

Susceptibility Assessment Criteria for Chloride-Induced Stress Corrosion Cracking (CISCC) of Welded Stainless Steel Canisters for Dry Cask Storage Systems

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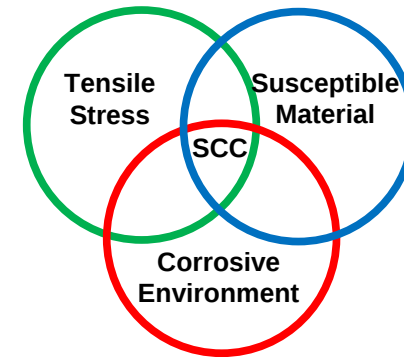


Overview

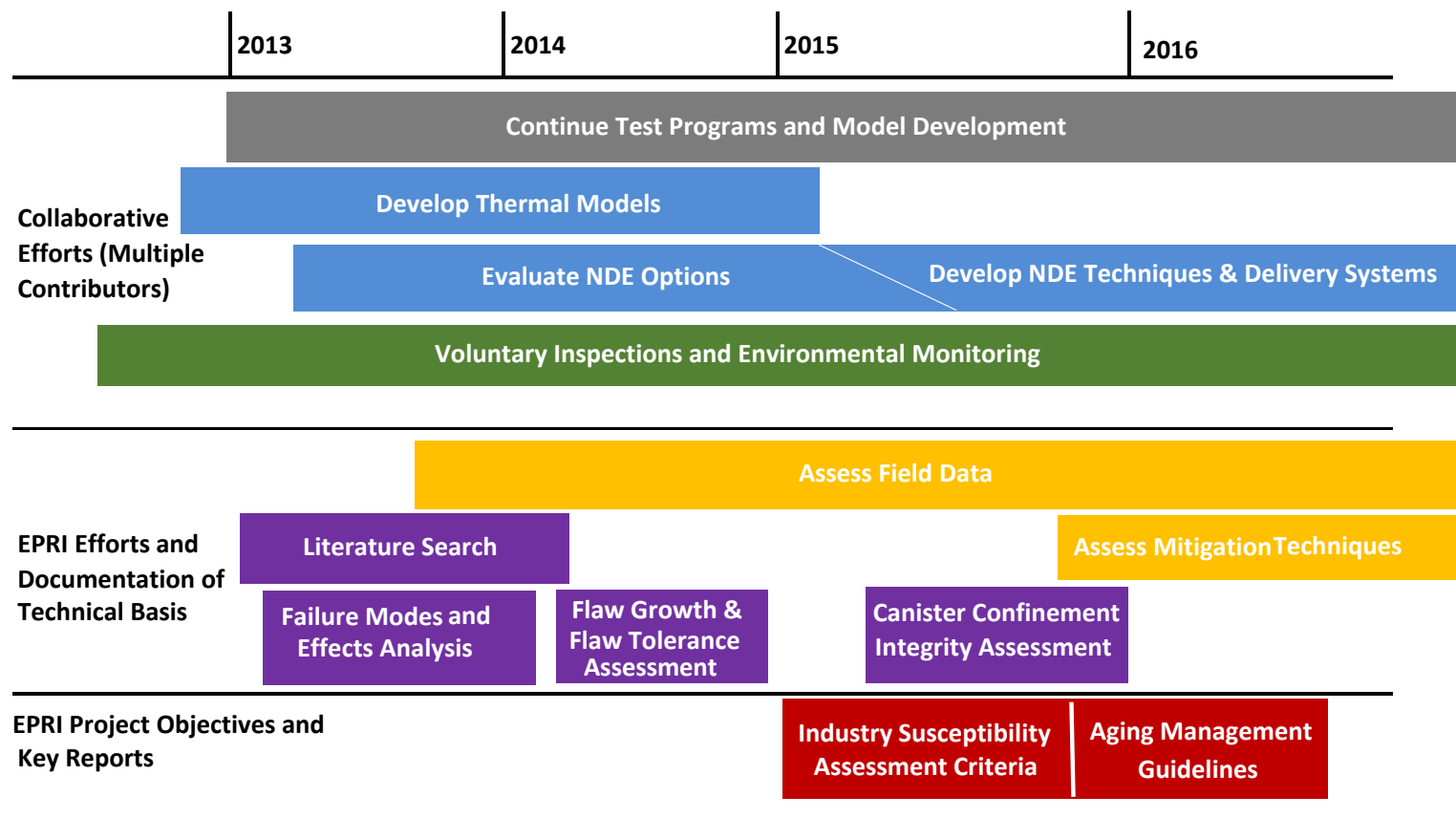
- Background
- Project Timeline
- Progression of Modeling
- Key Results
- Susceptibility Criteria Format
- Steps Beyond the RIRP

