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An Approach to Model Abstract of Pitting Corrosion in the Management of Spent Nuclear Fuel and High-Level Waste

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- Note:

  The NRC staff views expressed herein are preliminary and do not constitute a final judgment or determination of the matters addressed or of the acceptability of any licensing action that may be under consideration at the NRC.

  This presentation is based on the author's previous analysis.*

* T. Ahn, "Corrosion Damage of Canister (or Container) in Nuclear Waste Management: Perspective and an Approach for Model Abstraction," NRC ADAMS, www.nrc.gov/reading-rm/adams.html - ML13022A324, 2012

Outline

- Introduction
- Background
- Pitting Factor and General Corrosion
- Limited Pit Area: repassivation and cathode capacity
- Pit Repassivation in Crevice
- Active Dissolution of Crevice
- Pit-Induced Stress Corrosion Cracking
- Summary

Introduction

- Canisters (or containers) provide confinement of radionuclides from disposed/stored spent nuclear fuel and high-level waste
- Evaluation of canister performance assumes conditions exist for pitting and crevice corrosion, or stress corrosion cracking (SCC)
- For a pitting induced degraded canister, limited radionuclides may be released through the opening area

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Introduction (continued)

- **Uncertainties will be accommodated by inspection and mitigation strategies to ensure safety over long time periods**

- **Applying simplified and conservative system performance models**

- **Elicit expert views on the approach**

Background: Low General Corrosion Rate or Limited Opening Area

- **Selection of Confinement material has low general corrosion rate**
  - ✓ **anoxic neutral (non-chloride) environments such as geologic disposal in granitic host rock**
  - ✓ **long-term passive film**
- **Pit opening area could result in limited amount of radionuclide release**

Radionuclide Source Term: degradation of spent nuclear fuel and cladding

Transport Path: air, groundwater

Area Boundary: dose

Background:
Example Material and Environment

- Stainless Steels, Carbon Steels, and Nickel-Based Alloys

- Chloride Environments

- Not limited to these metals and environments

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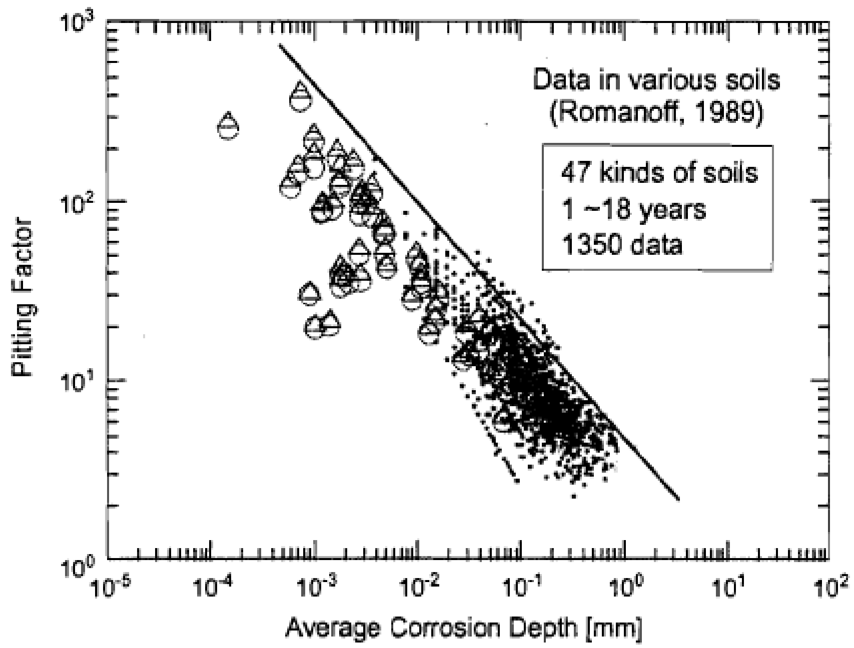
Background: Management of Spent Nuclear Fuel and High-Level Waste

- **Addresses long-term geologic disposal under various geochemical conditions at different potential sites:**
  - ✓ **safety during permanent isolation – aqueous corrosion of chloride, carbonate**
  - ✓ **assume no inspection and mitigation of canister**
- **Extended interim dry storage:**
  - ✓ **chloride-induced humid vapor corrosion**
  - ✓ **inspection and mitigation (remediation, if needed) may be pursued**

Pitting Factor and General Corrosion

- **Non-passive carbon steel in anoxic neutral (non-chloride) environments such as geologic disposal in granitic host rock**



(JNC, 2000)

Pitting factor is the ratio of the pit depth to the general corrosion depth, reaching to 1 with time in carbon steel under reducing and non-chloride disposal environmental conditions (Jung, et al., 2011; Féron, et al., 2008). Variation of the pitting factor for carbon steel with the average depth of corrosion derived from long-term corrosion tests and short-term laboratory measurements

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Limited Pit Area under: Repassivation and Cathode Capacity

Passive steels and nickel-based alloys in chloride environments

(1) Repassivation Model (Shibata, 1983)

- **Repassivation rate is independent of corrosion potential whereas pit initiation (survival) rate increases with corrosion potential**
- **The repassivation may be delayed (i.e., latent repassivation)**

(2) Point Defect Model (since Macdonald, et al., 1981; recent assessment by Ahn et, al., 2013)

- **Point defects (e.g., interstitial or vacancy) move and form voids.**
- **A large number of initially formed pits are expected to repassivate with time (i.e., latent repassivation)**
- **Exception: longer-term nucleation may occur at high pH and low ionic strength.**

