BWR Control Rod Update

Richard Matheny, Fuel Business Manager

Columbia

July 10, 2003

BWR Control Rod Agenda

- Introduction
- Experience
- Tritium Monitoring
- CR-99
- Schedules

Introduction - Westinghouse Design Evolution

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Introduction - Westinghouse Design Evolution

- Same basic design since 1969
- CR 70

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- CR 82

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Introduction - Westinghouse Design Evolution

- CR 82M-1

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- CR 99

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Introduction - Westinghouse Materials Evolution

- AISI 316L Stainless Steel

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Introduction - Summary of Design Evolution

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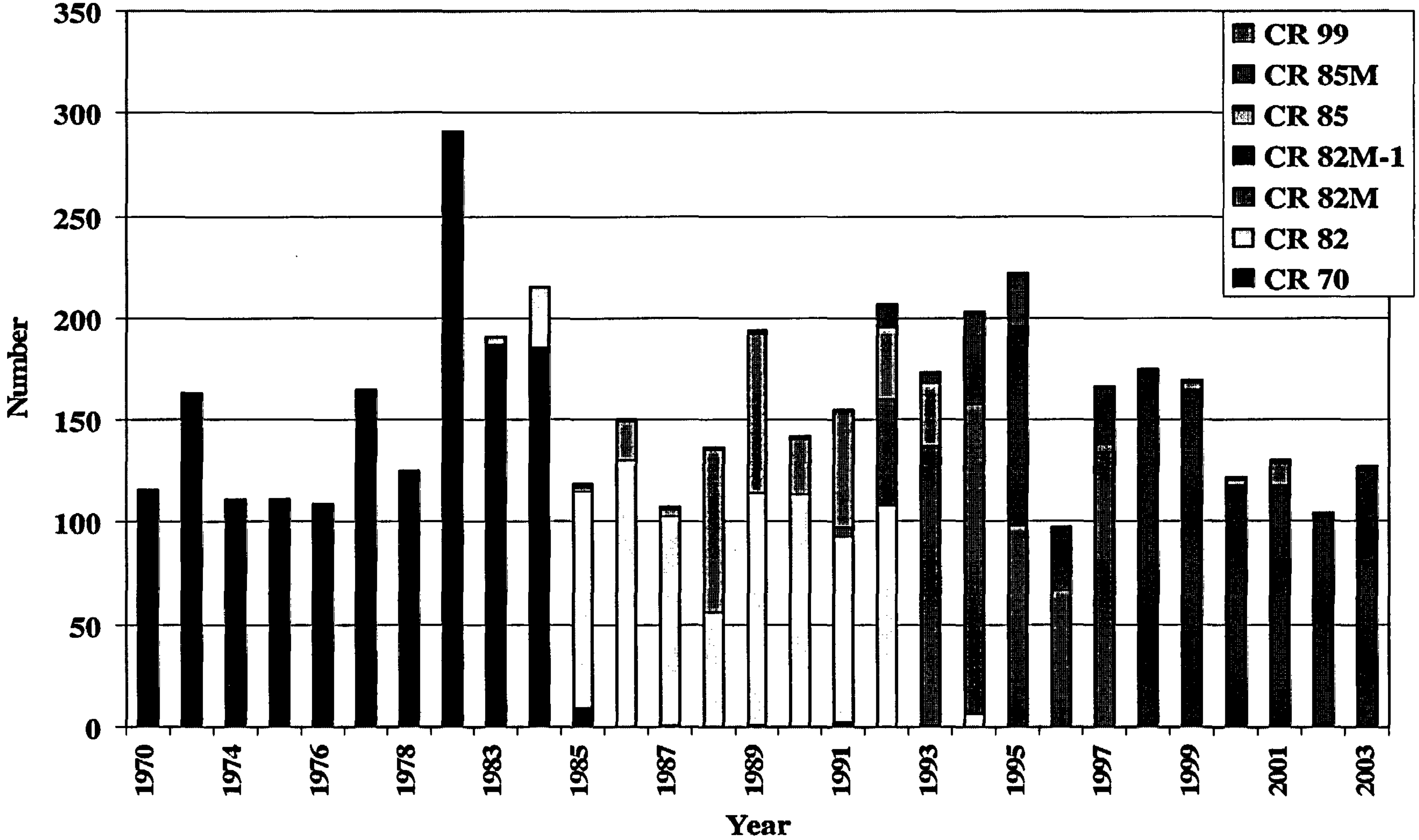
Experience - Deliveries Overview



