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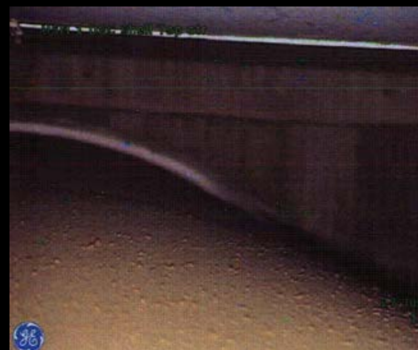
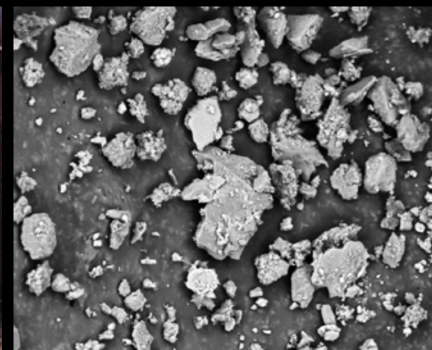
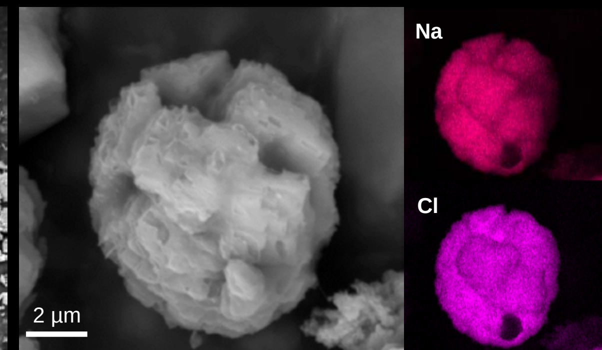

Fuel Integrity during Long Term Interim Storage: Evaluating SCC of SNF Storage Canisters

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Sandia National Laboratories

Overview

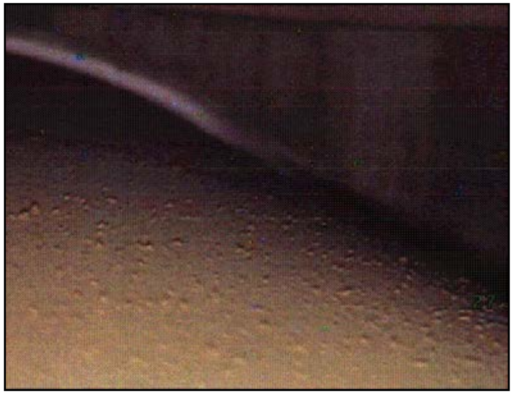
- Background: Recognition of canister stress corrosion cracking (SCC) as the primary concern during long-term interim storage
- Criteria required for SCC to occur
  - Corrosive Environment
  - Tensile stress
  - Susceptible material
- Modeling SCC
  - Environment
  - Tensile stress
  - SCC crack growth model and parameterization
  - Model results
- Evaluating SCC for in-service storage canisters—robotics and sensors

Performance of Long-Term Interim Storage

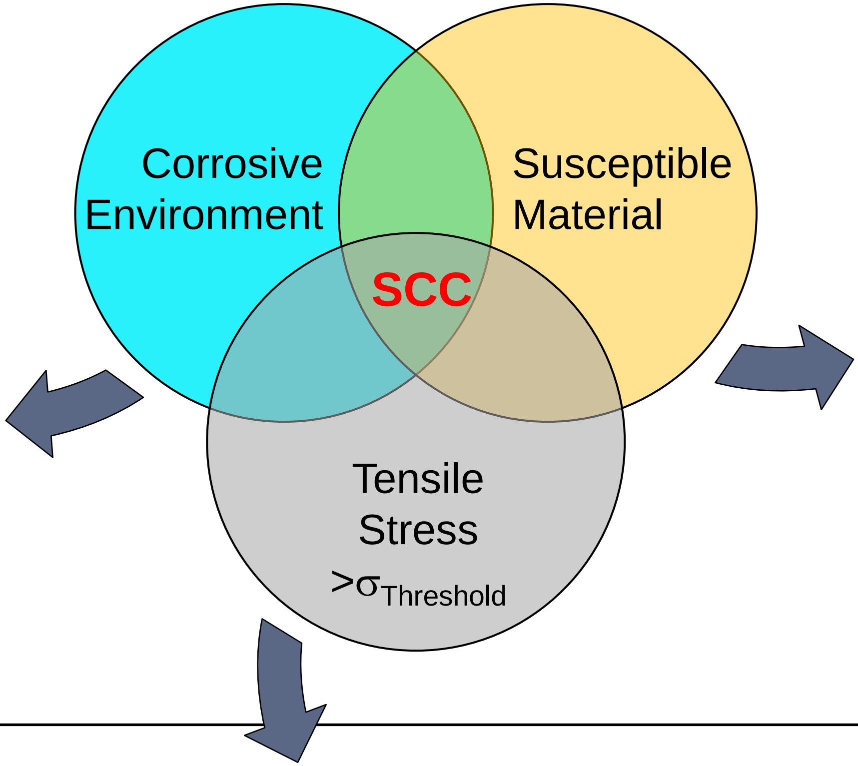
- With the termination of the Yucca Mountain Project, the United States currently has no permanent disposal pathway for SNF. Dry storage casks, originally certified for 20-40 years, may be required to perform their function for decades beyond their original design criteria.
- Gap analyses conclude that SCC of dry storage canisters is one of the most important risks to the performance of long-term interim storage:
  - Nuclear Waste Technical Review Board (NWTRB 2010)
  - Electric Power Research Institute (EPRI 2011)
  - DOE Used Fuel Disposition Program (Hanson et al. 2012)
  - Nuclear Regulatory Commission (NRC 2012)
- Canister penetration by SCC could result in:
  - Required repackaging prior to transport
  - Air/water ingress and fuel degradation, increasing risk during repackaging for disposal
- Work begins to assess the occurrence of canister SCC and the potential for canister penetration during the interim storage period.

Criteria for Stress Corrosion Cracking

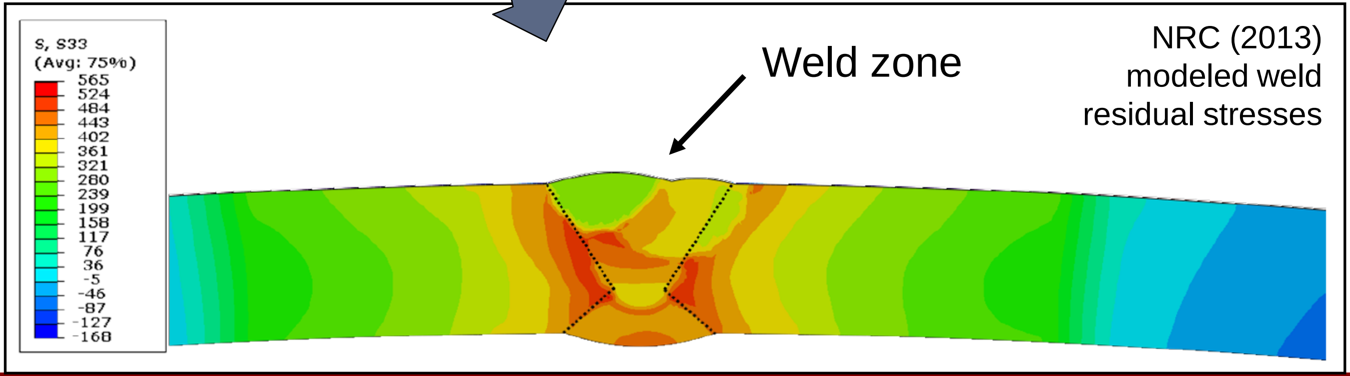
To evaluate the potential for occurrence of SCC, each must be considered



Dust on canister surface at Calvert Cliffs (EPRI 2014)



Weld zone, Ranor 304 SS plate

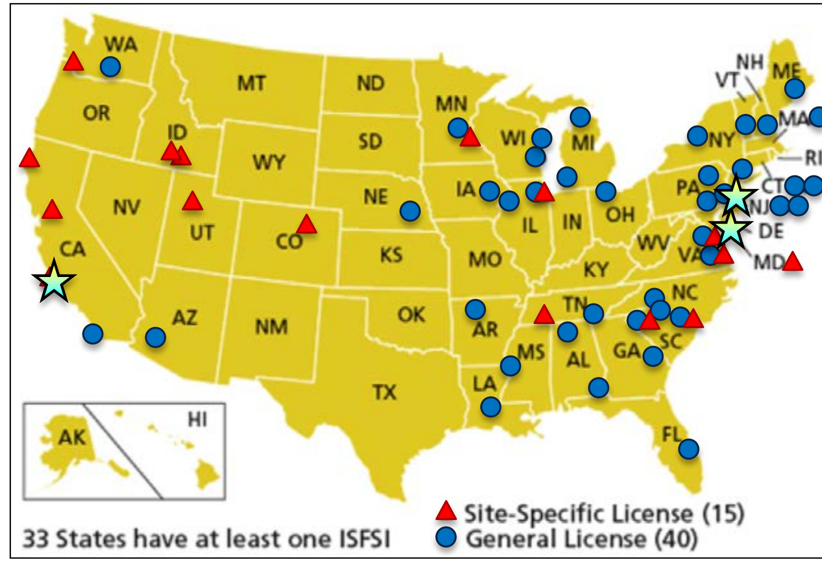


Corrosive Environment

- **Canisters are stored in passively ventilated overpacks, and accumulate dust on the surface. Salts in the dust can absorb water (deliquesce), to form brines which may be corrosive.**
- **Many Independent Spent Fuel Storage Installations are at coastal sites. Possible deposition of chloride-rich sea-salts, and formation of corrosive brines.**

Calvert Cliffs NUHOMS system

Diablo Canyon HI-STORM system



- **EPRI sampling program: Assess the composition of dust on the surface of in-service stainless steel SNF storage canisters, with emphasis on the deliquescent salts.**
- **ISFSI locations sampled:**
  - **Calvert Cliffs, MD: Transnuclear NUHOMS system, horizontal storage canister (June, 2012)**
  - **Hope Creek, NJ: Holtec HI-STORM system, vertical canister (Dec, 2013)**
  - **Diablo Canyon, CA: Holtec HI-STORM system (Jan, 2014)**
- **Samples delivered to Sandia National Laboratories for analysis**

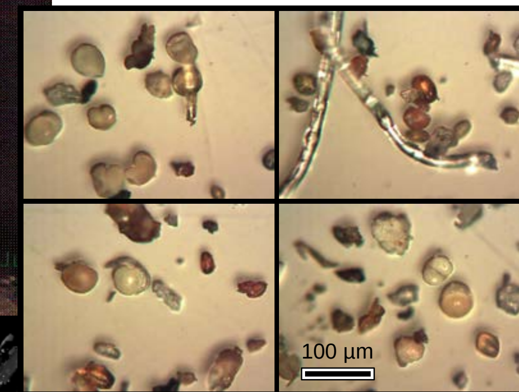
Results: Calvert Cliffs

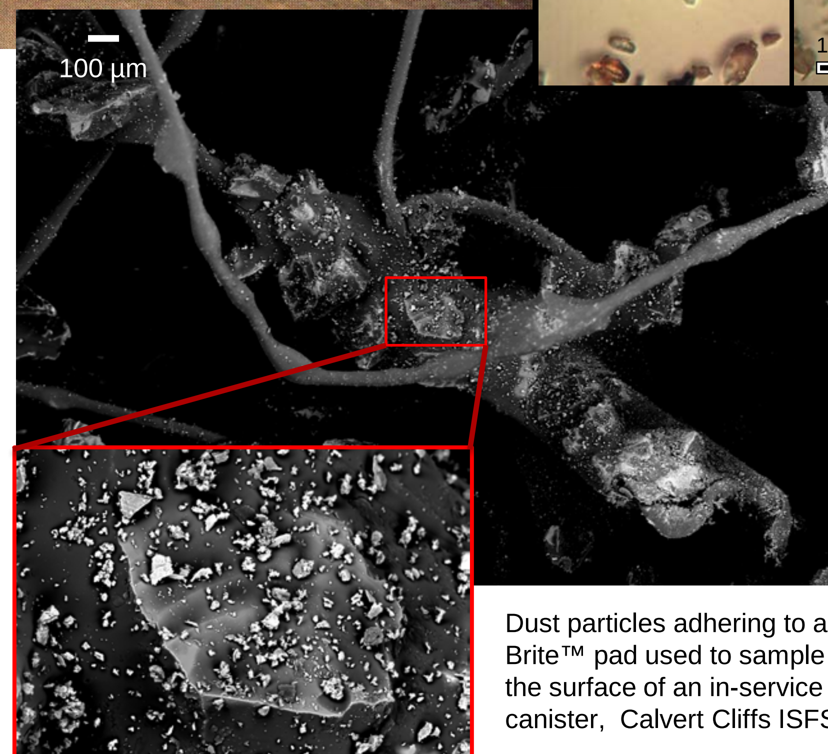
- The canister upper surface was more heavily coated with dust and salts due to gravitational settling. Samples from upper surface contained abundant pollen.
- The soluble salts are Ca- and SO_4-rich. Gypsum is the dominant salt phase present.
- Chlorides comprise a small fraction of the total salt load, and are dominantly NaCl.

Despite the proximity to the coast, the dusts sampled from in-service containers at Calvert Cliffs do not appear to have a large sea salt component. Chesapeake Bay is brackish, and may be sheltered sufficiently to limit wave-generated sea-salt aerosols.

Dust on the storage canister surface, Calvert Cliffs ISFSI.

Pollen grains in dust on the upper surface of the canister.

