

BWR Control Rod Update

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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



- CR 99



Introduction - Westinghouse Materials Evolution

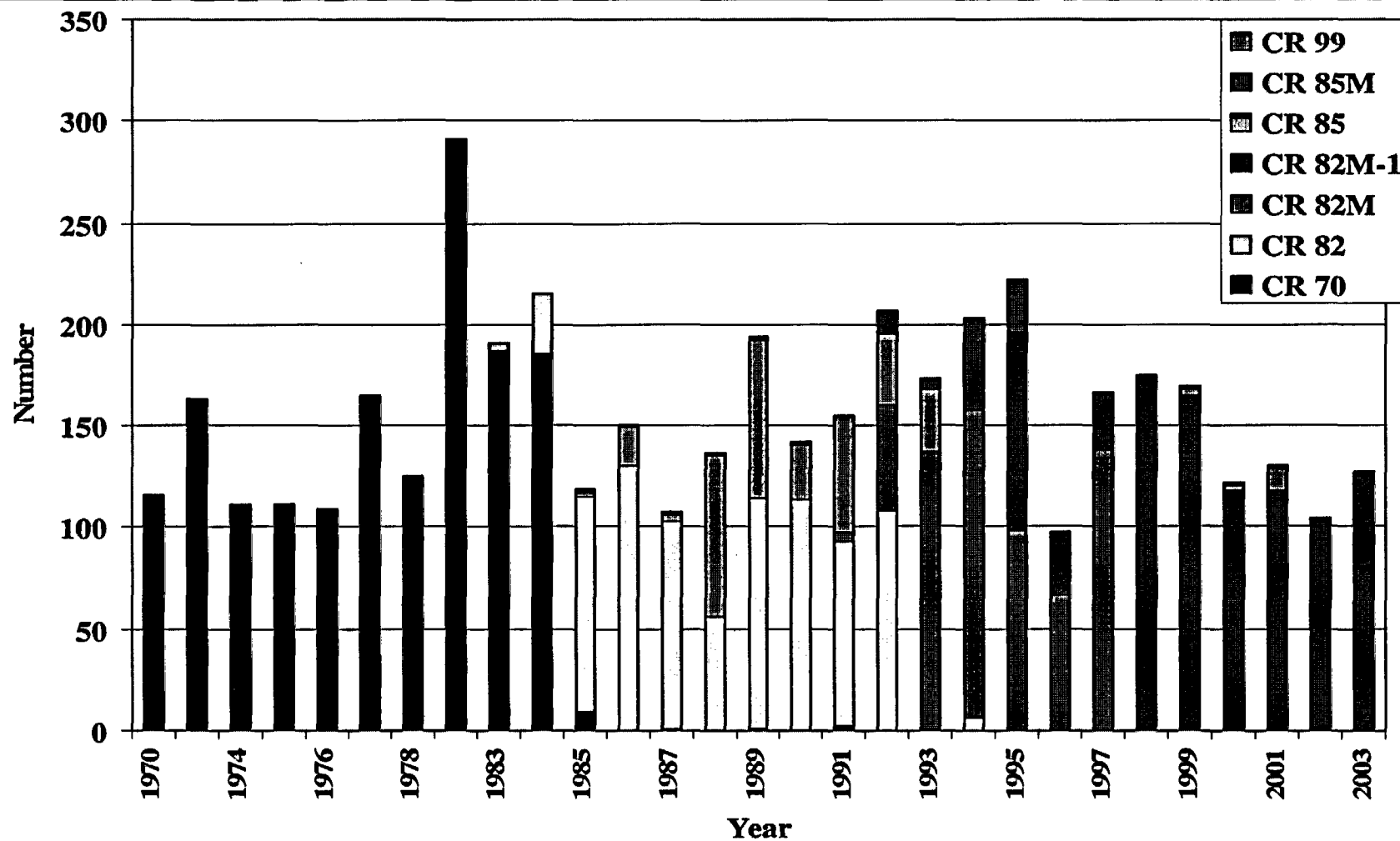
- AISI 316L Stainless Steel



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

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
 - $10\text{B} + \text{n} \rightarrow 7\text{Li} + 4\text{He} + 2,8 \text{ MeV}$
 - 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



Experience - Blade Wing Thickness Measurement

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Experience - Blade Wing Thickness Measurement



