Conceptual Screening Process for Identifying ISFSIs Potentially Affected by Marine Atmosphere SCC, and the Associated Timeframes

NOTE: *This conceptual screening process is based upon currently available data and principally on NUREG/CR-7030; however, current data is insufficient to be able to determine under what conditions and the associated time scales that the potential for stress corrosion cracking (SCC) exists in stainless steel dry spent nuclear fuel (SNF) storage canisters deployed at ISFSIs. It is recognized that additional data, through R&D and in-situ inspections, is needed in order to produce a usable screening process. The intent of this DRAFT is only to identify a general concept of the process, and may also be helpful in identifying high priority areas for R&D and in-situ inspection data collection. Red highlighted-italicized text below is intended to demonstrate where data is insufficient and important to producing a usable screening process.*

Purpose

Develop criteria for the bounding (typically minimum threshold) conditions under which SCC of austenitic stainless steel (304, 304L, 316, 316L) dry storage canisters' (SS-DSCs) confinement boundary could occur. Conditions include, but are not limited to material type, material stresses, chloride concentration, relative humidity, and cask surface temperature. The screening criteria will incorporate a method for determining the condition based time scale under which SCC could occur. These screening criteria are focused on objective parameters that control the phenomenon of SCC for SS-DSCs, and where values can be easily obtained by ISFSI owners, such as salt air concentration, or determined with relative certainty through predictive models, such as canister surface temperature.

Screening Criteria

Potential for chloride induced SCC requires all three of the following conditions to be simultaneously true in order for initiation of crack propagation 1) material conditions that are susceptible, 2) residual stress, and 3) corrosive environment (in the case of DSCs this is driven by deliquescence of salt in high relative humidity). The following screening criteria will determine if/when these conditions could be present for a particular ISFSI and DSC. It is noted that a potential for SCC does not mean that there will be a loss of the confinement safety function, but rather that additional evaluation is needed to determine if there is a potential for a through-wall crack, and whether a through-wall crack would result in a loss of confinement, and whether a loss of confinement has an adverse effect on public health and safety.

1. Presence of Susceptible Material Conditions
   - 1.1. Is material Stainless Steel 304, 304L, 316 or 316L?
     - ___ Yes: Continue to 2.1
     - ___ No: STOP – DO NOT USE THESE SCREENING CRITERIA
2. Site Atmospheric Conditions
   - 2.1. Is ISFSI located in an area of concern for chloride induced SCC *[salt concentration in air > XX mg/m2 as Cl (304 and 304L); >XXX mg/m2 as Cl (316 and 316L)]*?
     - ___ Yes – Record time to deposition threshold (using equation) ______: Continue to 3.1
     - ___ Unknown – Assume deposition threshold reached within *__?? years__*: Continue to 3.1
     - ___ No: STOP – ISFSI is not located in area of concern for chloride induced SCC
3. Sufficient Residual Stress (Look at highest stresses – typically weld areas)
   - 3.1. Is weld tensile stress greater than threshold value? *(Residual Stress Threshold not yet determined)*
   - 3.2. ___ Yes – Record maximum weld tensile stress ______: Continue to 4.1 *(Actual weld stresses typically not known)*
     - ___ Unknown – Assume the stress is sufficient *equal to material's yield strength*[2,8,11,14]: Continue to 4.1
     - ___ No: STOP – Stresses are insufficient - NOT SUCSEPTIBLE – No Potential for chloride induced SCC
4. Deliquescence of Salt
   - 4.1. Determine cask with coolest surface temperature[3,6]
     - ___ Record cask designation
     - ___ Attach graph *(best estimate thermal model)* of cask surface temperature with time, out to 60 years
     - ___ Continue to 4.2

4.2. Determine salt type and contaminants deposited on casks (e.g MgCl, NaCl, dust)?[12] *(needs more data on behavior of different salt types)*
 ___ Identify/use appropriate sale threshold model (e.g. Figure 43 for NaCl and MgCl)
 ___ Unknown salt type: conservatively assume limiting salt type
 ___ Continue to 4.3