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Limited Pit Area: Repassivation and Cathode Capacity (continued)

Pit Survival Rate (from Point Defect Model) ~ EXP [- λ (t - t_{ind})]

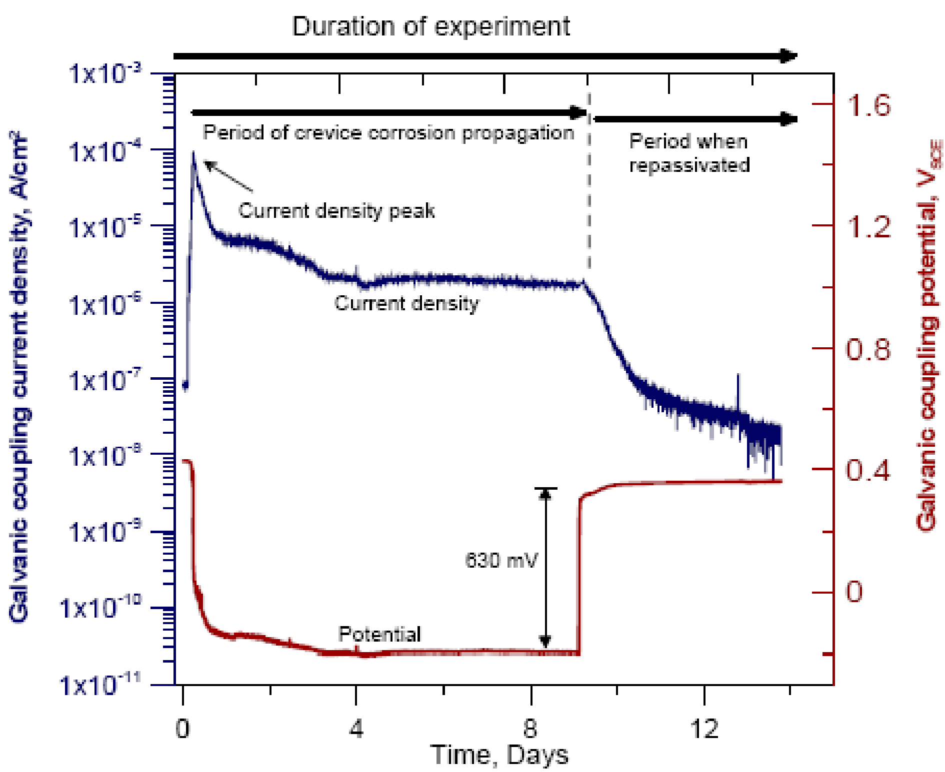
λ : latent repassivation constant

t : time

t_{ind} : pit induction time

(3) Thin water layer and low cathode capacity near a pit limits pit density and depth (Shukla, et al., 2011; Cui, et al., 2005)

Pit Repassivation in Crevice



- Measured Current Density and Potential Using the Single Crevice Assembly for an Alloy 22 Cylindrical Specimen Galvanically Coupled to a Large Alloy 22 Plate in 5 M NaCl Solution with the Addition of 2 x 10^{-4} M $CuCl_2$ at 95 ºC [203 ºF], mV(SCE) (He and Dunn, 2005)

- A large number of pits initially formed in the crevice were repassivated under open-circuit conditions

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Active Dissolution in Crevice

- **Wide-spread corrosion attack in stainless steel appeared under crevice corrosion in 5% NaCl fog at ambient temperature and ~20 days (DeForce, 2010). Long-term effects have not been studied.**
- **Pits inside crevice may form when the crevice electrode potential is in the passive regime, reaching a modified breakdown potential in the crevice.**
- **When the crevice electrode potential reaches the anodic dissolution regime, faster dissolution of the crevice area may occur.**

Pit-Induced SCC

Probability	0.001	0.05	0.25	0.75	0.95
K (MPa $m^{1/2}$)	0.43	1.57	2.59	4.57	6.94

Cumulative probability of stress intensification factor,
$K(MPa\ m^{1/2}) = \pi^{1/2}$ x stress x $(crack\ size)^{1/2}$, 1 MPa $m^{1/2}$ = 0.91 ksi $in^{1/2}$

- **A Precursory Step for SCC**
- **Data on SCC with Pitting in a Chloride-Bearing Environment with Sufficient Stress and Aqueous Conditions (EPRI, 2005).**
- **Cumulative Probability of Stress Intensification Factor Using Observed Pit Sized and an Example Weld Stress (Shirai, et al., 2011).**
- **Possible Stress Intensifications Fall in the Range of Values in Measured Laboratory Tests (EPRI, 2005)**

Summary

- The canister serves to confine radionuclides. If a canister degrades, limited radionuclides may be released through the pit opening
- For carbon steel in anoxic (non-chloride) environment, pitting occurs from the initial oxygen environment, followed by a very low general corrosion rate.
- The pit area can be limited by repassivation and cathode capacity in passive metals.
- A large number of pits initially formed in the crevice are repassivated under open-circuit conditions of nickel-based alloy (Alloy 22) in 5 M NaCl solution with copper chloride addition at 95 ºC [203 ºF].
- Active dissolution of stainless steel occurred under crevice corrosion in 5% NaCl fog at ambient temperature. Long-term effects continue to be studied.
- Pits in stainless steel can serve as a precursory step for SCC in a chloride-bearing environment.

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