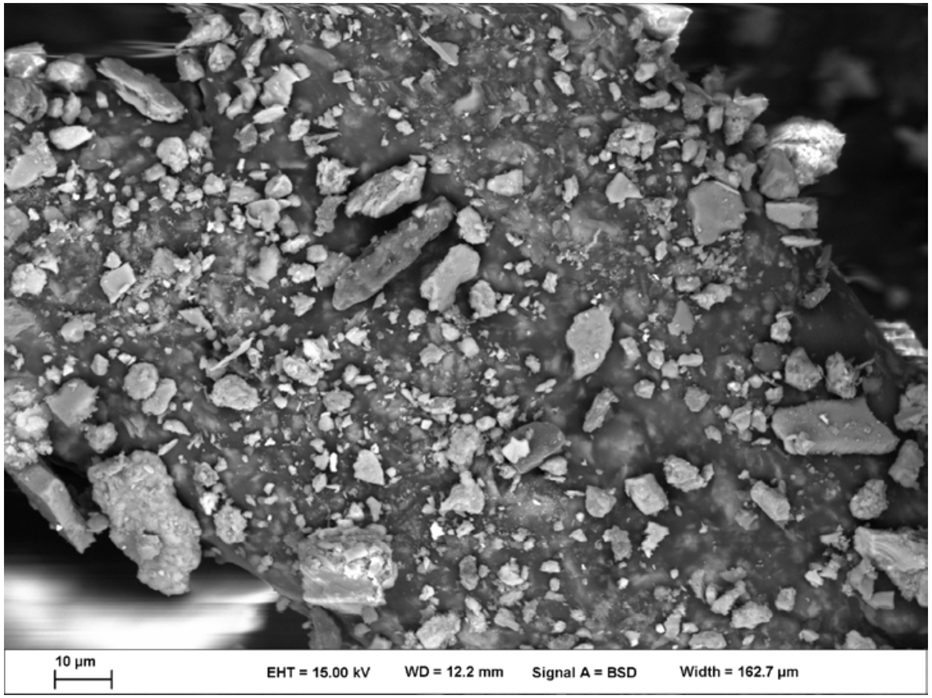


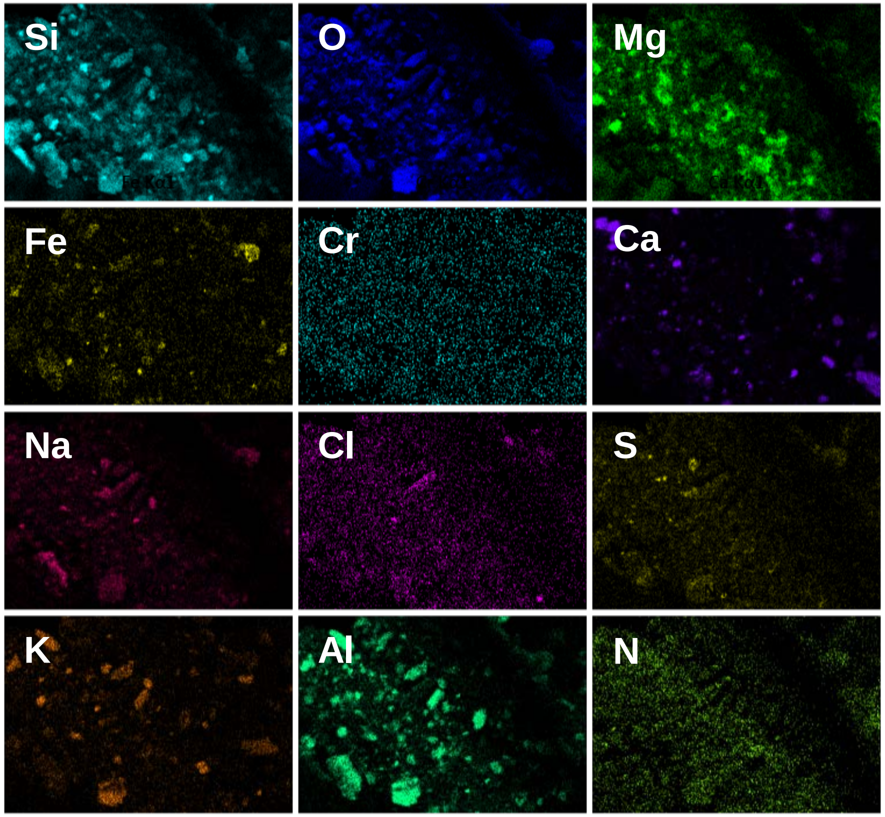


Dust particles adhering to a Scotch-Brite™ pad used to sample dust on the surface of an in-service storage canister, Calvert Cliffs ISFSI.

Results: Hope Creek

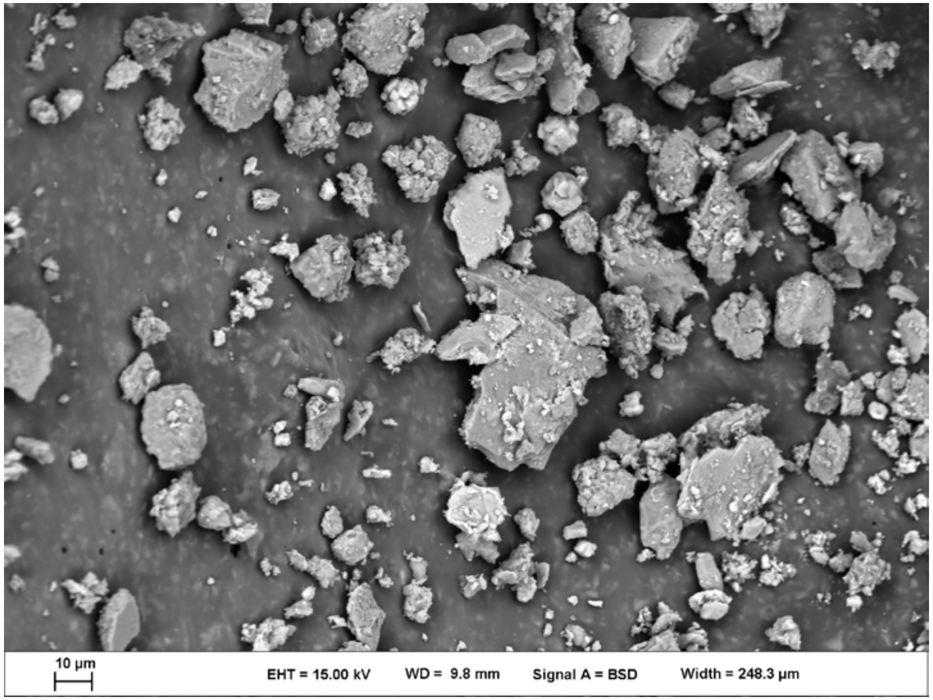
- Flat canister top much more heavily coated than vertical sides.
- Dust dominated by insoluble minerals (quartz, clays, aluminosilicates). Soluble salts minor; dominantly gypsum, carbonates. Sparse chlorides, mostly isolated grains of NaCl.
- **Despite the proximity to the coast, the dusts sampled from in-service containers at Hope Creek do not have a large sea salt component. The Delaware River is brackish, and may be sheltered sufficiently to limit wave-generated sea-salt aerosols.**

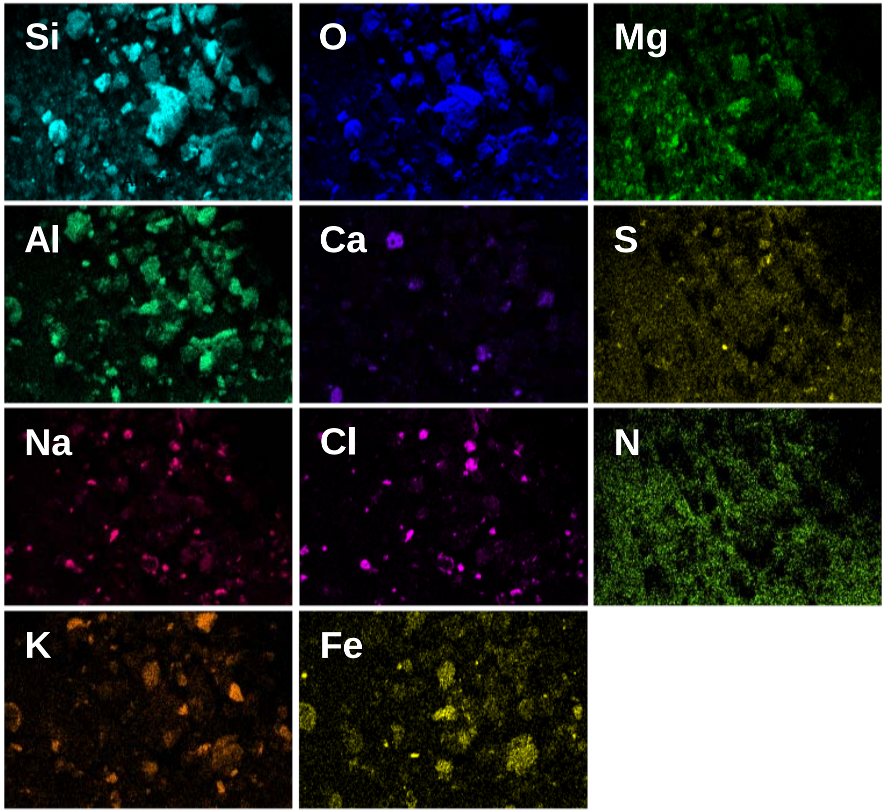




Results: Diablo Canyon

- Canister sides lightly coated, tops heavily coated.
- Dust dominated by insoluble minerals (quartz, clays, aluminosilicates), but chloride-rich soluble salts are abundant, present as sea-salt aggregates.
- **Heavy wave action at the Diablo Canyon site generates abundant sea-salt aerosols. Although 400 feet above sea level, Diablo Canyon canisters have a significant amount of sea-salts on the canister surfaces.**





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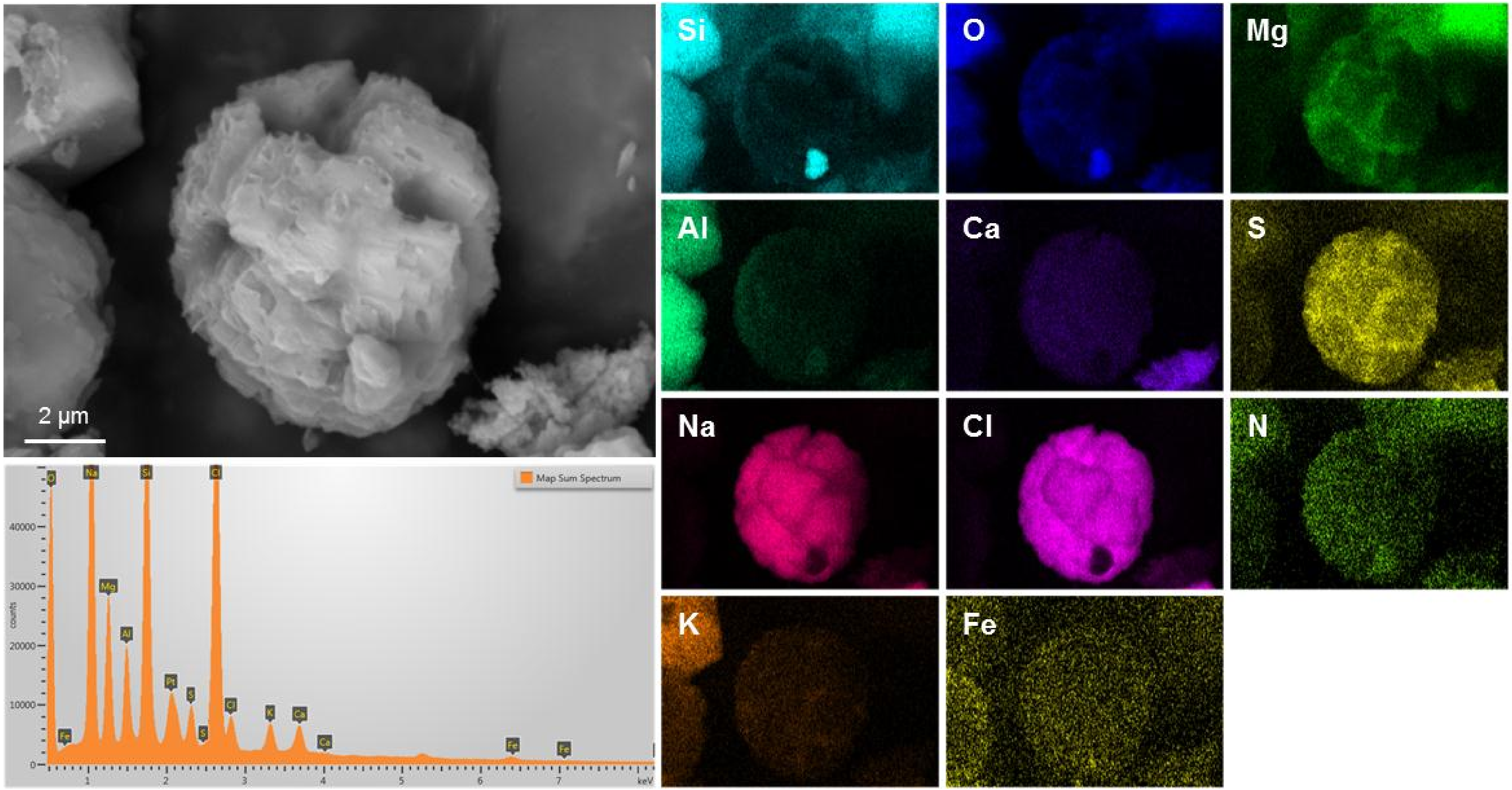
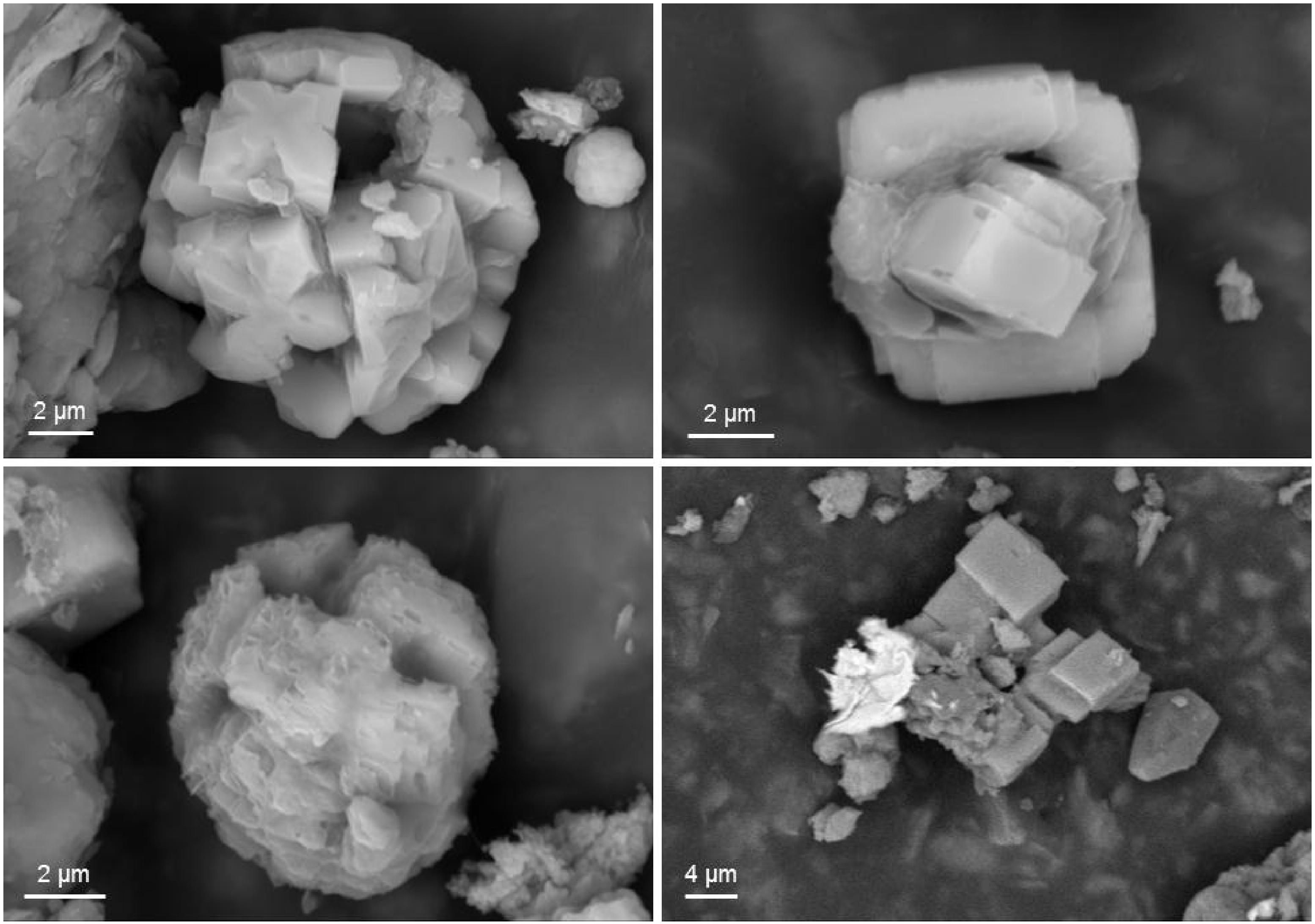


Diablo Canyon Sea-salt Aerosols



Results of Dust Sampling from In-Service Canisters

- Dusts on Calvert Cliffs and Hope Creek canisters are largely insoluble minerals; salt loads are limited and are largely Ca-sulfate and nitrate-rich. NaCl was observed as rare isolated grains.
- Dusts on Diablo Canyon canisters are sea-salt rich. Sea-salts are present are present in both the fine (<2.5µm) and coarse (>2.5µm fraction). Larger grains are spherical aggregates or euhedral crystals of halite, with associated Mg-sulfate, and lesser amounts of Ca and K.

