

Susceptibility Assessment Criteria for Chloride-Induced Stress Corrosion Cracking (CISCC)

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Issue, Action, and Goals

■ Issue

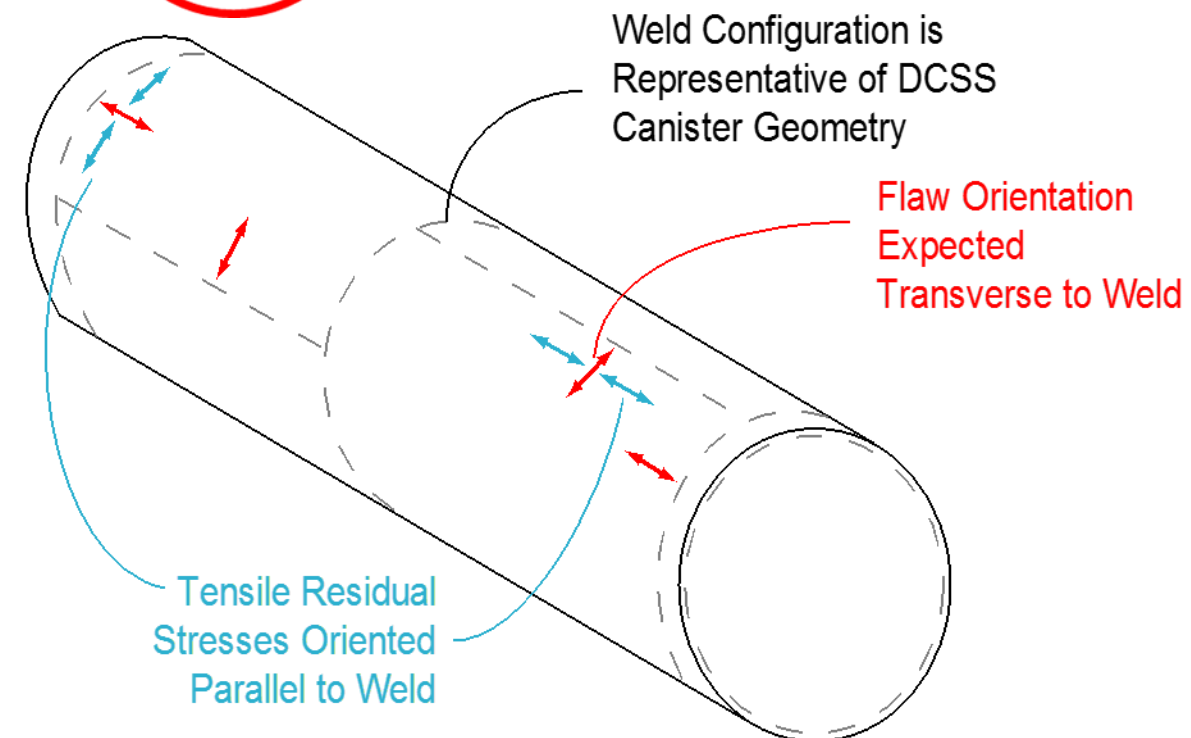
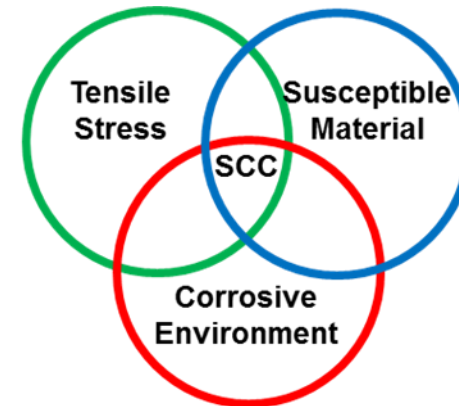
- Chloride-Induced Stress Corrosion Cracking (CISCC) is a potential degradation mechanism for used fuel storage canisters in dry cask storage systems

■ 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



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

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

- 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)

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

- Designed to assess 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_{CI} calculated:

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

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

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
	$1.5 \leq X_{Cl} < 2.5$	+2
	$2.5 \leq X_{Cl} < 4$	+3
	$4 \leq X_{Cl} < 5$	+4
	$X_{Cl} \geq 5$	+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); CI 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 ($X_{cl} < 1.5$), factor = 1
 - Loaded in 2009 (6 Years in storage)
 - $X_{cl} = 6 / [(11 - 8) + (10 / 8)] = 1.4$
- Material (304); factor = 3
- Heat load (between 6.5 kW and 16 kW); factor = 1
 - Current heat load ~13 kW
- $V_{can} = 1 + 3 + 1 = 5$

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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