Enclosure 12 to AEP-NRC-2018-66

WCAP-18394-NP, Revision 1 "Fatigue Crack Growth Evaluations of D.C. Cook Units 1 and 2 RHR, Accumulator, and Safety Injection Lines Supporting Expanded Scope Leak-Before-Break" (Non-Proprietary)

WCAP-18394-NP
Revision 1

September 2018

Fatigue Crack Growth Evaluations of D.C. Cook Units 1 and 2 RHR, Accumulator, and Safety Injection Lines Supporting Expanded Scope Leak-Before-Break

Westinghouse

WCAP-18394-NP
Revision 1

Fatigue Crack Growth Evaluations of D.C. Cook Units 1 and 2 RHR, Accumulator, and Safety Injection Lines Supporting Expanded Scope Leak-Before-Break

September 2018

Author: Eric D. Johnson*
Structural Design and Analysis - II

Reviewer: Momo Wiratmo*
Structural Design and Analysis - II

Approved: Benjamin A. Leber, Manager*
Structural Design and Analysis - II

*Electronically approved records are authenticated in the electronic document management system.

Westinghouse Electric Company LLC
1000 Westinghouse Drive
Cranberry Township, PA 16066, USA

TABLE OF CONTENTS

LIST OF TABLES

1.0 INTRODUCTION

1.1 PURPOSE

The application of Leak-Before-Break (LBB) for the Accumulator lines, the Residual Heat Removal (RHR) lines, and the Safety Injection (SI) lines at the D.C. Cook Nuclear Plant Units 1 and 2 have been documented in References 1-1, 1-2, and 1-3, respectively. The evaluation of Fatigue Crack Growth (FCG) for these piping systems had been excluded from the demonstration of LBB on the basis that FCG is not a requirement defined in the Standard Review Plan 3.6.3 (References 1-4 and 1-5).

Requests for Additional Information (RAIs) issued by the U.S. Nuclear Regulatory Commission (NRC), following their initial review of the License Amendment Request (LAR) for these LBB evaluations, have indicated that FCG analyses have become a requirement based on precedence since past LBB evaluations for other plants and other piping systems have typically included FCG evaluations. The purpose of this report is to serve as documentation of the FCG evaluation for the D.C. Cook Units 1 and 2 Accumulator, RHR, and SI lines to support the justification of LBB as documented in References 1-1, 1-2, and 1-3.

1.2 BACKGROUND

Fatigue crack growth evaluations have historically been included with the documentation for demonstrating LBB of the associated piping system. While the SRP 3.6.3 requirements for the demonstration of LBB (References 1-4 and 1-5) do not explicitly include criteria related to performing an FCG analysis, the results are commonly presented as a defense-in-depth justification in relation to other LBB criteria. Specifically;

- Degradation related to cyclic fatigue: An FCG evaluation supplements a conventional fatigue evaluation and reinforces that small postulated surface flaws do not become through-wall flaws during the entire operating life of the piping system.

- Stability of a through-wall flaw: FCG provides an assurance that a leakage flaw can be identified and addressed prior to growing to a critical flaw size. While FCG is not explicitly performed for a through-wall flaw, correlation can be drawn against the very small growth of a surface flaw over the operating life of the plant. Through this correlation, it can be justified that the growth of a through-wall leakage flaw would generally take several months, years, or even decades of operation before growing to a critical size. This demonstration reinforces that sufficient time is available for the flaw to be identified and for the plant to be shutdown without any concern of rupture.

1.3 METHODOLOGY

The demonstration of FCG for each of the piping systems is established through the utilization of a representative FCG evaluation. These representative FCG evaluations are based on a generic Pressurized Water Reactor (PWR) piping system design or based on the design of an operating plant with comparable design considerations. Since these representative FCG evaluations are not plant-specific to D.C. Cook, a review of the fundamental FCG evaluation input parameters is performed to identify and assess differences between the representative plant design and D.C. Cook. This comparison includes consideration of the piping geometry and material properties, operating temperature and pressure of the piping systems, operating transients for the design life of the plants, and piping loads experienced at the evaluated locations. For each of these analysis parameters, the representative FCG evaluations are shown to be bounding or equivalent to the D.C. Cook piping systems. For instances where an input of the representative FCG evaluation is not bounding or equivalent to D.C. Cook, justification will be provided to establish that that the associated impact to the FCG evaluation and conclusions would be negligible.

