

# Effect of Non-Chloride-Rich Atmospheric Salts on Stress Corrosion Cracking of Type 304 Stainless Steel—Scoping Study

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NACE 2013, Orlando, Florida  
March 17–21, 2013



# Outline

- Background
- Objective
- Experimental approaches and procedure
- Results
- Summary

# Dry Cask Storage Systems



- Spent fuel may be placed in dry storage after several years of cooling in pool
- The dry storage systems may consist of welded austenitic stainless steel canister inside concrete vault or overpack at independent spent fuel storage installation (ISFSI) sites



# Potential for SCC of Dry Storage Canisters

- Canisters may be exposed to atmospheric particulates through external vents in the vault or overpack.
- A number of research programs have evaluated the potential for stress corrosion cracking (SCC) of the canisters exposed to chloride-rich salts.
- There is limited information concerning the effects of non-chloride-rich atmospheric particulates that could be byproducts of industrial, commercial, or agricultural activities

# Identification of Particulates

- References reviewed include data from Environmental Protection Agency and the Interagency Monitoring of PROtected Visual Environments
- Primary sources identified include
  - Coarse particulates from crustal material
  - Sulfates from combustion sources such as coal
  - Ammonium from livestock and fertilizers
  - Nitrates from combustion sources such as fossil power plants

# Objective

- Evaluate the SCC susceptibility of type 304 stainless steel exposed to non-chloride-rich atmospheric salts that could represent airborne particulates at locations where dry storage is in proximity to industrial, commercial, or agricultural activities

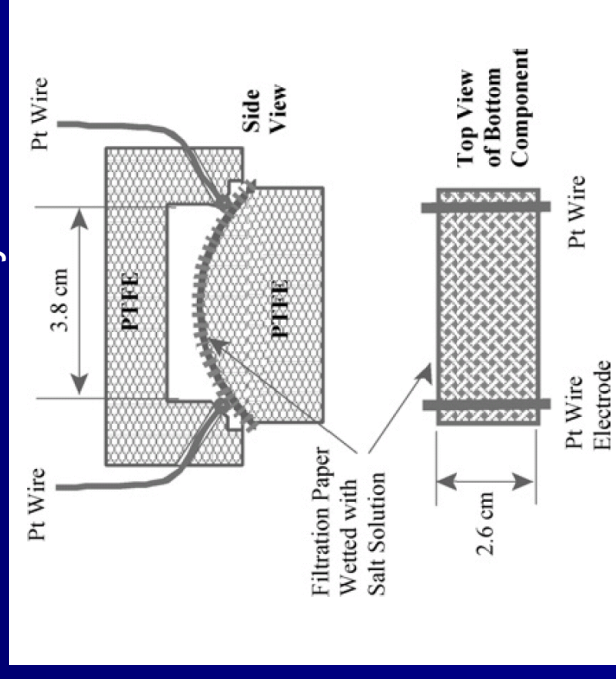
# Technical Approaches

- Deliquescence and efflorescence tests
  - Determine the relative humidity (RH) at which particulates can absorb moisture by deliquescence to support SCC tests
  - Measure by conductivity cells and particulates in beakers
  - Test at temperatures of 35, 45, and 60 °C
- SCC tests
  - Determine if SCC will initiate at temperatures and RH where deliquescence occurs
  - Observe for crack initiation on grade 304 stainless steel U-bend specimens deposited or immersed in particulates
  - Specimens exposed at 35 or 45 °C and absolute humidity about 30 g/m<sup>3</sup>