4.3. Determine temperature threshold for deliquescence[3,4,7,13]
 ___ Record atmospheric absolute humidity at ISFSI over 1 year (convert to canister surface RH)[13]
 ___ *Correlate humidity and salt type data to temperature threshold for deliquescence (Temp where AH crosses salt deliquescence threshold)*
 ___ ALTERNATIVELY: Assume XX °C
 ___ Continue to 4.4

4.4. Determine earliest time for which possible to deliquesce (when 3.2 cross 3.4 temperature threshold) [3,4,7,9]
 ___ Time is less than 60 years - Record earliest time ___: Continue to 5.1
 ___ Time is greater than 60 years – STOP – Potential for SCC does not occur within initial or renewal license

5. Potential for SCC

5.1. Determine time to crack initiation
 ___ Number of days above Threshold RH before SCC possible ____days (*304 & 304L=112, 316L=896*)[5]
 ___ Years from start of deliquescence to potential for SCC ____yr (*need data to correlate*)
 ___ Time is less than 60 years - Determine earliest time for crack initiation ___ (3.5+4.1): Continue to 6
 ___ Time is greater than 60 years (3.5+4.1) – STOP – Potential for SCC does not occur within initial or renewal license

6. Perform additional evaluations
 ___ Is a through-wall crack possible?
 ___ Would a through-wall crack result in a loss of confinement?
 ___ Evaluate need for mitigation, and perform if necessary to ensure cask safety functions are maintained, and required response time

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Assumptions

1) Sea salt is assumed to deliquesce at NaCl threshold. ISFSI must justify assumption that salt deposition on cask is not pure MgCl; otherwise pure MgCl deliquescence threshold must be assumed.
2) In absence of a known stress threshold and the canister's residual stress, it must be assumed that there is sufficient stress for chloride-induced SCC. Note that it has not been confirmed whether DPCs in use do or do not have sufficient residual stress for chloride-induced SCC.
3) The time controlling parameter for conditions favorable for chloride-induced SCC is expected to be the deliquescence of salt, which is limited by the canister surface temperature (e.g. residual stress is not time dependent and it is expected that salt deposition could occur in a few years if salt air concentrations are high). It is noted that canister surface temperatures below 85C might be susceptible to chloride-induced SCC, however, based upon NUREG/CR-7070 and expected actual atmospheric conditions chloride-induced SCC may not occur until surface temperatures are below 60C in MgCl environments or below 40C in NaCl environments.
4) There is a lower temperature threshold, below which chloride-induces SCC will not occur. Current estimates place that at 30 or 40 C.

Technical Bases

NUREG/CR-7070

1. Methods are conservative compared to actual cask conditions (page v)
2. Typical welding process on stainless steel canister can lead to residual stresses near material yield strength (page 2)
3. cask surfaces of 85C (185F) and above do not deliquesce even at high humidity ~60g/m3 AH (page 48, 59)
4. sample at 43C deliquesced because RH at surface briefly reached ~75% (threshold for NaCl) (page 44)
5. time to SCC in lab: 304 and 304L=4wk (cycle=112), 316L=128wk(cycle=896) (figures 40, 41, 42)
6. possibility of deliquescence controlled by cask temp, bulk absolute humidity converted to RH, and compared with threshold (page 47, 48 and figure 43)
7. test absolute humidity was around 60 g/m3, NOAA reports US coast average around 30 g/m3 (page 49)
8. u-bend samples had stresses higher than material yield stress (likely higher than those for dry cask) (page 49)
9. conservative assumption that RH at surface must be over 30% for SCC development (page 49)
10. assumption that each day of reaching threshold RH equals one wet/dry cycle; allows comparison of field and lab data; cycle above=day below RH threshold(page 50)
11. no SCC seen on half-u-bend samples, despite favorable conditions (deliquescence) (page 51)
12. Na Salt, Corpus Christi salt, and simulated sea salt all deliquesce at the RH of NaCl in Figure 43 (75%), Mg salt will deliquesce at 35%; (page 54)
13. absolute humidity does not vary significantly with distance from surface, only a few g/m3 drop as get closer to heated u-bend (page 56)
14. half-u-bend samples had no SCC, suggesting tensile stress not sufficient; potential explanation that lack of stressing elemnt to supply constant strain could have caused substantial residual stress relaxation (page 57)

