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Susceptibility Assessment Criteria

for Chloride-Induced Stress Corrosion Cracking (CISCC)

John Broussard

Dominion Engineering, Inc.
On Behalf of EPRI

REG CON
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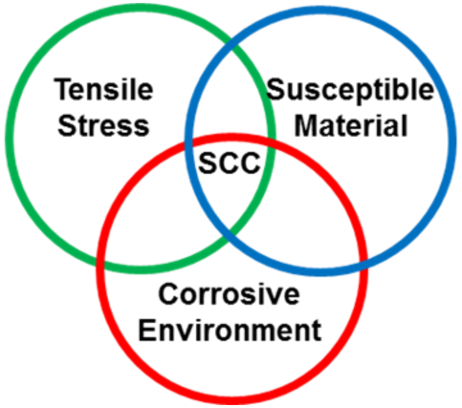
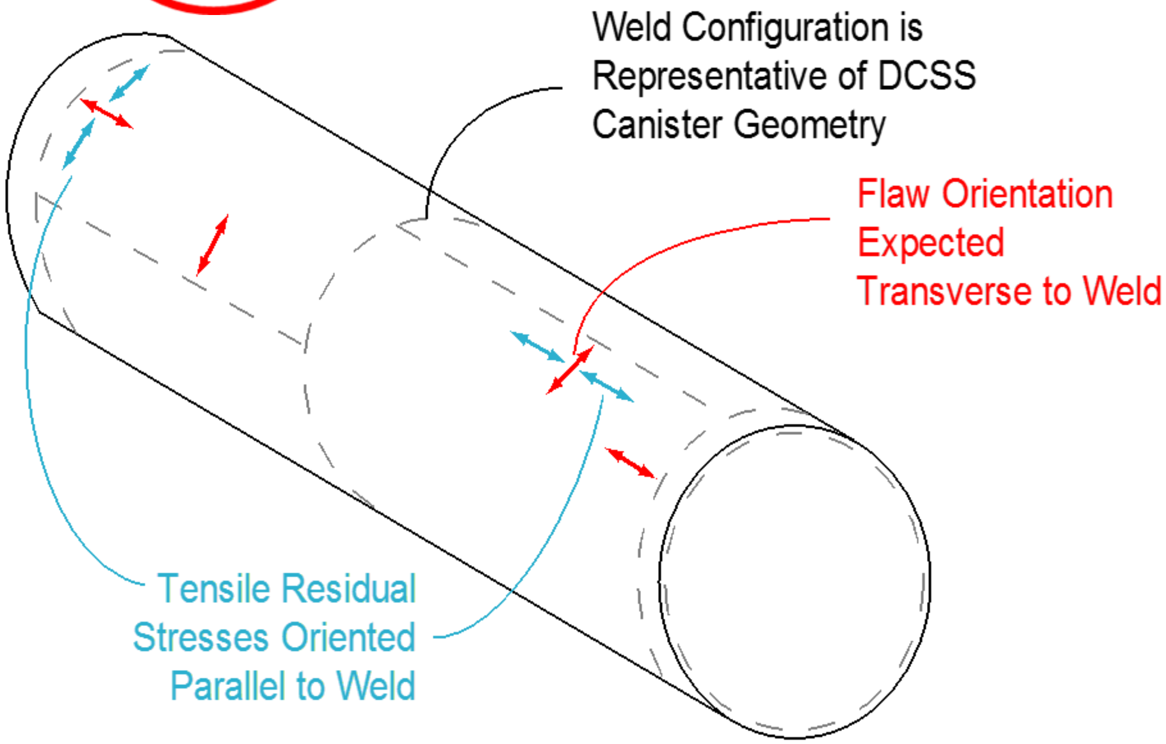
Issue, Action, and Goals

- Issue
  - Chloride-Induced Stress Corrosion Cracking (CISCC) is a potential degradation mechanism for used fuel storage canisters in dry cask storage systems
- Action
  - Develop susceptibility assessment criteria to identify canisters that are most susceptible to CISCC
- Goals
  - Devote inspection resources to the most susceptible locations first
  - Gain better understanding of CISCC timeframe based on conditions of most susceptible canisters





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Susceptibility Assessment Criteria

