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Plant Crack Growth Rate Monitoring

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BWRVIP Presentation to NRC
Rockville, MD
September 21, 2017

Introduction

- Several BWRVIP projects have been undertaken to ensure that noble metal applications are performed in a proper and timely manner in accordance with vendor recommendations.
- BWRVIP guidance has been issued that requires plants applying OLNC to control water chemistry to ensure that sufficient hydrogen is present relative to oxidants to produce low ECP at surfaces on which noble metal is deposited to mitigate IGSCC.
- The ultimate way to assess effectiveness is to measure the extent to which crack growth rates are lowered.
- Available data are presented and future plans are discussed in this presentation.

Topics

- Core Shroud Crack Mitigation
- Mitigation of CRD Stub Tube Leaks
- Core Shroud Reinspection Results
- Summary

Core Shroud Crack Mitigation

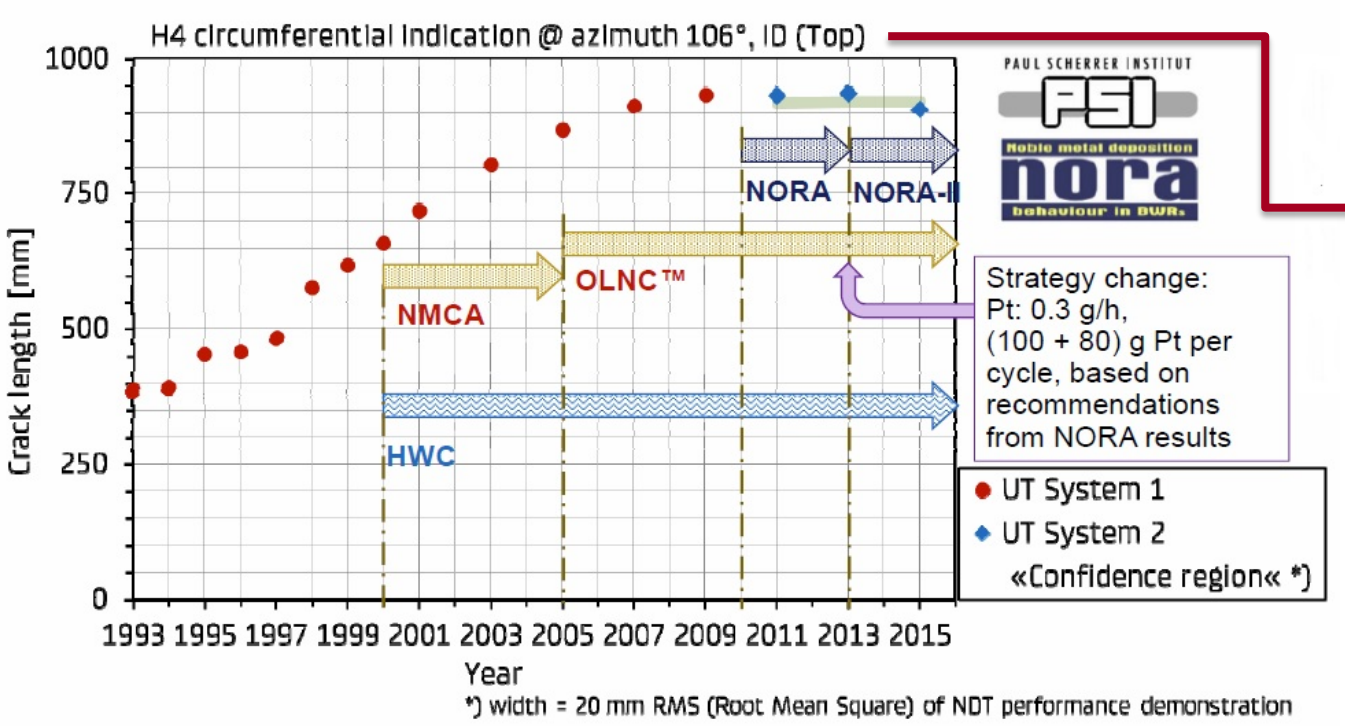
BWR4-G Core Shroud Cracking

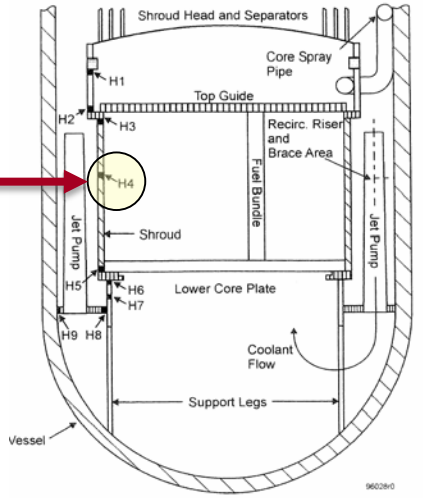
- 12 month fuel cycles.
- First plant to report shroud cracking (1990); tie-rods installed.
  - First indications of circumferential cracks in the HAZ of H4 weld.
- Implementation of chemistry programs to mitigate IGSCC
