak Interim Storage Container Temperatures (Example: Calvert Cliffs ISFI)



# Environmental Conditions

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







# Is Localized Corrosion Possible Under Atmospheric Conditions?

- For corrosion resistant materials such as Ni-Cr-Mo-W alloys or many stainless steels, theoretical limitations imply crevice corrosion is unlikely under these conditions
- 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)



# Work Described in this Presentation

- Experiments began during the YMP in order to assess if multi-salt assemblages on the waste package surface could initiate and sustain localized corrosion.
- Secondary goal is to strengthen the corrosion stifling argument
  - Significant support in the form of modeling results which indicate that cathodic limitations will likely dominate
  - Critical need for a dataset which could provide direct support to the stifling argument

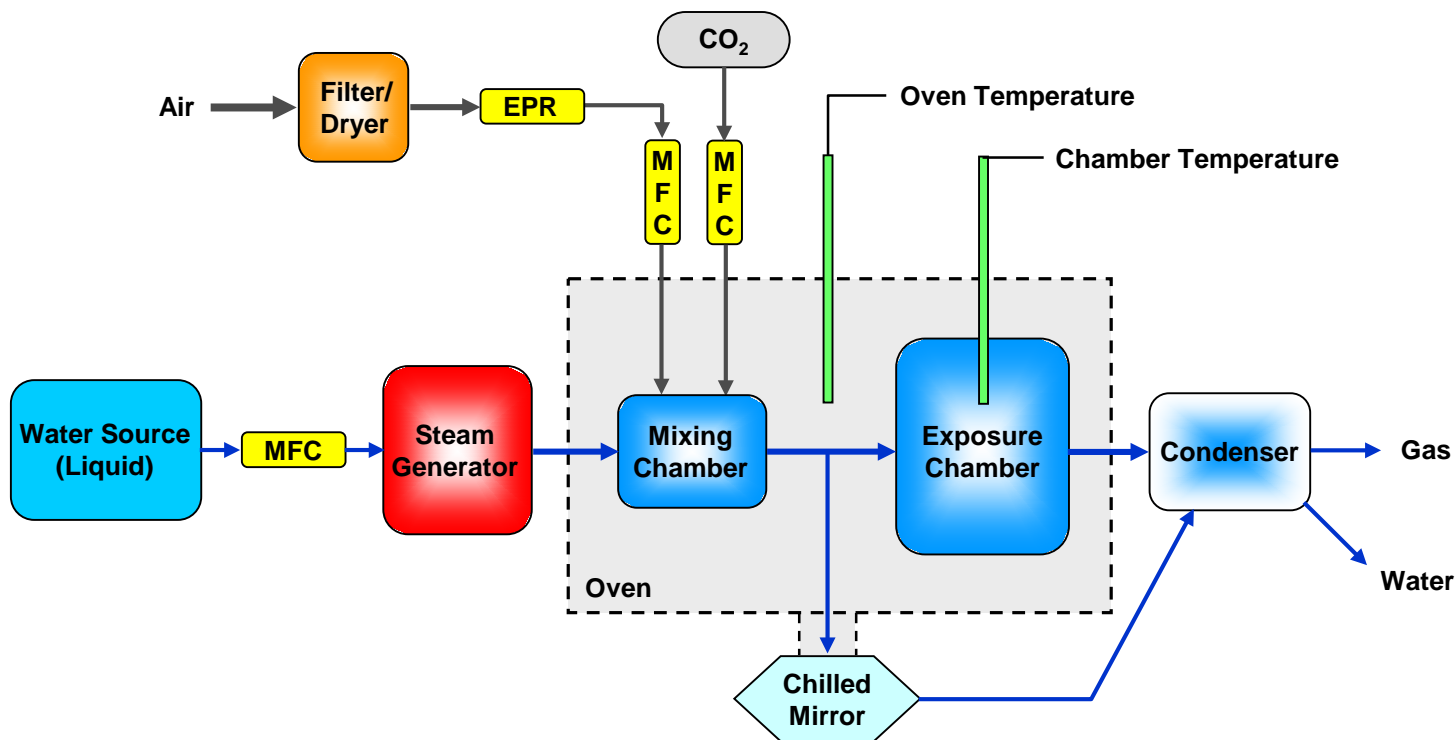


# Experimental Approach

**Goal:** Establish if localized corrosion (crevice corrosion) can initiate under deliquescent conditions

- A series of relevant materials is being evaluated
  - *Long term disposal:* Alloy 22 and less corrosion resistant analogs
  - *Interim storage:* 304 and 303SS
- Thin film of salt (with known mass loading) deposited on surface, followed by the use of a traditional PTFE coated ceramic crevice former
- Exposure to elevated temperature and dewpoint environment for periods of up to 100 days