# Deliquescence and Efflorescence Tests

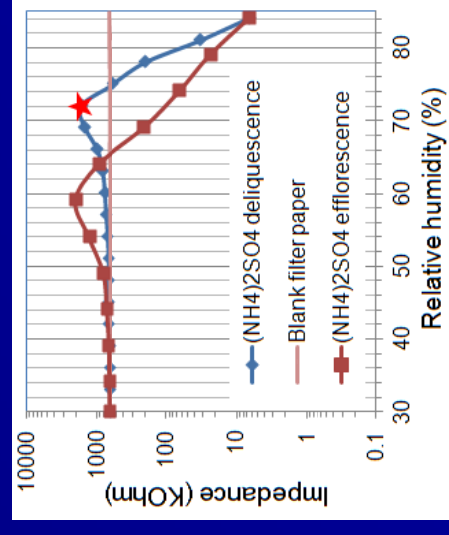
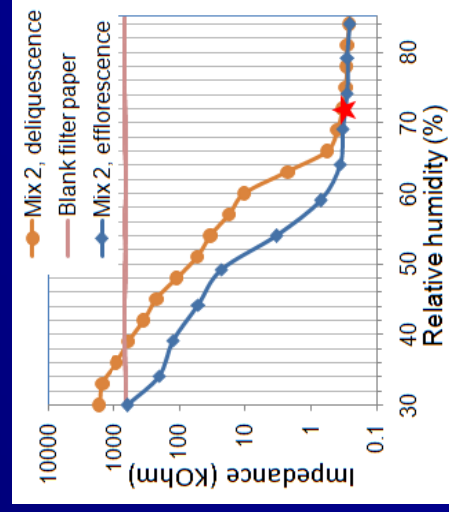
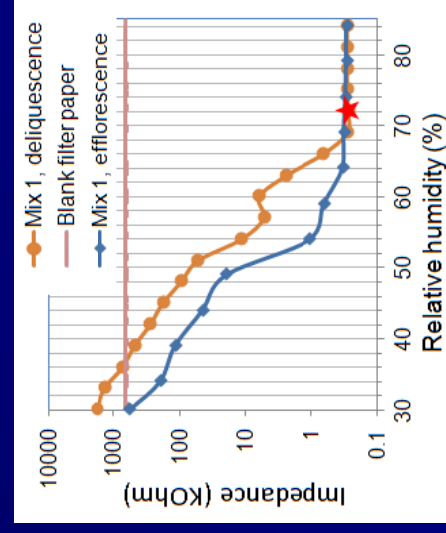
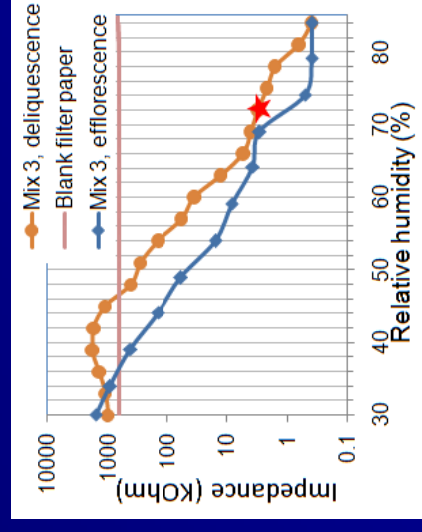
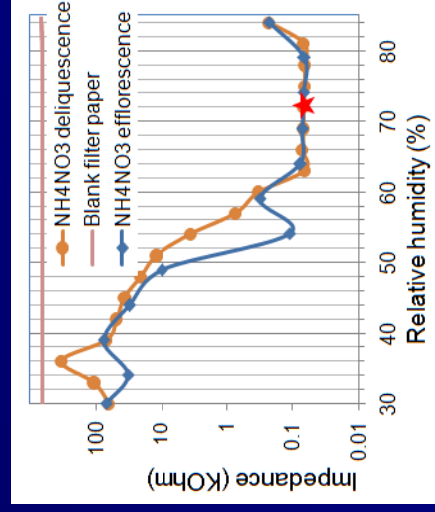
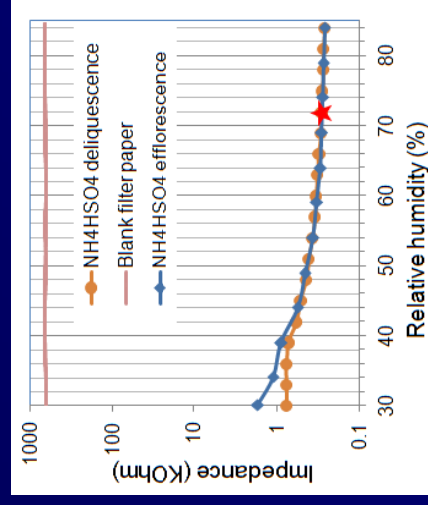
- Pure particulates tested:
  - $(\text{NH}_4)_2\text{SO}_4$
  - $(\text{NH}_4)\text{HSO}_4$
  - $\text{NH}_4\text{NO}_3$
- Mixtures tested representing geographic, seasonal, and diurnal variation of particulates:
  - $(\text{NH}_4)_2\text{SO}_4 + \text{NH}_4\text{NO}_3$  with  $\text{SO}_4^{2-}/\text{NO}_3^-$  mole ratios of 0.5, 1.0, and 3.0