The representative FCG evaluations are performed following the methodology of Section XI, Appendix A of the ASME Code. The FCG evaluations consider a set of initial flaw sizes which typically range from 10% up to 35% of the approximate pipe wall thickness. These ranges of initial flaw sizes are based on acceptance standards from Section XI of the ASME Code for flaw inspections and detectability. Although flaw detectability is not a specific consideration for the demonstration of LBB, this same initial flaw basis is considered in this report due to the use of these representative FCG evaluations. Relative to the LBB evaluation, these ranges of initial flaw sizes are appropriate for the purpose of demonstrating that flaw growth is stable, regardless of the initial flaw size.

1.4 REFERENCES

1-1 Westinghouse Reports, WCAP-18295-P (Proprietary) and WCAP-18295-NP (Non-proprietary), "Technical Justification for Eliminating Accumulator Line Rupture as the Structural Design Basis for D.C. Cook Units 1 and 2, Using Leak-Before-Break Methodology," January 2018.

1-2 Westinghouse Reports, WCAP-18302-P (Proprietary) and WCAP-18302-NP (Non-proprietary), "Technical Justification for Eliminating Residual Heat Removal Line Rupture as the Structural Design Basis for D.C. Cook Units 1 and 2, Using Leak-Before-Break Methodology," January 2018.

1-3 Westinghouse Reports, WCAP-18309-P (Proprietary) and WCAP-18309-NP (Non-proprietary), "Technical Justification for Eliminating Safety Injection Line Rupture as the Structural Design Basis for D.C. Cook Units 1 and 2, Using Leak-Before-Break Methodology," January 2018.

1-4 Standard Review Plan: Public Comments Solicited; 3.6.3 Leak-Before-Break Evaluation Procedures; Federal Register/Vol. 52, No. 167/Friday August 28, 1987/Notices, pp. 32626-32633.

1-5 NUREG-0800 Revision 1, March 2007, Standard Review Plan: 3.6.3 Leak-Before-Break Evaluation Procedures.

2.0 ACCUMULATOR LINE FATIGUE CRACK GROWTH ASSESSMENT

To determine the sensitivity of the 10-inch Accumulator line piping to the presence of small, circumferentially oriented, surface cracks subjected to operating transients, a representative FCG analysis is compared with the operating conditions of the 10-inch Accumulator lines of D.C. Cook Units 1 and 2. The crack growth for the representative analysis demonstrates that small surface flaws would not develop to through-wall flaws during the plant operating life.

The representative FCG evaluation considers a 10-inch, Schedule 140 piping component, consistent with D.C. Cook, and utilizes a crack growth law for stainless steel material type in a PWR water environment. Due to similarities in the piping geometry and line configuration, the D.C. Cook Accumulator line normal operating piping loads (e.g., deadweight and thermal expansion forces and moments) and the associated stresses are similar to the loads and stresses from typical analyses of PWR Accumulator line piping systems. Based on this comparison of piping loads and stresses, it is determined that the pipe loadings considered in the representative FCG evaluation are appropriate for the estimation of FCG in the D.C. Cook Accumulator lines.

The operating conditions for the representative Accumulator line are evaluated at a temperature of 558°F and an internal pressure of 2285 psi. The respective operating parameters for the D.C. Cook Accumulator lines are a temperature of 549°F and an internal pressure of 2345 psi. These differences in temperature and pressure will have an insignificant impact on the FCG results. The FCG evaluation is dependent on stress ranges, so while there is a difference in pressure of 60 psi (approximately three percent), the pressure stress ranges are consistent for crack growth.

