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

Online Monitoring of Material Aging and Degradation

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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 decision
- 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
  - Spend 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

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Project Overview (continued -1)

- **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**

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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**

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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)

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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**

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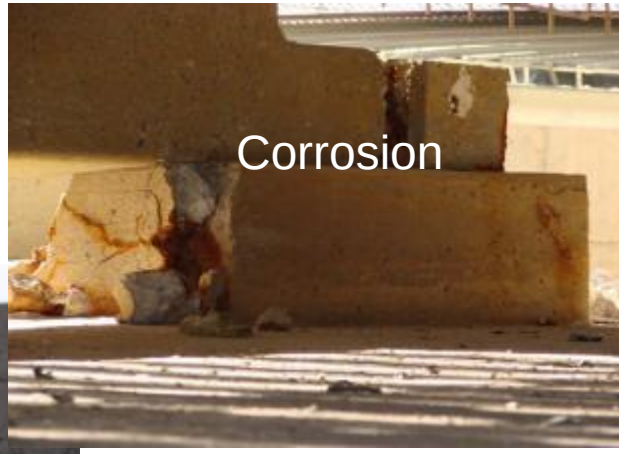
Other Degradation Modes

- **Besides ASR, other degradation modes exist**



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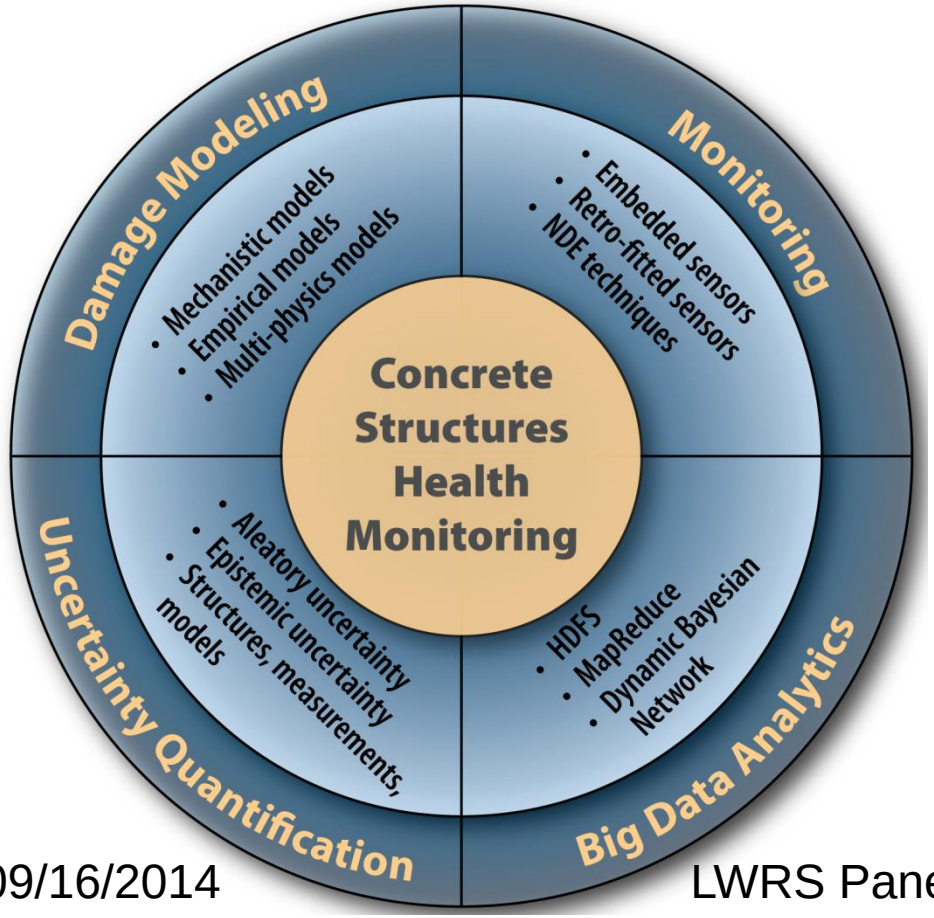
Concrete Structural Health Monitoring Framework

- **A systematic approach proposed to assess and manage aging concrete structures requires an integrated framework**



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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**