Field data indicate that in at least some near-marine ISFSI locations, chloride-rich sea-salt aerosols comprise a large fraction of dusts deposited on canister surfaces. Once deliquescence occurs, SCC may be possible.

Tensile Stresses and Material Susceptibility

Canister mockup –weld characterization

Sandia was funded by the DOE to purchase a cylindrical canister mockup, made using identical procedures and materials as in-service canisters. Weld residual stresses are currently being measured on this canister, after which, the mockup will be sectioned, and material properties will be measured in the weld and heat affected zone regions.

Mockup:

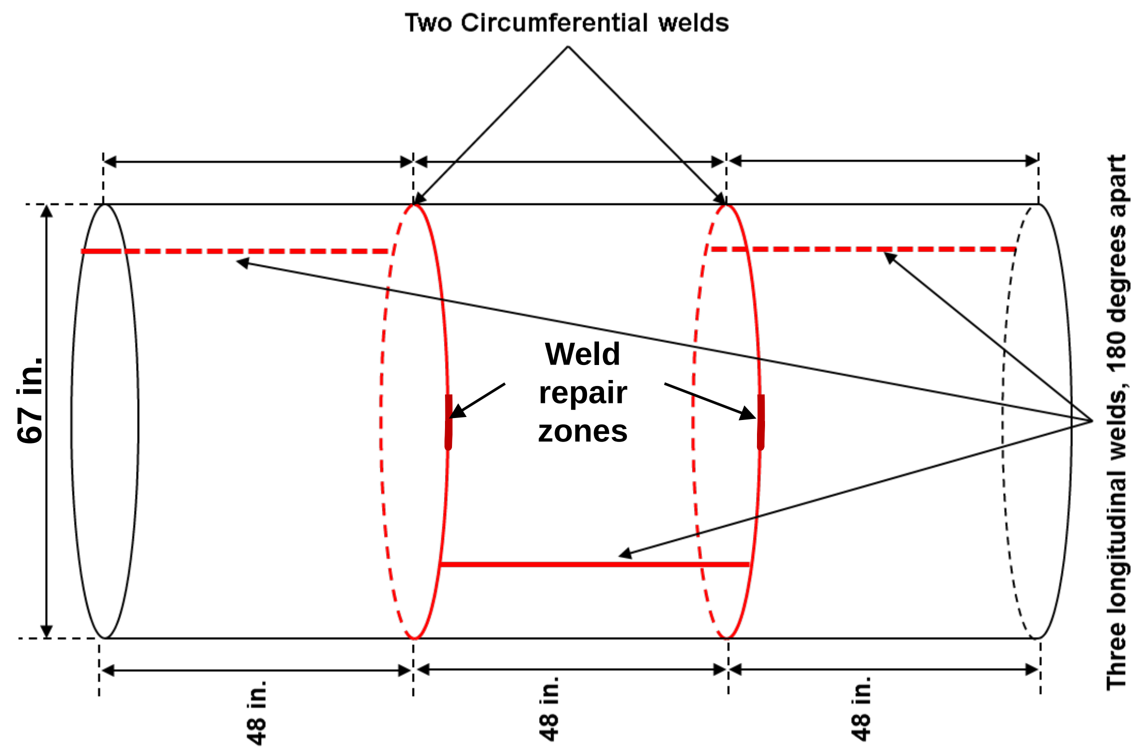
- Made by Ranor
- NUHOMS type, 5/8” wall thickness

Welds:

- 3 Longitudinal welds
- 2 Circumferential welds
- 2 weld repair zones

Characterize:

- Weld residual stresses
- Weld, HAZ textural changes
- HAZ sensitization
- Cold-working



Residual Stress Measurements

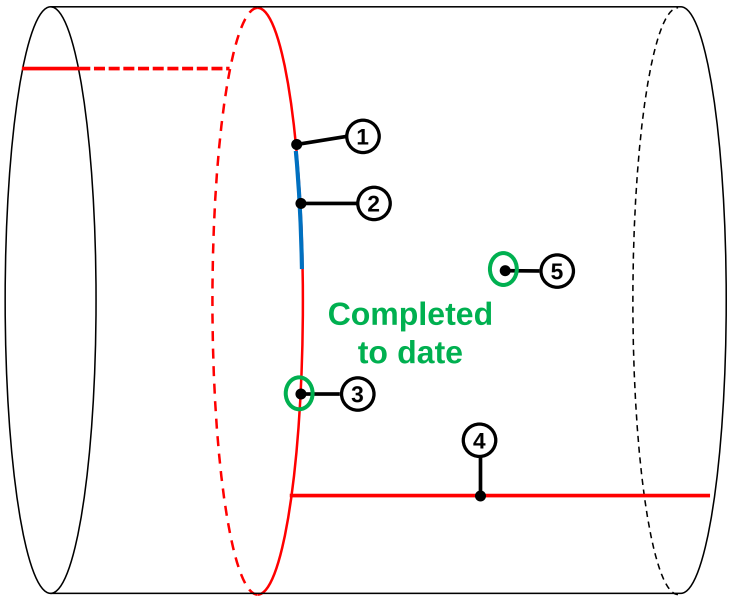
Key areas are being evaluated:

1,2: Weld Repair

3: Circumferential Weld (Centerline and HAZ)

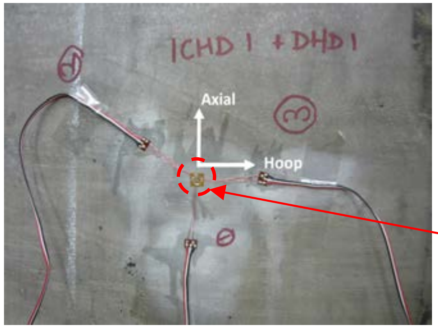
4: Longitudinal Weld (Centerline and HAZ)

5: Base metal (far from welds)

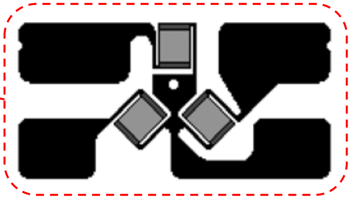


iCHD and iDHD provide a one-dimensional map of the initial stress state without cutting up the structure, capturing the effect of the cylindrical constraint

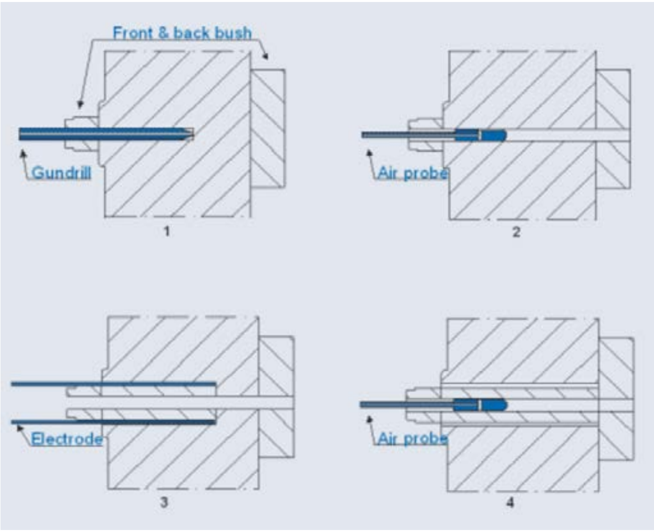
Near-Surface stresses assessed via incremental center-hole drilling



Incremental center-hole drilling Strain gauges on the metal surface measure relaxation as a central hole is incrementally drilled into the sample.



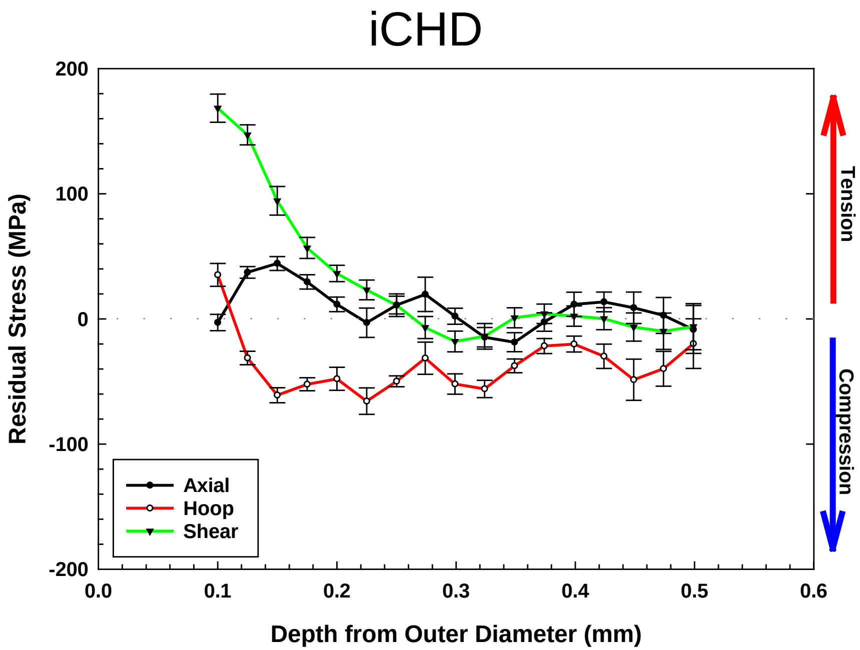
Through-wall stresses measured by incremental deep-hole drilling

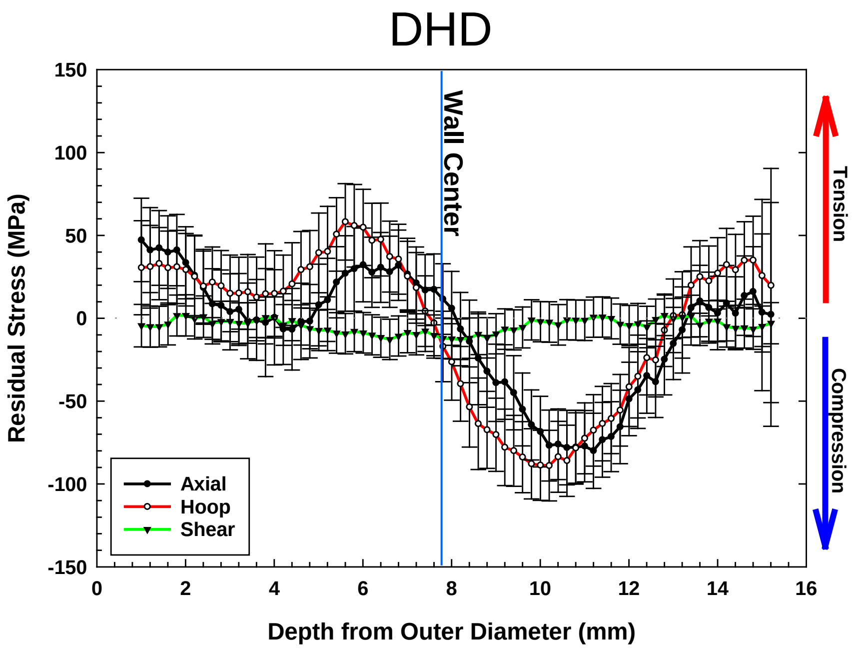


Incremental deep-hole drilling

- Hole precisely drilled through region to be characterized
- Air probe used to measure the inner diameter of the hole as a function of position
- EDM used to cut core around the hole, relaxing the constraint placed by the surrounding material
- Air probe used to measure the resulting distortion of the hole inner diameter
- Stress state calculated from displacements
- Complicated when stresses are high (requires modified technique)

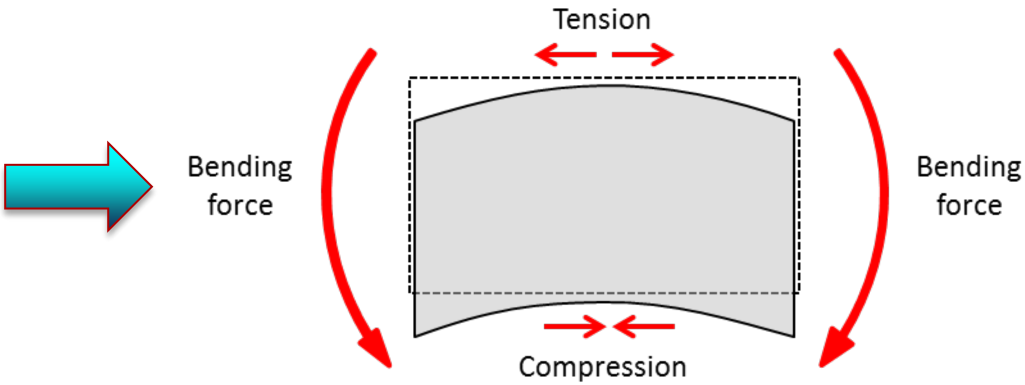
Residual Stresses in Base Metal, far from Welds