Salt Deliquescence Threshold by Temperature and Humidity (RH Surface correlated to Bulk AH) – NUREG/CR-7070

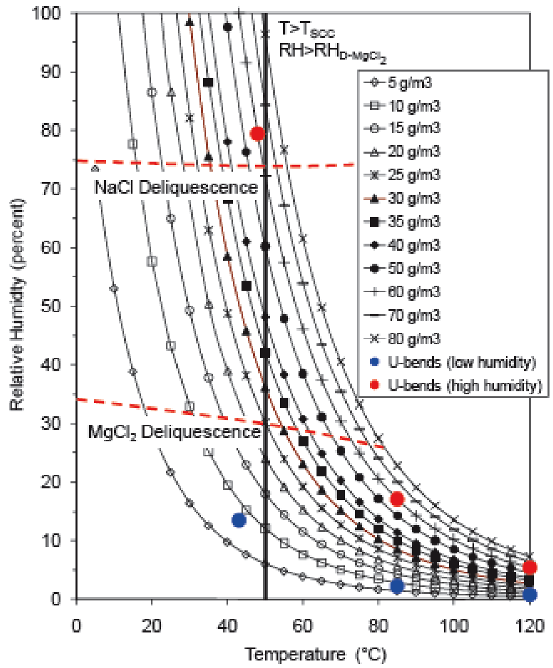


Figure 43 Evolution of the Relative Humidity as a Function of Temperature Computed for Various Absolute Humidity Values. The Region Between the Red (Maximum Humidity) and Blue (Minimum Humidity) Symbols Indicate the Expected Environmental Conditions Near the U-Bend Surface in the Salt Fog Test

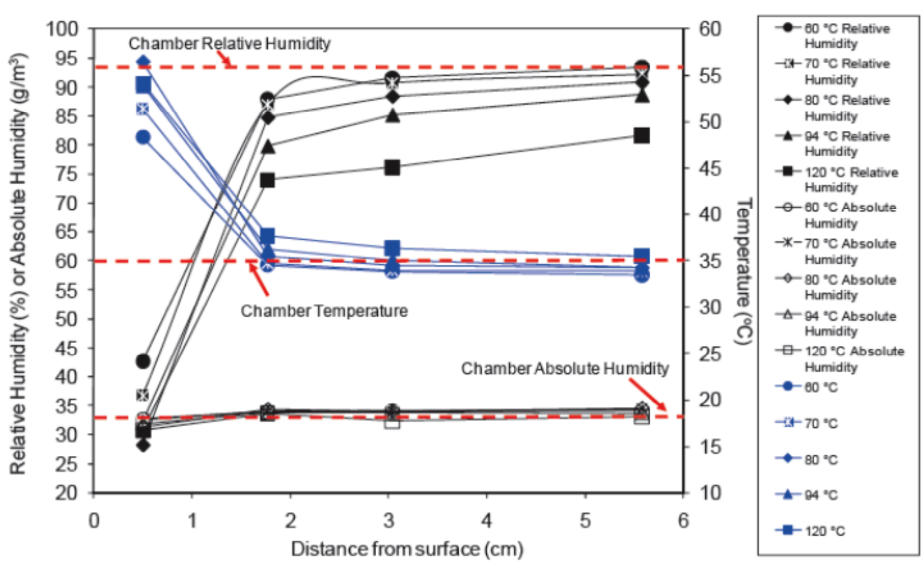
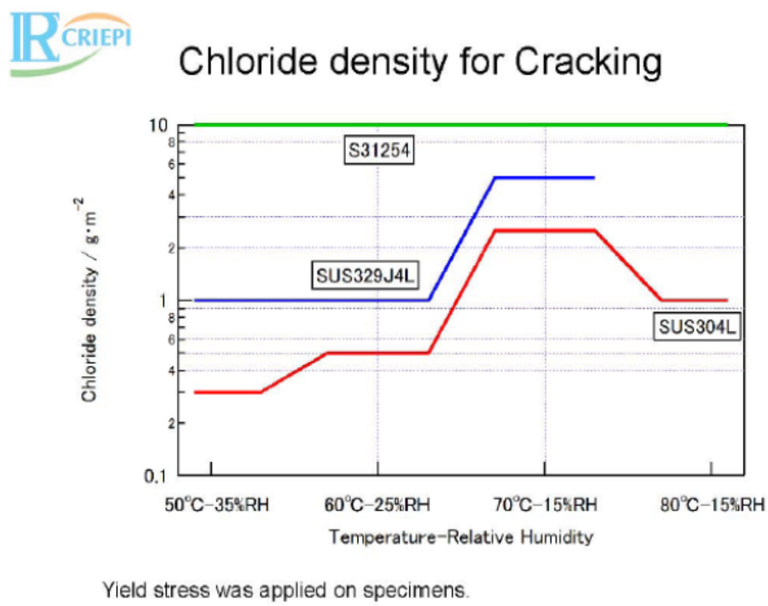