  - 2000: NMCA+HWC
  - 2005: Initial On-Line NobleChem™ (OLNC) application
    - First two applications were partial (approx. 18% and 50% of full annual amount)
    - 2007 – 2013: Single annual applications, ~199 g Pt at injected at 0.8 g/h
  - 2013: Optimization of OLNC strategy - 2 applications each cycle with Pt injection rate ~0.3 g/h
    - 1) 80 - 90 days after start-up of reactor, 100 g of Pt injected over 330 h
    - 2) ~4 – 5 months later, 80 g of Pt injected over about 260 h

Summary: BWR4-G Core Shroud Crack Mitigation

- Circumferential cracks in the HAZ of H4 weld detected for the first time in 1990 grew at a constant rate until 2005.
- After NMCA was performed in 2000, UT inspections of the core shroud ID indicated that the desired reduction in crack growth rate had not been achieved.
  - Extensive evaluations concluded that the most likely cause for the observed behavior was non-catalytic crack flanking produced by a nine-week period with no hydrogen following NMCA.
- After OLNC was started in 2005, the crack growth rate decreased.
  - No new cracks have been found since 2005.
- Pt injection strategy was changed in 2010 to 2 applications each cycle, with the same total amount, 0.3 g/h based on PSI NORA results.
- There has been no crack growth in the H4 weld between 2009 and 2015.