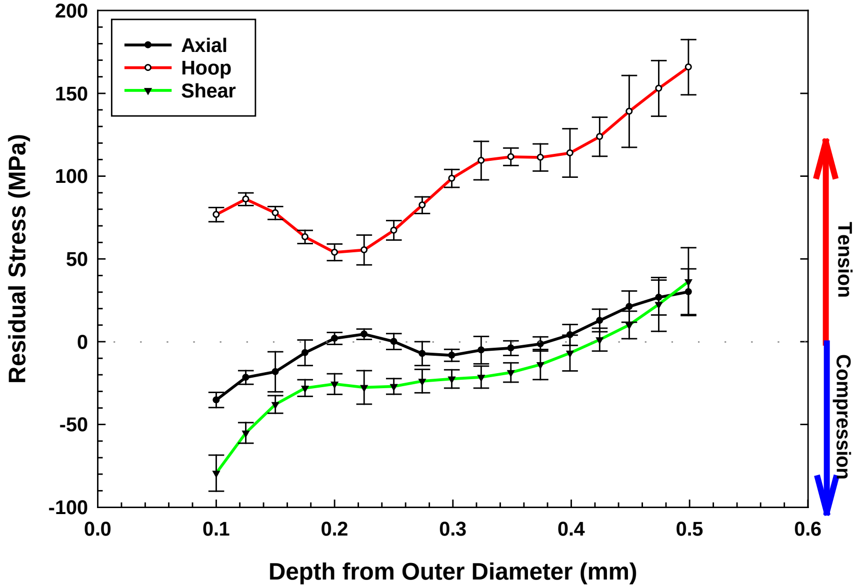
Overall stress state is consistent with the forming process

- Stresses on OD tensile
- Stresses in ID compressive

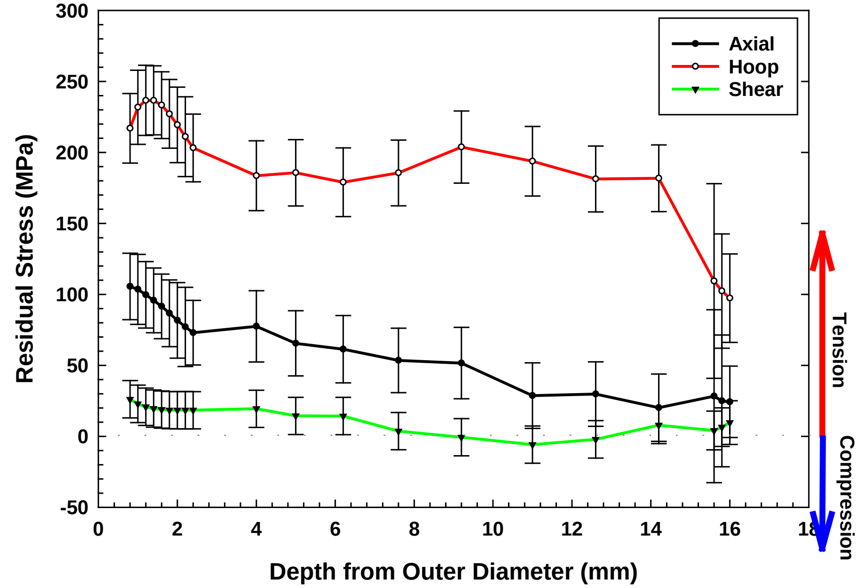


Residual Stresses, Circumferential Weld HAZ

iCHD



DHD/iDHD



iCHD results

- Hoop stress tensile at surface, increasing with depth
- Axial stresses low, slightly compressive, becoming weakly tensile with depth
- iCHD data likely to exhibit positional variability; any single reading is qualitative.

DHD/iDHD results

- DHD near surface, iDHD at greater depths
- Hoop stress strongly tensile through-wall
- Axial stress lower in magnitude, but tensile through-thickness.

- **Similar results (high through-wall tensile stresses) were also obtained for a circumferential weld *centerline* location.**
- **Additional characterization activities, including contour mapping (2D stress mapping) on sections cut from the mockup, are ongoing.**

Summary: Can through-penetrating SCC potentially occur on SNF interim storage canisters?

- **Analysis of dusts collected from in-service canisters at near-marine sites shows that chloride-rich sea-salts can comprise a significant fraction of deposited aerosol particles. (Corrosive environment ✓)**
- **Evaluation of canister weld residual stresses indicates that through-wall tensile stresses are present in welds and HAZ. To date, only data for circumferential welds are available. (Tensile stresses ✓)**
- **Canisters are 304 SS or in some cases 316 SS, materials known to be susceptible to SCC in near-marine environments. Factors affecting susceptibility (degree of sensitization, cold working, surface finish) will be evaluated on the Sandia mockup. (Susceptible material ✓)**

Evaluations to date indicate that SCC is likely to occur, at least, at some sites.

But what are penetration rates, relative to estimated interim storage times? How does the risk of penetration vary with atmospheric conditions, storage system design, thermal loads, and other parameters? **SNL and others are attempting to evaluate this with predictive SCC models.**

Probabilistic Model for the Performance of Long-Term Interim Storage

- DOE UFD effort to quantify uncertainty in the performance of Long-Term SNF Interim Storage (led by R. Dingreville). One major part: Estimation of SCC penetration times.
- Major goal of SCC model—identify most important parameters for evaluating canister corrosion performance (penetration times). Used to prioritize research needs; ultimately, to inform inspection intervals at different sites.
- Current model is simplified: the functional form has been developed and is being used to identify data needs for the model, and to allow testing of parameter sensitivities.
- Model development is an ongoing process.

Environment

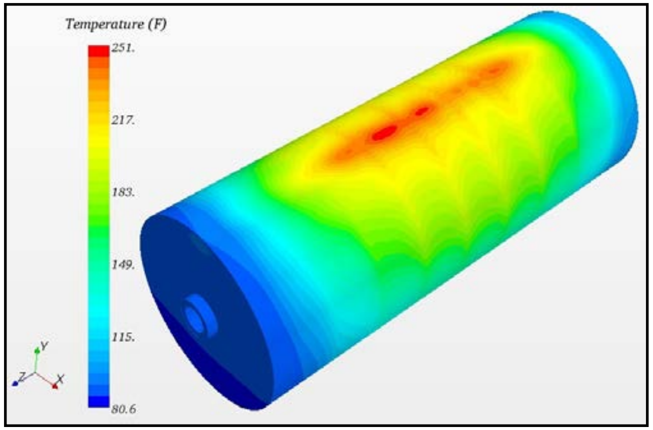
- **Aqueous conditions—a deliquescent brine must be present.**
  - **Deliquescence is *f* (T, AH, salt composition):**
    - Temperature on the waste package surface at any given location, as a function of time and heat load. PNNL CFD thermal models of horizontal canister in overpack
    - Ambient environment: absolute humidity (AH) and temperature as a function of time. NOAA site data
    - Composition of salts (controls deliquescence RH) *Assume sea-salt assemblage*
- **Brine must be corrosive (chloride-rich).**
  Assume sea salts.
- **Threshold chloride concentration for corrosion?** *Assume None.*

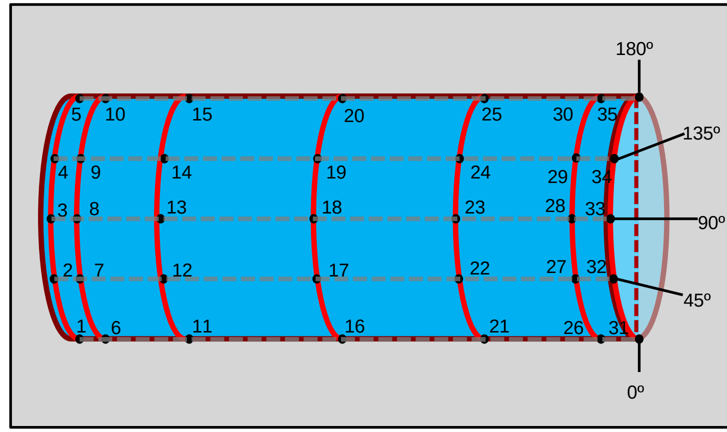
  Experimentally, corrosion has been observed at loads as low as 5-20 mg m^{-2} (Tokiwai et al. 1985; Taylor 1994; Fairweather et al. 2008). The UK Nuclear Decommissioning Authority has suggested operational limits of 1 mg m^{-2}, for temperatures of 30º–50ºC.

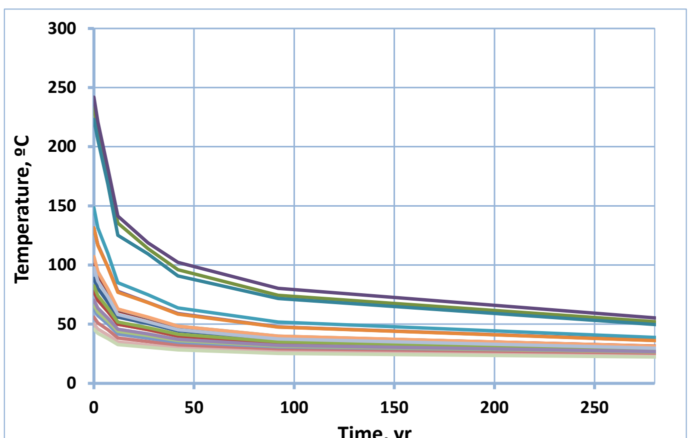
Modeling the Environment: Waste Package Surface Temperatures

<u>Changes in location-specific surface temperature is important to determine:</u>

- Timing of deliquescence and potential corrosion initiation
- Temperature-dependent corrosion parameters (e.g. crack growth rate)







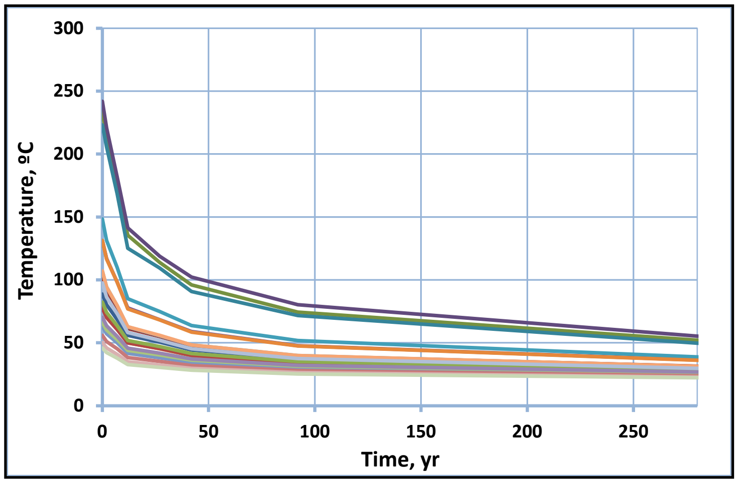
<u>PNNL thermal models</u>

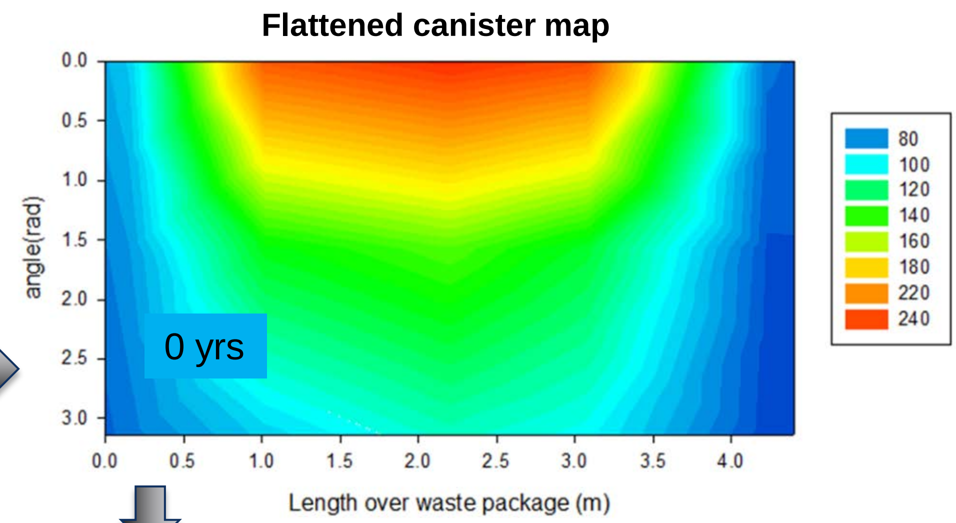
- Provide surface temperatures through time at 35 points on the canister surface.
- 8 decay heat loads (24–2 kW, corresponding to 0-292 yrs out of the reactor).
- Vertical and horizontal canisters

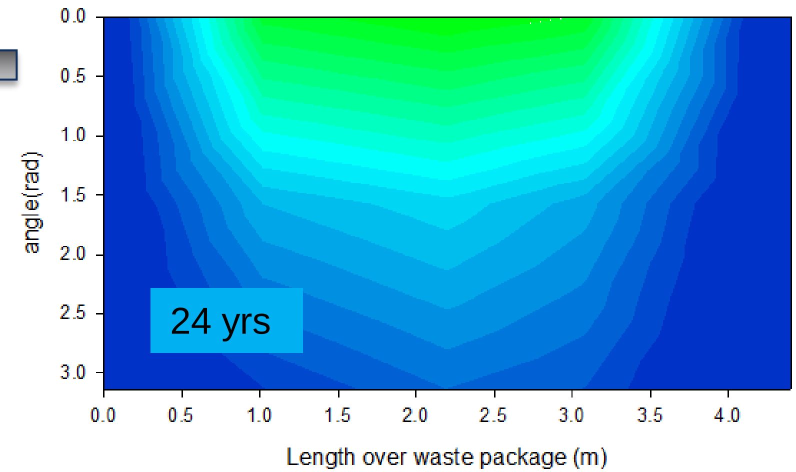
- For the SCC model, interpolate in time and space, to get the temperature at any point on the canister surface, at any point in time.
- Implement ambient T (weather data) as a delta on predicted surface T
- Variability in time-out-of-reactor captured by shifting the starting conditions.