The operating transient set and applicable operating cycles considered for the 10-inch Accumulator line FCG evaluation are shown in Table 2-1. Comparatively, Table 2-2 shows the set of transients which have been projected for the D.C. Cook Accumulator lines for the 60-year period of extended operation. It is noted that crack growth for the Accumulator lines is dominated by the transients which include actuation of the Accumulator, SI, or RHR systems. For the representative FCG evaluation, Table 2-1 shows that the transient cycles with Accumulator/SI/RHR actuation bound the cycles for the D.C. Cook 60-year projections shown in Table 2-2. For the remaining reactor coolant loop (RCL) design transients without Accumulator/SI/RHR actuation, the total number of design cycles in the representative FCG evaluation is slightly less than the total number of cycles for the D.C. Cook 60-year projection. This difference would have a negligible effect on the FCG evaluation since the RCL design transients without Accumulator/SI/RHR actuation have a small contribution to the total crack growth as compared to the transients with Accumulator/SI/RHR actuation.

Additionally, for the representative FCG evaluation, the severities of transients with Accumulator/SI/RHR actuation, including the magnitude and rate of change in pressure, temperature, and piping loads, are equivalent to the severities of the D.C. Cook transients with Accumulator/SI/RHR actuation. The severities of the transients without Accumulator/SI/RHR actuation in Table 2-1 are characteristic of the D.C. Cook cold leg transient groupings in Table 2-2. As such, the transients and cycles for the representative FCG evaluation are applicable to the D.C. Cook Accumulator lines for the 60-year period of extended operation.

Results of the 10-inch Accumulator line FCG evaluation are presented in Table 2-3. Beyond showing that small surface flaws would not develop to through-wall flaws over the operating life of the plant, the FCG evaluation also demonstrates that the growth of a flaw will be very slow. These results support the justification that flaw growth would be insignificant in between the time when leakage reaches 8 gpm and the time that the plant would be shutdown. Based on this justification, it is concluded that fatigue crack growth is not a concern for the 10-inch Accumulator lines of D.C. Cook Units 1 and 2.

Table 2-1 Transient Set for Accumulator Line FCG Evaluation

Transient Name	Cycles
(transients with actuation of Accumulator, SI, or RHR systems)	
High Head Safety Injection	110
Accumulator Actuation, Inadvertent During Cooldown	4
Inadvertent RCS Depressurization	20
RHR Operation During Refueling	80
RHR Operation During Plant Cooldown	200
Accumulator Actuation, Accident Operation	21
(transients <u>without</u> actuation of Accumulator, SI, or RHR systems)	
Unit Loading	13200
Unit Unloading	13200
Step Load Increase	2000
Step Load Decrease	2000
Feedwater Cycling	2000
Reactor Trip - Cooldown, No SI	160
Control Rod Drop	80
Turbine Roll Test	20
Steady State and Random Fluctuations	3200000

Table 2-2 60-Year Transient Projections for D.C. Cook Accumulator Lines

Transient Name	Cycles
(transients with actuation of Accumulator, SI, or RHR systems)	
High Head Safety Injection - A	49
High Head Safety Injection - B	
Inadvertent Accumulator Blowdown	4
Inadvertent RCS Depressurization - A	20
Inadvertent RCS Depressurization - B	
Refueling	80
RHR Operation - Plant Cooldown	200
(transients without actuation of Accumulator, SI, or RHR systems)	
Cold Leg Transients - Group 1	33210
Cold Leg Transients - Group 2	80
Cold Leg Transients - Group 3	410
Cold Leg Transients - Group 4	65
Cold Leg Transients - Group 5	21

Table 2-3 D.C. Cook Accumulator Line 60-Year Fatigue Crack Growth Results

a,c,e

3.0 RESIDUAL HEAT REMOVAL LINE FATIGUE CRACK GROWTH ASSESSMENT

To determine the sensitivity of the 14-inch RHR line piping to the presence of small, circumferentially oriented, surface cracks subjected to operating transients, a representative FCG analysis is compared with the operating conditions of the 14-inch RHR lines of D.C. Cook Units 1 and 2. The crack growth for the representative analysis demonstrates that small surface flaws would not develop to through-wall flaws during the plant operating life.