BWR4-G UT Results of Cracking in the H4 Weld





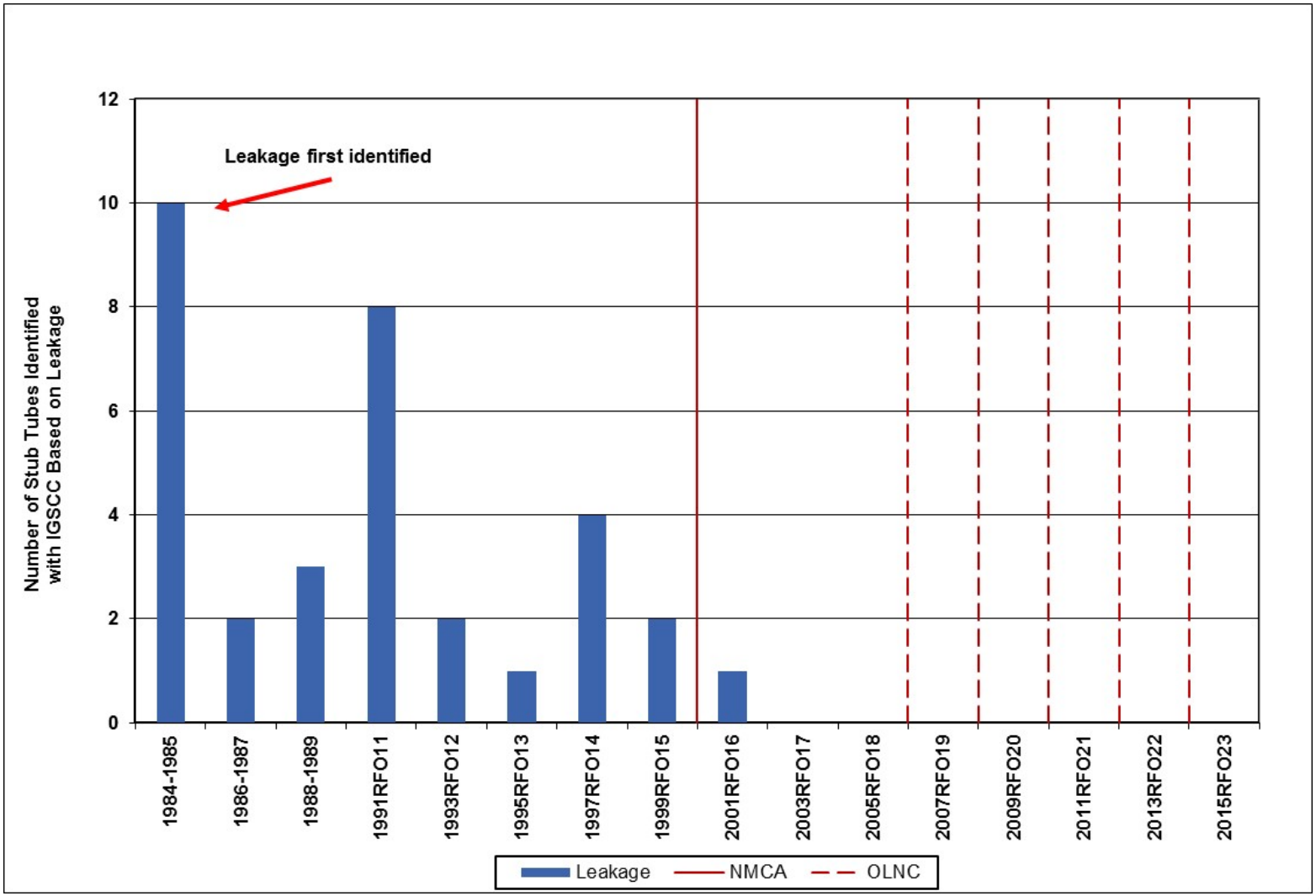
Leber, H. J., et al., "Mitigation and Assessment of SCC at the Core Shroud of Muehleberg Nuclear Power Plant" International Light Water Reactors Materials Reliability Conference and Exhibition, Chicago, IL, August 1-4 2016.

Mitigation of CRD Stub Tube Leaks

BWR2-A CRD Stub Tube Leaks

- The plant has 129 CRD penetrations that were fabricated from furnace sensitized Type 304 stainless steel.
- Two to three CRD penetrations would be identified as leakers per refueling outage prior to HWC and NMCA implementation in 2000.
- Without IGSCC mitigation, predictions indicated that 2 – 3 CRD penetration leaks would continue.
- The actual failure rate from 11.5 to 17 Effective Full Power Years (EFPY) was 1.4/EFPY.
- NMCA was applied during a mid-cycle outage in May 2000.
  - One additional leaking penetration was found 6 months after NMCA during the following a refuel outage in 2001; likely a pre-existing condition.
- OLNC was initially applied in December 2006, and reapplied annually.
- There have been no new leaking penetrations in eight successive refuel outages (through 2017) or in forced outages.
- These results demonstrate the effectiveness of NMCA and OLNC in mitigating IGSC in the lower plenum with low hydrogen injection.

Mitigation of CRD Stub Tube Cracking



CRD Stub Tube Leakage Stopped after NMCA and OLNC

Core Shroud Reinspection Results

Core Shroud Reinspection Results

- Crack lengthening and deepening was evaluated for nine inspections at eight plants, and available results were presented in *BWRVIP-62 Rev. 1*.
  - Four HWC-M plants
  - Four NMCA+HWC plants
  - One NMCA plant that transitioned to OLNC
- Crack deepening results are complicated by changes in the stress intensity factor (K) with depth, so only crack lengthening is discussed here.
- The crack lengthening was evaluated for HWC-M, NMCA, OLNC and for all mitigated CGRs combined in comparison with NWC.
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- Combined results for HWC-M, NMCA and OLNC crack lengthening CGRs are 40-50% less than the corresponding NWC rates.