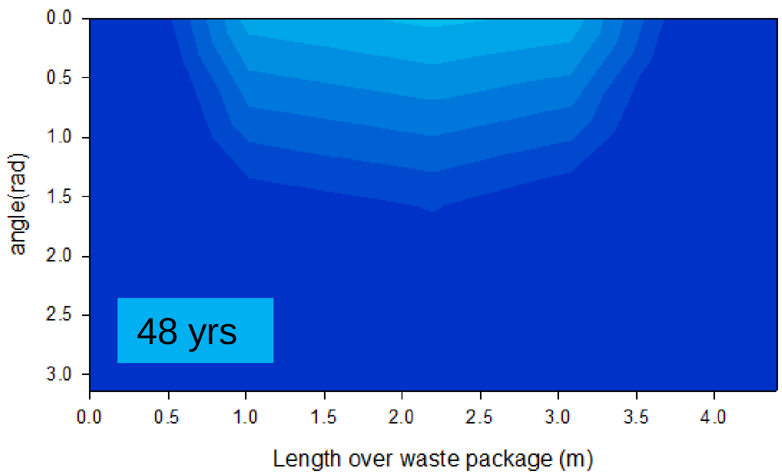
Modeling the Environment: Waste Package Surface Temperatures

Results of interpolation

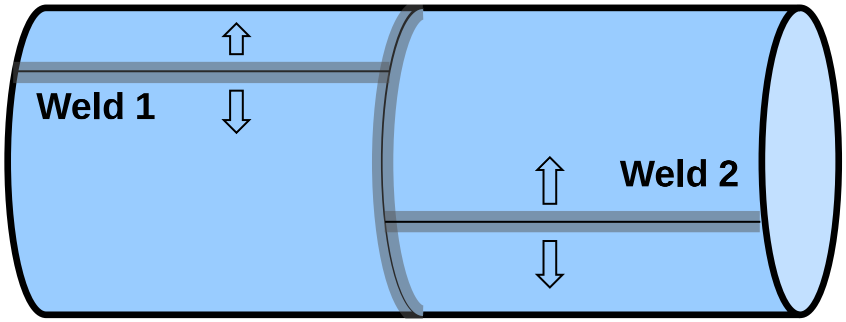








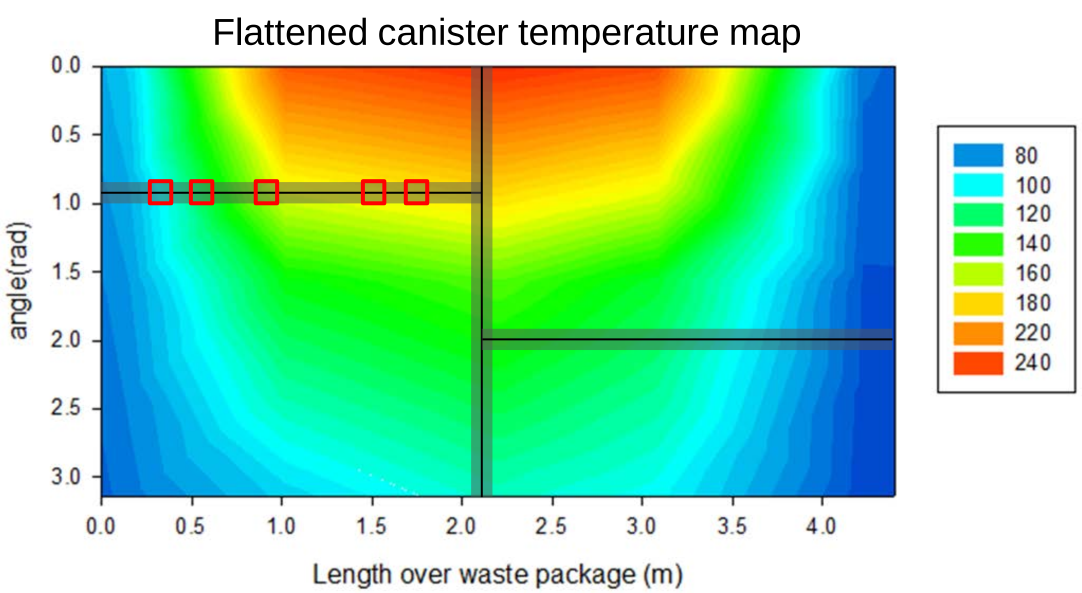
Weld locations : Implementation in the SNL probabilistic model



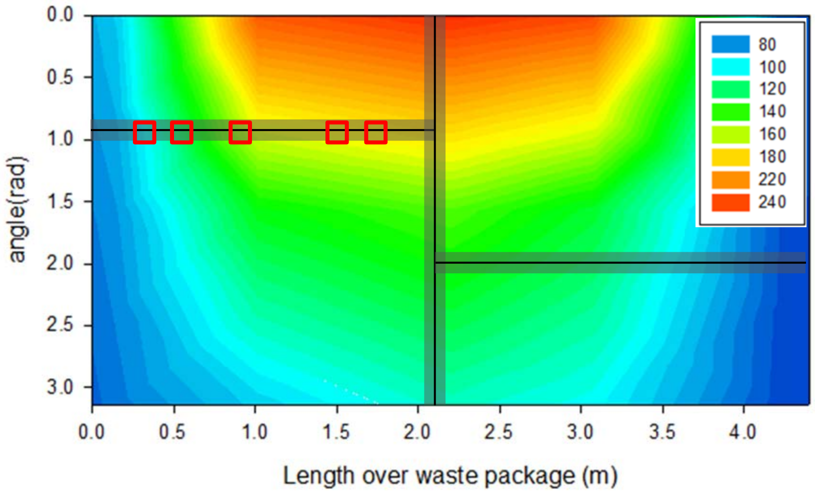
Welds: Locations uncertain, sampled once per realization

- Original model: 2 longitudinal welds
- Circumferential and base-plate welds have been added in newest version.

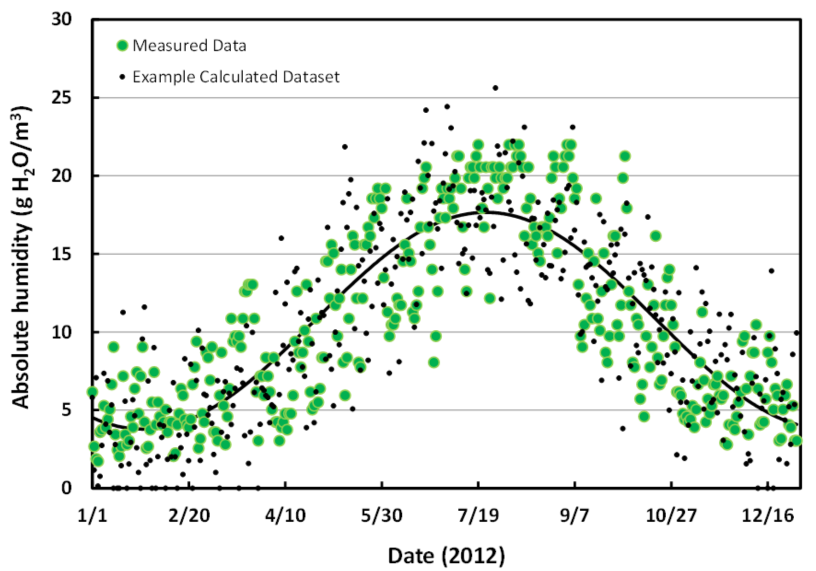
Divide welds into 10 cm segments and calculate a temperature history for each segment.



Modeling the Environment: RH at the Weld Locations



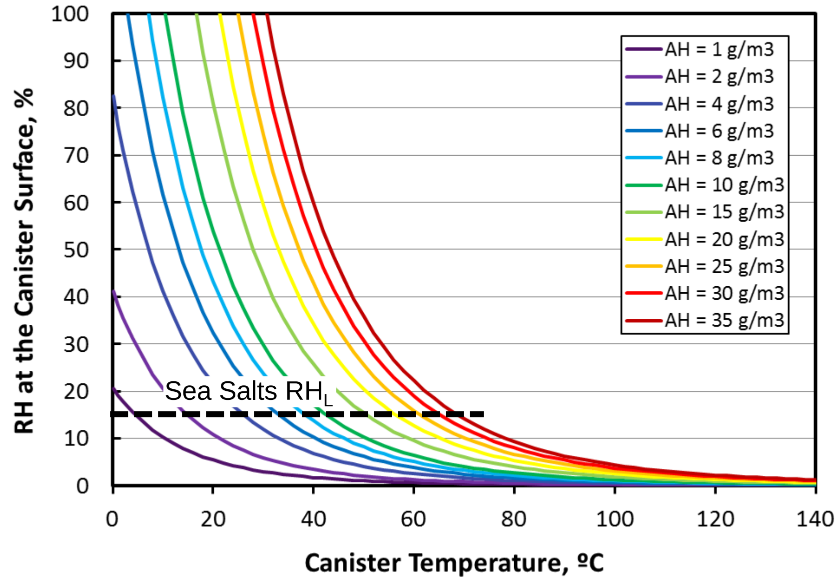
Surface temperature estimates



Site-specific National Weather Service data

Canister surface RH = *f*(Ambient AH; canister surface T)

Use weather data and predicted canister surface temperature to predict RH at any location and time.



Timing of corrosion initiation—point in time at which RH_L is first reached.

Summing time when $RH>RH_L$ provides "time of wetness"

12-hour averages in T and AH.

Weather data representing 64 ISFSI sites

Susceptible Material

- 304/316 stainless steels are susceptible to SCC
- However, several factors affect susceptibility:
  - Composition: 304 is more susceptible than 316
  - Sensitization—in the HAZ near the weld, segregation of Cr and C as Cr-rich carbides along the grain boundaries results in Cr-depleted zones along grain boundaries, creates a region more susceptible to corrosion near the weld (function of carbon content: 304L/316L less susceptible)
  - Degree of cold working
  - Surface finish
  - Presence of iron or steel contamination on the stainless steel surface

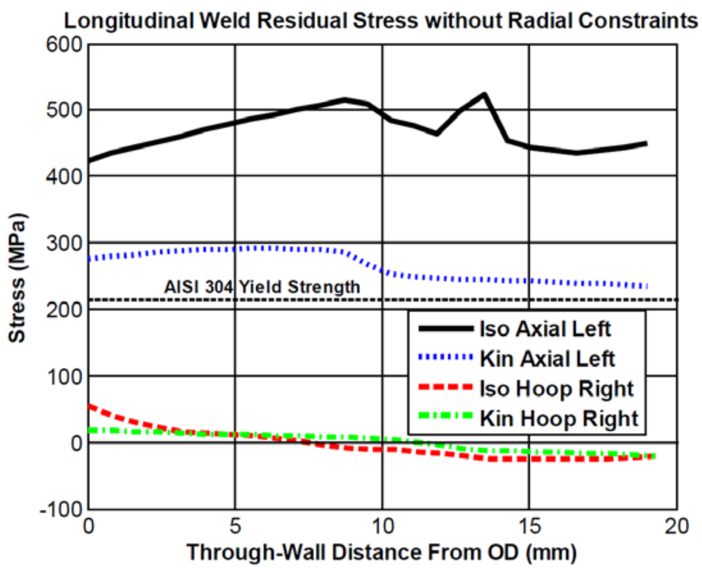
<u>Model implementation</u>: Implicitly capture variability by using corrosion data from samples that were treated in several different ways (base metal, sensitized, weld material, HAZ). Note that data are limited, and do not support separation on the basis of sample pre-treatment.

Canister mockup will provide information on some of these parameters (e.g., sensitization) for one typical canister type.

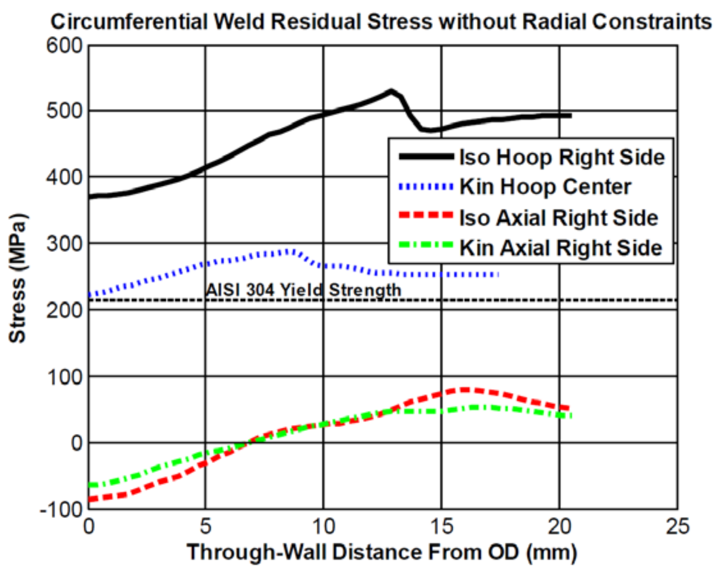
Tensile Stress

- Few measured data available on representative welds. *(SNL mockup measurements have not yet been implemented)*
- Probabilistic SCC model uses NRC (2013) WRS modeling results
- Through-wall tensile stresses in at least one direction for both longitudinal and circumferential welds.
- Tensile stresses in weld HAZs approach the yield stress for the metal, more than sufficient to support initiation and propagation of SCC.
- Implementation: Utilize NRC modeled stress profiles (parametrically vary between profiles based on kinematic and isotropic strain hardening models).

Longitudinal welds



Circumferential welds



Stress Corrosion Cracking Model

- SCC model based on approach by Turnbull et al. (2006a, b)
- Assumes SCC initiates from localized corrosion pre-cursors (corrosion pits)
- Submodels
  - Pitting initiation model
  - Pitting growth model
  - Model for pit-crack transition
  - Model for crack growth

Stress Corrosion Cracking Model

- Pitting initiation model—implemented a statistical model based on the rate of formation of stable pits. However, data were lacking to parameterize for atmospheric SCC. Original model used a simplified approach—pitting initiates as soon as aqueous conditions are predicted. Currently being modified.
- Pitting growth model—the commonly used form:

$$x_{pit} = \alpha_{pit} t^{\beta_{pit}}$$

x_{pit} = pit depth

t = time after initiation

α_{pit} = scaling factor

β_{pit} = exponent that is a function of the pit geometry and determines the shape of the growth curve with time.

- Model for pit-crack transition—function of pit depth.
  - Occurs when calculated pit growth rate (which slows with depth) is equal to the calculated crack growth rate (which increases with depth). Forced to be at 50–70 µm, based on observations. (Assumption used to back-fit α_{pit} in the pitting growth model)
  - Approximately equal to the depth at which the equivalent stress corrosion crack would have a crack-tip stress intensity factor (*K*) that exceeds the K_{th} for SCC growth.

Stress Corrosion Cracking Model

- Model for crack growth:
  - In general:

$$\frac{dx_{crack}}{dt} = \dot{x}_{crack} = \alpha_{crack}\, f(T)\, f(K)\, f(R_a)\, f([Cl^-])\, f(m_{Cl}) f(pH)\, f\left(\sigma_{ys}\right) \ldots$$

  - Implemented a version incorporating only effect of T, K:

$$\frac{dx_{crack}}{dt} = \alpha_{crack} \cdot exp\left[-\frac{Q}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right] \cdot (K - K_{th})^{\beta_{crack}}$$

dx_{crack}/dt = crack growth rate
α_{crack} = crack growth amplitude
Q = activation energy for g=crack growth
R = universal gas constant (8.314 J mol^{-1} K^{-1})
T = temperature (K) of interest
T_{ref} = reference temperature (K) at which α was derived.
K = crack tip stress intensity factor
K_{th} = threshold stress for SCC
β_{crack} = stress intensity factor exponent.