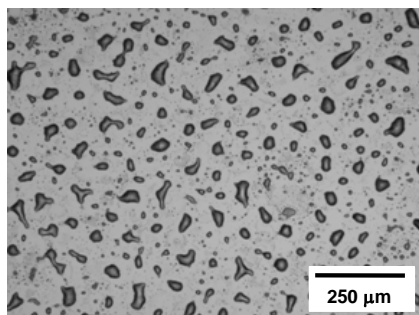
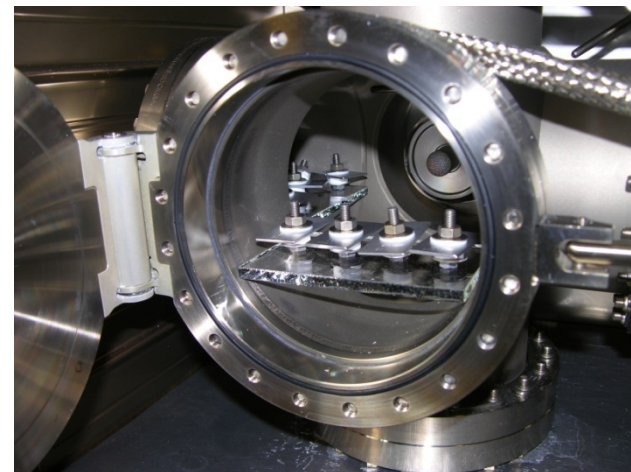
# Elevated Temperature, High Dewpoint Exposure System



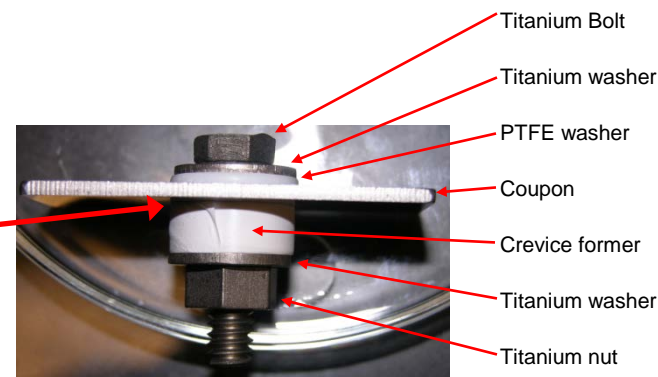
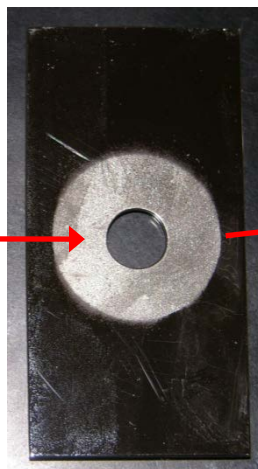
EPR = Electronic Pressure Regulator and MFC = Mass flow controller

# Experiments in Nitrate-Rich Brines

- Alloy 22, Inconel 625, Hastelloy C276, and 80:20 Ni:Cr evaluated
- PTFE coated ceramic crevice former torqued to 70 in-lbs
- Approximately 400  $\mu\text{g}/\text{cm}^2$  of 4 salt mixture  
Mole fraction:      0.126 NaCl                      0.228  $\text{NaNO}_3$   
                         0.268  $\text{KNO}_3$                       0.378  $\text{Ca}(\text{NO}_3)_2$
- $T=180^\circ\text{C}$ ,  $T_d=\sim 94.5^\circ\text{C}$  (pure steam) or  $\sim 92^\circ\text{C}$  for 25 days
- Crevice former and salt on one side of coupon which was polished to a mirror finish