Experience - Deliveries Details

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Experience - US Deliveries Details

- Total of [ ] a, c BWR control rods delivered in US
  - Browns Ferry 2/3
  - Brunswick 1/2
  - Clinton
  - Dresden 2/3
  - Hatch 1/2
  - Hope Creek
  - James A. Fitzpatrick
  - La Crosse
  - La Salle 1
  - Limerick
  - Millstone 1
  - Nine Mile Point 1
  - Peach Bottom
  - Quad Cities 1/2
  - River Bend

Experience - Inspections

- Westinghouse has delivered more than 4400 BWR control rods. All have fulfilled their safety duty

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- Westinghouse has an extensive control rod database

Experience - Inspections (General)

- All Westinghouse control rod designs are easily inspected
  - Simple visual inspection
  - Low cost inspection
  - No special tools needed
  - Inspection verifies the condition of the control rods
- Easily inspected control rod a clear advantage
  - Lower risk of costly future inspection programs

Experience - Inspections (Lessons Learned)

- Fast Neutron Irradiation of Stainless Steel
  - Material properties are changed due to irradiation
    - Increased hardness
    - Increased yield and ultimate strength
    - Segregation of elements to and from the grain boundaries e.g. Cr
  - Irradiation leads to susceptibility to IASCC (Irradiation Assisted Stress Corrosion Cracking)

Experience - Inspections (Lessons Learned)

- Thermal Neutron Irradiation of Boron Carbide
  - $^{10}B + n \rightarrow {}^{7}Li + {}^{4}He + 2{,}8$ MeV
  - Helium is trapped in the boron carbide (well above 90%). Results in volume swelling
  - Helium release leads to pressure build-up in the control rod blade
  - Tritium (T) production by other neutron absorption reactions. Also fast neutrons. T retained in boron carbide structure, LiT

Experience - Inspections (Lessons Learned)

- Hafnium Hydriding

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Experience - Inspections (Lessons Learned)

- Control Rod Crack Mechanism
  - Irradiation Assisted Stress Corrosion Cracking (IASCC)
  - IASCC dependent on the following factors:
    - Stresses in the stainless steel structural material due to boron carbide swelling
    - Material sensitization - Chromium depletion in grain boundaries and other mechanisms
    - Oxidizing environment - Normal BWR water chemistry
- Remedies against IASCC

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Experience - Neutron Radiography Inspection Results

- Pool-side Inspections
  - During the 80´s and the 90's, Westinghouse performed an extensive study regarding boron carbide wash-out in case of cracks in control rod blades.
  - Examinations of control rods operated as shutdown rods as well as operated as CCC rods were performed.

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Experience - Neutron Radiography Inspection Results

- Pool-side Inspections (cont´d)

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Experience - Neutron Radiography Inspection Results

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Experience - Neutron Radiography Inspection Results

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Experience - Blade Wing Thickness Measurement

- Measurement to determine boron carbide swelling
  - Measurement of blade wing thickness before and after operation.
  - Increased thickness tells about boron carbide swelling.
  - Measuring equipment developed by Westinghouse.

Experience - Blade Wing Thickness Measurement

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Experience - Blade Wing Thickness Measurement

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Experience - Blade Wing Thickness Measurement

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Experience - Blade Wing Thickness Measurement

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Experience - Visual Inspection Results for CR-82

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Experience - Visual Inspection Results for CR-82M-1

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Experience - Visual Inspection Results for CR-99

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Tritium Monitoring

- Objective
  - Gain knowledge about Control Rod status in the reactor without inspections

- Relative Contribution of Tritium to Reactor Water
  - CCC Control Rod Blade failure
  - Several Shut Down Control Rod Blades failures
  - Fuel Rod failure, production from Deuterium, production from Lithium

Tritium Monitoring

- Tritium Release
  - Tritium in a control rod blade is produced a factor of 10,000 times less than Lithium. In an intact control rod blade the tritium is considered to be bound to Lithium
  - In case of cracks and water ingress, Lithium reacts readily with water. Tritium (T) replaces hydrogen in water molecules (H2O) to form HTO
  - Exchange of water in a rod with cracks results in tritium activity in the reactor water

