BWRVIP-174NP, Revision 1: BWR Vessel and Internals Project

Review of BWR Core Shroud UT Re-Inspection Results for Plants Mitigated with NMCA, OLNC, and HWC

1019062NP

Final Report, August 2009

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This report is based on the following previously published report:

BWRVIP-174: BWR Vessel and Internals Project, Review of BWR Core Shroud UT Re-Inspection Results for Plants Mitigated with NMCA and HWC. EPRI, Palo Alto, CA: 2007. 1014994.

REPORT SUMMARY

This report documents an evaluation of ultrasonic inspection results through 2008 to assess the effect that hydrogen water chemistry, with and without a noble metal catalyst, has on mitigating crack growth in core shroud welds of operating boiling water reactors (BWRs). This report is Revision 1 of BWRVIP-174NP and supersedes the previous version, *BWRVIP-174: BWR Vessel and Internals Project, Review of BWR Core Shroud UT Re-Inspection Results for Plants Mitigated with NMCA and HWC* (1014994).

Background

Visual and ultrasonic testing (UT) examinations of shrouds have been conducted since the early 1990s. Results of these inspections have shown the shroud to be one of the most frequently cracked and actively cracking components in BWR plants. To reduce crack growth rates (CGRs) and crack initiation in the shroud, as well as in other components, all U.S. BWRs as of 2004 achieved some level of stress corrosion cracking (SCC) mitigation through hydrogen water chemistry (HWC) injection. This mitigation occurred either at moderate HWC levels or at low HWC levels with Noble Metal Chemical Application (NMCA) or On-Line NobleChem™ (OLNC). Review of shroud UT reinspection results provides important quantitative information on the effectiveness of plant mitigation activities.

Objective

To evaluate data obtained from UT of several BWR core shroud welds and assess the effect of hydrogen water chemistry on CGRs

Approach

The project team compared results of similarly performed core shroud UT inspections to evaluate crack growth data of existing SCC indications in multiple BWRs that have been operating with moderate HWC (MHWC), NMCA, or OLNC. Crack growth data were compared with normal water chemistry (NWC) rates that were developed first by EPRI from previous studies and then supplemented in this study.

Results

Inspection data support the current industry disposition crack-lengthening rate of 5×10^{-5} in/hr (3.5×10^{-7} mm/sec). These data showed that there were still a limited number of indications that continued to lengthen even with mitigation techniques in place. The review determined that outside diameter (OD) cracks were growing at a significantly reduced lengthening rate as compared to either inside diameter (ID) indications or CGRs in a NWC environment, although this is based primarily on one plant's results. The lengthening data showed slower CGRs for NMCA plants compared to MHWC plants. The study concluded that deepening rates for

mitigated plants were lower than rates measured for plants operating under NWC and that MHWC deepening rates are slower than NMCA rates.

EPRI Perspective

The core shroud provides structural support to the reactor core and fuel assemblies to maintain the core geometry. Inspections of reactor vessel internals using ultrasonic techniques provide valuable information to assess the effects of water chemistry on CGRs and to validate predictive models. Understanding crack growth characteristics of the shroud and the effectiveness of HWC mitigation is important in assessing and maintaining the structural margin of BWR internals. The BWR Vessel and Internals Project (BWRVIP) plans to continue to provide updates, like this report, periodically to include inspection data from additional operating BWRs.

Keywords

Core shroud
Hydrogen water chemistry
Boiling water reactor crack growth
Ultrasonic testing

NOMENCLATURE

Abbreviations used in the report are defined below.

BWR	Boiling Water Reactor
BWRVIP	BWR Vessel and Internals Project
BF-2	Browns Ferry Unit 2
BF-3	Browns Ferry Unit 3
BRN1	Brunswick Unit 1
BRN2	Brunswick Unit 2
CGR	Crack Growth Rate
ECP	Electrochemical Corrosion Potential
FW	Feedwater
GEH	GE-Hitachi Nuclear Energy Alliance
HAZ	Heat Affected Zone
HWC	Hydrogen Water Chemistry
ID	Inside Diameter
IGSCC	Intergranular Stress Corrosion Cracking
KKM	Kernkraftwerk Muehleberg
MHWC	Moderate HWC
MONT	Monticello
NMP2	Nine Mile Point Unit 2
NWC	Normal Water Chemistry
NMCA	Noble Metal Chemical Application, also called NobleChem™
NRC	Nuclear Regulatory Commission
OLNC	Online NobleChem™
OD	Outside Diameter
PB-2	Peach Bottom Unit 2
PB-3	Peach Bottom Unit 3
Pt	Platinum
SCC	Stress Corrosion Cracking
SUS1	Susquehanna Unit 1
UT	Ultrasonic Testing