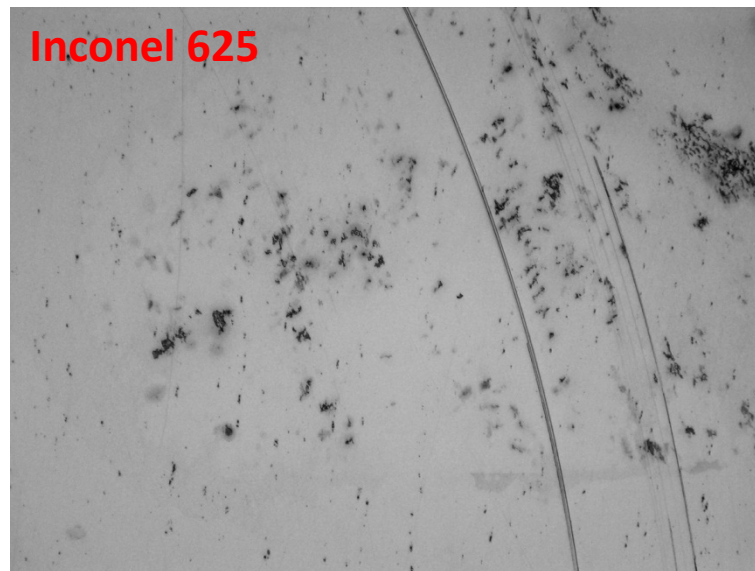
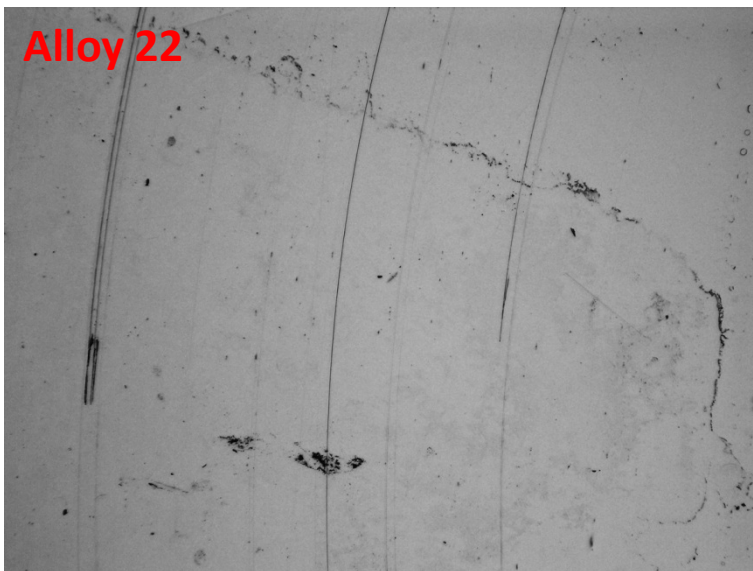
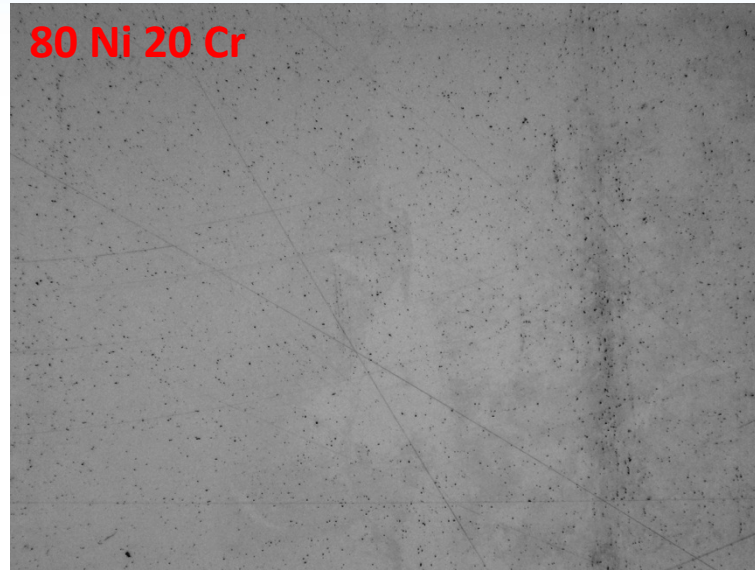
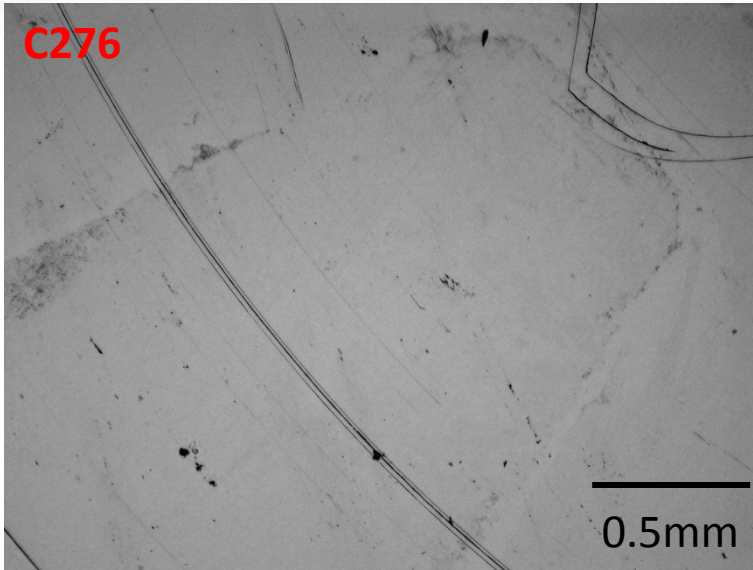
Salt mixture on an Alloy 22 Coupon