HWC-M (3 Plants) vs. NWC Lengthening Distributions

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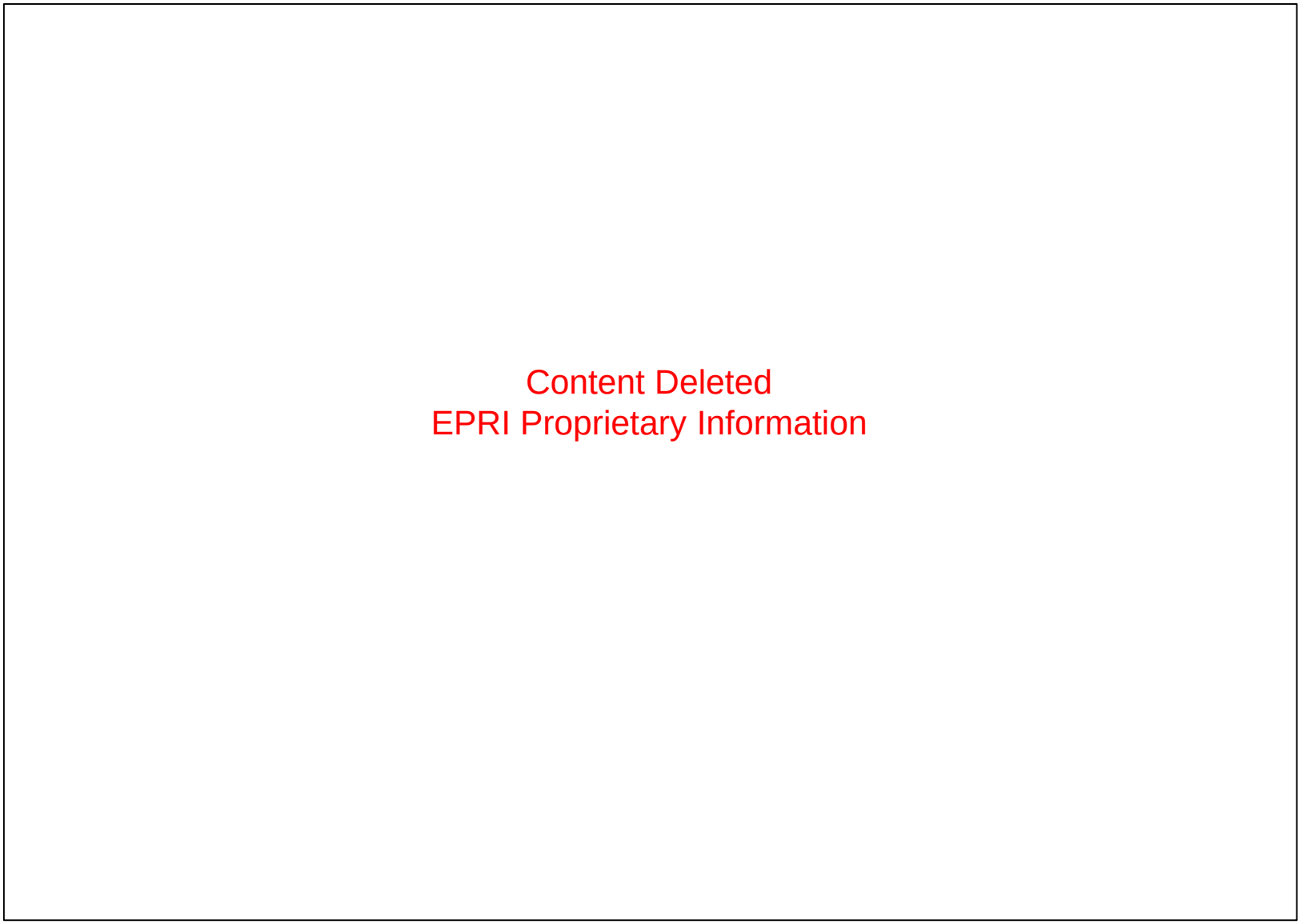

