Used Nuclear Fuel Storage

Aging Management

Keith Waldrop
Principal Technical Leader

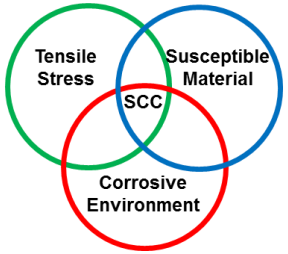
31st Spent Fuel Management Seminar
13 January 2016

Overview

- Canister Aging Management
  - Modeling
  - Inspection capability
- High Burnup Aging Management

Welded Stainless Steel Canister Aging Management

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



- Goals
  - Develop aging management guidance for recommended inspection and mitigation
  - Develop and demonstrate inspection capability

Failure Modes and Effect Analysis

- FMEA process is structured to systematically identify the potential failure modes of a system, their relative likelihood, and their consequences to the system
- Scope limited to welded stainless steel canisters exposed to air during the lifetime of extended storage
- Focused on identifying credible failure modes for welded SS canisters under design basis conditions
- **Chloride-Induced Stress Corrosion Cracking (CISCC)** identified as the most likely of potentially active degradation mechanisms to lead to through wall penetration; would release helium overpressure, then allow air ingress over time; not likely to release particulates

Flaw Growth and Tolerance Assessment

- Crack growth model developed based on limited available data
  - Timeframe for initiated crack to go thru wall
- Assessments performed using load data available in FSARs; accident loads (such as canister drop) not included; accident pressure (such as resulting from blocked vents) was evaluated
- Canisters are highly flaw tolerant under typical loads and under accident pressure
- Depressurization is likely to be relatively rapid compared to later steps
- Air ingress will take much longer (likely years) to replace most of the helium than depressurization time
  - “Breathing” mechanism is more rapid than diffusion
- Helium depressurization and air ingress rates are strongly dependent on crack opening displacement and area

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
  - 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

Confinement Integrity Assessment

- Objective:
  - Develop and document a model that can calculate probability of a through-wall flaw for a given set of input conditions
  - Compare relative change in probability of a through-wall flaw for a variety of inspection regimes
  - Use these comparisons to develop aging management guidelines that optimize inspection resources
- Approach:
  - Model applies Monte Carlo analysis based on flaw growth analysis, with consideration of initiation and modeled inspections
- Inspection Regime Variables Modeled:
  - Inspection coverage (% of canister weld heat affected zones and crevices)
  - Probability of detection (variations on this parameter will inform NDE project)
  - Inspection scope (number of canisters inspected and susceptibility ranking)
  - Inspection frequency (time interval between inspections)

CISCC Aging Management Guidelines

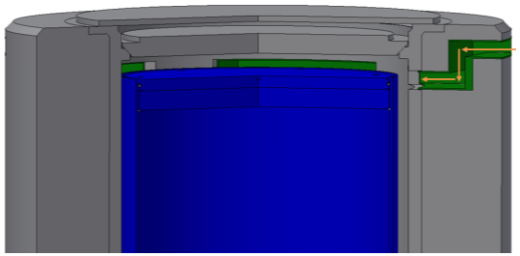
- EPRI developed technical basis will be applied to providing aging management guidance specific to the issue of CISCC
- EPRI working with Advisory Panel (members, vendors, national lab) to review and revise drafts
- EPRI guidance is likely to precede action from ASME Task Group
- Working with NEI task group developing *Industry Guidance for Operations-Based Aging Management for Dry Cask Storage (NEI 14-03)*
- Seeking collaboration and consensus
- Publication in 2016

EPRI Technical Reports

- 2013
  - Failure Modes and Effects Analysis (FMEA) of Welded Stainless Steel Canisters for Dry Cask Storage Systems. 300200815
- 2014
  - Flaw Growth and Flaw Tolerance Assessment for Dry Cask Storage Canisters. 3002002785
- 2015
  - Susceptibility Assessment Criteria for Chloride-Induced Stress Corrosion Cracking (CISCC) of Welded Stainless Steel Canisters for Dry Cask Storage Systems. 3002005371
- 2016
  - *Aging Management Guidelines for Chloride-Induced Stress Corrosion Cracking (CISCC) of Welded Stainless Steel Canisters for Dry Cask Storage Systems*

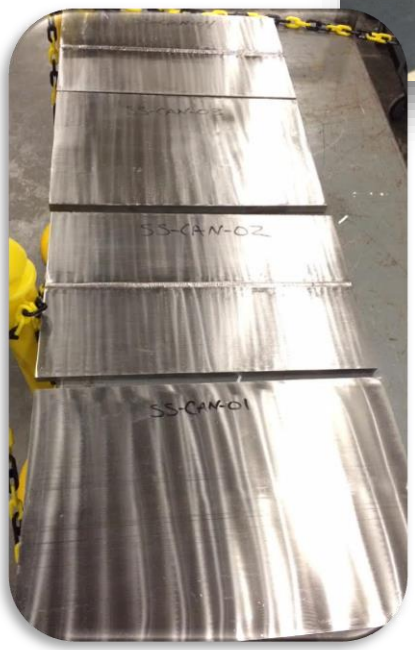
NDE for DCSS

- Issue: Canister inspections pose challenging conditions for NDE
  - High radiation dose (1-10,000 R/hr)
  - High temperatures (~70-250+°F)
  - Challenging access
- Action: Build Mockups, Demonstrate NDE capability, Develop delivery system(s), Collaboration
- Goals: In-situ demonstration of NDE probe in combination with delivery system in 2017; encourage demonstration of multiple technologies by multiple stakeholders