*(All titanium hardware electrically isolated from the sample)*



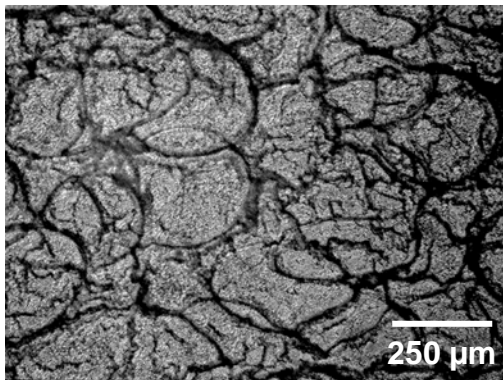
# Nickel Alloys in Nitrate Rich Brines



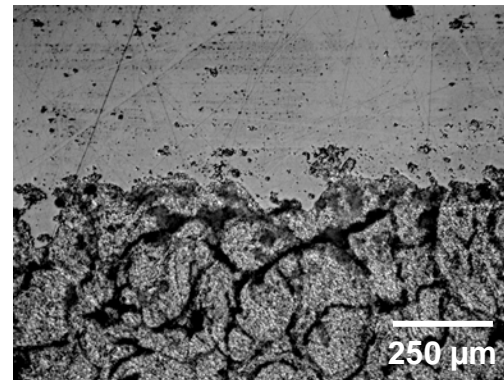
No crevice  
corrosion  
initiation

# Experiments in Chloride-Rich Brines

- Alloy 22, Inconel 625, Hastelloy C276, 80:20 Ni:Cr, 304SS, and 303SS evaluated
- PTFE coated ceramic crevice former torqued to 70 in-lbs, Mirror finish on coupon surface
- Range of salt loadings from 50 to 250  $\mu\text{g}/\text{cm}^2$  of a NaCl-KCl mixture
- $T=105^\circ\text{C}$ ,  $T_d=\sim 94.5^\circ\text{C}$  (pure steam) for test intervals of 100 days