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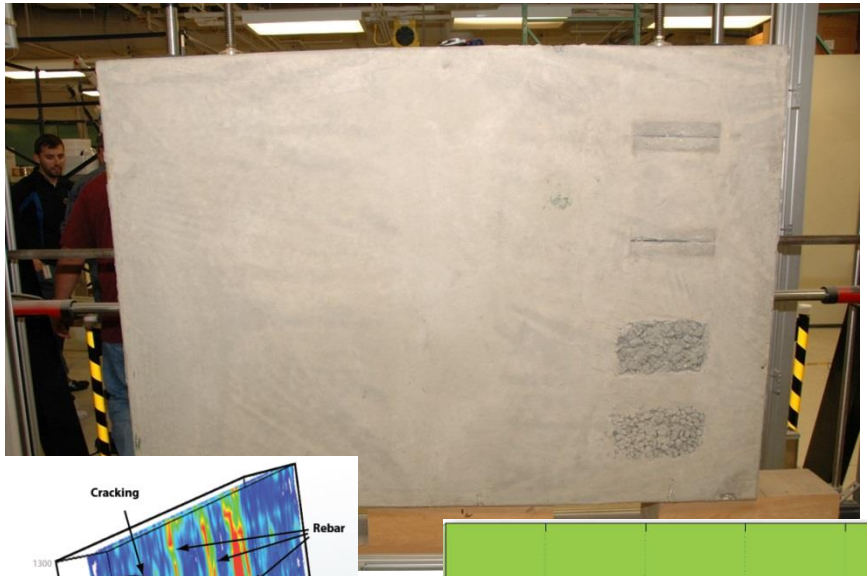
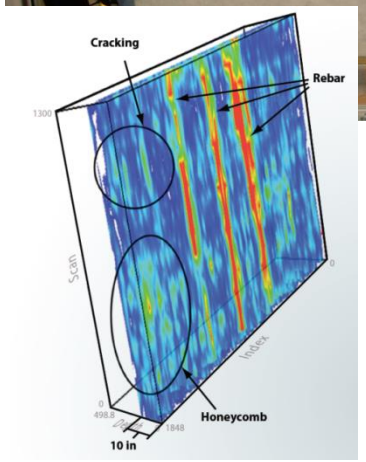
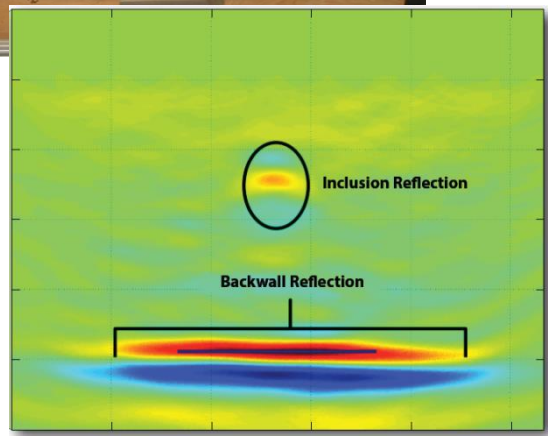
NDE of Concrete at ORNL







- **Shear-Wave Ultrasonics**
  - Ultrasonic linear array device
  - Shear wave ultrasonic array device
- **Ground-penetrating radar**
- **Air-coupled impact-echo**
- **Air-coupled ultrasonic surface wave**
- **Semi-coupled ultrasonic tomography**

Clayton, D. *Non-destructive Evaluation Techniques for Nuclear Power Plant Concrete Structures.* LWRS Newsletter, February, 2014

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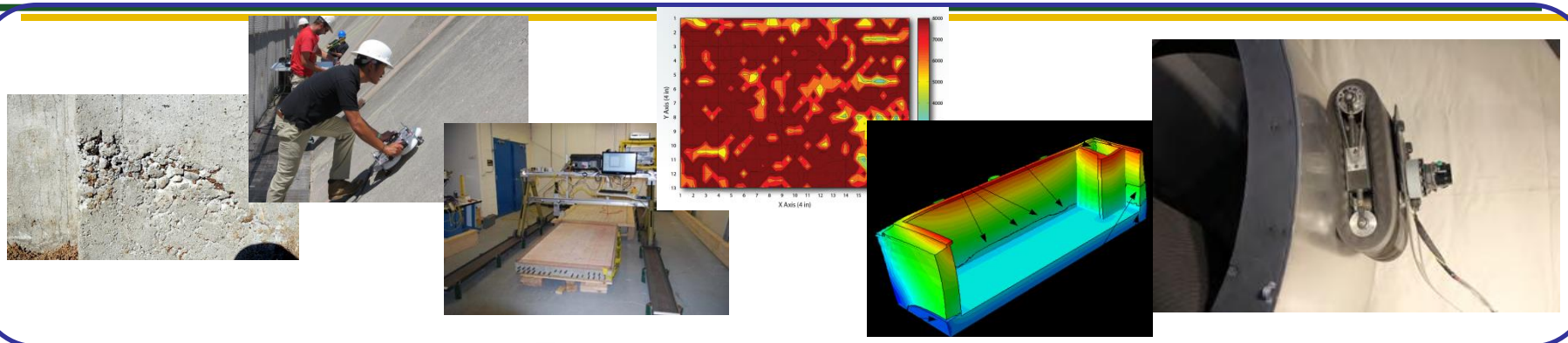
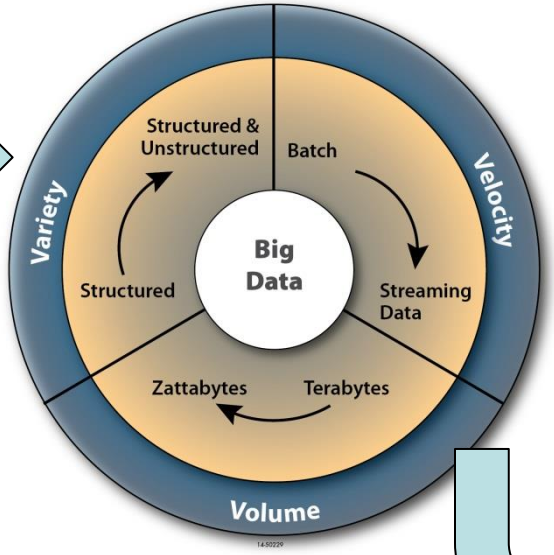
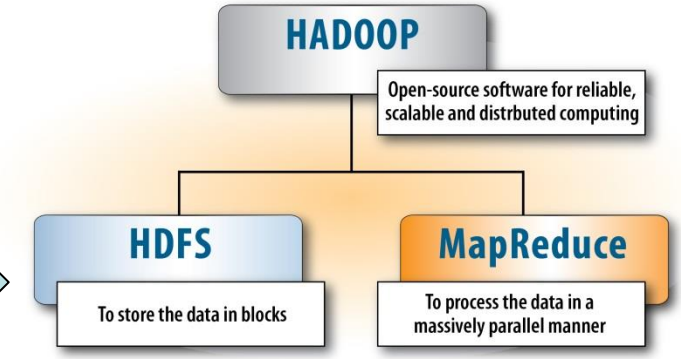
Data Analytics







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

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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)

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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

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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)