EXECUTIVE SUMMARY

The objective of this study was to evaluate the effect of water chemistry mitigation on crack growth in core shrouds of operating BWRs. As new inspection results accumulate, the report is expanded through revisions. This report is Revision 1 of BWRVIP-174NP and supersedes the previous version, *BWRVIP-174: BWR Vessel and Internals Project, Review of BWR Core Shroud UT Re-Inspection Results for Plants Mitigated with NMCA and HWC* (1014994). The Revision 0 evaluation included four plants: Nine Mile Point 2 and Muehleberg (KKM), which are Noble Metal Chemical Application (NMCA) plants plus Susquehanna Unit 1 and Brunswick Unit 1, moderate Hydrogen Water Chemistry (MHWC) plants. The Revision 1 evaluation included five plants: KKM (OLNC), Browns Ferry 3 and Peach Bottom 3 (NMCA), and Brunswick 2 and Monticello (MHWC). The program was directed at evaluating both crack lengthening and crack deepening. The effort relied on previous approaches and the existing Normal Water Chemistry (NWC) lengthening and deepening data compiled by the BWRVIP as a basis for comparison. That work, augmented with additional NWC and H1 data from the Revision 1 inspections, is presented in Appendix A of this report. These findings provide insight into the benefit of mitigation by effective HWC achieved either through injection of moderate levels of hydrogen or through the use of lower levels of hydrogen injection along with NMCA or OLNC that serves as a catalyst to promote efficient reduction of oxidizing species. There were several findings based on the data.

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CONTENTS

1 INTRODUCTION AND BACKGROUND 1-1

1.1 Implementation Requirements 1-2

2 PLANT OPERATION HISTORY AND UT INSPECTION TIMING 2-1

3 MITIGATION AND WATER CHEMISTRY HISTORY BY PLANT 3-1

4 UT INSPECTION DATA AND ANALYSIS 4-1

4.1 Overview of Methods for Determining Crack Growth Rates 4-1

4.2 Nine Mile Point Unit 2: Shroud Inspections in 2000 and 2004 4-2

4.3 Susquehanna Unit 1: Shroud Inspections in 2000 and 2004 4-2

4.4 Brunswick Unit 1: Shroud Inspections in 1996 and 2006 4-3

4.5 Muehleberg (KKM): Shroud Inspections between 2000 and 2005 4-4

4.6 Brunswick Unit 2: Shroud Inspections in 2001 and 2005/2007 4-4

4.7 Monticello: Shroud Inspections in 1996 and 2005 4-5

4.8 Browns Ferry 3: Shroud Inspections in 2006 and 2008 4-5

4.9 KKM: Shroud Inspections between 2005 and 2007 4-6

4.10 Peach Bottom 3: Shroud Inspections in 1999 and 2005 4-6

5 EVALUATION OF MITIGATION ON CRACK GROWTH RATES 5-1

5.1 Lengthening Comparisons 5-1

5.2 Deepening Comparisons 5-2

5.3 Summary of Mitigation Effectiveness 5-2

6 SUMMARY AND CONCLUSIONS 6-1

7 REFERENCES 7-1

A BWRVIP NORMAL WATER CHEMISTRY (NWC) REFERENCE INSPECTION DATA A-1

A.1 Background A-1

A.2 Approach A-2
A.3 Results A-3
A.3.1 Browns Ferry Unit 2 ..... A-3
A.3.2 Browns Ferry Unit 3 ..... A-3
A.3.3 Brunswick Unit 2 ..... A-4
A.3.4 Peach Bottom Unit 2 ..... A-10
A.3.5 Susquehanna Unit 1 ..... A-10
A.3.6 Muehleberg A-15
A.3.7 Nine Mile Point 2 ..... A-16
A.3.8 Peach Bottom 3 ..... A-16
A.3.9 Browns Ferry 3 H1 ..... A-16
A.3.10 Monticello H1 ..... A-16
A.4 Cumulative Probability Plots A-23