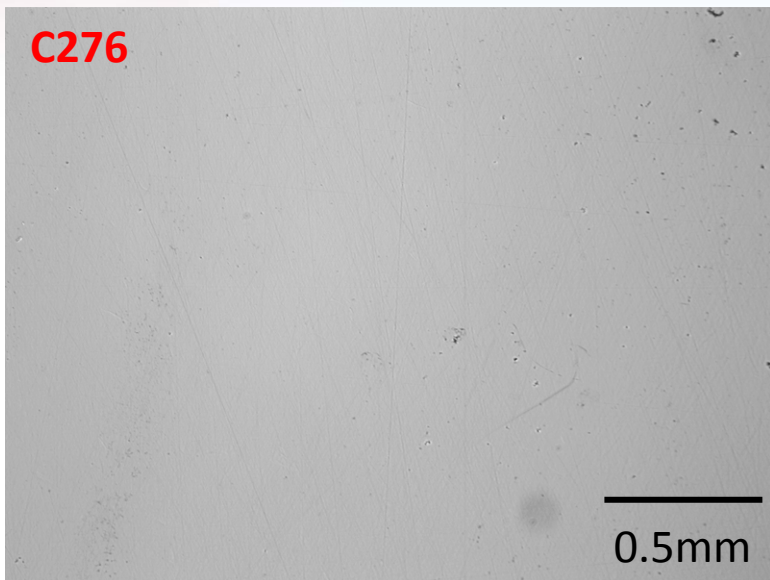
120  $\mu\text{g}/\text{cm}^2$



Wiped region

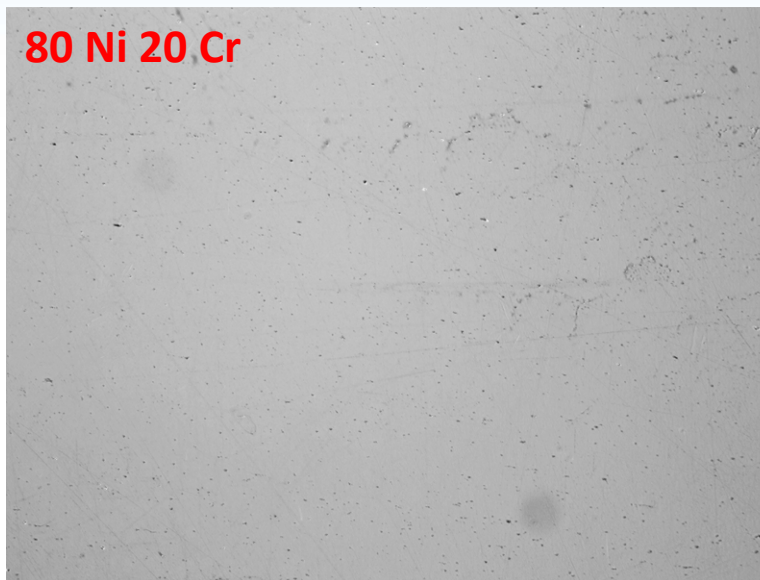
# Nickel Alloys in Chloride Brines

C276

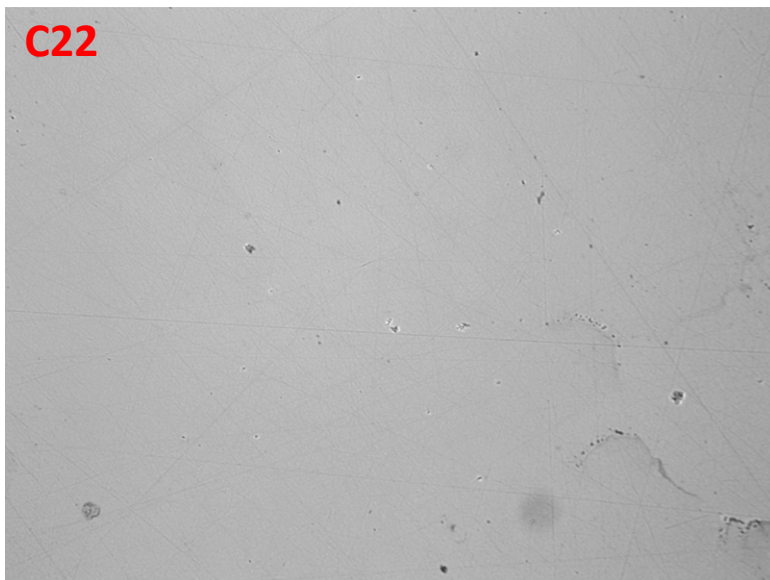


0.5mm

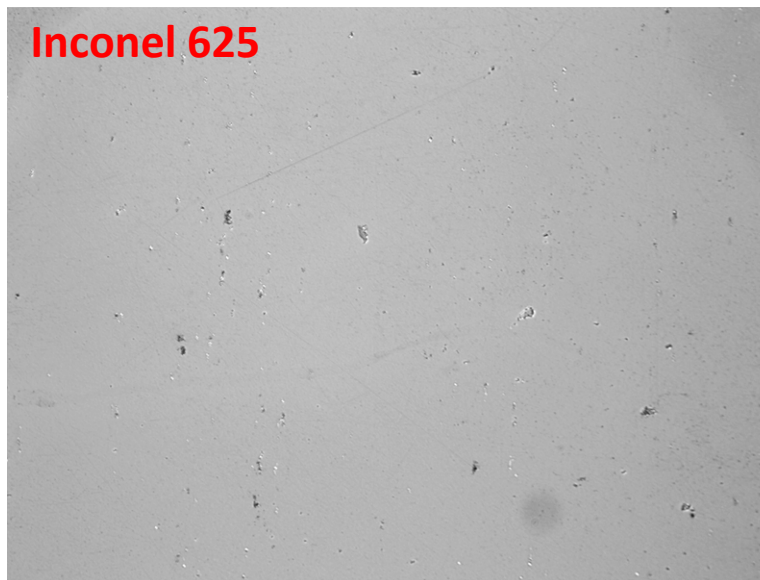
80 Ni 20 Cr



C22



Inconel 625



No crevice  
corrosion  
initiation



# Significant Attack on 303SS

To alleviate concern that technique was not capable of supporting crevice corrosion even on highly susceptible materials, 303SS was introduced into the test matrix



