



U.S. DEPARTMENT OF
ENERGY

Nuclear Energy

**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 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
 - 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



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



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**



Other Degradation Modes

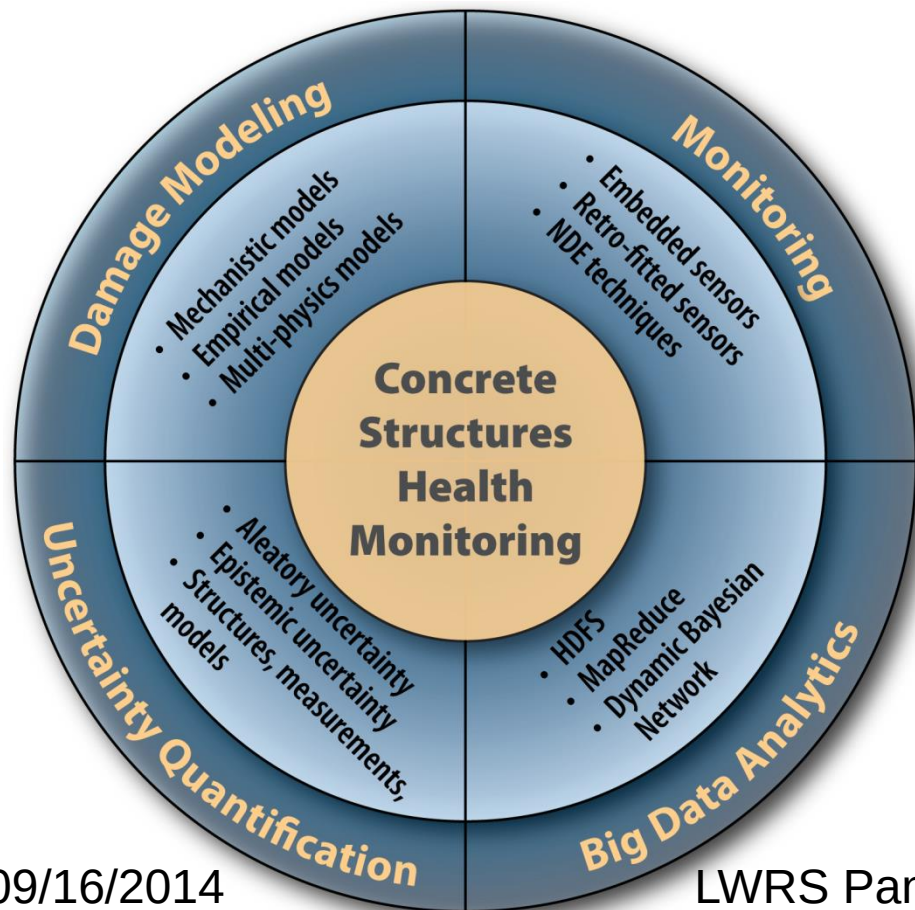
■ Besides ASR, other degradation modes exist





Concrete Structural Health Monitoring Framework

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



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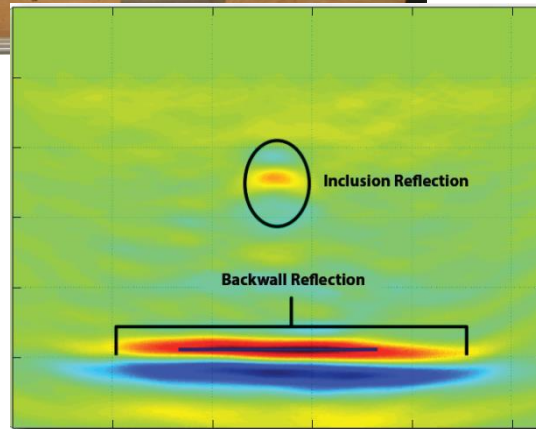
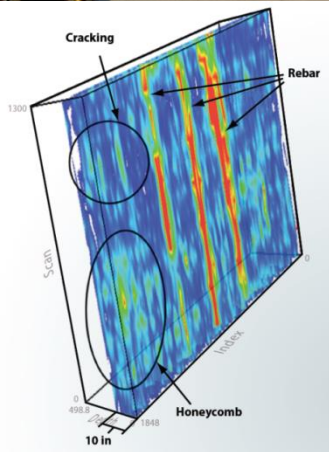