***B* MHWC INSPECTION DATA AND CGRS B-1**
B.1 Report Revision 0 Inspections B-1
B.2 Report Revision 1 Inspections B-1

***C* NMCA INSPECTION DATA AND CGRS C-1**
C.1 Report Revision 0 Inspections C-1
C.2 Report Revision 1 Inspections C-1

***D* OLNC INSPECTION DATA AND CGRS D-1**
D.1 Report Revision 1 Inspections D-1

LIST OF FIGURES

Figure 4-1 NMP2 NMCA vs. NWC Lengthening CGRs 4-7
Figure 4-2 NMP2 NMCA vs. NWC Deepening CGRs 4-8
Figure 4-3 SUS1 MHWC vs. NWC Lengthening CGRs 4-9
Figure 4-4 SUS1 MHWC vs. NWC Deepening CGRs 4-10
Figure 4-5 BRN1 MHWC vs. NWC Deepening CGRs 4-11
Figure 4-6 KKM NMCA vs. NWC Lengthening CGRs 4-12
Figure 4-7 KKM NMCA vs. NWC Deepening CGRs 4-13
Figure 4-8 BRN2 MHWC vs. NWC Lengthening CGRs 4-14
Figure 4-9 BRN2 MHWC vs. NWC Deepening CGRs 4-15
Figure 4-10 MONT MHWC vs. NWC Lengthening CGRs 4-16
Figure 4-11 MONT MHWC vs. NWC Deepening CGRs 4-17
Figure 4-12 BF-3 NMCA vs. NWC Lengthening CGRs 4-18
Figure 4-13 BF-3 NMCA vs. NWC Deepening CGRs 4-19
Figure 4-14 KKM OLNC vs. NWC Lengthening CGRs 4-20
Figure 4-15 KKM OLNC vs. NWC Deepening CGRs 4-21
Figure 4-16 PB-3 NMCA vs. NWC Lengthening CGRs 4-22
Figure 4-17 PB-3 NMCA vs. NWC Deepening CGRs 4-23
Figure 5-1 MHWC (3 Plants) vs. NWC Lengthening CGR Distributions 5-4
Figure 5-2 NMCA (4 Plants) vs. NWC Lengthening CGR Distributions 5-5
Figure 5-3 All Mitigation (7 Plants) vs. NWC Lengthening CGR Distributions 5-6
Figure 5-4 Comparison of ID and OD Lengthening CGRs Under Mitigated and NWC Conditions 5-7
Figure 5-5 MHWC (4 Plants) vs. NWC Deepening CGR Distributions 5-8
Figure 5-6 NMCA (4 Plants) vs. NWC Deepening CGR Distributions 5-9
Figure 5-7 All Mitigation (8 Plants) vs. NWC Deepening CGR Distributions 5-10
Figure 5-8 Comparison of ID and OD Deepening CGRs Under Mitigated and NWC Conditions 5-11
Figure A-1 NWC Lengthening CGR Distribution A-24
Figure A-2 NWC Deepening CGR Distribution A-25
Figure A-3 Change in NWC Lengthening Distribution Between Report Revisions A-26
Figure A-4 Change in NWC Deepening Distribution Between Report Revisions A-27

LIST OF TABLES

Table 2-1 History of Mitigation and Inspections 2-1
Table 3-1 Plant Hydrogen Water Chemistry (HWC) Availability 3-3
Table A-1 Plants Evaluated A-3
Table A-2 Browns Ferry 2 Crack Growth Rate Data Population A-5
Table A-3 Browns Ferry 3 Crack Growth Rate Data Population A-7
Table A-4 Brunswick 2 Crack Growth Rate Data Population A-9
Table A-5 Peach Bottom 2 Crack Growth Rate Data Population A-11
Table A-6 Susquehanna 1 Crack Growth Rate Data Population A-12
Table A-7 Muehleberg Crack Growth Rate Data Population A-15
Table A-8 NMP2 Crack Growth Rate Data Population A-17
Table A-9 PB-3 Crack Growth Rate Data Population A-20
Table A-10 BF-3 Crack Growth Rate Data Population A-21
Table A-11 MONT Crack Growth Rate Data Population A-22
Table B-1 Susquehanna Unit 1 H4 HAZ 2000 and 2004 Cracking and Associated Lengthening and Deepening Rates B-2
Table B-2 Brunswick Unit 1 H4 and H6a HAZ 1996 and 2006 Cracking and Deepening Rates B-3
Table B-3 Brunswick Unit 1 H6b and H7 HAZ 1996 and 2006 Cracking and Deepening Rates B-4
Table B-4 BRN2 H4 2001-2005 Inspection Results and Associated Lengthening and Deepening Rates B-5
Table B-5 BRN2 H6b 2001-2007 Inspection Results and Associated Lengthening and Deepening Rates B-6
Table B-6 MONT H1-H6 1996-2005 Inspection Results and Associated Lengthening and Deepening Rates B-7
Table C-1 NMP2 H4 Lower HAZ 2000 and 2004 Cracking and Associated Lengthening and Deepening Rates C-2
Table C-2 NMP2 H4 Upper HAZ 2000 and 2004 Cracking and Associated Lengthening and Deepening Rates C-3
Table C-3 NMP2 H5 Lower HAZ 2000 and 2004 Cracking and Associated Lengthening and Deepening Rates C-4
Table C-4 NMP2 H5 Upper HAZ 2000 and 2004 Cracking and Associated Lengthening and Deepening Rates C-4
Table C-5 KKM H3 and H4 HAZ 2001, 2003 and 2005 cracking and deepening rates C-5