Conductivity cell



# Deliquescence and Efflorescence Test Results at 35 °C

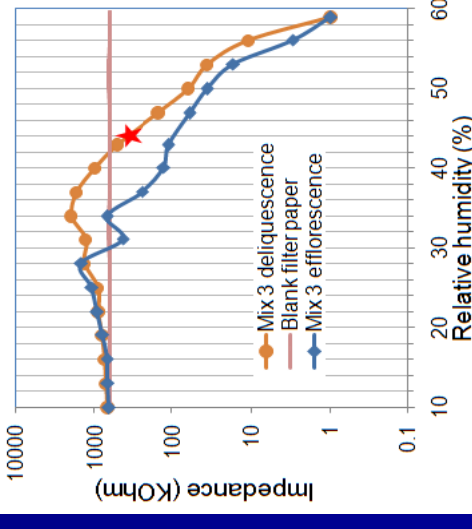
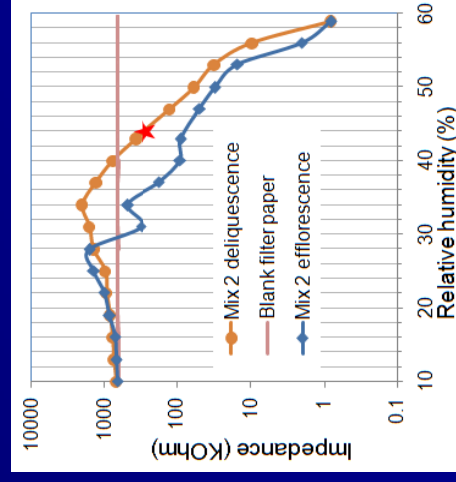
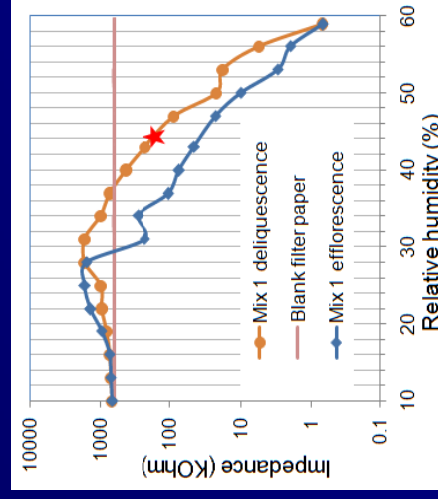
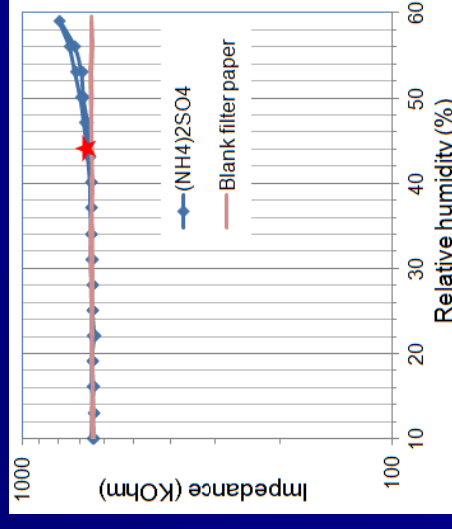
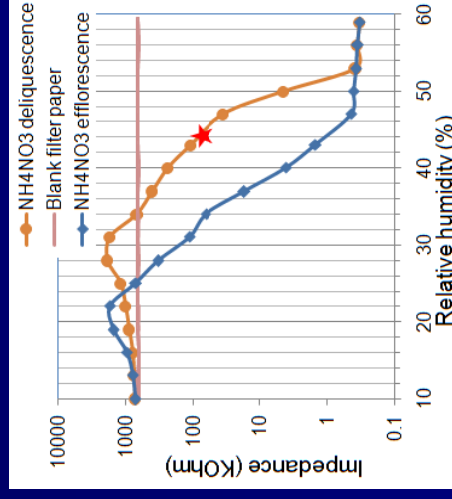
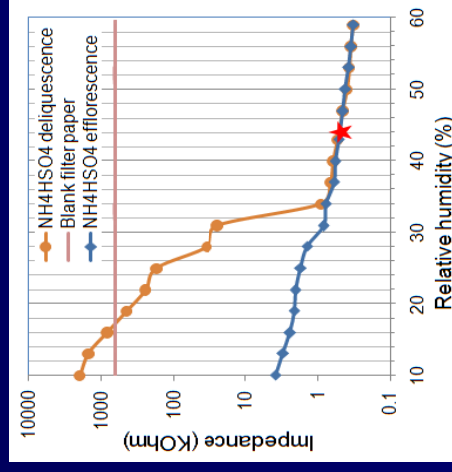
- At 35 °C, the RH is about 72% at AH of 30 g/m<sup>3</sup>
- All species deliquesced below RH of 72% except (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>