Tritium Monitoring

- Reference Level
  - In a reactor without control rod blade failures a reference level is determined by production from the neutron capture in Deuterium and Lithium in the reactor water and neutron capture in Lithium in the fuel rod cladding.
  - The reference level is typically 2 · 10-3 μCi/cc

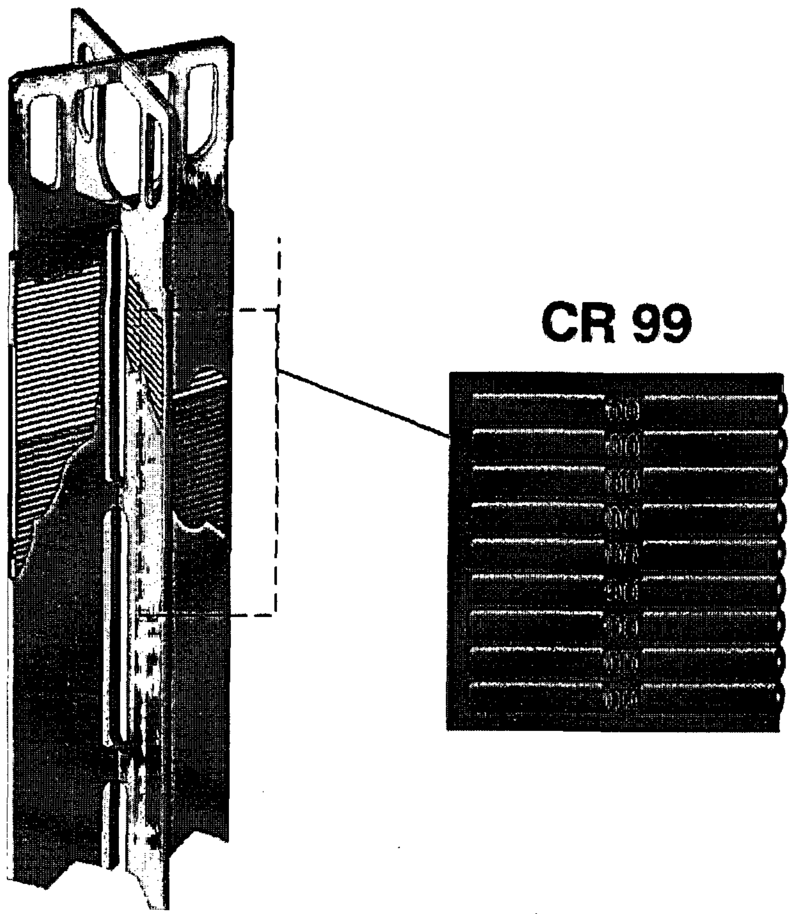
Tritium Monitoring

- Deviations from the Reference Level
  - The type of deviation from the reference level gives information about control rod blade failure
  - Typically:
    - A slow increase over a long time period indicates several shut down rods with failures, or a CCC rod with medium exposure and low degree of cracking
    - A peak in the tritium curve indicates a CCC rod with high exposure and several cracks
    - The increased tritium activity in the reactor water must be evaluated together with exposure data for the complete control rod blade inventory

Tritium Monitoring Program

- Goal
  - Implement Tritium Monitoring as part of a Control Rod Management Program
  - Limit control rod blade inspections to occasions with significantly increased tritium levels

CR-99 - General Description



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CR-99 - Reason for New Design

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CR-99 - Features

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CR-99 - Development

- Guide pad sample irradiation in Forsmark 1

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CR-99 - Development

Boron carbide pins after irradiation

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CR-99 - Development

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CR-99 - Development

- Demo rods Olkiluoto 1 (TVO 1)

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CR-99 - Development

- Demo rods Oskarshamn 3

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CR 99 - First Design Deliveries

- CR 99 rods have been delivered to:

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CR 99 - Re-design of Boron Carbide Pin

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CR-99 - Re-design of Boron Carbide Pin

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CR-99 - Re-design of Boron Carbide Pin

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CR 99 - Re-Design Deliveries

- Planned Deliveries

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Schedules

- Westinghouse BWR Control Rod Experience Update Meeting
  - Summer 2003
- CR-99 Topical Report
  - October 2003
  - To support Spring 2005 insertions in US plants
- Updated CR-82M-1 Topical Report
  - Similar format to CR-99 Report
  - Fall 2003

Schedules - Topical Report Content

- General Design Requirements, including

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Schedules - Topical Report Content

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