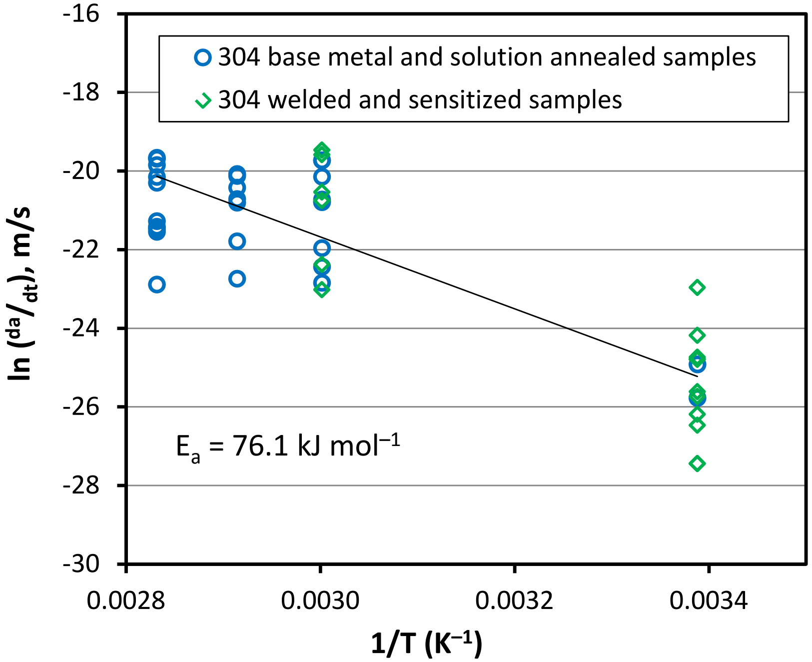
Where $K = \sigma_{applied} Y \sqrt{\pi x_{crack}}$

$\sigma_{applied}$ = tensile stress
Y = shape factor
x_{crack} = depth

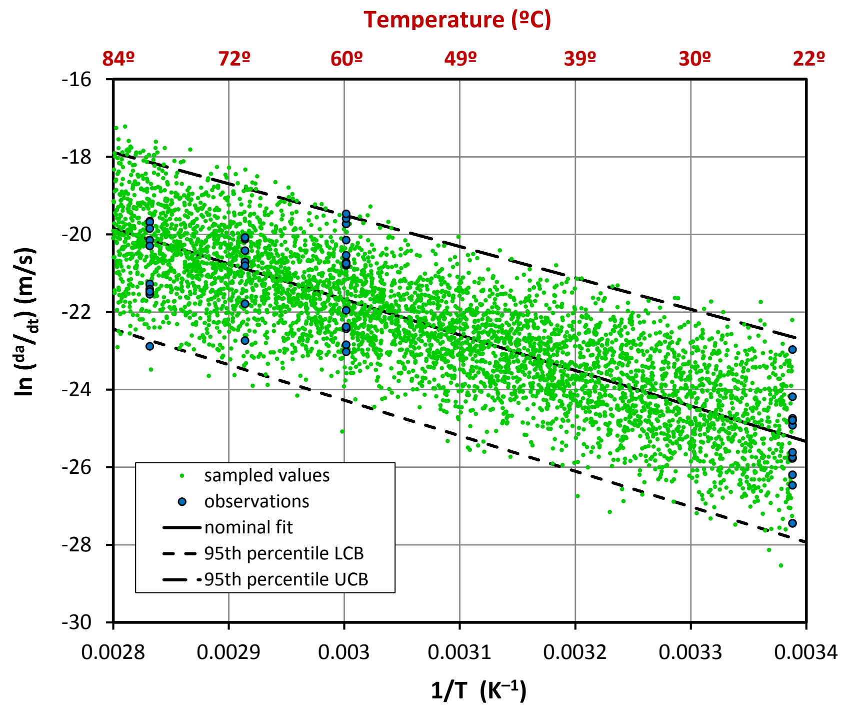
Stress Corrosion Cracking Model

Parameterization SCC propagation model was parameterized using measured SCC growth rates in literature. Data were for base metal, sensitized, weld and HAZ, and annealed samples. While individual data sets show some systematic differences as a function of sample type, variability between data sets is greater that within-set variability due to materials. Therefore, no attempt was made separate data on the basis of pre-treatment. Crack growth rate parameters sampled once per realization.

Experimental data

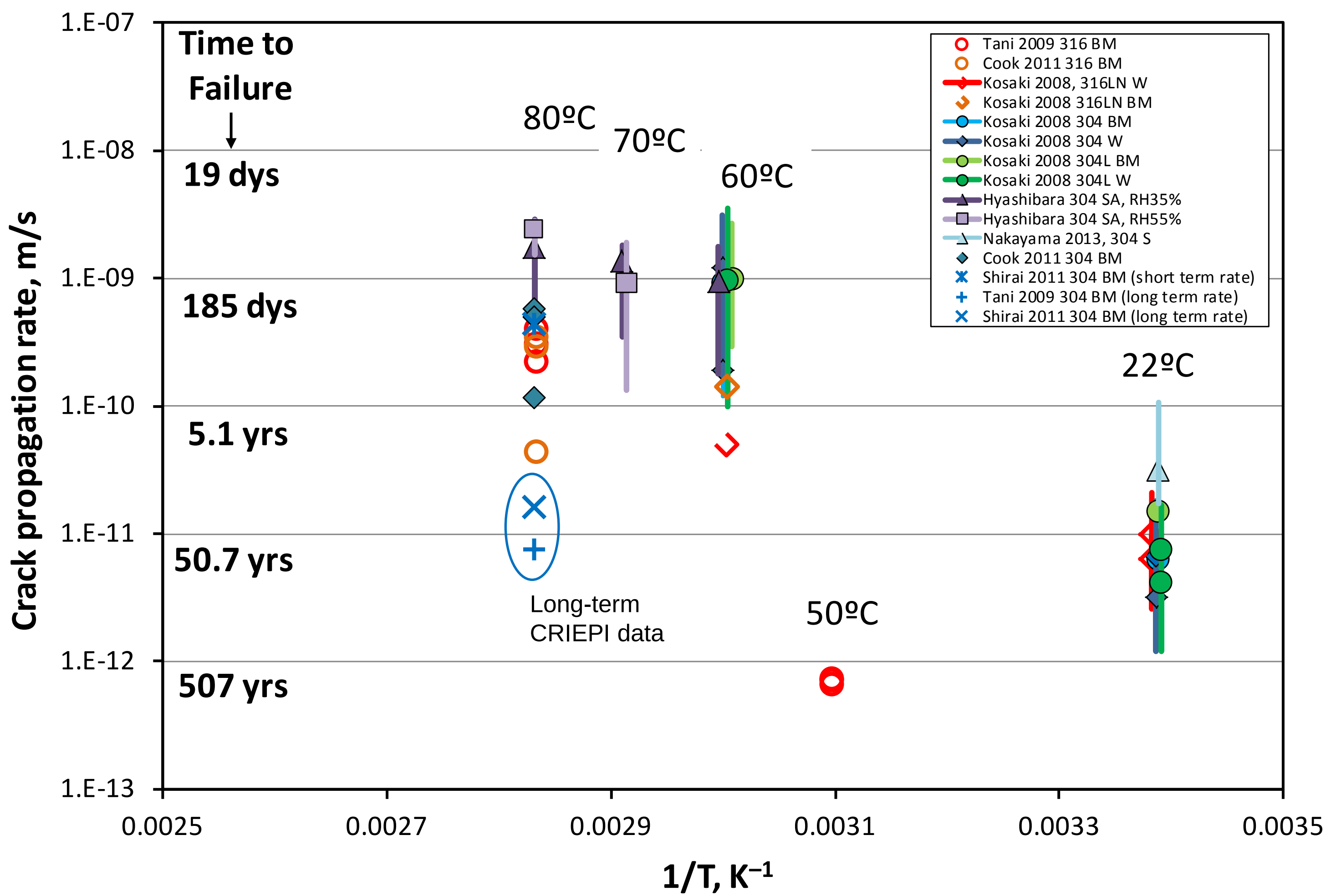


Data plus sampled values (n = 5000)



SCC Model, Literature Crack Growth Rates

304 SS and 316 SS, atmospheric corrosion



Base Case: Definition

- Base Case parameters
  - Horizontal canister
  - 24 kW (maximum heat load as per license)
  - 2 Longitudinal welds (no circumferential weld)
  - RH_L = 15%
  - NRC modeled WRS profiles (sampled between isotropic and kinematic strain-hardening models)
- 200 realizations
  - Weather—daily averages for T, AH (1-day timestep for 100 years)
  - Crack growth rate parameters sampled once per realization
  - Horizontal weld locations sampled once per realization
- Parameter importance determined by linear rank and quadratic regression methods, recursive partitioning, and multivariate adaptive regression splines.

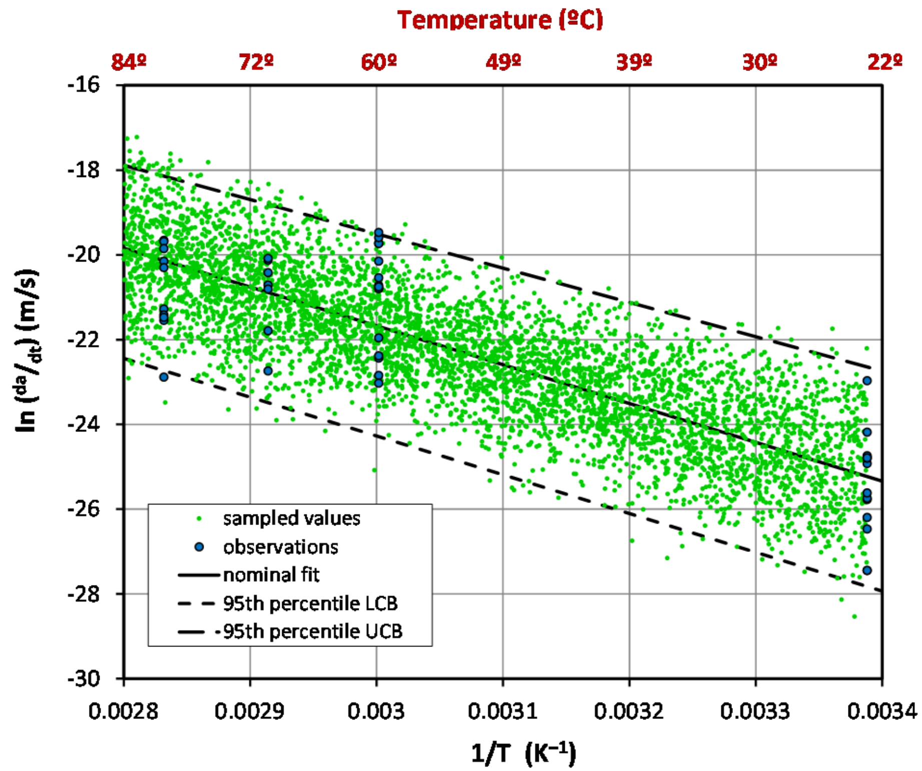
Probabilistic Canister SCC Model Results

- **Probabilistic SCC model is highly conservative, assumes:**
  - Once aqueous conditions are predicted, pitting incubation time = 0
  - Corrosive salts are always present
  - No threshold salt load for corrosion
  - High through-wall tensile stresses

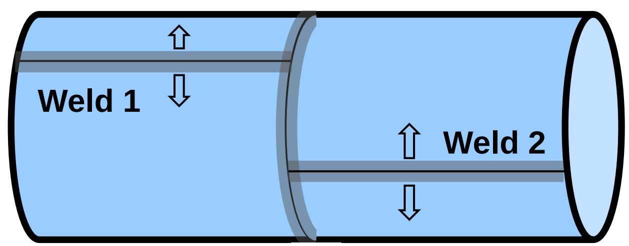
The model is intended to evaluate parameter sensitivity. Actual predicted times are very conservative. For this reason, the predicted through-wall cracking times are not presented here; rather the differences in predicted penetration times for scenarios with different parameterization are provided.

Base Case Results:
Parameter uncertainties of greatest importance

- Crack growth rate parameters: crack growth rate at 80ºC and crack growth pre-factor (α_{crack}) account for 60%-80% of the observed variance; crack growth exponent (β_{crack}) another 6%-15%.



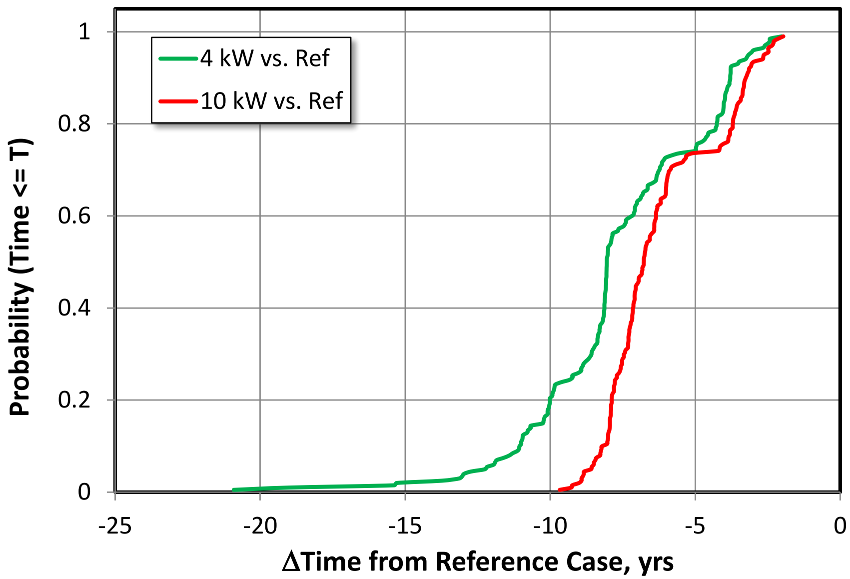
- Weld locations—slight asymmetry in canister heating makes location of second weld important (5%-15% of observed variance).



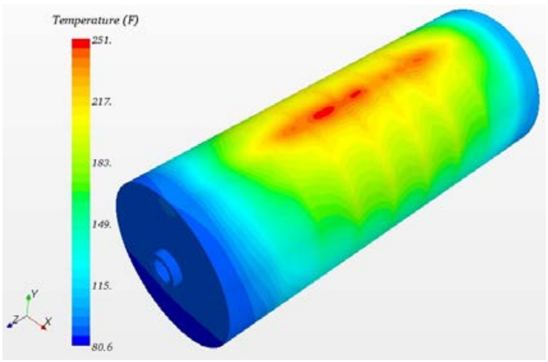
Sensitivity Analyses: Effect of Initial Heat Load

Two alternative cases run, with 4 kW and 10 kW heat loads (*base case: 24 kW*)

Results: lower initial heat loads result in earlier predicted penetration, but the difference is small, generally less than 10 years. Hot fuel and high canister temperatures are only slightly protective.

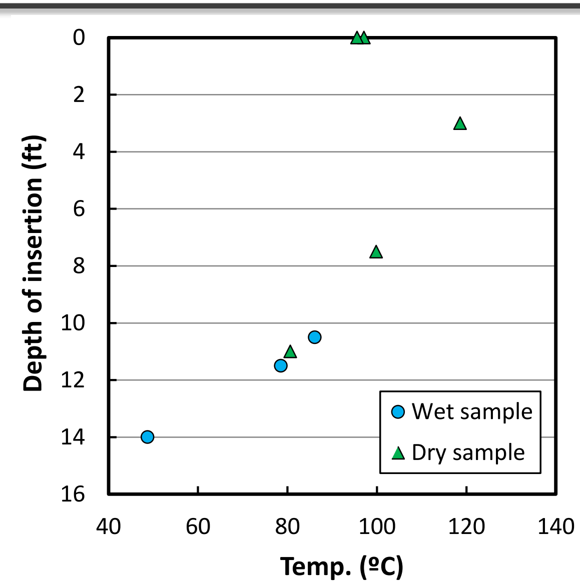


Efficient passive cooling means that some part of the canister rapidly reaches temperatures low enough to allow deliquescence.



