Overview of NRC Research in Support of Developing the Technical Bases for Subsequent License Renewal

Rob Tregoning
Nuclear Regulatory Commission

Regulatory Information Conference
March 8, 2016

Outline

- Research objectives and structure
- Neutron fluence (i.e., radiation dose) evaluations
- Reactor pressure vessel (RPV) embrittlement at high fluence
- Aging of reactor vessel internals
- Research on concrete degradation
- Electrical cable qualification and condition assessment
- Summary

Research Objectives & Structure

- Objectives of NRC's research activities
  - Support NRC's evaluation of subsequent license renewal (SLR) applications
  - Develop technical basis for providing reasonable assurance of safe operation
  - Confirm adequacy of the nuclear industry's aging management programs
- Structure of NRC's research activities
  - **Near-term**: Complete before first license application is received
  - **Longer-term**: Complete before first plant enters into the subsequent license renewal period

Neutron Fluence Evaluations

Ben Parks, Matthew Hardgrove,
and Jay Wallace
Nuclear Regulatory Commission

Key Technical Issues & Research Initiatives

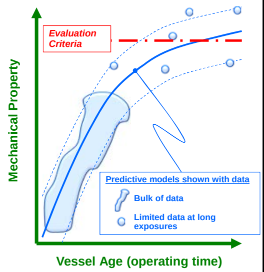
- Guidance for determining fluence [summarized in Regulatory Guide (RG) 1.190] is focused on the reactor vessel, in the area surrounding the reactor core
- Broadening the application of fluence methods in RG 1.190 requires new guidance:
  - Calculating fluence over longer distances from the core
  - Qualifying methods to calculate and use fluence for locations other than just the core periphery (e.g., vessel nozzles, concrete bioshield, upper internals)
- Research has been initiated to address these issues.
  - Currently scheduled for completion in late 2018.

Reactor Pressure Vessel Embrittlement at High Fluence

Mark Kirk, Carolyn Fairbanks,
Allen Hiser, and Robert Tregoning
Nuclear Regulatory Commission

Key Technical Issues

- **Adequacy of predictive models**
  - Evaluate validity of current models to the end of the SLR period
  - Ensure that the additional regions of the reactor pressure vessel subject to radiation effects during SLR are adequately addressed
- **Adequacy of generic evaluation criteria**
  - Evaluate need to update criteria to the end of the SLR period
  - Need for updates driven by developing knowledge on embrittlement trends and plant operating needs



Research Initiatives

- **Indirect measurement of fracture toughness**
  - **Objective**: Evaluate validity of current model of radiation effects to the end of SLR
  - **Approach**
    - Compile applicable data and supporting documentation.
    - Evaluate technical basis to determine adequacy of current model
  - **Status**: Evaluation is ongoing
  - Expected completion in 2016
- **Direct measurement of fracture toughness**
  - **Objective**: Develop method to evaluate radiation effects by directly measuring fracture toughness
  - **Approach**
    - Develop an ASME Code Case
    - Once completed, NRC will review adequacy of Code Case
  - **Status**: Code Case development is ongoing
- NRC is also monitoring industry activities to develop data on high-fluence radiation effects, commensurate with the end of SLR

Reactor Pressure Vessel

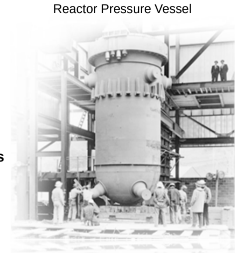


Photo Credit: https://www.asme.org/about-asme/who-we-are/engineering-history/landmarks/47-shippingport-nuclear-power-station

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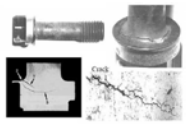
Aging of Reactor Vessel Internals

Appajosula Rao, Matthew Hiser,
Robert Tregoning, Amy Hull,
James Medoff, and Seung Min
Nuclear Regulatory Commission

Key Technical Issues

- Understand irradiation-assisted degradation (IAD) for stainless steels and high strength bolting at higher fluences associated with the SLR period
- Evaluate loss of fracture toughness for cast austenitic stainless steels (CASS)
  - Combined effect of thermal and neutron embrittlement
  - Thermal embrittlement from prolonged exposure at operating temperatures

Cracking in a PWR Baffle Bolt



Reference: NUREG/CR 7153, Expanded Materials Degradation Assessment Volume 2: Aging of Core Internals and Piping Systems, Prepared by Expert Panel: P. Andresen, K. Arioka, S. Bruemmer, J. Busby, R. Dyle, P. Ford, K. Gott, A. Hull, R. Staehle. 351pp, Oct. 2014.

