SAND2020-2881PE

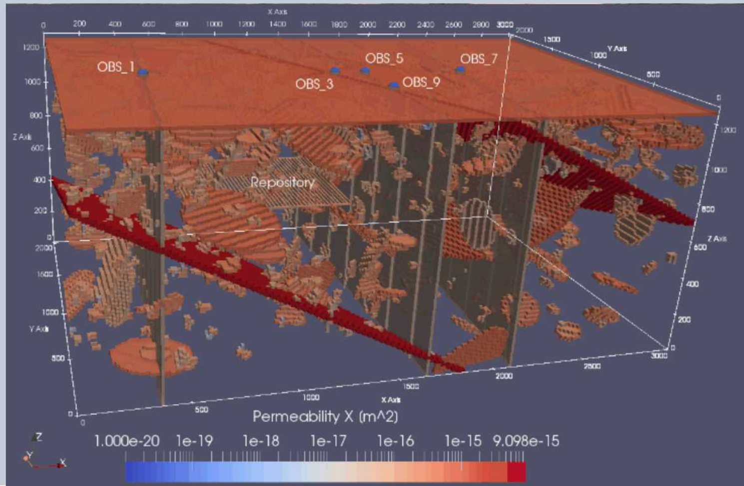
CISCC Program Overview

Sandia National Laboratories

SFWD

Spent Fuel & Waste Disposition

CISCC Program Meeting
March 4, 2020



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Overall Program Objectives

1) Improve prediction of timing and location of potential canister penetration by SCC

- Experimental work and modeling to describe the chemical/physical environment on canisters, how it evolves over time, and how it impacts corrosion processes and rates
- Characterization of the material properties of the canister weld zones and how they affect corrosion rates and processes
- Development of a probabilistic SCC model to evaluate the importance of individual parameter uncertainties on canister penetration rates.

2) Develop and evaluate repair and mitigation strategies for canister CISCC

- Development of mitigation strategies, focusing on friction stir welding and cold spray techniques, optimizing for material properties (stresses, microstructure), and corrosion resistance.

3) Crack consequence analysis

- Experimental work and transport modeling to evaluate particle releases through possible SCC cracks

Program Objectives

CISCC prediction

1. **Improve prediction of timing and location of potential canister penetration by SCC**
    - Determine electrolyte (deliquescent brine) physical and chemical characteristics and how they evolve over time
        - Initial compositions
        - Evolution over time and temperature
    - Determine the relationship between surface environment and damage (pitting/SCC) distributions and rates (SNL, PNNL, SRNL)
        - Temperature and RH
        - Salt surface load and spatial distribution
    - Develop quantitative understanding of the effects of variability in material properties and mechanical environment on corrosion.
        - Weld/heat-affected zone(HAZ)/base metal material properties (sensitization, texture, mineralogy)
        - Tensile stress intensity and depth profile
    - Evaluate dust and salt transport/deposition in SNF dry storage systems (PNNL)
    - *Incorporate data developed above into probabilistic model for canister SCC, evaluate model sensitivities, and modify work scope appropriately*

Program Objectives
Mitigation and Repair

2. Support work to develop and evaluate repair and mitigation strategies for canister CISCC

- Develop and optimize friction stir welding (FSW) and cold spray processes for CISCC mitigation and repair
  - Fabricate samples for corrosion testing (PNNL)
  - Corrosion testing of samples (SNL)
  - Evaluate stress redistribution in response to welds/repairs (ORNL)
- Support NEUP programs as TPOCs, collaborators (SNL, PNNL, SRNL, ORNL), providing guidance on:
  - Mitigation techniques
  - Corrosion testing methods