Background

- Chloride Induced Stress Corrosion Cracking (CISCC) of stainless steel reactor components has occurred when three elements are all present:
 - Elevated stress
 - Susceptible Material
 - Corrosive Environment
 - Surface contamination by atmospheric chlorides
 - Sufficient humidity
- EPRI has a multi-year project to
 - Evaluate susceptibility to CISCC for welded stainless steel used fuel canisters
 - Develop related aging management guidelines



Project Timeline



Progression of Modeling

■ Failure Modes and Effects Analysis

- Qualitative judgments of frequency/probability, detectability, & severity over time based on literature and limited calculations
- Define boundaries of the degradation problem & guide approach to subsequent assessments

■ Canister Flaw Growth and Flaw Tolerance

- Model flaw growth to through-wall
- Determine consequential flaw sizes

■ Susceptibility Assessment Criteria

- **Model the process of canister degradation based on the pathways identified in the FMEA**

■ *Canister Confinement Integrity Assessment*

- *Probabilistic analysis to determine the benefit of various monitoring, mitigation, & inspection regimes*

Susceptibility Criteria Format

- ISFSI Susceptibility Ranking (Z_{ISFSI})
 - Direct resources to locations where CISCC is more likely to occur
 - Results from sites identified as more susceptible may help to refine aging management recommendations (improve technical basis, identify bounding locations)
 - Proximity to chloride source and local absolute humidity are key variables
- Canister susceptibility ranking (H_{CAN} and V_{CAN}) intended to identify canister(s) to be inspected at a given site and to guide scope expansion if needed
 - Geometry (horizontal or vertical) affects locations of maximum chloride deposition and locations of minimum temperature
 - Canister material, storage duration, and fuel load power are key variables

ISFSI Susceptibility Ranking

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

- Chloride starting value is based on proximity to a marine shore
- Chloride adjustments are made for elevation, for proximity to a cooling tower (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

ISFSI Susceptibility Ranking

- Ranking value will range from 1 to 10
- Ranking value will be constant with time
- Ranking value will be an input to Horizontal and Vertical Canister Rankings

Canister Susceptibility Ranking

- Ranking value will range from 1 to 10
- Ranking value will increase with time
- Ranking will be different for vertical and horizontal canisters
- Within a given geometry, ranking values may be used to identify bounding canisters at different sites
 - 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

Horizontal and Vertical Canister Ranking

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

- Separate paths are needed because the different geometries have different specific locations of concern 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

Canister Locations of Higher Susceptibility

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 Ranking Parameters - Deposition

- Deposition parameter reflects both canister age and environmental characteristics
- The parameter is established based on the value of X_{CI} , which is calculated using:
 - The storage duration of the canister
 - The Z_{ISFSI} value for the canister site
- At higher Z_{ISFSI} values, X_{CI} increases faster (i.e., higher X_{CI} for a given storage duration)

Canister Ranking Parameters - Material

- The material alloy factor provides credit to canisters constructed from alloys that are more resistant to CISCC initiation.
- Different values are provided for 304, 304L(N), 316, and 316L(N).
- The primary differences among these alloys are the limitation of the carbon content to reduce the potential for sensitization during welding (–L/–LN) and the addition of molybdenum (type 316) to increase the passivity of the surface oxide layer.

Canister Ranking Parameters - Power

- Decreasing thermal power causes decreasing canister surface temperature.
- Deliquescence for a significant portion of time each year at atmospheric levels of absolute humidity tends to begin at 25°C above atmospheric temperature.
- The relationship between thermal power levels and temperature at various points on the canister is different for horizontal and vertical canisters.

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

Susceptibility Assessment Criteria Schedule

- Susceptibility Assessment Criteria draft report currently in review cycle
 - EPRI staff
 - Advisory panel (comprised of vendors, DOE, NEI, utilities)
 - EPRI High Level Waste Technical Advisory Committee
- Publication anticipated in September 2015

Steps Beyond the RIRP Resolution

- Canister Confinement Integrity Assessment
 - Probabilistic assessment of flaw growth
 - Compare various inspection regimes (optimize resources, aiming for detection prior to 75% through-wall)
- Aging Management Guidelines
- Continue to follow CISCC testing, modeling and inspection results



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