# Deliquescence and Efflorescence Test

## Results at 45 °C

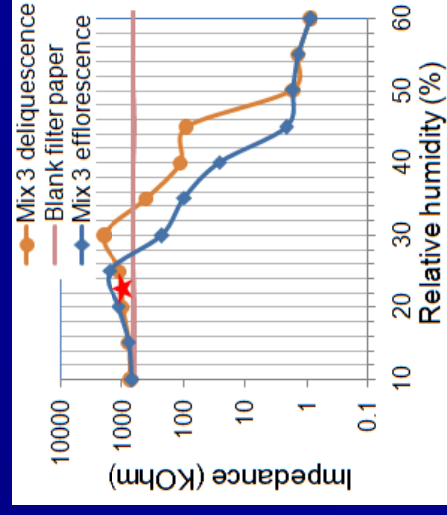
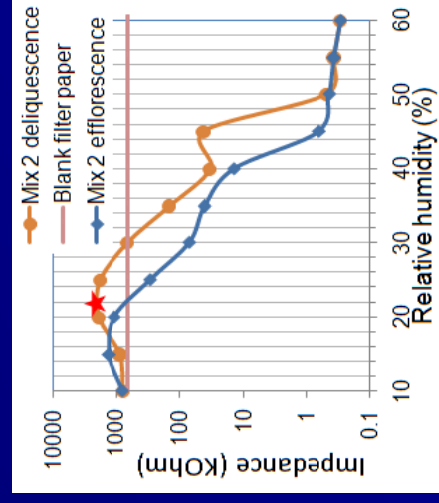
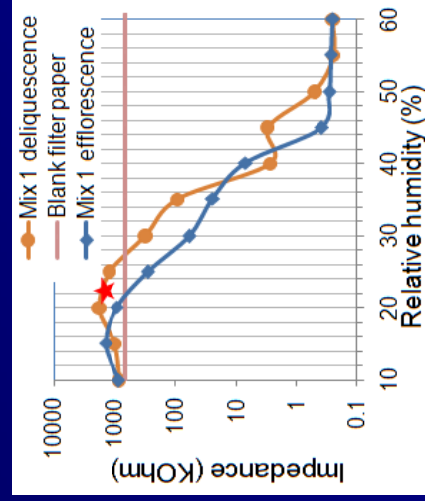
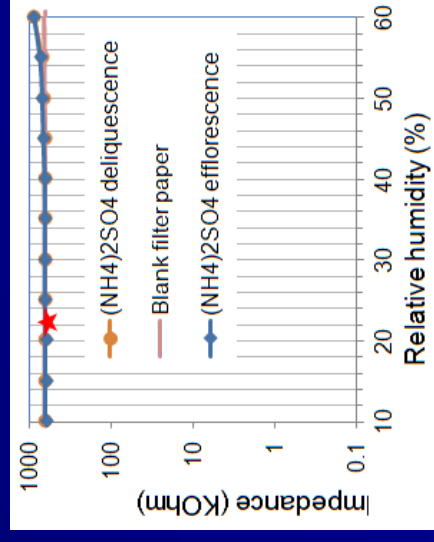
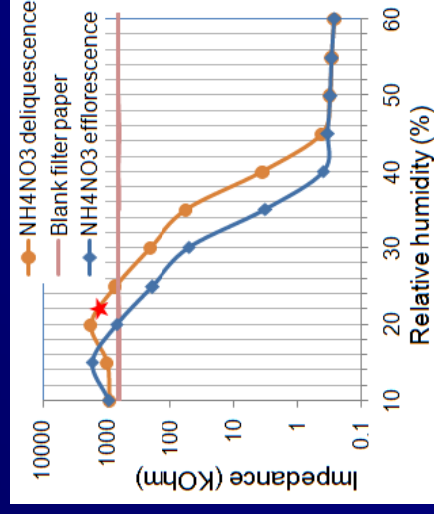
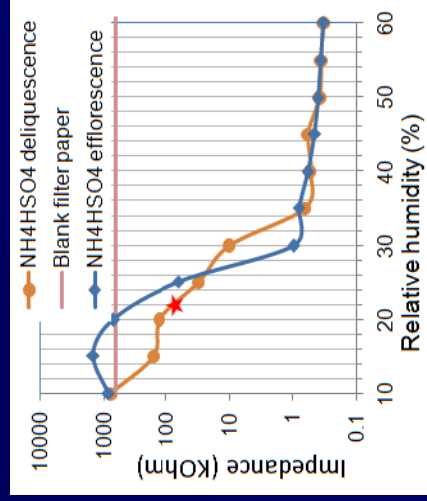
- At 45 °C, the RH is about 44% at AH of 30 g/m<sup>3</sup>
- All species deliquesced below RH of 44% except (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>



# Deliquescence and Efflorescence Test

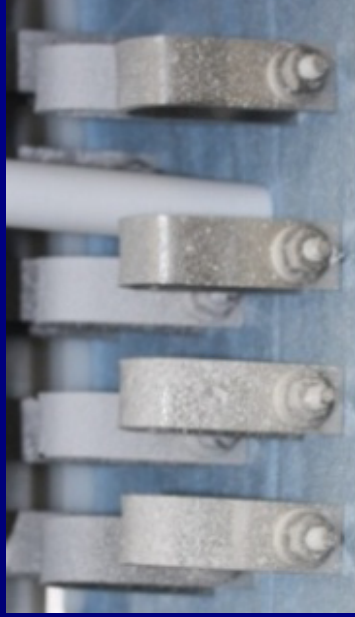
## Results at 60 °C

- At 60 °C, the RH is about 22% at AH of 30 g/m<sup>3</sup>
- No significant deliquescence at RH below 22%, therefore no SCC tests were performed at this temperature



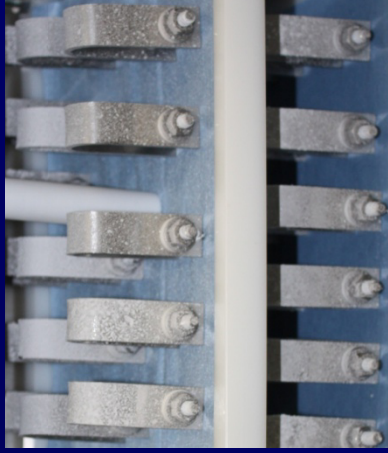
# Stress Corrosion Cracking Tests

- Type 304 stainless steel single U-bend specimens following ASTM G30 and G58 procedures
  - As-received
  - Sensitized
  - Welded
- Either duplicate or triplicate specimens of each metallurgical condition were used during test
- The salt was deposited on specimens by exposing heated U-bends to atomized salt solutions from a spray bottle