Program Objectives
Crack consequence

3. Crack consequence analysis

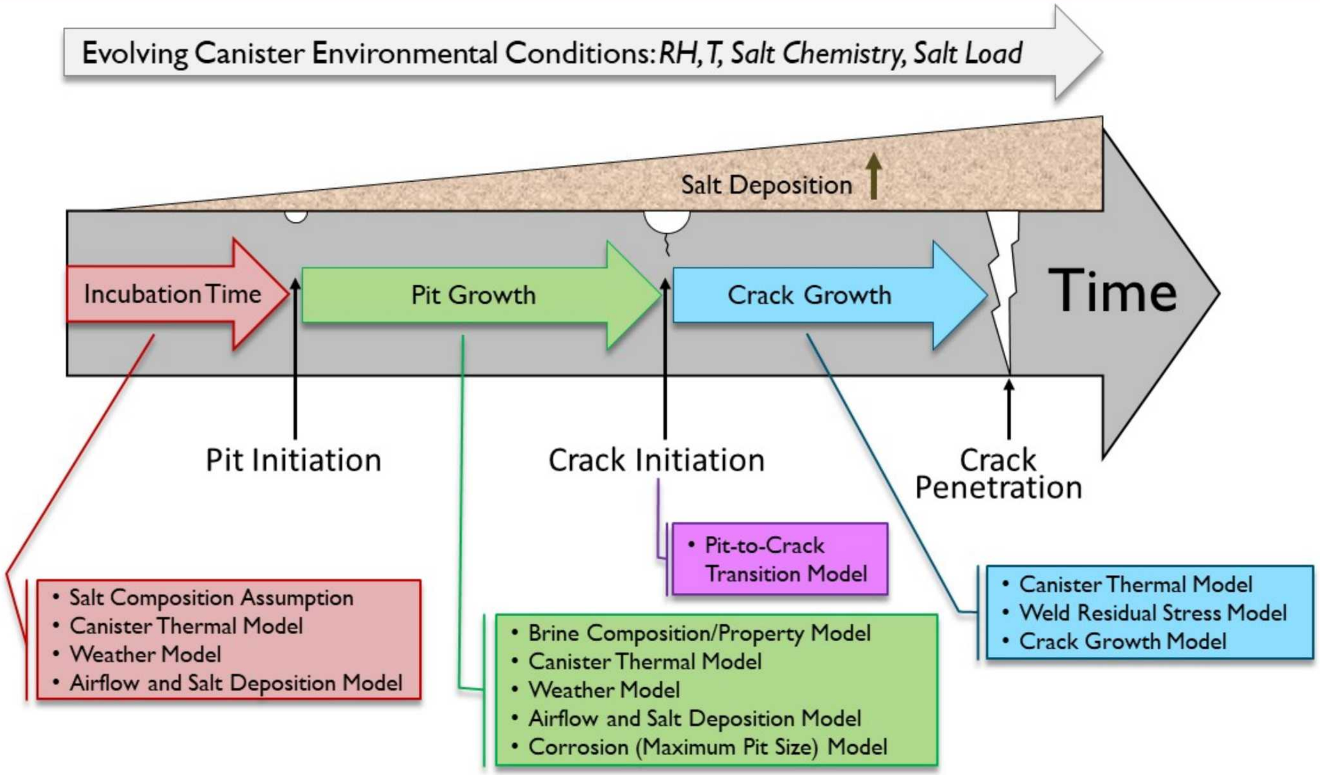
- Experimental evaluation of gas and particle transport through cracks (SNL)
  - Source term and crack flow modeling (SNL, PNNL, ORNL)
  - Prototypical crack sample preparation (SNL, PNNL(?), EPRI, others?)

Crack consequence analysis will not be discussed in this meeting. We will focus on the corrosion program.

INTEGRATED MECHANISTIC/PROBABILISTIC MODEL FOR CANISTER SCC

Current model developed by SNL is a work in progress.

Current and planned experimental work is intended to parameterize this model.