The representative FCG evaluation considers a 14-inch, Schedule 160 piping component, consistent with D.C. Cook, and utilizes a crack growth law for stainless steel material type in a PWR water environment. Due to similarities in the piping geometry and line configuration, the D.C. Cook RHR line normal operating piping loads (e.g., deadweight and thermal expansion forces and moments) and the associated stresses are similar to the loads and stresses from typical analyses of PWR RHR line piping systems. Based on this comparison of piping loads and stresses, it is determined that the pipe loadings considered in the representative FCG evaluation are appropriate for the estimation of FCG in the D.C. Cook RHR lines.

The operating conditions for the representative RHR line are evaluated at a temperature of 611°F and an internal pressure of 2235 psi. The respective operating parameters for the D.C. Cook RHR lines are a temperature of 617°F and an internal pressure of 2235 psi. The operating pressure values are equivalent and the difference in temperature will have an insignificant impact on the FCG results.

The operating transient set and applicable operating cycles considered for the 14-inch RHR line FCG evaluation are shown in Table 3-1. Comparatively, Table 3-2 shows the set of transients which have been projected for the D.C. Cook RHR lines for the 60-year period of extended operation. It is noted that the representative FCG evaluation does not include the Heatup/Cooldown transient with 200 operating cycles. The exclusion of the Heatup/Cooldown transient is determined to be bounded by the inclusion of other transients which are not defined for the D.C. Cook RHR lines. Unit Loading/Unloading from 0-15% Power (500 cycles), Inadvertent RCS Depressurization (20 cycles), Control Rod Drop (80 cycles), and Inadvertent Safety Injection (60 cycles) are each comparable or more severe than the Heatup/Cooldown transient. The 200 cycles for Heatup/Cooldown are fully enveloped by the combined 660 cycles of the additional transients.

The transients in both Table 3-1 and Table 3-2 are standard RCL design transient and the respective transient definitions are equivalent in the severity of the magnitude and rate of change in pressure, temperature, and piping loads. As such, the transients and cycles for the representative FCG evaluation are applicable to the D.C. Cook RHR lines for the 60-year period of extended operation.

Results of the 14-inch RHR line FCG evaluation are presented in Table 3-3. Beyond showing that small surface flaws would not develop to through-wall flaws over the operating life of the plant, the FCG evaluation also demonstrates that the growth of a flaw will be very slow. These results support the justification that flaw growth would be insignificant in between the time when leakage reaches 8 gpm and the time that the plant would be shutdown. Based on this justification, it is concluded that fatigue crack growth is not a concern for the 14-inch RHR lines of D.C. Cook Units 1 and 2.

Table 3-1 Transient Set for RHR Line FCG Evaluation

Transient Name	Cycles
Unit Loading	18300
Unit Unloading	18300
Step Load Increase	2000
Step Load Decrease	2000
Large Step Load Decrease with Steam Dump	200
Feedwater Cycling	18300
Unit Loading Between 0 and 15% Power	500
Unit Unloading Between 0 and 15% Power	500
Loss of Load	80
Loss of Power	40
Partial Loss of Flow-Dead Loop	80
Partial Loss of Flow-Active Loop	80
Reactor Trip with no Inadvertent Cooldown	230
Reactor Trip with Cooldown; No Safety Injection	160
Reactor Trip with Cooldown Actuating Safety Injection	10
Inadvertent RCS Depressurization	20
Control Rod Drop	80
Inadvertent Safety Injection	60
Turbine Roll Test	20
Steady-State and Random Fluctuations	3200000