Degradation Modeling

- **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**



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**

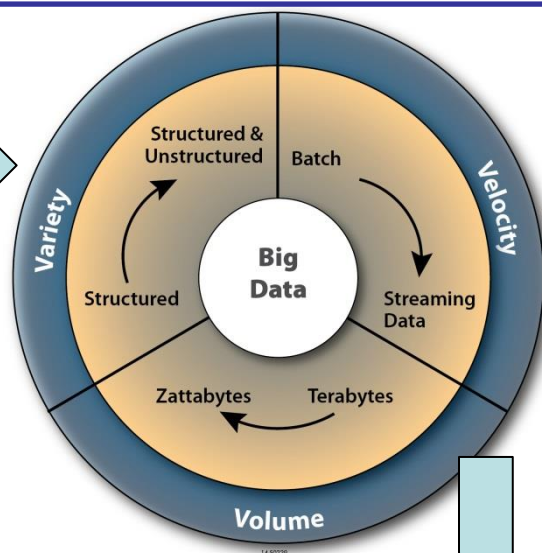
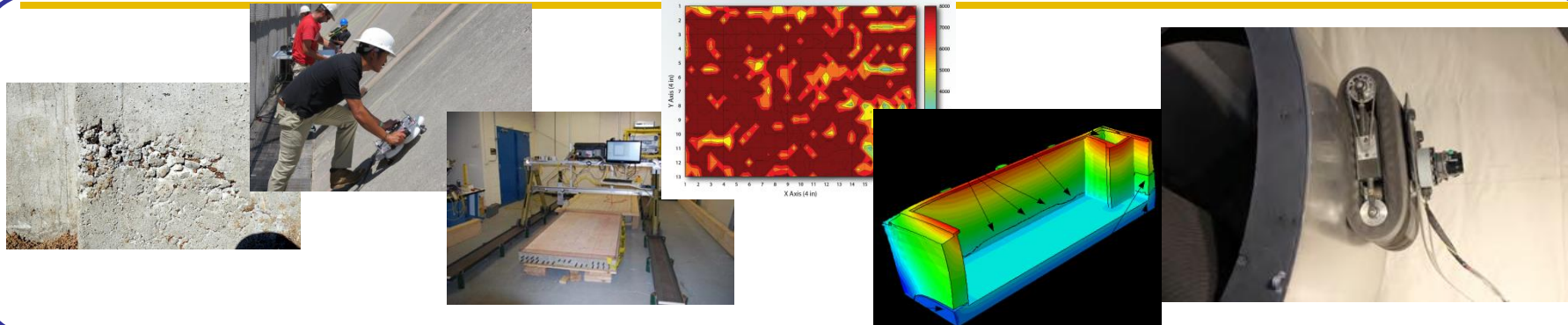
Clayton, D. *Non-destructive Evaluation Techniques for Nuclear Power Plant Concrete Structures*. LWRS Newsletter, February, 2014



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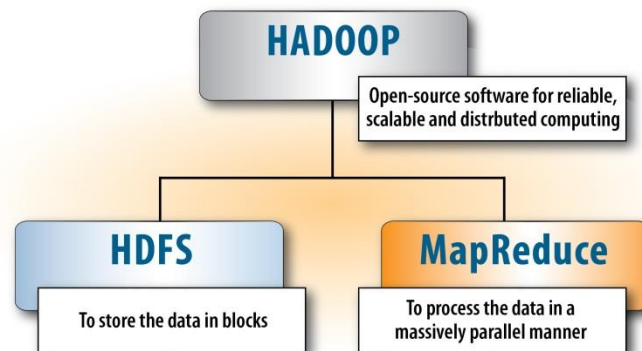
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Data Analytics



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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

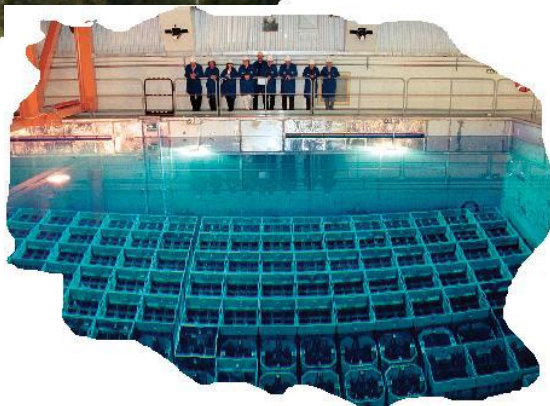
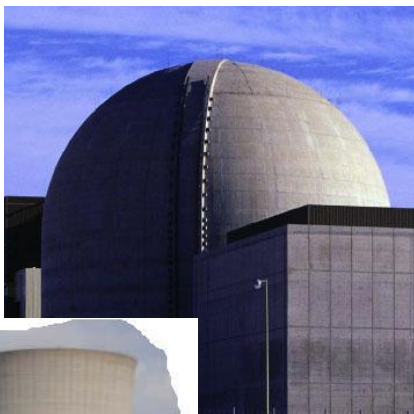
- Organize asset data in an **hierarchical** and **structured** manner
- Perform **diagnosis** and **prognosis**
- Toolbox/software should have **open architecture** for managing and evaluating data

Concrete Structures Aging References (COSTAR)





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)