ISSUES

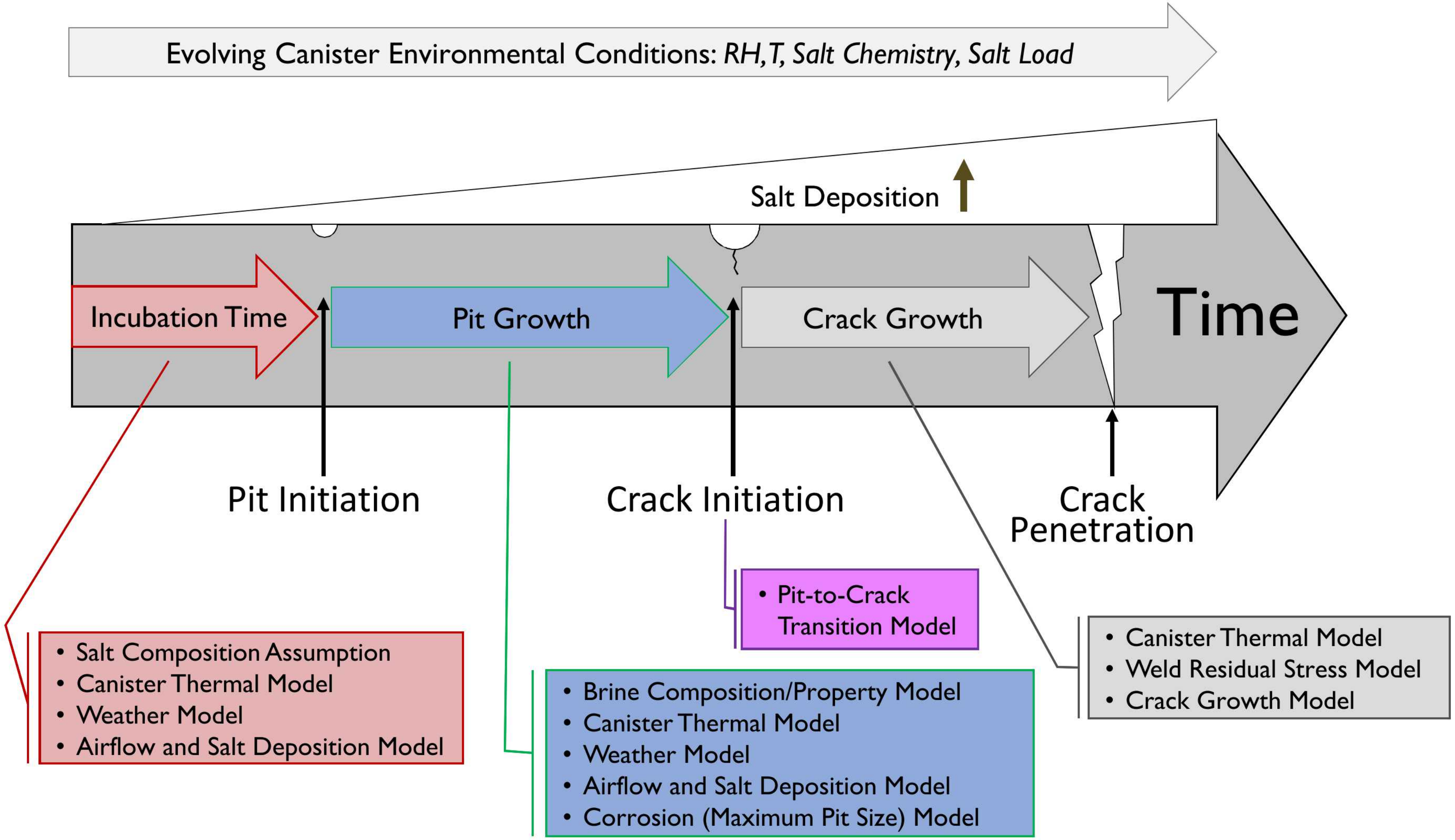
- Models and framework contains numerous assumptions and oversimplifications based on lack of data or mechanistic basis
- Sub-models have not been adequately validated

NEEDS

- Data for improved sub-model development and validation
  - *Data on salt compositions/deposition rates at ISFSI sites*
  - *Statistical pitting and SCC data for canister-relevant conditions*
- Improved scientific understanding of underlying mechanisms governing brine evolution, corrosion (pitting/SCC)