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NMCA (4 Plants) vs. NWC Lengthening CGR Distributions

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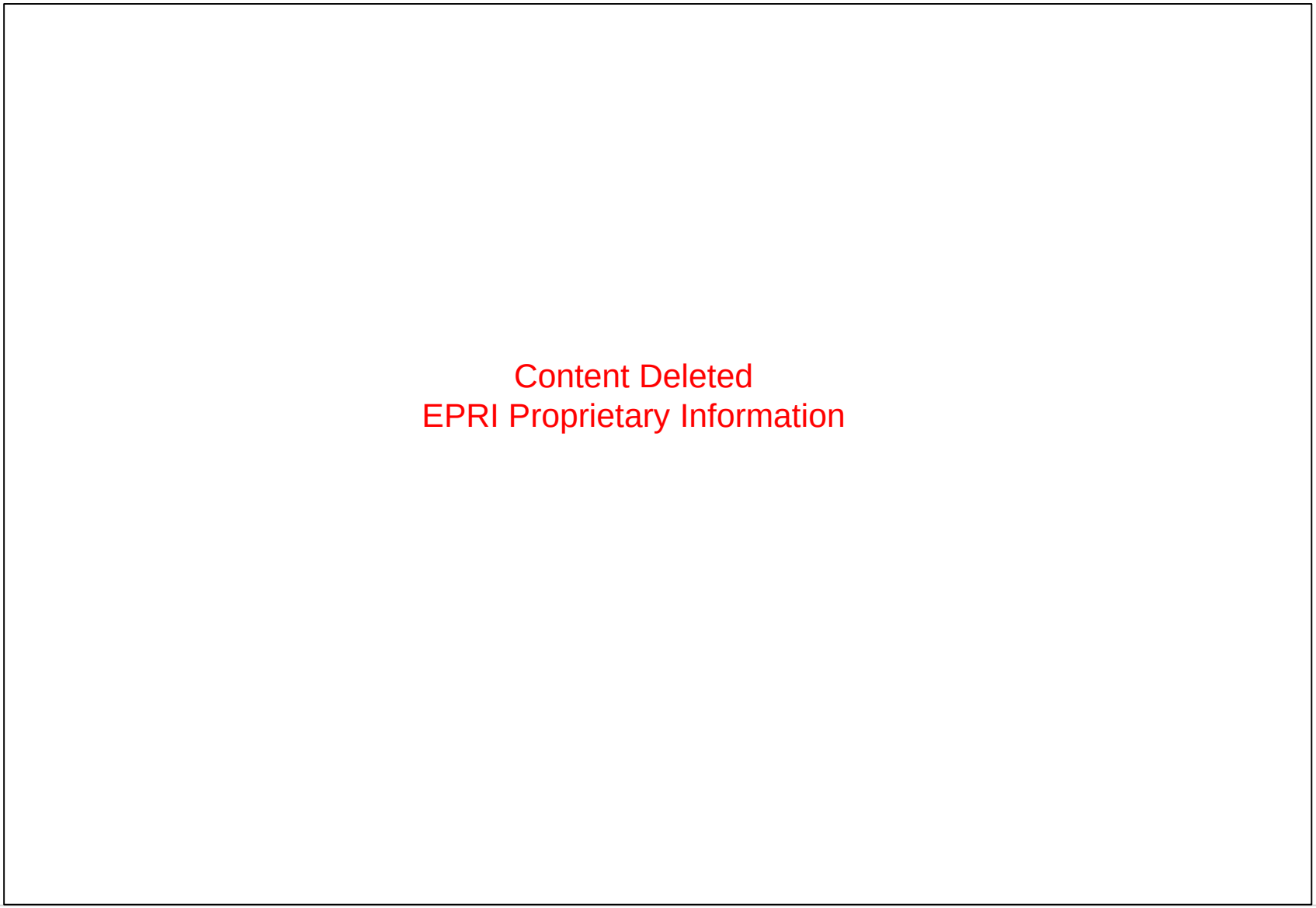