# SCC Tests at 45 °C and 44% RH

- Test started at 45 °C and 44% RH by exposing specimens in temperature and relative humidity-controlled chamber

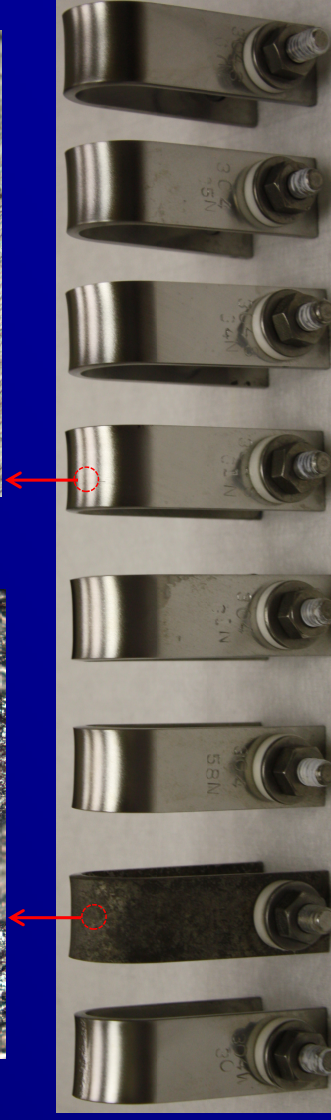
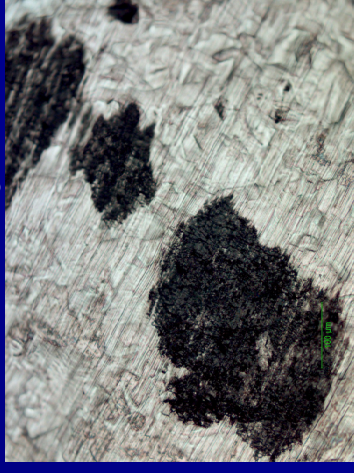
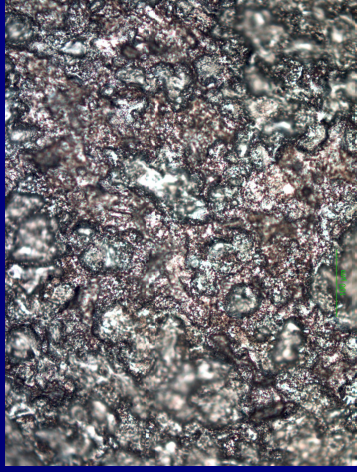


- No cracking was observed from surface after six weeks exposure to various salts

## Specimens removed after six weeks

General corrosion was observed for specimens exposed to  $\text{NH}_4\text{HSO}_4$

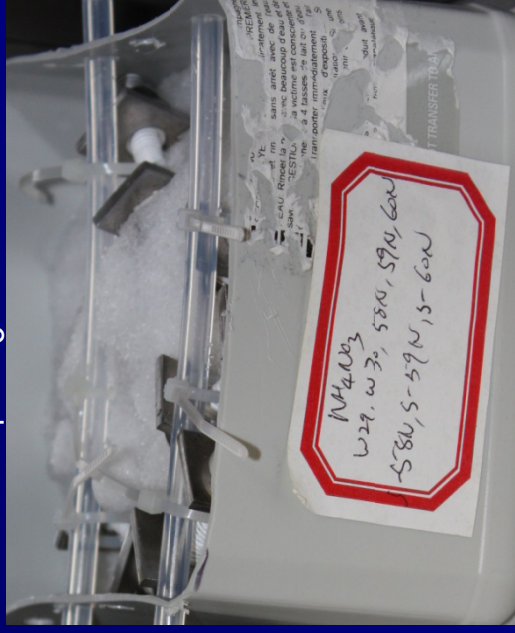
A few pits on the sensitized specimen exposed to  $(\text{NH}_4)_2\text{SO}_4 + \text{NH}_4\text{NO}_3$  mixture ( $\text{SO}_4^{2-}/\text{NO}_3^- = 0.5$ )