INTEGRATED MECHANISTIC/PROBABILISTIC MODEL FOR CANISTER SCC

CURRENT STATUS

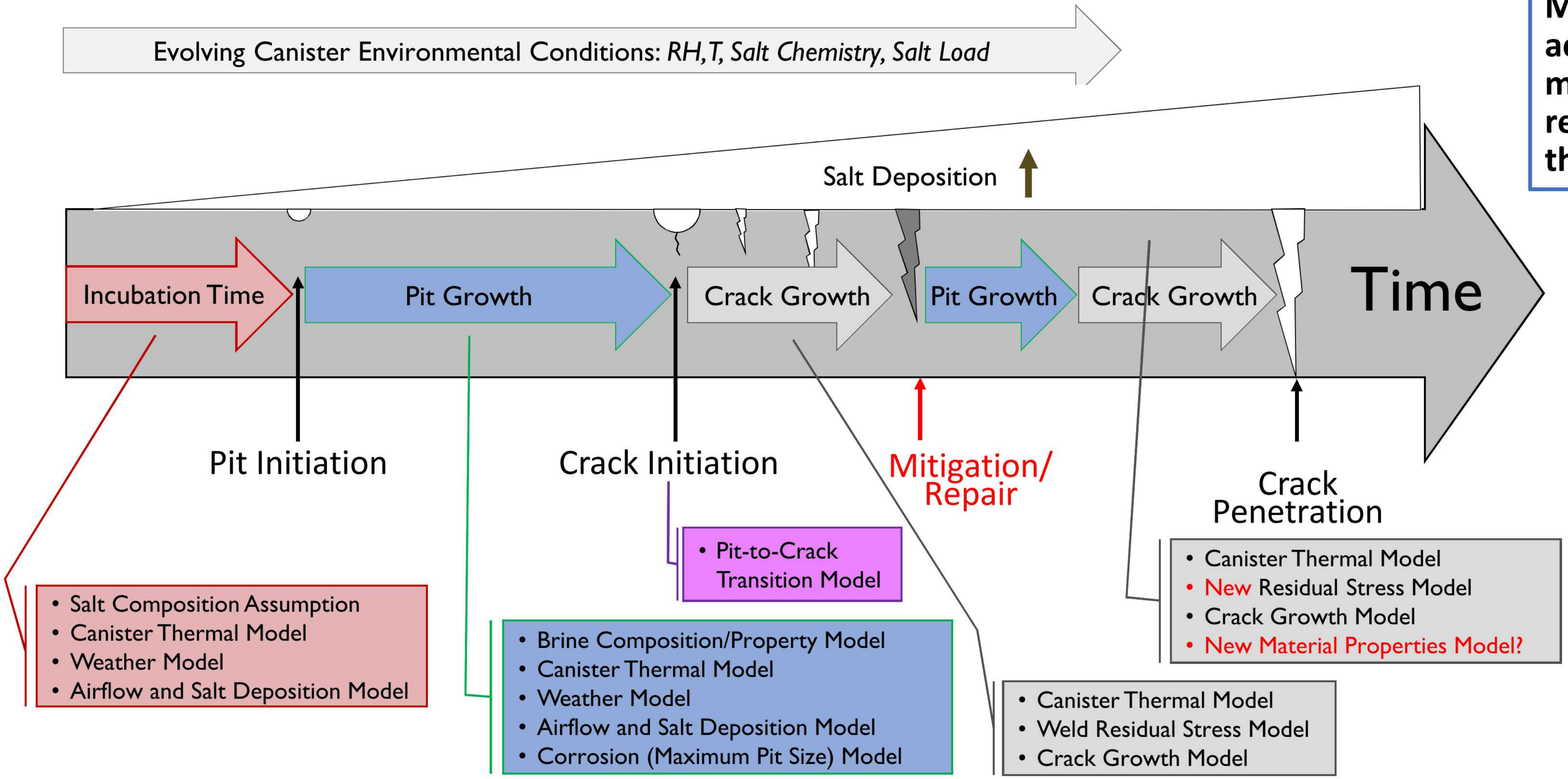


Current status: Several updates/modifications needed:

- Salt deposition model appears invalid—use PNNL model data to evaluate
- Repassivation potential (E_{rp}) model invalid—replace with model based on experimental data
- Update crack growth model with new data; make consistent with ASME code case.
- Reformulate pit-to-crack transition model to account for pit shape/crack initiation dependence on brine composition.

INTEGRATED MECHANISTIC/PROBABILISTIC MODEL FOR CANISTER SCC

UPDATING THE MODEL FOR MITIGATION AND REPAIR



Modify model to account for mitigation and repair? Resetting the clock…

Weld Mitigation and Repair

National Labs:

- Develop and optimize friction stir welding (FSW) and cold spray processes for CISCC mitigation and repair
  - Fabricate samples for corrosion testing (PNNL)
  - Corrosion testing of samples (SNL)
  - Evaluate stress redistribution in response to welds/repairs (ORNL)