- Criteria define site conditions and canister parameters associated with earlier potential for CISCC initiation and growth
- Criteria allow ranking of canisters to set priorities for inspection and other aging management efforts
- Document includes
  - Factors Affecting Susceptibility to CISCC
  - **ISFSI Susceptibility Assessment Criteria**
  - **Canister Susceptibility Assessment Criteria**
  - Guidance for Use of Rankings
  - Summary of Susceptibility Assessment Criteria and Conclusions
  - Modeling Overview
  - Chloride Aerosol Deposition (Model Description)
  - Atmospheric Absolute Humidity Assessment (Guidance for Data Gathering and Calculation)

ISFSI Susceptibility Ranking

$$Z_{ISFSI} = Cl_{starting} + Cl_{adj} + AH_{adj}$$

- Designed to assess the extent to which a given environment affects likelihood of CISCC initiation
- Primarily based on chloride aerosol concentration
- Chloride starting value is based on proximity to a marine shore
- Chloride adjustments are made for elevation (within close proximity to marine shore), for proximity to a cooling tower (saline/low-saline/non-saline), and for proximity to salted roads
- Absolute humidity adjustment is based on local atmosphere annual average data, this affects the amount of time a surface is likely to support deliquescence

Chloride (Cl) Criteria - Basis

- $Cl_{starting}$ value decreases with distance from marine shore
  - Chloride concentration in aerosol measurements and dry deposition measurements decreases exponentially with distance from marine shore
  - Specific values based on (1) CASTNET and IMPROVE aerosol databases, (2) chloride deposition measurements, and (3) wet candle measurements at marine locations
- Cl_{adj} values account for other specific factors that influence chloride aerosol concentration
  - Values reflect expected change in aerosol concentration relative to marine shore aerosol concentration
  - Values based on data in published studies with deposition and aerosol measurements

Absolute Humidity (AH) Criteria - Basis

- Combined effects of temperature and humidity tend to be reflected by average AH
- AH_{adj} value range is about 1/3 of $Cl_{starting}$ max value
  - Reflects relative impact of variation in AH versus variation in chloride aerosol
  - Impact of chloride aerosol concentration varies by factor of 10 or more vs AH impact varies by factor of 2 to 3

ISFSI Susceptibility Ranking

Distance to:		Z_{ISFSI} Value
Marine Shore	Less than 90 m	9
	90 m to 1 km	8
	1 km to 5 km	5
	5 km to 20 km	2
	More than 20 km	1
Elevation	Maximum elevation between the ISFSI and marine shore of >90 m, AND < 5 km to marine shore	-1
Cooling Tower	> 1000 m	0
	≤ 1000 m (Non-saline)	+1
	≤ 1000 m (Low-saline)	+2
	≤ 1000 m (Saline)	+3
Salted Highway	> 200 m	0
	≤ 200 m	+2

AH (g/m^3)	Z_{ISFSI} Value
< 8	-1
8 to 12	0
12 to 15	+1
> 15	+2

Rank will range from 1 to 10 (higher values are truncated).

Rank will be constant with time.

Canister Susceptibility Ranking (Horizontal and Vertical)

$$H_{CAN}, V_{CAN} = Deposition + Material + Heat$$

- Designed to asses CISCC susceptibility for a specific canister at a given ISFSI at a given point in time
- Separate paths are needed because the different geometries have different specific locations of interest and different heat profiles
- Rankings cannot be used to make any comparison of the susceptibility of horizontal canisters relative to the susceptibility of vertical canisters
- Although the canister geometries have different deposition profiles, they are weighted in the same manner due to high variability and uncertainty in deposition rate

Deposition Criteria – Formula and Basis

- *Deposition* factor reflects time canister spends in environment – calculated based on Z_{ISFSI} and storage time
- Intermediate parameter X_{Cl} calculated:

$$X_{Cl} = \frac{SD}{\left[\left(11 - Z_{ISFSI} \right) + \left(\frac{10}{Z_{ISFSI}} \right) \right]}$$

- *Deposition* factor increases from 1 to 5 with increasing X_{Cl}
- Z_{ISFSI} = 1 needs 10 times longer than Z_{ISFSI} = 10 to reach same value of X_{Cl}