Table 3-2 60-Year Transient Projections for D.C. Cook RHR Lines

Transient Name	Cycles
Heatup and Cooldown	200
Unit Loading at 5%	18300
Unit Unloading at 5%	18300
10% Step Load Increase	2000
10% Step Load Decrease	2000
Large Step Load Decrease - Steam Dump	200
Hot Standby (equivalent to Feedwater Cycling)	18300
Loss of Load	80
Loss of Power	40
Partial Loss of Flow	80
Reactor Trip from Full Power	400
Turbine Roll Test	10
Steady State Fluctuations	infinite

Table 3-3 D.C. Cook RHR Line 60-Year Fatigue Crack Growth Results

a,c,e

4.0 SAFETY INJECTION LINE FATIGUE CRACK GROWTH ASSESSMENT

To determine the sensitivity of the 6-inch SI line piping to the presence of small, circumferentially oriented, surface cracks subjected to operating transients, a representative FCG analysis is compared with the operating conditions of the 6-inch SI lines of D.C. Cook Units 1 and 2. The crack growth for the representative analysis demonstrates that small surface flaws would not develop to through-wall flaws during the plant operating life.

The representative FCG evaluation considers a 6-inch, Schedule 160 piping component, consistent with D.C. Cook, and utilizes a crack growth law for stainless steel material type in a PWR water environment. Due to similarities in the piping geometry and line configuration, the D.C. Cook SI line normal operating piping loads (e.g., deadweight and thermal expansion forces and moments) and the associated stresses are similar to the loads and stresses from typical analyses of PWR SI line piping systems. Based on this comparison of piping loads and stresses, it is determined that the pipe loadings considered in the representative FCG evaluation are appropriate for the estimation of FCG in the D.C. Cook SI lines.

The operating SI line conditions for the representative SI line bound a range of temperatures from 120°F to 653°F and a range of internal pressure from 2235 psi to 2385 psi. The respective operating parameters for the D.C. Cook SI lines are temperatures of 120°F (cold leg and hot leg SI lines) and 618°F (hot leg SI lines) and an internal pressure of 2235 psi. The D.C. Cook operating temperature and pressure values are within the range of operating parameters for the representative FCG evaluation.

The operating transient set and applicable operating cycles considered for the 6-inch SI line FCG evaluation are shown in Table 4-1. Comparatively, Table 4-2 shows the set of transients which have been projected for the D.C. Cook SI lines for the 60-year period of extended operation. It is noted that the evaluated SI line location does not experience transient effects due to the set of RCL design transients. The SI lines are attached to the Accumulator line piping and are not subjected to the cold leg piping transients. Additionally, the transients which involve Accumulator and RHR actuation do not apply directly to the SI lines, but these transients are conservatively considered in the SI line FCG evaluation since the associated flow stream passes the branch between the Accumulator and SI lines and could result in mixing effects.

For the representative FCG evaluation, the severities of transients with Accumulator/SI/RHR actuation, including the magnitude and rate of change in pressure, temperature, and piping loads, are equivalent to the severities of the D.C. Cook transients with Accumulator/SI/RHR actuation. As such, the transients and cycles for the representative FCG evaluation bound the D.C. Cook SI lines for the 60-year period of extended operation.

Results of the 6-inch SI line FCG evaluation are presented in Table 4-3. Beyond showing that small surface flaws would not develop to through-wall flaws over the operating life of the plant, the FCG evaluation also demonstrates that the growth of a flaw will be very slow. These results support the justification that flaw growth would be insignificant in between the time when leakage reaches 8 gpm and the time that the plant would be shutdown. Based on this justification, it is concluded that fatigue crack growth is not a concern for the 6-inch SI lines of D.C. Cook Units 1 and 2.