NEUP: Five projects, all started in FY18

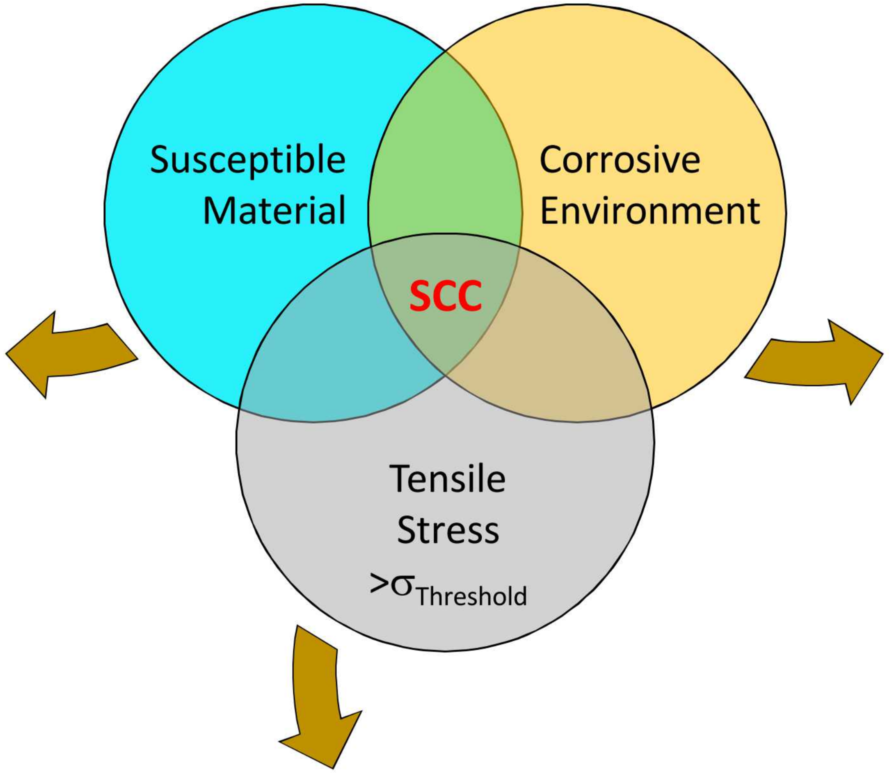
*National labs (SNL, PNNL, SRNL, INL) are collaborators and/or TPOCs on all of these.

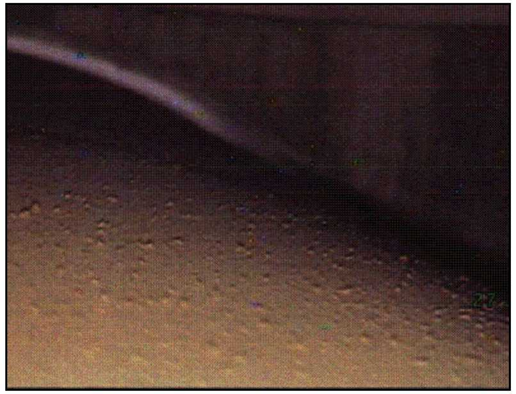
1. Purdue University (Project 18-15559): Cold Spray Repair & Mitigation of Stress Corrosion Cracks in Spent Nuclear Fuel Dry Storage Canisters
2. The Ohio State University (Project 18-15531): Repair and Mitigation of Chloride-Induced Pitting and Chloride-Induced Stress Corrosion Cracking in Used Nuclear Fuel Dry Cask Canister Materials
3. University of Idaho (Project 18-15261): Friction Stir Based Repair Welding of Dry Storage Canisters and Mitigation Strategies: Effect of Engineered Barrier Layer on Environmental Degradation
4. University of Wisconsin (Project 18-15332): Low-Force Solid-State Technologies for Mitigation of Stress Corrosion Cracking in Dry Storage Canisters
5. University of Cincinnati (Project 18-15372): Development of Repair and Mitigation Methods for Enhancing Stress Corrosion Cracking Resistance of Austenitic Stainless Steel Spent Nuclear Fuel Canisters

A FEW IMPORTANT POINTS:
CRITERIA FOR STRESS CORROSION CRACKING

All three criteria will be met at some sites, once salts deliquesce. ***Stress corrosion cracking of dry storage canisters will eventually occur at some sites.***

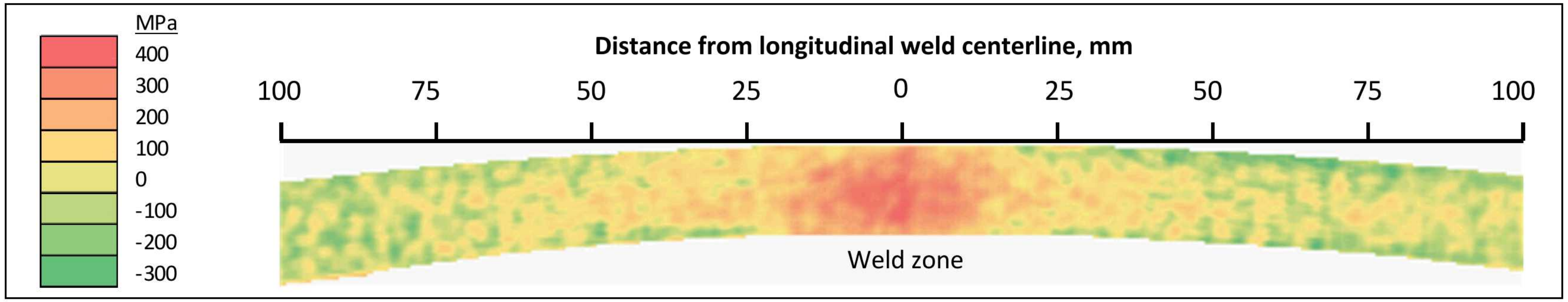
Weld zone, Ranor 304 SS plate





Dust on storage canister surface at Calvert Cliffs (EPRI 2014)