Horizontal canister:

Modeled canister surface temperatures, fuel ~19 years in dry storage (~7.61 kW)



Vertical canister:

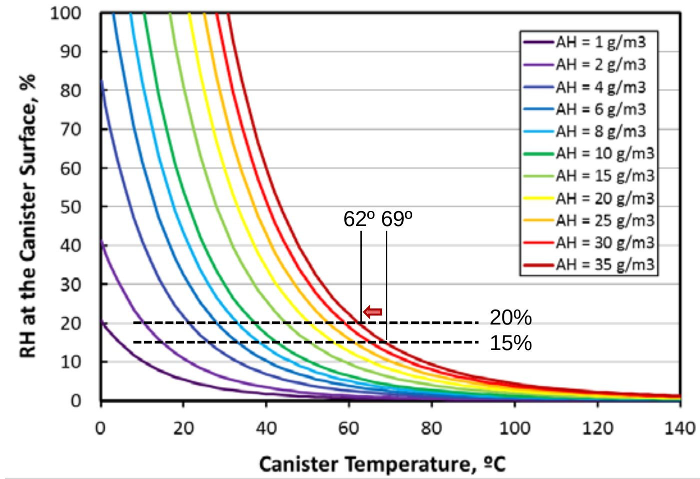
Measured canister surface temperatures, fuel ~2 years in dry storage (~17 kW)

Sensitivity Analyses: Change in RH_L

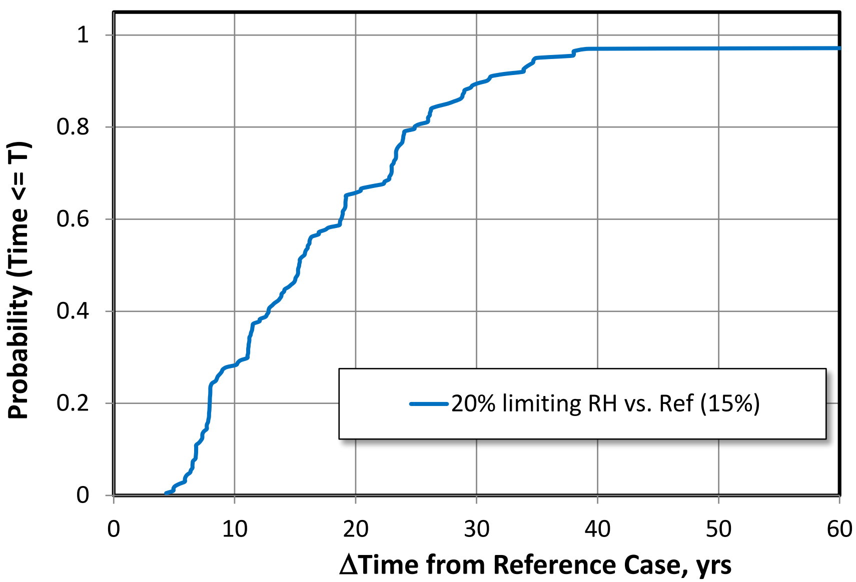
RH_L = 20% (*base case: RH_L = 15%*)

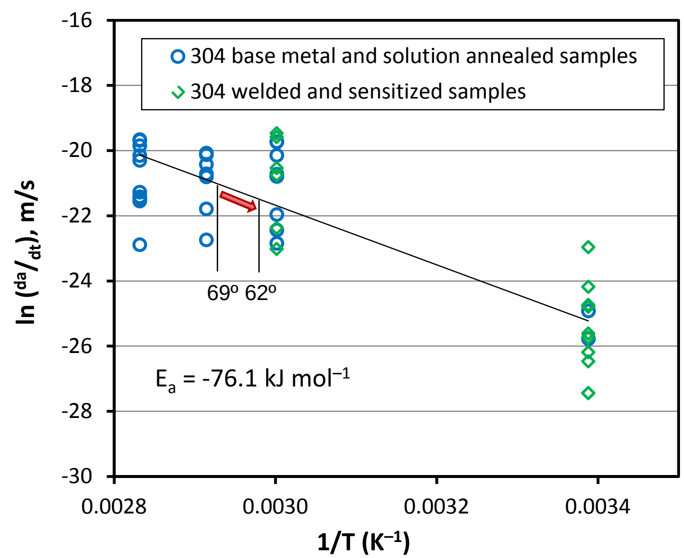
Results: increasing the limiting RH for corrosion from 15% to 20% has a relatively large effect on predicted penetration times. This is because:

- RH_L controls the timing and temperature at which corrosion initiates
- corrosion rate is strongly temperature-dependent (high activation energy).



At AH =35 g/m^3: Changing RH_L from 15% to 20% shifts the temperature at which corrosion can occur from 69ºC to 62º.



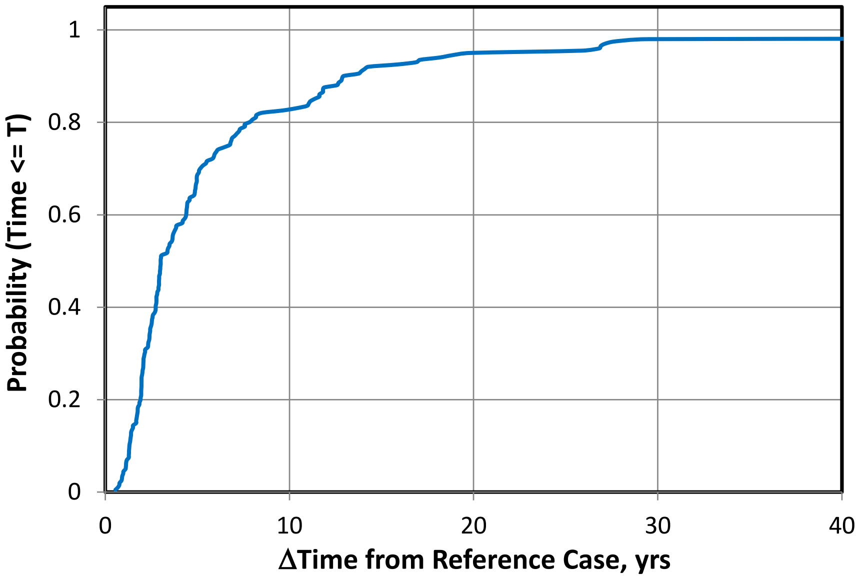


Shifting the temperature at which corrosion can occur from 69ºC to 62ºC reduces the maximum crack growth rate by almost a factor of 2.

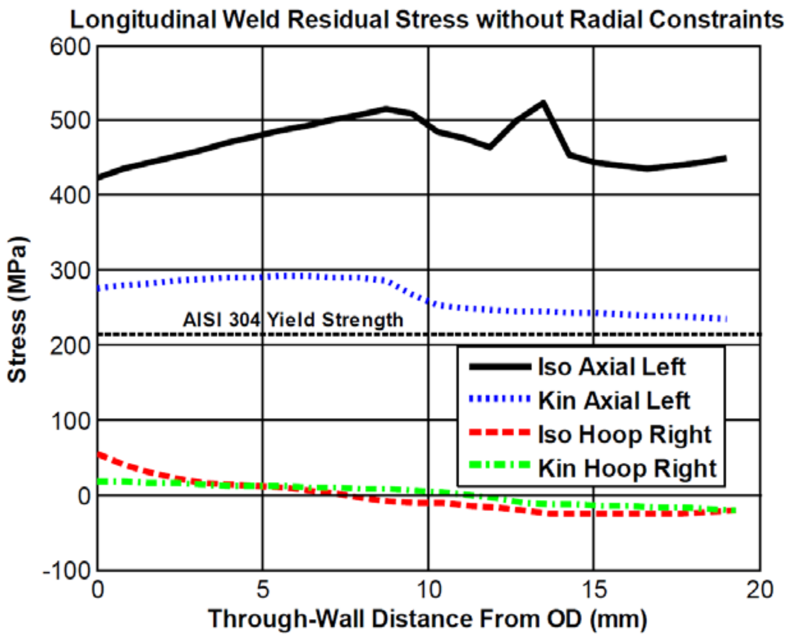
Sensitivity Analyses: Weld Residual Stress Profile

Tensile stress constant at 205 MPa (304 SS yield strength) (*base case: sample NRC (2013) WRS model results*)

Results: Using σ_{ys} as the through-thickness $\sigma_{tensile}$ results in slower through-wall penetration, but the difference is small (generally less than 10 years), because the crack growth rate varies as a function of the square root of the ratio of the assumed tensile stresses—a maximum of $\sqrt{\sim 500/205}$, or a factor of 1.6.



NRC 2013 modeled WRS profiles



Summary, SCC Model – Important research needs

- **Assumptions controlling probabilistic SCC model results:**
  - **Pitting incubation time = 0** (*insufficient data available to develop a model for pit initiation*)
  - **Corrosive salts are always present** (*reasonable at near-marine sites; unlikely(?) at inland sites*)
  - **No threshold salt load** for corrosion initiation or continued growth (*experimental data show threshold is very low for initiation, little data for the effect of salt load on crack growth rate*)
  - **High through-wall tensile stresses**, based on NRC (2013) WRS modeling data (*mockup data to be added*)

  These must be evaluated experimentally, and replaced, if possible, with more realistic approaches.

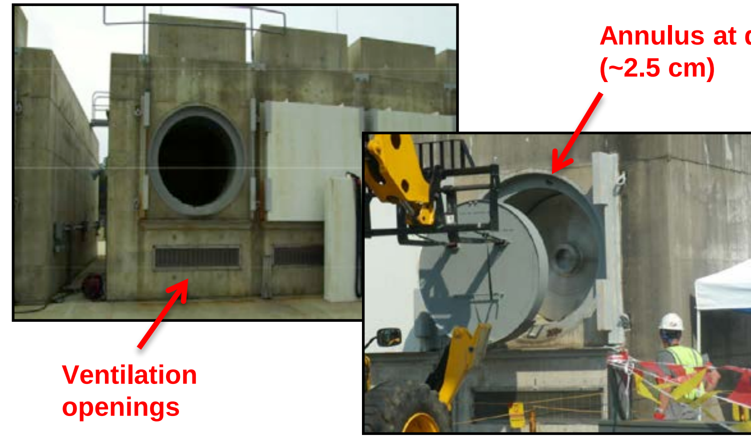
- **Given the above assumptions, the dominant factors controlling penetration times are:**
  - **Crack growth rates as a function of temperature, salt load, and other factors**—high crack growth rates at temperatures when RH_L is initially exceeded lead to rapid crack growth.
  - **Assumed threshold RH for corrosion (RH_L)**.
  - Assumed to be 15%; increasing this to 20% doubled predicted penetration times.
  - Controls temperature and timing of initial corrosion
  - Controls time-of-wetness.

  These must be evaluated experimentally to reduce parameter uncertainty.

Given that SCC appears to be a real risk, and that penetration rates are poorly understood, there is a need to develop methods for evaluating SCC on in-service canister surfaces.

Storage System Designs: Limited Access

Horizontal Systems (~40% of total)



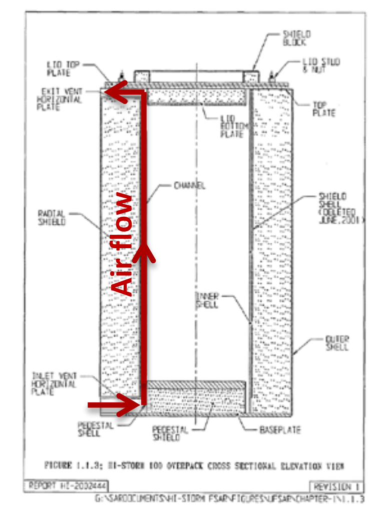
Annulus at door (~2.5 cm)

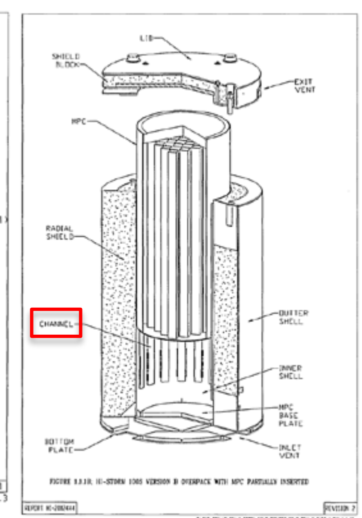
Ventilation openings

Vertical Systems (~60% of total)

Annulus between canister and wall (~5-8 cm)

Clearance at ribs (~ 1 cm)





Storage systems: Access

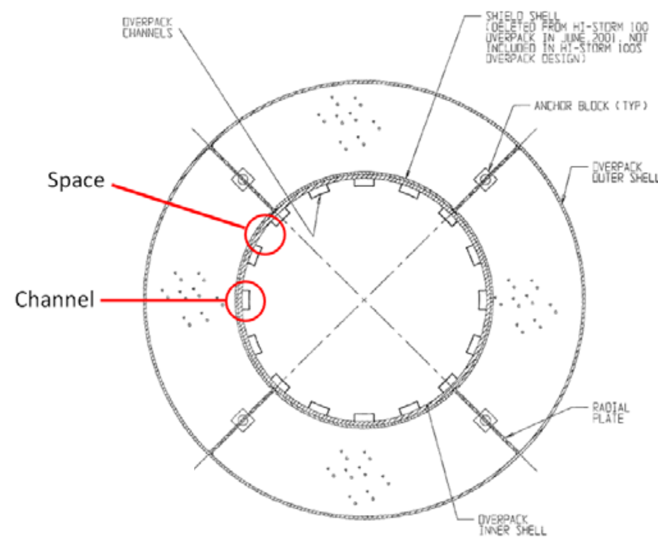
Access to canister surface is NOT trivial!