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OLNC (1 Plant, prior NMCA) vs. All NWC Lengthening Crack Growth Rates

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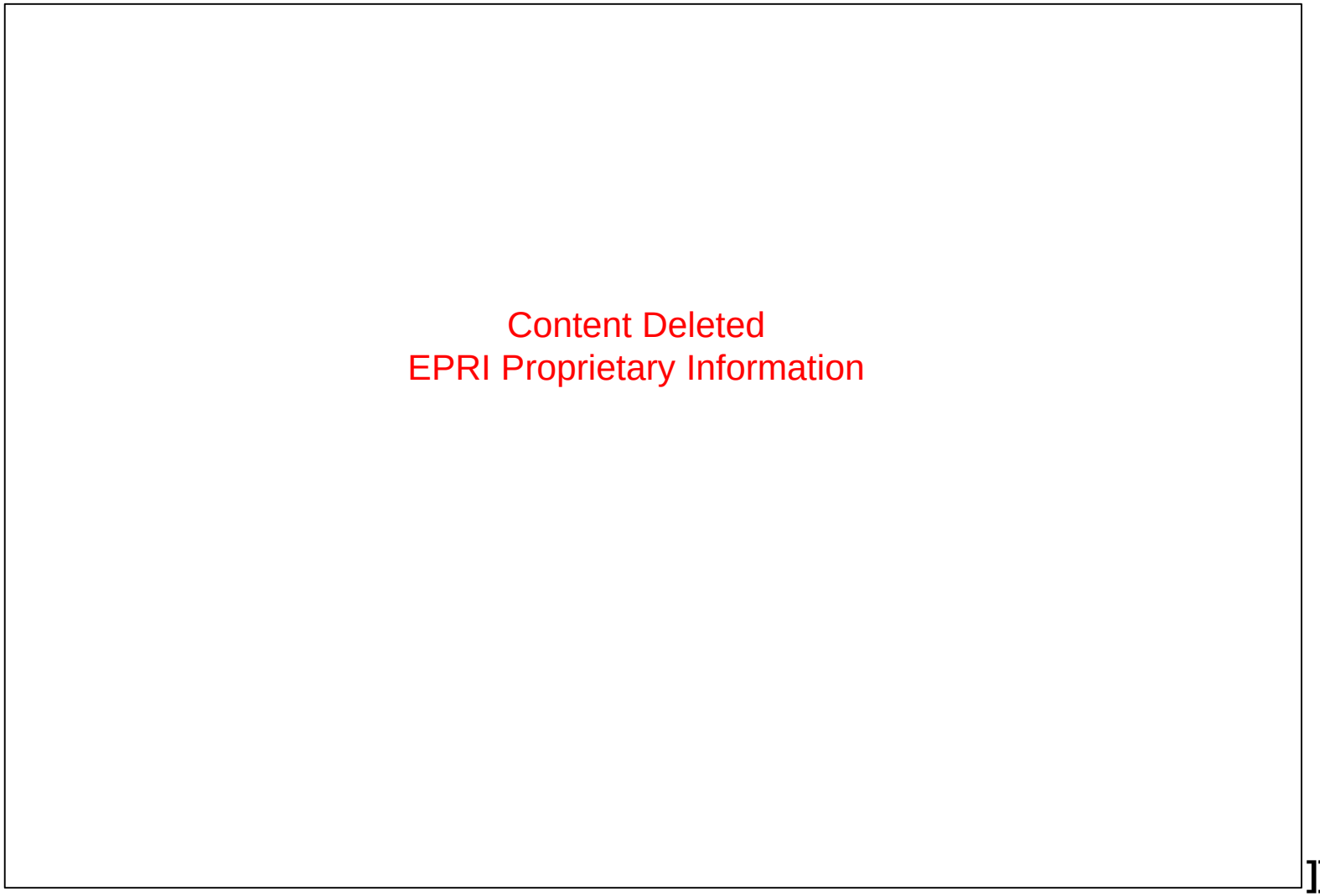