Residual stresses measured by contour method, longitudinal weld heat-affected zone



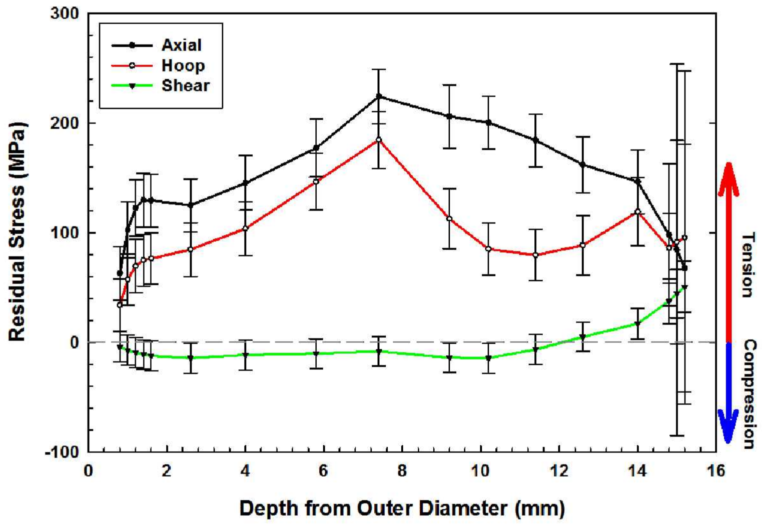
A FEW IMPORTANT POINTS:
CONDITIONS ARE NOT AS BENIGN AS SOME SUGGEST

Photos from EPRI/Industry Calvert Cliffs Canister Inspection (EPRI 2014, Report 1025209)

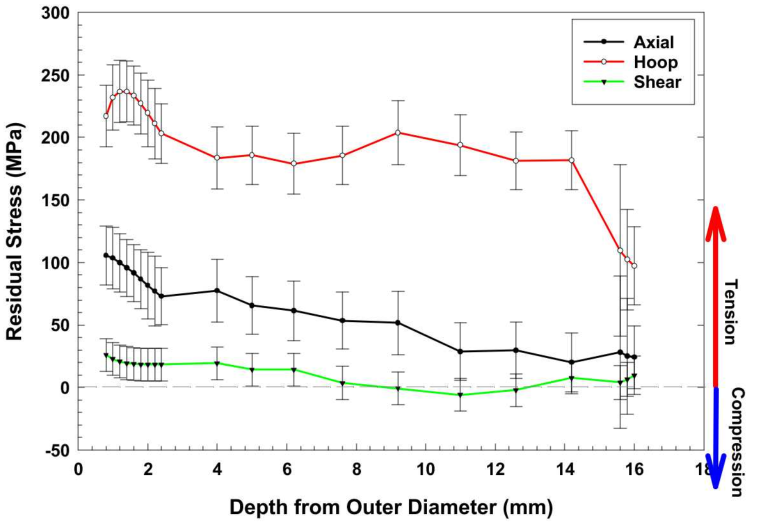
A FEW IMPORTANT POINTS:
WHAT DO SCC CRACKS LOOK LIKE?

This is reality: High tensile stresses both parallel and perpendicular to the weld.

Residual stresses measured by deep hole drilling method, longitudinal weld heat-affected zone



Residual stresses measured by deep hole drilling method, axial weld heat-affected zone



Or, do cracks look like this?

One of the goals of the SNL big plate test was to evaluate this.

A few important points:
Can we really adequately detect SCC cracks?

Can we really adequately detect SCC cracks?

- If we detect a crack on a canister, how do we conclusively show that no other cracks are present?
- If we cannot rule out additional cracks, what form does the repair have to take?

If cracks are "spiderwebs", how does that impact repair and mitigation choices?

- Repairing an area, as opposed to a linear feature
- Repairing structurally, instead of simply sealing the crack