Material Criteria - Basis

- *Material* factor considers relative susceptibility to initiation for 304, 304L(N), 316, and 316L(N) stainless steels
- Values range from 0 for Type 316L(N) to +3 for Type 304
- Change in material from Type 304 to Type 316 equivalent to 2/5 of the full *Deposition* factor range
  - Deposition factor increases from 1 to 5 in 10 years at $Z_{ISFSI} = 10$
  - Atmospheric testing supports increase in initiation time of at least 5 years for 316 vs 304

Heat Criteria - Basis

- *Heat* factor considers effect of residual decay heat load on canister surface temperature
  - Decreasing decay heat with time increases surface area subject to deliquescence
- Factor starts at 0 for decay heat loads where little to no surface area is at a temperature likely for deliquescence
- Factor increases to 2 at lower decay heat loads where larger surface areas are at susceptible temperatures
- Increase in canister rank due to increasing temperatures judged to be 2/5 of the effect of *Deposition* factor
  - Reflects uncertainty of thermal profiles and deliquescence behavior

Canister Susceptibility Ranking

Parameter	Value	Value
Deposition Factor	$X_{Cl} < 1.5$	+1
	$1.5 \le X_{Cl} < 2.5$	+2
	$2.5 \le X_{Cl} < 4$	+3
	$4 \le X_{Cl} < 5$	+4
	$X_{Cl} \ge 5$	+5
Canister Alloy	316L(N)	0
	316	+1
	304L(N)	+2
	304	+3

Parameter	Value	H_{CAN} Value
Current Decay Heat Load	> 20 kW	0
	9 to 20 kW	+1
	< 9 kW	+2

Parameter	Value	V_{CAN} Value
Current Decay Heat Load	> 16 kW	0
	6.5 to 16 kW	+1
	< 6.5 kW	+2

Rank will range from 1 to 10 (higher values are truncated).

Rank will increase with time.

Horizontal and Vertical Canister Specific Locations of Interest

Factor for CISCC Susceptibility	**Locations on Horizontal Canister**	**Locations on Vertical Canister**
Tensile Stresses on OD	Regions in the vicinity of welds (e.g. within about 2 thicknesses)	Regions in the vicinity of welds (e.g. within about 2 thicknesses)
Low Surface Temperature	Lids; shell along canister underside and along ends	Lower region of canister OD
Elevated Chloride Deposition	Upward-facing surfaces of canister shell	Top lid; possibly the areas in the vicinity of the overpack inlets
Crevice-like Geometry	Support rail contact region	Areas where canister contacts the overpack channels/standoffs*
Material Condition	Areas of heavy grinding or mechanical damage (e.g. gouges)	Areas of heavy grinding or mechanical damage (e.g. gouges)
More Susceptible Location(s)	Shell welds at canister ends (top surface); support rail interface near welds	Canister sides near welds at the bottom of the canister

* These features are not present in all overpack designs for vertical canisters.

Canister Inspection Priorities

- Within a given geometry, canister ranking values may be used to identify bounding canisters
  - A same site bounding canister rank must be greater by at least 1
  - At different sites
    - Bounding canister rank must be greater by at least 2
    - Z_{ISFSI} at bounding canister site must be equal or greater
- Additional considerations are provided for identification of canister(s) to be inspected

Qualitative Considerations for Identifying Candidate(s) for Canister Inspection Among Equally Ranked Canisters

- Canister in storage the longest
- Specific canister placement
- Pre-load storage and installation experience
- Fabrication record information

Ranking Example

- ISFSI Rank
  - Very near marine shore (< 90 m); Cl starting value = 9
  - High elevation (>90 m); adjustment = -1
  - No cooling tower/salted highway; adjustments = 0
  - AH is between 8 and 12 g/m3; factor = 0
  - Zisfsi = 9 - 1 + 0 + 0 = 8
- Canister Rank (Vertical)
  - Deposition (Xcl < 1.5), factor = 1
    - Loaded in 2009 (6 Years in storage)
    - Xcl =6/[(11-8) + (10/8)] = 1.4
  - Material (304); factor = 3
  - Heat load (between 6.5 kW and 16 kW); factor = 1
    - Current heat load ~13 kW
  - Vcan = 1 + 3 + 1 = 5

Publication

- Published September 2015
- *Susceptibility Assessment Criteria for Chloride-Induced Stress Corrosion Cracking (CISCC) of Welded Stainless Steel Canisters for Dry Cask Storage Systems*
- EPRI Product ID: 3002005371
- Public report

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