Table C-6 BF-3 H1, H2, H4 and H7 2006-2008 Inspection Results and Associated Lengthening and Deepening Rates C-6
Table C-7 PB-3 H3 and H4 1999-2005 Inspection Results and Associated Lengthening and Deepening Rates C-7
Table D-1 KKM H3 and H4 2005-2007 Inspection Results and Associated Lengthening and Deepening Rates D-2

1
INTRODUCTION AND BACKGROUND

Visual and UT examinations of shrouds have been conducted since the early 1990s. The results of these inspections have shown the shroud to be one of the most frequently cracked and actively cracking components in the BWR plants. As such, understanding shroud crack growth characteristics is important in assessing structural margin. As of 2004, all US BWRs achieved some level of stress corrosion cracking (SCC) mitigation through hydrogen water chemistry (HWC) injection, either at moderate HWC levels or at low HWC levels in conjunction with Noble Metal Chemical Application (NMCA), also referred to as NobleChem™. Similar mitigation has been implemented at a number of international plants as well. In general, these mitigation strategies should significantly reduce crack growth rates and crack initiation in the shroud, as well as other components. Review of shroud UT re-examination results provides important feedback on the effectiveness of plant mitigation activities.

A meaningful comparison of shroud inspection results requires at least two inspections done with similar and systematic inspection methods, i.e., UT examination. Visual examinations are subject to variation in surface cleanliness and condition, and they provide only surface length information, usually on one surface only.

Shroud UT examination generates substantial amounts of data, which take weeks to fully evaluate to produce a shroud examination report. These reports provide the details of the inspection results from that examination. However, the standard inspection reports do not include any inspection-to-inspection comparison of results of specific indications. This type of comparison is very important for several reasons. Specifically, these data can be used to estimate the rates of crack growth, both in the length and in the depth direction, that are used to evaluate structural margin of the shroud. While the data used to establish the growth rates for flaw evaluations are based on appropriate laboratory crack growth studies, the plant data can be used to confirm the predictions. For plants that are implementing HWC, NMCA or OLNC to mitigate crack growth, these data are particularly important to confirm the effectiveness in reducing crack growth.

This program was designed to build the database as inspection results increase year by year. It started in 2007 (Revision 0) with the evaluation of crack growth in four plants: two MHWC plants and two NMCA plants. The MHWC plants for which data was available are Brunswick Unit 1 (BRN1) and Susquehanna Unit 1 (SUS1). The NMCA plants in this initial study were Nine Mile Point 2 (NMP2) and Muehleberg (KKM). Revision 1 in 2008 included two MHWC plants, Brunswick 2 (BRN2) and Monticello (MONT), two NMCA plants, Browns Ferry 3 (BF-3) and Peach Bottom 3 (PB-3), and one OLNC plant, KKM. The available data allowed a comparison over a period with operation using effective HWC. UT inspection data taken with comparable inspection systems were available, meeting a second criterion needed to make the

data most useful. The report first presents a history of the plant operation with details of the water chemistry during the time between the two shroud inspections and the methods used to determine the crack growth data. These processes follow the approaches developed by the BWRVIP for assessing rates under NWC conditions and make use of the data from that effort which is included as Appendix A along with more recent NWC data. Using these approaches, the plant specific data are presented and then used separately and together to evaluate crack lengthening and deepening rates.

The report had two purposes: the crack growth data was first to be compared with the NWC rates. It was then used to benchmark the disposition rates used in structural evaluations of core shrouds. For crack lengthening, the disposition rate of 5×10^{-5} in/hr has been the accepted rate for use in both BWRVIP-01 and BWRVIP-76 [1, 2]. For crack deepening, the rate of 2.2×10^{-5} in/hr is the accepted rate, as proposed in BWRVIP-14, for operation under NWC conditions [3, 4]. The rate of 1.1×10^{-5} in/hr was also accepted by the NRC for operation with effective HWC [4][1]. With the evaluation of MHWC, NMCA and OLNC plants, these data could be used to evaluate the entire BWR fleet.

1.1 Implementation Requirements

This report is provided for information only. Therefore, the implementation requirements of Nuclear Energy Institute (NEI) 03-08, Guideline for the Management of Materials Issues, are not applicable.

[1] It should be noted that both of these deepening rates were accepted by the NRC only for use with core shrouds up to a fluence of 5×10^{20} n/cm^2.

2
PLANT OPERATION HISTORY AND UT INSPECTION TIMING

As discussed in the introduction, this report was directed at evaluating crack growth rates of existing IGSCC indications in the core shrouds of several MHWC plants, several NMCA plants and one OLNC plant, KKM. KKM is unique to date in that it has both NMCA and OLNC results represented in this study. All of the plants were inspected and then operated with mitigation for the period between inspections. For KKM, the effectiveness of the NMCA results may have been compromised due to the risk of crack flanking as described in [5]. Table 2-1 lists the history of mitigation as well as the timing of the inspections for the plants in the study.