Research Initiatives: IAD

Fluence (dpa)	Plate	Weld	Heat-Affected Zone
1	Previous research	Ongoing	
2			
5		Ongoing	
8			
10	Ongoing	Beyond expected fluence at 80 years	
25			
50			
65	Planning		
80			

Expected fluence at 80 years

Testing and characterization includes crack growth rate (CGR), fracture toughness (FT), tensile properties, and microstructure (void swelling).

IAD Research Initiatives: Stainless Steel Plate Testing

- **Scope**
  - Plate material at 10, 25, 50 displacements per atom (dpa)
- **Approach**
  - Harvest materials from the reactor vessel internals from the Zorita (Spanish) reactor
  - Evaluate mechanical properties and microstructure
- **Collaboration**
  - Participating with Electric Power Research Institute (EPRI) and international regulators and utilities
- **Status**
  - Harvesting complete; testing is ongoing
- Expected completion by the end of 2016

IAD Research Initiatives: Stainless Steel Weld and HAZ Testing

- **Scope**
  - Weld/heat-affected zone (HAZ) material at 1, 2, 5, and 8 dpa
- **Approach**
  - Harvest weld and HAZ materials from core barrel of Zorita reactor
  - Test as-harvested materials without further irradiation
  - Conduct additional irradiation to achieve higher fluences
  - Evaluate mechanical properties and microstructure
- **Collaboration**
  - EPRI
  - Halden Reactor Project
- **Status**
  - Harvesting complete; testing and irradiation will be initiated in 2016
- Expected completion in 2024

IAD Research Initiatives: High-Fluence Stainless Steel Testing

- **Scope**
  - Stainless steel plate material at 65, 80 dpa
- **Approach**
  - Further irradiate Zorita plate materials followed by material evaluation
  - Evaluate mechanical properties and microstructure
- **Collaboration**
  - Planned participation with EPRI
  - Soliciting participation by DOE and others
- **Status**
  - Searching for optimal irradiation source and developing testing conditions
  - Evaluating options to most efficiently implement program

Research Initiatives: CASS

- **CASS and welds gap analysis**
  - **Scope**
    - Update database of CASS fracture toughness properties
    - Address combined neutron and thermal effects on fracture toughness
  - **Approach**
    - Conduct literature review to gather latest research
    - Update method to evaluate fracture toughness
  - **Status**: Two reports are being finalized: NUREG/CR-4513, Rev. 2; Letter report on welds
  - Expected completion in June 2016
- **Testing of irradiated CASS**
  - **Scope**: Measure combined neutron and thermal effects on fracture toughness
  - **Approach**
    - Thermally age material to 10,000 hours, then irradiate material to 3 dpa
    - Perform fracture toughness testing in reactor environment
  - **Status**: Currently conducting testing
  - Expected completion in 2017

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Research On Concrete Degradation

Madhumita Sircar, Jacob Philip,
and Angela Buford
Nuclear Regulatory Commission

Key Technical Issues

- Expanded Materials Degradation Assessment identified four degradation mechanisms with potential knowledge gaps for assessing integrity of concrete structures during SLR period
  - **Alkali-Silica Reaction (ASR)**
  - **Effects of irradiation on concrete structures**
  - Creep and potential for creep-fracture interaction of post-tensioned containment
  - Effects of potential boric acid attack on concrete and steel in pressurized water reactor (PWR) spent fuel pools (SFP)


ASR Cracking in Concrete

Reference: NUREG/CR 7153, Expanded Materials Degradation Assessment Volume 4: Aging of Concrete and Civil Structures , Prepared by Expert Panel: H. Graves, Y Le Pape, D Naus, J. Rashid,. V. Saouma, A. Sheikh, J. Wall, 137pp, Oct. 2014.