Evaluation of the impact of salt loading was pursued for 304SS (difficult to interpret 303SS results as material was too active) to explore stifling argument



# Stainless Steels in Chloride Rich Brines

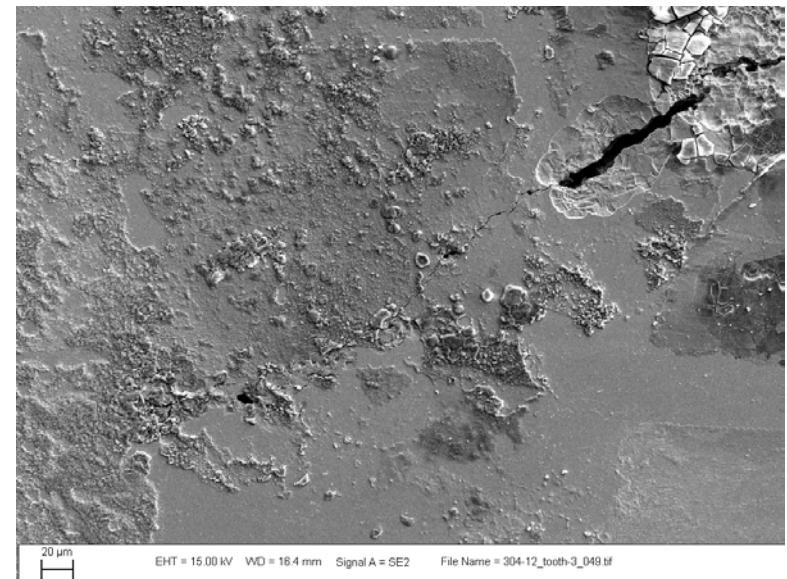
- Three different mass loadings evaluated (50, 100, and 200  $\mu\text{g}/\text{cm}^2$ )
- Initiation observed at all mass loadings, but extent of attack correlated with mass loading
- Samples exhibited SCC in a number of cases, but did not correlate with mass loading
- 303SS too susceptible – significant attack wherever salt mixture was present