Table 2-1
History of Mitigation and Inspections

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MITIGATION AND WATER CHEMISTRY HISTORY BY PLANT

The water chemistry data used is limited and relies on data obtained from the different utilities when made available. This information coupled with the operational information in Table 2-1 provides the basis that these plants were mitigated over most or all of the time between inspections thereby allowing a reasonable assessment of the mitigation effectiveness.

Table 3-1 displays the water chemistry for NMP2 over the period from the first injection of hydrogen in cycle 8 to the end of cycle 9. It should be noted that there was a period of time following the startup of cycle 8 before NMCA was injected. Additionally, hydrogen injection did not start until early 2001. These two periods of time (approximately 9 months) could have led to additional crack growth under NWC conditions. However, the evaluation assessed NMCA/HWC effectiveness based on the entire time between inspections.

Table 3-1 details the hydrogen injection rate and availability for the time between inspections at Susquehanna Unit 1. [[

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Table 3-1 gives the water chemistry history for KKM operation following the 2001 shroud inspection. [[

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BRN1 initially started operating on HWC in 1990. The level of injection was changed in the mid-1990s. For the time between the 1996 and 2006 inspections, the plant was considered to be operating on effective HWC.

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BRN2 and MONT both began HWC operation for piping mitigation in the early 1990s and subsequently increased injection rate to the levels shown in Table 3-1. For the period between the two shroud inspections, both plants injected hydrogen at the planned rate for MHWC mitigation. [[

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KKM began OLNC injections just before the 2005 outage, with continued injections in January 2006 and 2007. These initial injections had lower Pt input than for typical "production" injections. The injections each year, relative to a hypothetical average over the fuel surface area, were as follows:

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The CGRs from 2001-2005 were thought to be influenced by crack flanking. KKM's ongoing shroud inspections provide an excellent opportunity to observe quantitatively, through shroud CGR changes, whether OLNC improves the mitigation of SCC at that plant.

Table 3-1
Plant Hydrogen Water Chemistry (HWC) Availability

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Table 3-1
Plant Hydrogen Water Chemistry (HWC) Availability (continued)

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4
UT INSPECTION DATA AND ANALYSIS

The evaluation was based on comparing UT data that was taken with similar processes. The shroud inspection data reports served as the basis for the evaluations. The methods were directed at developing average crack lengthening and deepening rates and then using the compilation of data to evaluate the behavior of each plant, to compare plant to plant data and to evaluate the role, if any, of the location of cracks (ID or OD).

4.1 Overview of Methods for Determining Crack Growth Rates

For the majority of inspections, the UT evaluations reported the heat affected zone (HAZ) with cracking, the shroud surface with the indication, the starting location, the end location and the maximum depth associated with each indication around the circumference of the weld. Tables listing the specific information are presented in the appendices.

Consistent with the evaluation methods developed by the BWRVIP, the inspection data used did not include any NDE uncertainty since these values are dependent on the inspection system. For these comparisons, efforts were made to align the indications from the first inspection with those detected in the second inspection. At times, there was a need to slightly bias the first set to match the latter set around the circumference. In some cases, a set of initial flaws had coalesced to form the flaw recorded in the later inspection. For these cases, the extreme ends of the flaws from the initial inspection were compared with the ends of the flaw recorded in the later inspection. No efforts were made to record rates associated with coalescence since there could be uncertainty in the total time associated with flaw growth. Where multiple flaws were involved, the largest recorded depth from each location was used for the deepening calculation.

If the initial measurement of depth was larger than the later measurement, the calculated value of crack growth was shown as a negative value in the appendix tables, but was set to zero for the plots. Similarly, if length comparisons indicate an inactive crack, that CGR was set to zero for the plots. The CGR data are presented in a cumulative distribution format, from lowest to highest CGR. The zero CGR data points are not plotted, but the position of the positive CGR data relative to the cumulative distribution y-axis reflect the number of zero CGRs in each distribution.

To simplify the analysis, the crack growth rates were based on assuming 8000 hot operating hours per year. This value, also used in the BWRVIP efforts presented in Appendix A, is a good representative number that tends to slightly underestimate the current time. This assumption would also likely add at most 1-2% conservatism in the rate, a value well below the UT measurement uncertainty.

The welds for which there were inspection data varied from plant to plant. Likewise, the time between inspections varied for the different plants. These details will be presented in the next sections where the actual plant data and crack growth calculations are discussed.