Research Initiatives: ASR

- **Effects of ASR on Structural Performance** - National Institute of Standards and Technology (NIST)
- **Prediction of Concrete Aging and Deterioration Through Accelerated Tests, Non-Destructive Evaluation and Stochastic Multiscale Computations** - Northwestern University
- **Experimental and Numerical Investigation of Alkali-Silica Reaction in Nuclear Power Plants** - University of Colorado
- **Status:** Research programs scheduled for completion by 2018
- More information provided in RIC technical session T7 on ASR
  - Tuesday, March 8 at 3:30 pm

Research Initiatives: Irradiation Effects

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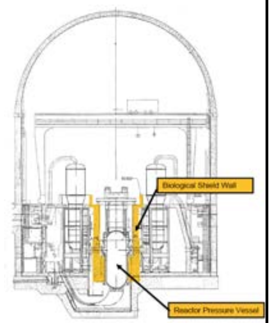
- **Objectives**
  - Estimate the level of radiation on concrete structures close to the reactor pressure vessel for the SLR period
  - Assess the significance of radiation on structural integrity and shielding performance of concrete
- **Approach**
  - Phase I
    - Evaluate existing information on radiation effects
    - Identify structures (or portions thereof) which may be above these thresholds during the SLR period.



Research Initiatives: Irradiation Effects

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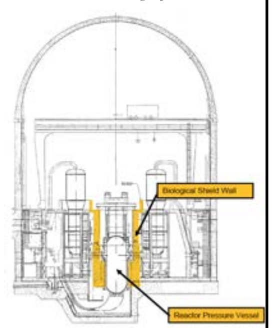
- **Approach, cont.**
  - Phase II
    - Test concrete harvested from the Zorita nuclear power plant and laboratory specimens to confirm relationship between radiation level and performance.
    - Determine conditions under which structural or shielding performance may be compromised.
  - Evaluate aging management strategies for structures in close proximity to reactor pressure vessel
- **Status**
  - Project has just been initiated
- Research is planned for completion by end of 2020



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Electrical Cable Qualification and Condition Assessment

Darrell Murdock, Sheila Ray,
Clifford Doutt and Mohammad Sadollah
Nuclear Regulatory Commission

Key Technical Issues

- Staff assessment and the Expanded Materials Degradation Assessment identified following issues related to ensuring acceptable performance of cables through SLR
  - Environmental qualification
  - Condition monitoring
  - Diffusion limited oxidation
  - Activation energy
  - Synergistic effects between thermal and radiation aging
  - Inverse temperature effects
  - Dose rate effects
  - Effect of submergence on cable degradation

Reference: NUREG/CR 7153, Expanded Materials Degradation Assessment Volume 5: Aging of Cables and Cable Systems, Prepared by Expert Panel: R. Bernstein, S. Burnay, C. Doutt, K. Gillen, R. Konnik, S. Ray, K. Simmons, G. Toman, G. Von White II, 125pp, Oct. 2014.

Thermal Aging of Jacketed Cables

Naturally Aged Cable from Nuclear Power Plant

Research Initiatives

- **Assessment of Condition Monitoring Methods**
  - **Objective**
    - Age cables to end of SLR period to evaluate cable degradation and the acceptability of several condition monitoring techniques
  - **Approach**
    - Use new and naturally aged cable samples
    - Evaluate condition monitoring techniques during the aging process
    - Conduct aging synergistically at low radiation dose rates and temperatures
  - **Status**
    - Preparing for functionality testing of the experimental facilities
    - Commence cable aging once the functionality tests are completed
  - Project should be completed by the end of 2019

Research Initiatives

- **Evaluation of Cable Degradation in a Submerged Environment**
  - **Objective**
    - Evaluate EPRI's proposed criteria for aging management
  - **Approach**
    - Review the technical basis for the acceptance criteria associated with using the Tan-Delta method for assessing aging management of cables in submerged environment
  - **Status**
    - This review is underway
  - The evaluation of EPRI's criteria should be completed by the summer of 2016

Summary

- Technical issues are being addressed by the NRC through research and evaluation
  - Support NRC's evaluation of subsequent license renewal applications
  - Develop technical basis for providing reasonable assurance of safe operation
  - Confirm adequacy of the nuclear industry's aging management programs
- Research is being conducted in several technical areas that are important to nuclear power plant safety
  - Neutron fluence evaluations
  - Reactor pressure vessel embrittlement at high fluence
  - Aging of reactor vessel internals
  - Concrete degradation
  - Electrical cable qualification and condition assessment
- Research is structured into near-term and longer-term activities
  - Near-term: Complete before first license application is received
  - Longer-term: Complete before first plant enters into the subsequent license renewal period