- **Removing canister from overpack is undesirable; canister surface doses 1000-10,000 Rad/hr (dose risk)**
- **Access requires concerted effort of site operator, storage system vendor, and others. Dose plan must be developed, worker exposure monitored. (estimated dust sampling costs were ~$20K per sample)**
- **For HI-STORM, tack-welded gamma shield must be cut loose and removed, and replaced at the end of the exercise**
- **Once inside, channels limit access to surface and make navigating difficult**
- **However, narrow annulus has benefits—helps constrain device location (provides surface to push against).**

Removing the Gamma Shield

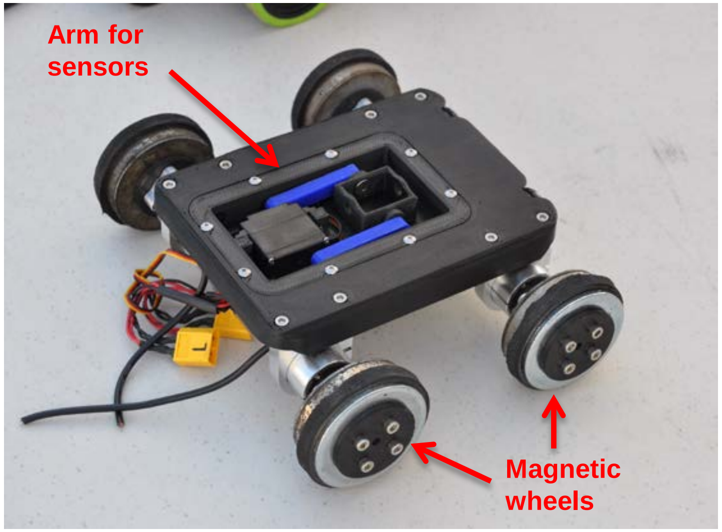
Sampling a HI-STORM 100 canister at Diablo Canyon

Sampling with the remote sampling tool



Tethered Robotic Delivery Systems:
Magnetic Robot

Magnetic Robot
(Robotic Technologies of Tennessee)



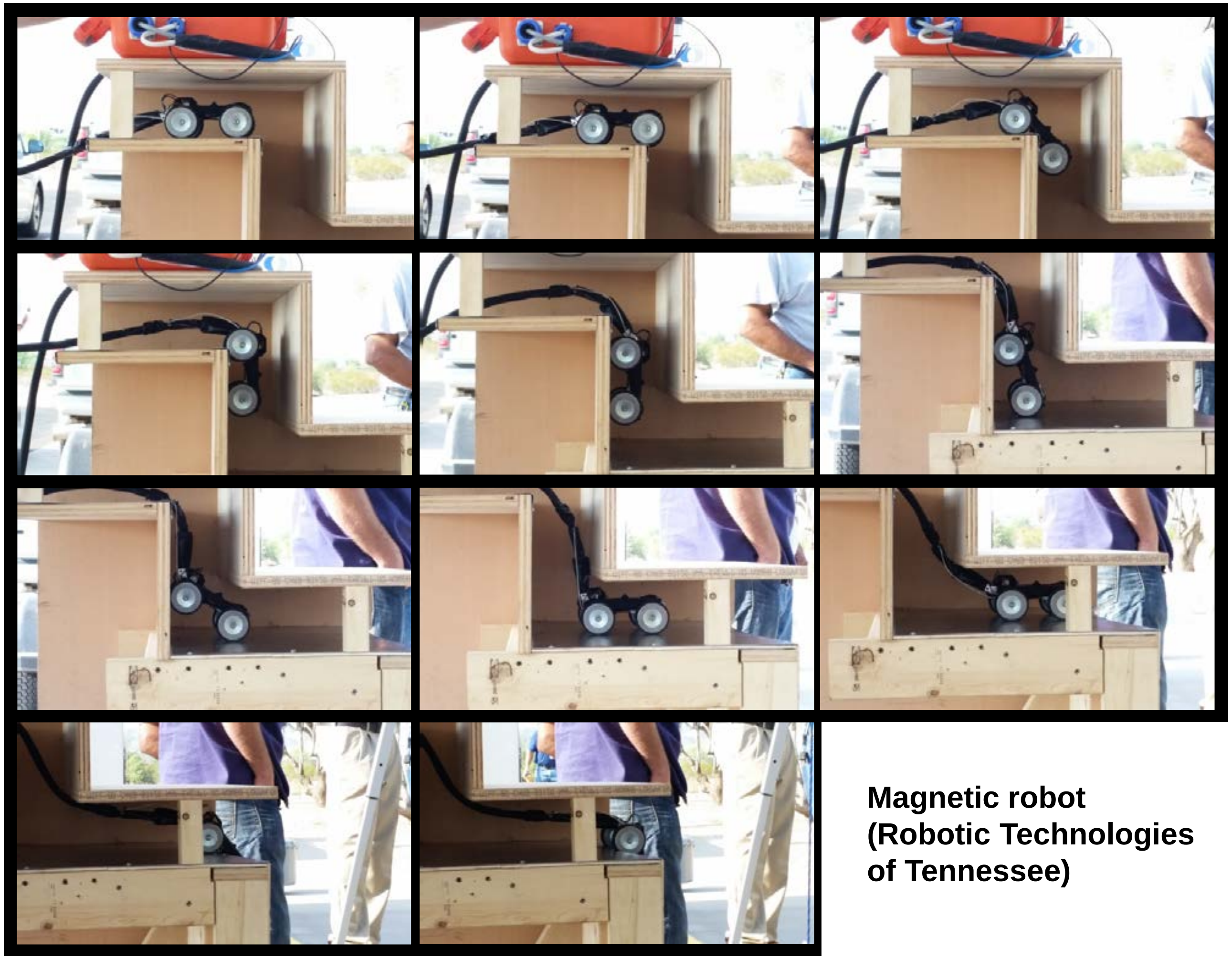
Testing a magnetic robot on a storage system cutaway, Palo Verde Nuclear Plant Education Center

<u>Magnetic Robots</u>: Robots with magnetic wheels can be used in storage systems that have a carbon steel-lined overpack

- Wheels contain powerful permanent magnets, allowing the robot to adhere to magnetic metals.
- Cannot be used on the canister itself (stainless steel is non-magnetic)
- Solenoid-driven arm presses NDE sensors onto metal surface

Magnetic Robot Navigates Through a Mockup of an Overpack Exhaust Vent

Robot navigates two right-angle bends in the vent channel



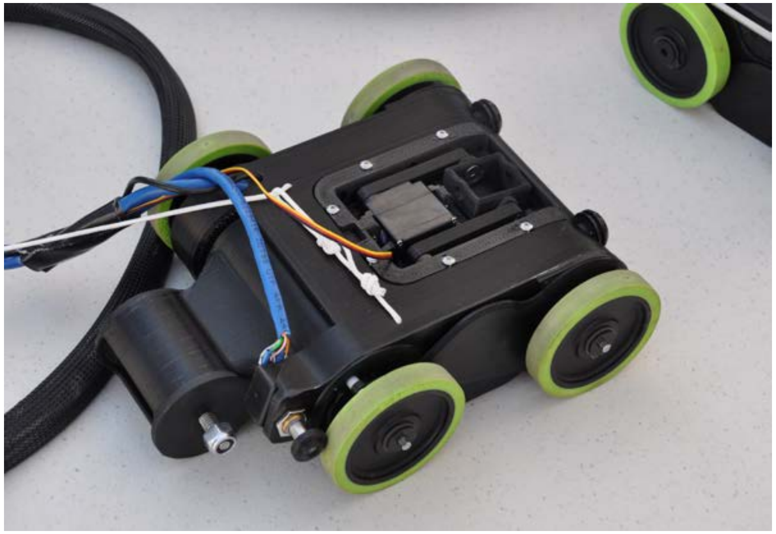
Magnetic robot (Robotic Technologies of Tennessee)

Robot rolls down overpack wall and enters annulus

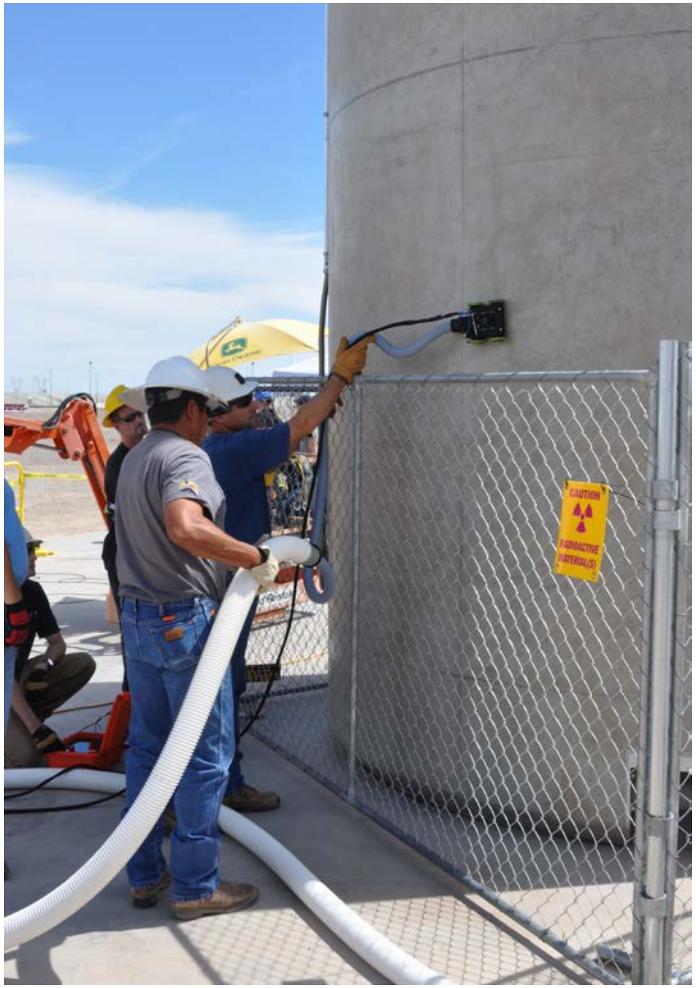
Tethered Robotic Delivery Systems:
Vacuum Robot

Sandia National Laboratories

Vacuum Robot
(Robotic Technologies of Tennessee)



Testing a vacuum robot on a storage system outer surface, Palo Verde Nuclear Plant



Vacuum Robots: Robots use vacuum suction to adhere to any smooth surface

- Sliding panels along the sides form a shutter, allowing the robot to pass over right-angle corners.
- Size limitations preclude building vacuum into robot; a vacuum line is necessary.
- Ineffective so far. Vacuum line is heavy, and friction in the line limits suction efficiency.

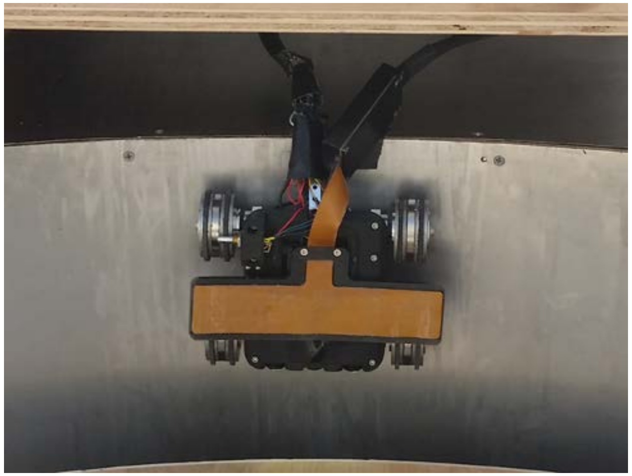
NDE Sensors

NDE methods for SCC cracks currently being evaluated:

- Visual inspections
  - Efficiency may be limited by high radiation field
    - "Snow" in images
    - Electronics degradation and failure
- Eddy current sensors
  - Arrays of coils allow inspection of broad strips
  - Motion control and "lift-off" problems
- Ultrasonic inspections
  - No couplant can be used
  - Acoustic or magnetic coupling
  - Some types can look sideways, allowing inspection under rails

Ultimate goal—determining inspection intervals.

Flexible eddy current array sensor (Eddyfi, Inc.), on magnetic robot (Robotic Technologies of Tennessee)



Magnetically coupled, side-looking ultrasonic sensor (Integrity Engineering, Inc.), on magnetic robot (Robotic Technologies of Tennessee)

Conclusions

- Stress corrosion cracking due to dust deliquescence is a real concern for SNF interim storage canisters
  - Inspections of surface deposits on in-service SNF interim storage canisters show that chloride-rich sea-salt deposits can be present.
  - Modeling and actual measurements (Sandia mockup canister) show that through-wall tensile stresses are likely to be present in storage canister weld regions
  - Current in-service storage canisters are largely 304/304L SS (some 316 SS), which is known to susceptible to SCC
- Attempts to model potential penetration of canisters by SCC yield varying results—an experimental program is currently underway to reduce uncertainties.
- In view of the risk, methods are being developed for *in situ* NDE evaluation of SCC on in-service storage canisters.
  - ASME committee to develop an inspection standard
  - Work by EPRI and DOE UFD/NEUP programs to evaluate robotic deployment systems and NDE sensor packages.

Backup Slides

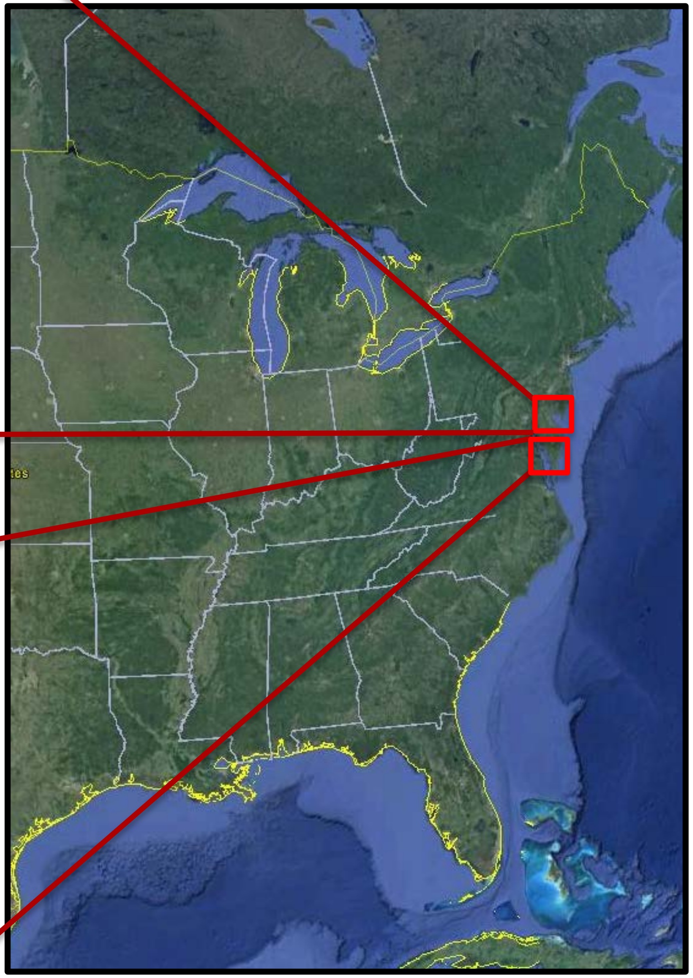
Sites Sampled

Hope Creek Site

ISFSI is ~0.25 miles from the Delaware River, 15 miles upstream from Delaware Bay

- Brackish water
- Sheltered from open ocean

Eastern U.S.



Calvert Cliffs Site

ISFSI is ~0.5 miles from Chesapeake Bay

- Sheltered bay
- Brackish water

Sites Sampled

Western U.S.

Diablo Canyon Site

ISFSI is ~1/3 mile from the shoreline, on a hill above the plant.

- Elevated (~400 feet) above sea level
- Rocky shore, breaking waves
- Open ocean