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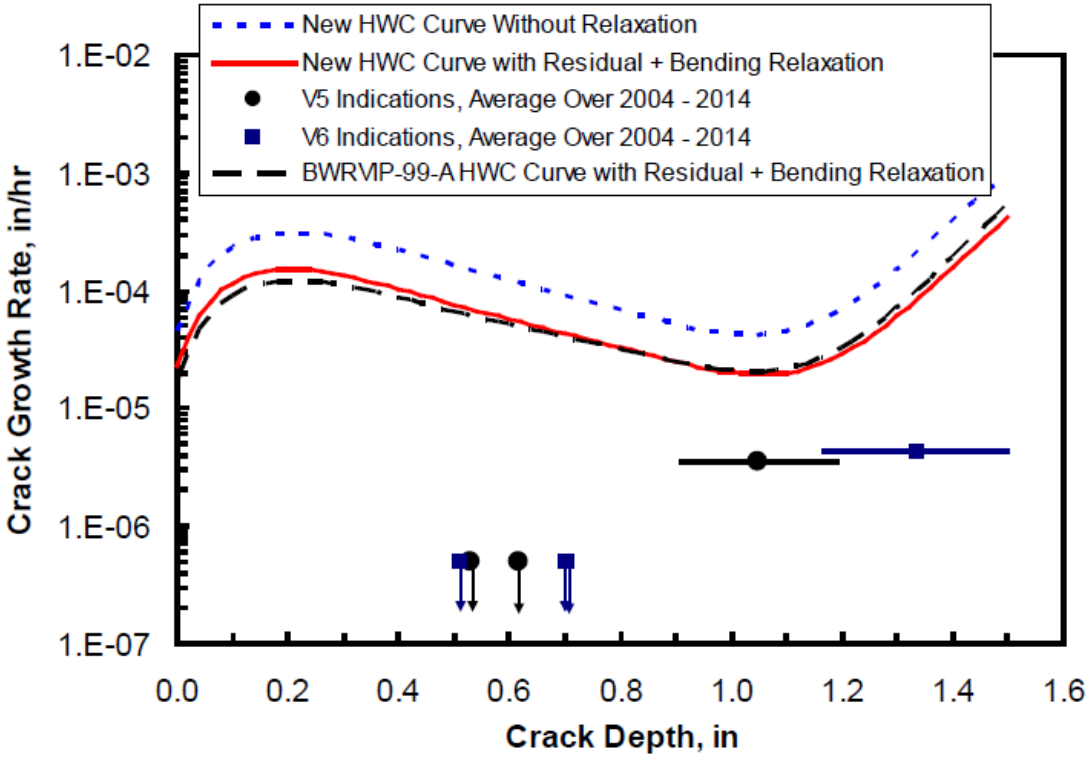
Comparison of IASCC CGR Models for HWC with Data from Core Shroud Vertical Weld Indications in a BWR-4



- Plant used NMCA and OLNC from 2004 to 2014
- Crack growth rates were well below the IASCC HWC curves indicating effective mitigation

Reference: Ernest Eason and Raj Pathania, "Disposition Curves for Irradiation-Assisted Stress Corrosion Cracking of Austenitic Stainless Steels in LWR Environments," Proceedings of the ASME 2015 Pressure Vessels & Piping Conference PVP 2015-45323

Core Shroud Reinspection Plans

- Shroud inspections have continued.
- Compilation and evaluation of new data was started in 2017.
  - Focus on results from inspections after the 2004 – 2008 timeframe.
  - Many additional plants have implemented OLNC since that time.
- The evaluation is to be completed in 2018.

Summary

- Core shroud cracking at a BWR4 has been mitigated with annual OLNC applications.
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- Cracking of furnace sensitized Type 304 stainless steel CRD stub tubes was stopped with NMCA, and there continues to be no leakage with OLNC.
- Core shroud reinspection results evaluated so far for HWC-M, NMCA and OLNC show that crack lengthening CGRs are 40-50% less than the corresponding NWC rates.
- Core shroud reinspection data continue to be collected, and evaluation of new data with more plants using OLNC is scheduled to be completed in 2018.

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