Office Of Nuclear Energy
Light Water Reactor Sustainability Program
Annual Review Meeting

Online Monitoring of Material Aging and Degradation
Vivek Agarwal
Idaho National Laboratory

September 16-18, 2014
Project Overview

Goal and Objectives

- The overall goal is to develop and demonstrate structural health management capability for passive assets in nuclear power plants.
- Structural health management will produce actionable information regarding structural integrity that supports operational and maintenance decisions.
- Initial project focuses on concrete structures in nuclear power plants.
- All nuclear power plants contain concrete structures:
  - Primary containment
  - Containment internal structures
  - Secondary containments/reactor buildings
  - Spent fuel pools and Cooling towers.
- The objective is to develop and demonstrate a health diagnosis and prognosis framework for aging concrete structures.
- Integrate into Electric Power Research Institute’s Fleet-Wide Prognostic and Health Management (FW-PHM) Suite software.
Participants

- Performed jointly by INL and Vanderbilt University
  - Principal Investigator – Vivek Agarwal (INL) and Sankaran Mahadevan (Vanderbilt University)
  - Collaborate with Oak Ridge National Laboratory on developing the scientific basis for modeling the degradation mechanisms and determining types of sensors to monitor the degradation
  - Extend EPRI’s FW-PHM capability to passive assets

Enable collaboration across different LWRS pathways, Universities, EPRI, Utilities, and Vendors

Leverage national and international research efforts

Project timeline FY2014 to FY2018
Accomplishments

Milestones

- Identification of degradation modes in nuclear concrete structures
- Non-destructive evaluation techniques
- Concrete structure health management framework

Deliverable

- Interim report on Concrete Degradation Mechanisms and Online Monitoring Techniques
Some Current Concrete Concerns

- Alkali-Silica Reaction (ASR) in reinforced concrete structures (Seabrook)
- Delamination cracking in tendons (Crystal River and Davis-Besse)
- Seismic impact on aged concrete structures

Source: U.S. Nuclear Regulatory Commission (NRC)
Alkali-Silica Reaction

- **ASR** is an intrinsic chemical reaction that forms a gel in concrete pores, expands, and causes stress and cracking of concrete.
- Can be associated with corrosion of steel reinforcement bars and other steel structures embedded in the concrete.
- Water containing sulfate or chloride causes ASR.

**Challenges**

- Extent of ASR occurrence
  - location throughout the plant
  - position within the thickness of the concrete wall
- Extent to which ASR has reduced mechanical properties of concrete.
Besides ASR, other degradation modes exist:

- Freeze-thaw
- Corrosion
- Sulfate Attack
- Cracking
A systematic approach proposed to assess and manage aging concrete structures requires an integrated framework.
Degradation Modeling

- Leverage existing modeling efforts
- Account for interaction between damage mechanisms
- Connect damage mechanisms to signatures
  - E.g. delamination, spalling, cracking, rebar corrosion, rebar debonding
- Facilitate damage diagnosis by combining models and modeling data

09/16/2014

LWRS Panel
Uncertainty Quantification

- **Aleatory uncertainty**
  - Natural variability
    - System properties
    - Operating environments

- **Epistemic uncertainty**
  - Data uncertainty
    - Sparse, imprecise, qualitative, faulty, or missing data
    - Big data (data quality, relevance, processing)
  - Model uncertainty
    - Model form, model parameters, solution errors

- **Bayesian network suitable for uncertainty integration**
  - Facilitates both diagnosis and prognosis
Aging Management Toolbox / Software

- Organize asset data in an **hierarchical** and **structured** manner
- Perform **diagnosis** and **prognosis**
- Toolbox/software should have **open architecture** for managing and evaluating data

Concrete Structures Aging References (COSTAR)

Fleet-wide Prognostic and Health Management

09/16/2014

LWRS Panel
Technology Impact

License renewal

- Has the durability and strength of reinforced concrete decreased
- Capable of withstanding physical and chemical attacks
- Difficult to assess the relationship between durability and performance as concrete ages
- Mitigation/remediation strategies
- Need a basis for establishing the probability of success of those strategies
Summary and Path Forward

- Individual techniques for damage modeling, health monitoring, data analytics, and uncertainty quantification
  - Initial focus on ASR damage
- Consider multiple damage mechanisms in concrete structures
  - Demonstrate for small structural components
- Integrate multi-physics simulation, full-field imaging, data analytics, and uncertainty quantification
  - Demonstrate for large structures
- Develop risk management framework
  - Demonstrate for representative structures
- Promising directions
  - Full-field imaging
  - Combination of multiple techniques (optical, thermal, acoustic)
  - Automated data collection (robotic vehicles)

09/16/2014 LWRS Panel