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 (H_2O) 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 $2 \cdot 10^{-3} \mu\text{Ci/cc}$

Tritium Monitoring

- Deviations from the Reference Level

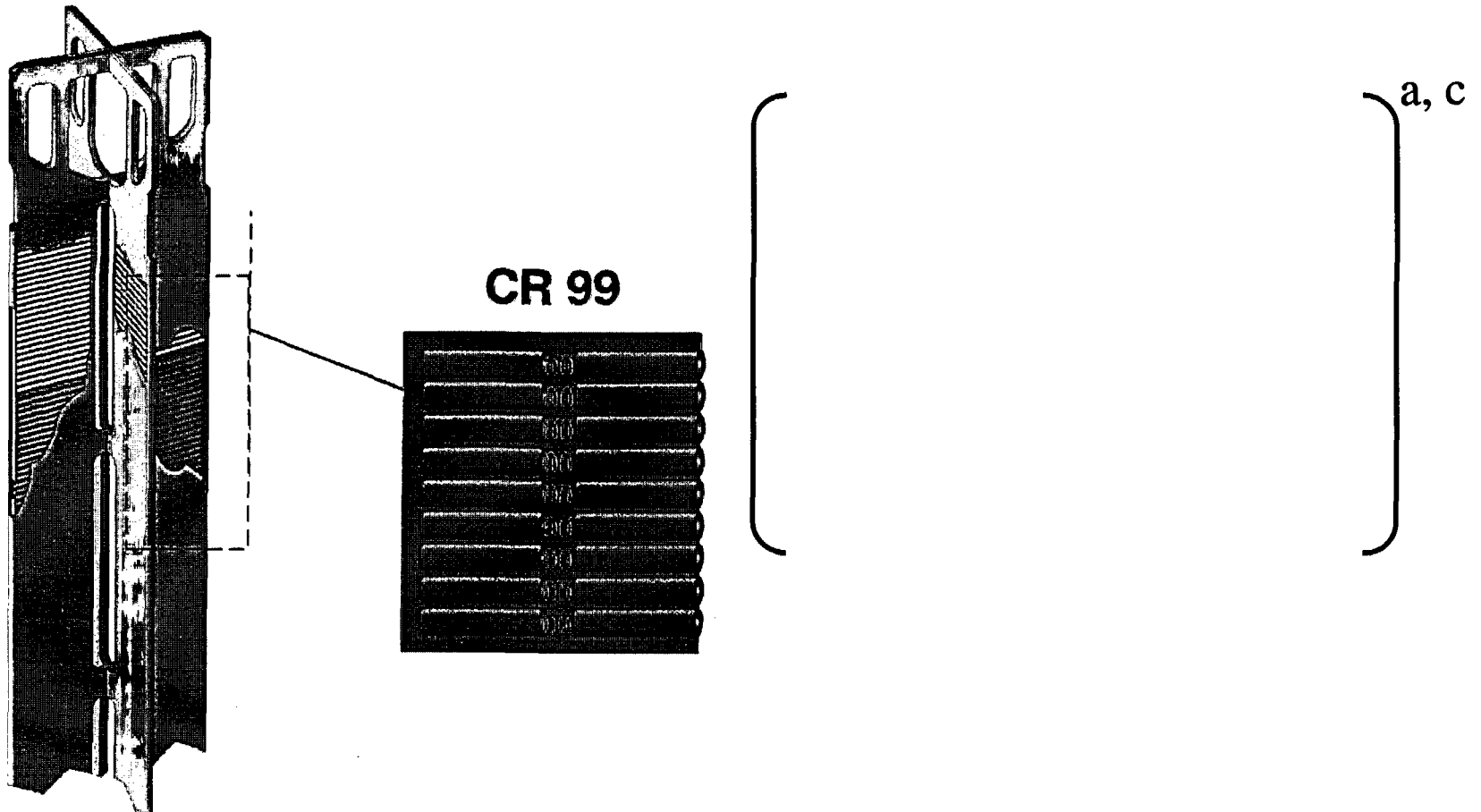
- The type of deviation from the reference level gives information about control rod blade failure
- Typically:
 - A slow increase over a long time period indicates several shut down rods with failures, or a CCC rod with medium exposure and low degree of cracking
 - A peak in the tritium curve indicates 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



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



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:



CR 99 - Re-design of Boron Carbide Pin



CR-99 - Re-design of Boron Carbide Pin



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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