## Further SCC Tests at 35 °C and 72% RH

- Remaining specimens from 45 °C–44% RH were placed in bins filled with salts to prevent the deliquescent solution from draining down from the U-bend specimens' apex. The specimens were suspended in the bin with the apex facing down
- The U-bend specimens were exposed for one month

Bin with specimens exposed to  $\text{NH}_4\text{NO}_3$  before test



Bin with specimens exposed to  $\text{NH}_4\text{NO}_3$  after one month



# SCC Test Results

- Except for extensive general non-uniform corrosion of specimens exposed to ammonium bisulfate salt, other specimens remained nearly pristine
- No cracking was

$\text{NH}_4\text{HSO}_4$



Welded

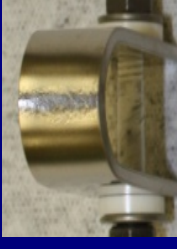


Sensitized



As-received

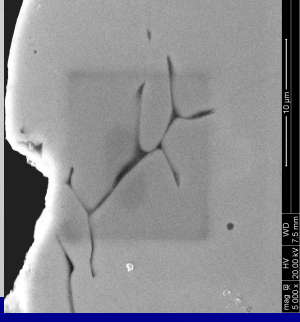
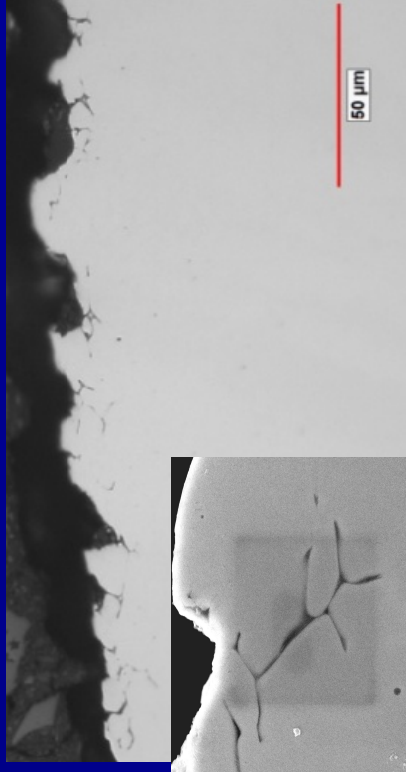
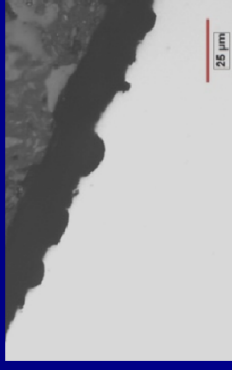
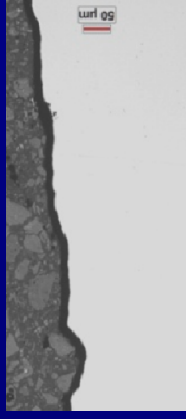
$\text{NH}_4\text{NO}_3$



- observed from surface or cross section of all specimens

Cross section of weld material of the welded specimen showing intergranular corrosion

Cross section of as-received and sensitized specimens showing non-uniform corrosion



# Summary

- Based on survey of environmental data, non-chloride particulates to which dry storage canisters may be exposed include ammonium nitrate, sulfate, and bisulfate salts.
- Testing indicates that ammonium nitrate, ammonium sulfate, and mixtures of those may deliquesce at absolute humidity less than  $30 \text{ g/m}^3$  at 35 and 45 °C.
- Exposure of type 304 stainless steel U-bend specimens deposited with the particulates at 35 and 45 °C indicates no evidence of SCC initiation, with only non-uniform corrosion for specimens exposed to ammonium bisulfate.

# Disclaimer

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