The following sections present the data developed based on the shroud inspections at plants to date. Tabulated inspection results and CGRs calculated from those results are presented in Appendix B for MHWC plants, in Appendix C for NMCA plants and in Appendix D for OLNC plants.

4.2 Nine Mile Point Unit 2: Shroud Inspections in 2000 and 2004

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4.3 Susquehanna Unit 1: Shroud Inspections in 2000 and 2004

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4.4 Brunswick Unit 1: Shroud Inspections in 1996 and 2006

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4.5 Muehleberg (KKM): Shroud Inspections between 2000 and 2005

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4.6 Brunswick Unit 2: Shroud Inspections in 2001 and 2005/2007

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4.7 Monticello: Shroud Inspections in 1996 and 2005

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4.8 Browns Ferry 3: Shroud Inspections in 2006 and 2008

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4.9 KKM: Shroud Inspections between 2005 and 2007

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4.10 Peach Bottom 3: Shroud Inspections in 1999 and 2005

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Figure 4-1
NMP2 NMCA vs. NWC Lengthening CGRs

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Figure 4-2
NMP2 NMCA vs. NWC Deepening CGRs

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Figure 4-3
SUS1 MHWC vs. NWC Lengthening CGRs

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Figure 4-4
SUS1 MHWC vs. NWC Deepening CGRs

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Figure 4-5
BRN1 MHWC vs. NWC Deepening CGRs

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Figure 4-6
KKM NMCA vs. NWC Lengthening CGRs

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Figure 4-7
KKM NMCA vs. NWC Deepening CGRs

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Figure 4-8
BRN2 MHWC vs. NWC Lengthening CGRs

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Figure 4-9
BRN2 MHWC vs. NWC Deepening CGRs

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Figure 4-10
MONT MHWC vs. NWC Lengthening CGRs

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Figure 4-11
MONT MHWC vs. NWC Deepening CGRs

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Figure 4-12
BF-3 NMCA vs. NWC Lengthening CGRs

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Figure 4-13
BF-3 NMCA vs. NWC Deepening CGRs

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Figure 4-14
KKM OLNC vs. NWC Lengthening CGRs

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Figure 4-15
KKM OLNC vs. NWC Deepening CGRs

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Figure 4-16
PB-3 NMCA vs. NWC Lengthening CGRs

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Figure 4-17
PB-3 NMCA vs. NWC Deepening CGRs

5
EVALUATION OF MITIGATION ON CRACK GROWTH RATES

As discussed in the previous section, crack lengthening and deepening is evaluated for nine inspections at eight plants to date. Four of these are MHWC plants, four are NMCA/HWC plants and one of the NMCA plants has become an OLNC plant. Note that there are only three plants referenced for MHWC lengthening, because there were no lengthening CGRs determined for BRN1, only deepening CGRs. To better assess the impact of these environments on crack growth, total cumulative distributions were prepared. The following sections compare the cumulative lengthening rates and deepening rates under HWC and NMCA with the NWC rates. Given that there is only data for one OLNC plant at this time, a plot is not developed for OLNC (see Figures 4-14 and 4-15 for that comparison).

5.1 Lengthening Comparisons

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5.2 Deepening Comparisons

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5.3 Summary of Mitigation Effectiveness

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Figure 5-1
MHWC (3 Plants) vs. NWC Lengthening CGR Distributions

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Figure 5-2
NMCA (4 Plants) vs. NWC Lengthening CGR Distributions

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Figure 5-3
All Mitigation (7 Plants) vs. NWC Lengthening CGR Distributions

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Figure 5-4
Comparison of ID and OD Lengthening CGRs Under Mitigated and NWC Conditions

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Figure 5-5
MHWC (4 Plants) vs. NWC Deepening CGR Distributions

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Figure 5-6
NMCA (4 Plants) vs. NWC Deepening CGR Distributions

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Figure 5-7
All Mitigation (8 Plants) vs. NWC Deepening CGR Distributions

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Figure 5-8
Comparison of ID and OD Deepening CGRs Under Mitigated and NWC Conditions

6
SUMMARY AND CONCLUSIONS

The objective of this study is to evaluate the effect of water chemistry mitigation on crack growth in core shrouds of operating BWRs. The evaluation includes MHWC, NMCA and OLNC plants. The program was directed at evaluating both crack lengthening and crack deepening. It should be noted that crack flanking most likely affected the lengthening measurements derived from the KKM NMCA data [5]. NWC data in Appendix A is used as the basis for comparison with the CGR results from mitigated plants. The findings and conclusions from the current effort follow:

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A
BWRVIP NORMAL WATER CHEMISTRY (NWC) REFERENCE INSPECTION DATA

(Reference: BWRVIP Letter 2007-156: Transmittal of BWR Core Shroud Crack Growth Rate Data for Normal Water Chemistry)