Mockups

- Existing mockups around the country were identified
  - None had flaws
  - Some cannot have flaws
  - Some sites have canisters only and others have the overpack as well
- EPRI has **8 QA flaw mockups** manufactured for industry use.
  - EPRI mockups have already been used by 2 vendors and 2 universities
- Sandia National Labs sent EPRI a full diameter, partial length mockup for continued development



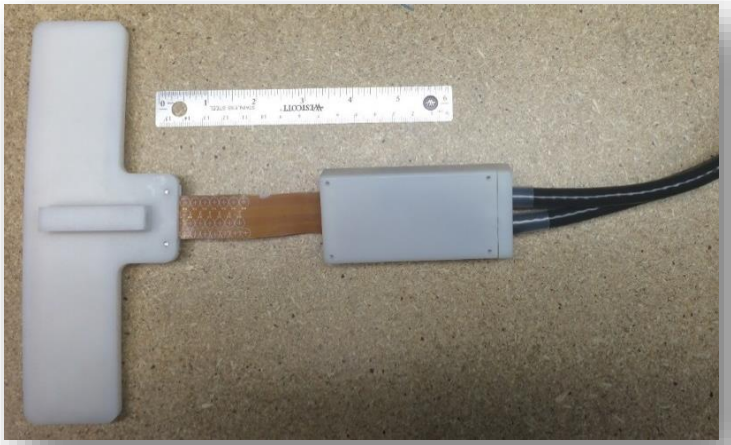
NDE Techniques Under Development at EPRI

EPRI Projects

- Eddy Current Array (ECA)
  - Using ECA in a new way to help differentiate flaws of interest
  - Excellent results obtained to date
- Guided Waves
  - Ability to find defects in inaccessible areas (under rails, supports, etc.)
- Acoustic Emission
  - Potential to monitor from outside of the cask
- Supplement above inspections using visual imaging (not VT)

Vendor Development Needs

- Gaps correlate to vendor strengths
  - Visual Techniques (VT-1 and VT-3)
  - UT Techniques for defect sizing
- Vendors are actively working in these (and other) areas



Robotic Development at EPRI

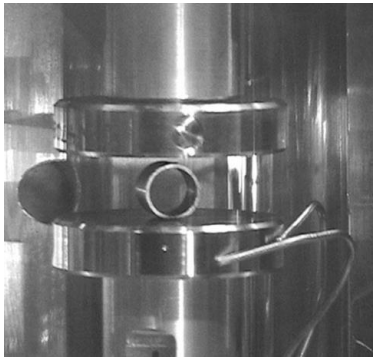
- EPRI is developing two different robotic delivery systems to improve inspection capabilities
  - Magnetic wheel robot
  - Vacuum suction robot

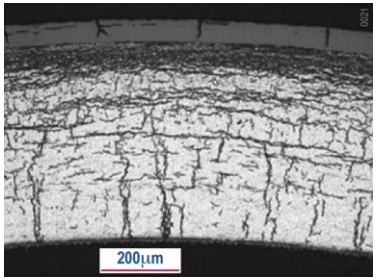
Magnetic wheel robot adheres to magnetic

Vacuum robot adheres to most

High Burnup Spent Fuel Data Project

- Issue
  - Lack of confirmatory data on high burnup fuel under real dry storage conditions
- Goals
  - Provide data on behavior of multiple types of high burnup cladding under typical dry storage conditions
  - Provide data for benchmarking models to predict performance of high burnup fuel over extended time periods



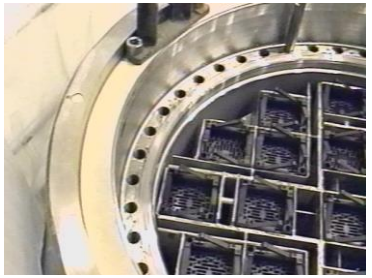


High Burnup Spent Fuel Data Project – Aging Management

- Calvert Cliffs and Prairie Island license renewals
  - AMP for HBU fuel relies on DOE/EPRI HBU Dry Storage Research Project
- Others storage license renewals under review or coming (10 licenses/CoCs, 58 sites by 2021)
- Transport
  - US plans for consolidated storage in 2020s
  - Other countries

High Burnup Spent Fuel Data Project

- Key activities
  - Identify, extract and ship sister rods to a national lab for baseline properties
  - Submit and obtain an NRC license amendment to store the cask
  - Modify the cask and fabricate instrumentation
  - Load the cask
  - Collect data (temperatures, gas composition)
    - Data will be available as soon as cask is loaded
- Schedule
  - Began in 2013
  - Load the cask and begin collecting data in 2017
  - Activity anticipated through 2027
    - Continue collecting data
    - Ship cask to fuel examination facility
    - Open cask, inspect, extract rods for post-characterization
  - Continue to store and monitor



Together…Shaping the Future of Electricity