Figure 50 Temperature, Absolute Humidity, and Relative Humidity Profiles as a Function of Distance from the U-Bend Samples Heated at Different Temperatures

Salt Deposition Threshold (Reference 5)

304 and 304L=0.3 g/m2 as Cl; 316L=1 g/cm2 as Cl



$$Q = \{5.07 - 0.022\,(T - 30)\}\,(1.55\,t \times C/10000)^{1/2}$$

Q: amount of salt deposition (mg/m^2 as Cl$^-$)
T: temperature of canister surface (°C)
t: time (hour)
C: airborne salt concentration (μg/m^3 as Cl$^-$)

$T = -0.575\,t + 89$, t: time (year)

(Shirai, et al., 2011)

Example: Using above equation, a salt air concentration greater than 50 mg/m2 as Cl is required for the salt deposition to reach the threshold for 304/304L (600 mg/m2 as Cl is required to reach threshold for 316L), within the first 60 years of storage.

Residual Stress Threshold

None available at this time.

Data Needs benefited by In-situ inspections

Cask Surface Temperature = correlate actual temperature with analytical models

Cask Surface RH = correlate relationship that bulk AH equals cask surface AH

Cask Surface Salt Deposition = correlate relationship of surface salt deposition with general area surface deposition

Visual Examination = correlate actual conditions with expected conditions

References

1. Effects of Marine Environments on Stress Corrosion Cracking of Austenitic Stainless Steels, EPRI 1011820, September 2005
2. Climactic Corrosion Considerations for Independent Spent Fuel Storage Installations in Marine Environments, EPRI 1013524, June 2006
3. Atmospheric Stress Corrosion Cracking Susceptibility of Welded and Unwelded 304, 304L, and 316L Austenitic Stainless Steels Commonly Used for Dry Cask Storage Containers Exposed to Marine Environments, US NRC, NUREG/CR-7030, October 2010
4. An Evaluation of Stress Corrosion Cracking (SCC) of Stainless Steel Canister in Marine Environment for Long-Term Dry Storage of Spent Nuclear Fuel, Presentation by T. Ahn et al, EPRI ESCP Meeting December 6-8, 2011
5. Sea Salt Deposition on the Canister Surface of Concrete Cask, Presentation by M Wataru et al, ISSF2010 in CRIEPI, November 16, 2010
6. Stress Corrosion Cracking of Stainless Steel Canister of Concrete Cask, Presentation by J. Tani et al,