A.1 Background

The NWC plants evaluated are BF-2 and -3, BRN2, KKM, PB-2 and -3, SUS1 and NMP2. In addition, shroud UT results for the H1 weld in mitigated plants, which is still considered to see an NWC environment, are added from BF-3 and MONT. As a result of NWC CGRs added as part of this study, the total data set is about 50% larger than that in BWRVIP-174 Revision 0. Data reports as provided to EPRI by utilities or the examination vendor were used for the evaluations documented herein. These data reports typically document the length of a detected crack, and the maximum depth of that crack. All data provided were reviewed, and examination results were summarized for each weld that was examined. These examination results were used to calculate the CGRs for each weld. The complete data population of CGRs calculated for all the plants mentioned was plotted as cumulative probability distributions. The summary of the inspection data by weld with detailed CGR calculations, and the cumulative probability distributions are documented in Appendices A.3 and A.4, respectively.

The following conventions were used in performing the CGR calculations:

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A.2 Approach

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Table A-1
Plants Evaluated

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A.3 Results

Results of the CGR calculations for each plant are tabulated below. The data are also plotted as cumulative probability vs. CGRs in Section A.4.

A.3.1 Browns Ferry Unit 2

Table A-2 summarizes the calculated crack growth results for Browns Ferry Unit 2 with inspection data from outages in 1994, 1996 and 1997.

A.3.2 Browns Ferry Unit 3

Table A-3 summarizes the calculated crack growth results for Browns Ferry Unit 3 with inspection data from outages in 1994, 1997 and 1998.

A.3.3 Brunswick Unit 2

Table A-4 summarizes the calculated crack growth results for Brunswick Unit 2 with inspection data from outages in 1994, 1996 and 1997.

Table A-2
Browns Ferry 2 Crack Growth Rate Data Population

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Table A-2 (continued)
Browns Ferry 2 Crack Growth Rate Data Population

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Table A-3
Browns Ferry 3 Crack Growth Rate Data Population

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Table A-3 (continued)
Browns Ferry 3 Crack Growth Rate Data Population

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Table A-4
Brunswick 2 Crack Growth Rate Data Population

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A.3.4 Peach Bottom Unit 2

Table A-5 summarizes the calculated crack growth results for Peach Bottom 2 with inspection data from outages in 1994 and 1996.

A.3.5 Susquehanna Unit 1

Table A-6 summarizes the calculated crack growth results for Susquehanna 1 with inspection data from outages in 1995 and 1996.

Table A-5
Peach Bottom 2 Crack Growth Rate Data Population

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Table A-6
Susquehanna 1 Crack Growth Rate Data Population

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Table A-6 (continued)
Susquehanna 1 Crack Growth Rate Data Population

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Table A-6 (continued)
Susquehanna 1 Crack Growth Rate Data Population

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A.3.6 Muehleberg

Table A-7 summarizes the calculated crack growth results for Muehleberg with inspection data from outages in 1995 and each after through 2000.

Table A-7
Muehleberg Crack Growth Rate Data Population

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A.3.7 Nine Mile Point 2

Table A-8 summarizes the calculated crack growth results for NMP2 with inspection data from outages in 1998 and 2000.

A.3.8 Peach Bottom 3

Table A-9 summarizes the calculated crack growth results for PB-3 with inspection data from outages in 1995 and 1999.

A.3.9 Browns Ferry 3 H1

Table A-10 summarizes the calculated crack growth results for the BF-3 H1 shroud weld region with inspection data from outages in 2006 and 2008.

A.3.10 Monticello H1

Table A-11 summarizes the calculated crack growth results for the MONT H1 shroud weld region with inspection data from outages in 1996 and 2005.

Table A-8
NMP2 Crack Growth Rate Data Population

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Table A-8 (cont'd)
NMP2 Crack Growth Rate Data Population

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Table A-8 (cont'd)
NMP2 Crack Growth Rate Data Population

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Table A-9
PB-3 Crack Growth Rate Data Population

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Table A-10
BF-3 Crack Growth Rate Data Population

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Table A-11
MONT Crack Growth Rate Data Population

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A.4 Cumulative Probability Plots

The data tabulated in the previous section was also plotted as cumulative probability versus crack growth rate. The results for length and depth CGRs are shown in Figures A-1 and A-2. The changes in the distributions from Revision 0 to Revision 1 of this report are shown in Figures A-3 and A-4.

The distributions shown are used when reviewing core shroud inspection results for HWC, NMCA and OLNC plants. This information is used comparatively to show the cracking mitigation benefits of those methods, as is done in Sections 4 and 5 of this report.