# Impact of Salt Loading on 304SS

## $50 \mu\text{g}/\text{cm}^2$

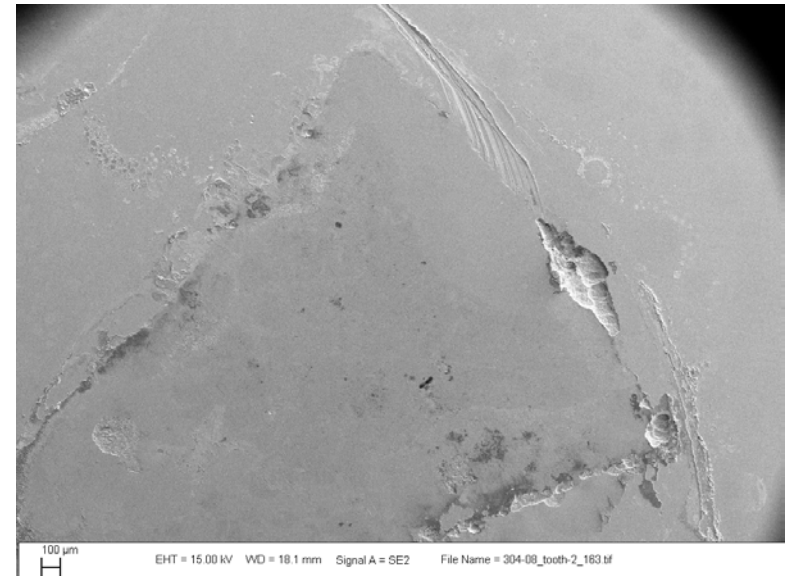
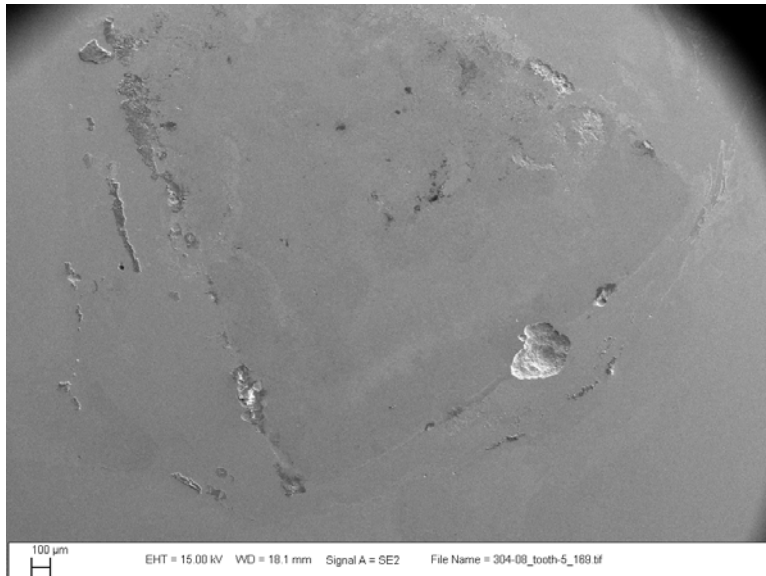
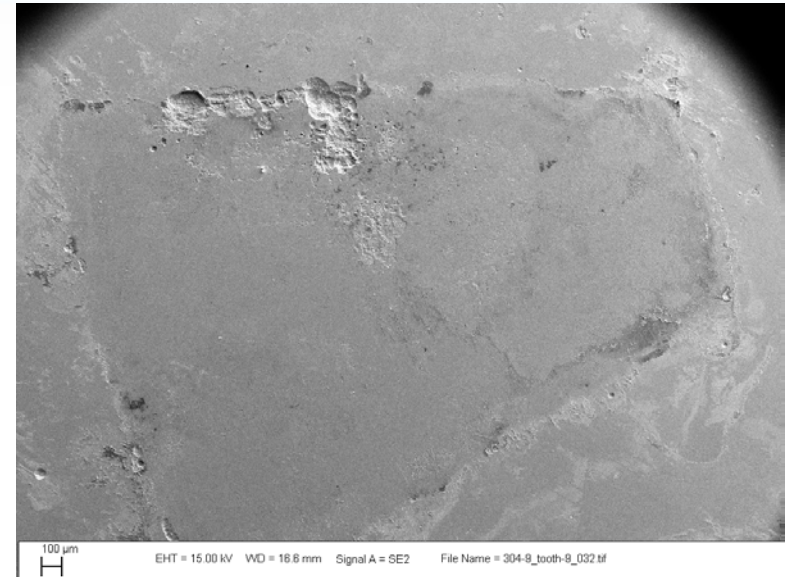
- At least small sites on most teeth
- Cracking observed on some teeth
- Propagation limited in extent



# Impact of Salt Loading on 304SS

## 100 $\mu\text{g}/\text{cm}^2$

- More teeth where crevice corrosion initiated
- Typically multiple sites on teeth where crevice corrosion initiated
- Propagation more extensive (further/deeper)