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Figure A-1
NWC Lengthening CGR Distribution

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Figure A-2
NWC Deepening CGR Distribution

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Figure A-3
Change in NWC Lengthening Distribution Between Report Revisions

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Figure A-4
Change in NWC Deepening Distribution Between Report Revisions

B
MHWC INSPECTION DATA AND CGRS

B.1 Report Revision 0 Inspections

Revision 0 of this report evaluated shroud UT results from four plants whose inspections were completed by 2007. Of those, two plants were MHWC plants, SUS1 and BRN1. Table B-1 has the SUS1 inspection results and calculated lengthening and deepening CGRs. Tables B-2 and B-3 have the BRN1 inspection results. As stated in Section 4, lengthening CGRs were not calculated because of the significant differences in length results between the different inspection vendors.

B.2 Report Revision 1 Inspections

Revision 1 of this report added shroud UT results from five plants whose most recent inspections were not included in Revision 0 or were done since then. Of those, two plants were MHWC plants, BRN2 and MONT. Tables B-4 and B-5 have the BRN2 inspection results and calculated lengthening and deepening CGRs. Table B-6 has the MONT inspection results and CGRs. The tables for the Section B-1 plants report only the aligned indications for which CGRs could be calculated. The tables for BRN2 and MONT report all indications measured. Those indications from the sequential inspections are paired where possible based on matching, or nearly matching azimuthal degree locations. The valid pairings, highlighted in green in the tables, are used to calculate the CGRs.

Table B-1
Susquehanna Unit 1 H4 HAZ 2000 and 2004 Cracking and Associated Lengthening and Deepening Rates

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Note: Susquehanna Unit 1shroud thickness is 2.0 inches (51mm).

Table B-2
Brunswick Unit 1 H4 and H6a HAZ 1996 and 2006 Cracking and Deepening Rates

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Note: Brunswick Unit 1 shroud thickness is 1.5 inches (38 mm).

Table B-3
Brunswick Unit 1 H6b and H7 HAZ 1996 and 2006 Cracking and Deepening Rates

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Table B-4
BRN2 H4 2001-2005 Inspection Results and Associated Lengthening and Deepening Rates

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Table B-5
BRN2 H6b 2001-2007 Inspection Results and Associated Lengthening and Deepening Rates

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Table B-6
MONT H1-H6 1996-2005 Inspection Results and Associated Lengthening and Deepening Rates

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C
NMCA INSPECTION DATA AND CGRS

C.1 Report Revision 0 Inspections

Revision 0 of this report evaluated shroud UT results from four plants whose inspections were completed by 2007. Of those, two plants were NMCA plants, NMP2 and KKM. Tables C-1 through C-4 have the NMP2 H4 and H5 inspection results and calculated lengthening and deepening CGRs. Table C-5 has the KKM inspection results for the period of NMCA operation.

C.2 Report Revision 1 Inspections

Revision 1 of this report added shroud UT results from five plants whose most recent inspections were not included in Revision 0 or were done since then. Of those, two plants were NMCA plants, BF-3 and PB-3. Table C-6 has the BF-3 inspection results and calculated lengthening and deepening CGRs. Table C-7 has the PB-3 inspection results and CGRs. The tables for the Section C-1 plants report only the aligned indications for which CGRs could be calculated. The tables for BF-3 and PB-3 report all indications measured. Those indications from the sequential inspections are paired where possible based on matching, or nearly matching azimuthal degree locations. The valid pairings, highlighted in green in the tables, are used to calculate the CGRs.

Table C-1
NMP2 H4 Lower HAZ 2000 and 2004 Cracking and Associated Lengthening and Deepening Rates

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Table C-2
NMP2 H4 Upper HAZ 2000 and 2004 Cracking and Associated Lengthening and Deepening Rates

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Table C-3
NMP2 H5 Lower HAZ 2000 and 2004 Cracking and Associated Lengthening and Deepening Rates

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Table C-4
NMP2 H5 Upper HAZ 2000 and 2004 Cracking and Associated Lengthening and Deepening Rates

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Table C-5
KKM H3 and H4 HAZ 2001, 2003 and 2005 cracking and deepening rates

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Table C-6
BF-3 H1, H2, H4 and H7 2006-2008 Inspection Results and Associated Lengthening and Deepening Rates

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Table C-7
PB-3 H3 and H4 1999-2005 Inspection Results and Associated Lengthening and Deepening Rates

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D
OLNC INSPECTION DATA AND CGRS

D.1 Report Revision 1 Inspections

Revision 1 of this report added shroud UT results from five plants whose most recent inspections were in 2007 or 2008. Of those, KKM was the only OLNC plant. Table D-1 has the KKM inspection results and calculated lengthening and deepening CGRs.

Table D-1
KKM H3 and H4 2005-2007 Inspection Results and Associated Lengthening and Deepening Rates

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