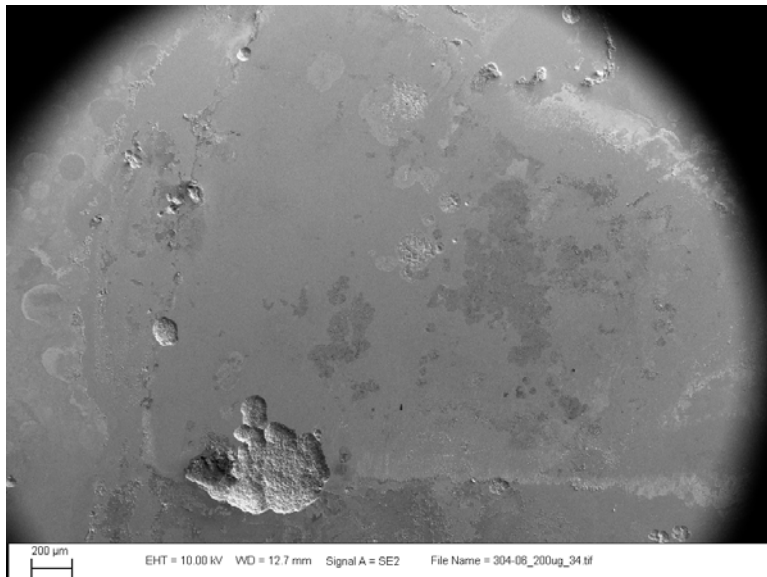
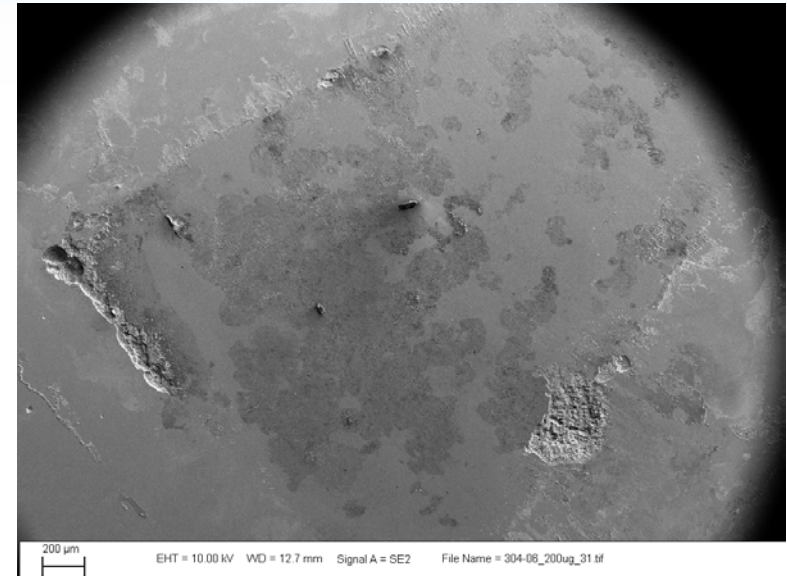




# Impact of Salt Loading on 304SS

## 200 $\mu\text{g}/\text{cm}^2$

- Crevice corrosion initiated on most teeth
- Typically multiple sites on teeth where crevice corrosion initiated
- Propagation more extensive (sites tended to be larger/deeper)





# Summary

- Containers for both interim storage and long term disposal will be under environmental conditions where salt particulates will be deposited that are capable of forming a brine at elevated temperature and humidity.
- Information from the literature suggests that localized corrosion under conditions where limited reactant is present should be difficult due to limitations in the cathodic capacity
- Tests at high temperature with a nitrate rich brine did not result in crevice corrosion initiation for a variety of Ni-Cr-X alloys
- Tests at moderate temperature with a chloride rich brine did not result in crevice corrosion initiation for a variety of Ni-Cr-X alloys
- Crevice corrosion initiation was observed on both 303 and 304SS under moderate temperature, chloride rich brines
- 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.



# Conclusions

- Ni-Cr-X alloys are resistant to crevice corrosion initiation where limited reactant and a thin electrolyte layer is present, consistent with assertions in the literature
- 304 and 303 SS were susceptible to crevice corrosion initiation
- The extent of damage on 304SS roughly correlated with the quantity of reactant present
- Results suggest that crevice corrosion will stifle under conditions where limited reactant is present, presumably due to cathodic limitations or consumption of the reactant





# Acknowledgements

## **At Sandia National Labs**

- Sam Lucero – Salt deposition and experimental setup
- Alice Kilgo – Surface preparation
- Kirsten Norman – Assistance with data analysis
- Bonnie McKenzie – Electron microscopy

## **NWTRB**

- David Duquette, Ron Latanison – Fruitful technical discussions