Table 4-1 Transient Set for SI Line FCG Evaluation

Transient Name	Cycles
(transients with actuation of Accumulator, SI, or RHR systems)	
Inadvertent RCS Depressurization	20
High Head Safety Injection	90
Post LOCA Operation	5
Inadvertent Accumulator Blowdown	5
HHSI Test During Refueling	85
RHR Operation during Plant Cooldown	200

Table 4-2 60-Year Transient Projections for D.C. Cook SI Lines

Transient Name	Cycles
(transients with actuation of Accumulator, SI, or RHR systems)	
High Head Safety Injection - A	49
High Head Safety Injection - B	
Inadvertent Accumulator Blowdown	4
Inadvertent RCS Depressurization - A	20
Inadvertent RCS Depressurization - B	
Refueling	80
RHR Operation - Plant Cooldown	200

Table 4-3 D.C. Cook SI Line 60-Year Fatigue Crack Growth Results

a,c,e

5.0 CONSIDERATION OF 8-INCH PIPING SEGMENTS

The SI line piping attached to the RCL hot leg and the RHR return line piping attached to the Accumulator lines both contain segments of piping which are 8-inch, Schedule 140 pipe size. The concern for crack growth in these 8-inch segments is addressed through comparison to the other representative FCG analyses that have been presented in the preceding sections.

In both cases, the 8-inch piping of the SI lines and RHR return lines are sufficiently away from the main RCL piping, and separated by a check valve, so that they would not experience the full set of RCL design transients. The SI line segments would only experience transients directly related to actuation of the SI system. The RHR return lines would experience transients directly related to actuation of the RHR system and also experience transient effects from the Accumulator system actuation due to mixing at the branch connection between the RHR return line and the Accumulator line. The RHR return lines would not see effects from actuation of the SI system, since the SI piping is upstream of the RHR return lines.

Respective to piping geometry; the 10-inch Accumulator lines and the 6-inch SI lines represent cases that would bound the 8-inch pipe size. The FCG evaluation for the 10-inch Accumulator lines included the full set of transients related to actuation of the Accumulator/SI/RHR systems as well as the remaining RCL transients without Accumulator/SI/RHR actuation (Table 2-1). The full set of design transients for the 10-inch Accumulator lines bound the set of transients which could be experienced by the 8-inch piping of the SI lines and RHR return lines. The FCG evaluation for the 6-inch SI lines included the full set of transients related to actuation of the Accumulator/SI/RHR systems (Table 4-1). These design transients for the 6-inch SI lines bound the set of transients which could be experienced by the 8-inch piping of the SI lines and RHR return lines.

Pipe sizes and transient sets for the 10-inch Accumulator lines and the 6-inch SI lines are shown to envelope the 8-inch segments of the SI lines and RHR return lines of D.C. Cook Units 1 and 2. The respective FCG results in Table 2-2 and Table 4-2 show that small surface flaws would not develop to through-wall flaws and that the growth of a flaw will be very slow. These conclusions for the 10-inch and 6-inch piping are applicable to the 8-inch piping segments of SI lines and RHR return lines. Based on this justification, it is concluded that fatigue crack growth is not a concern for the 8-inch piping segments of D.C. Cook Units 1 and 2.

6.0 CONCLUSIONS

This report documents the FCG evaluations for the Accumulator, RHR, and SI lines of D.C. Cook Units 1 and 2. For each piping system, results of the FCG evaluation show that small surface flaws would not develop to through-wall flaws and that the growth of a flaw will be very slow. These results support the justification that flaw growth would be insignificant in between the time when leakage reaches 8 gpm and the time that the plant would be shutdown. Based on this justification, it is concluded that fatigue crack growth is not a concern for the Accumulator, RHR, and SI lines of D.C. Cook Units 1 and 2.

The demonstration of FCG for these piping systems supports Leak-Before-Break evaluations which justify that the dynamic effects of the pipe rupture resulting from postulated breaks in the Accumulator, RHR, and SI line piping need not be considered in the structural design basis of D.C. Cook Units 1 and 2.

This page was added to the quality record by the PRIME system upon its validation and shall not be considered in the page numbering of this document.

Approval Information
Author Approval Johnson Eric D Sep-18-2018 11:19:57
Reviewer Approval Wiratmo Momo Sep-18-2018 11:23:34
Manager Approval Leber Benjamin A Sep-18-2018 12:05:14

Files approved on Sep-18-2018

*** This record was final approved on 9/18/2018 12:05:14 PM. (This statement was added by the PRIME system upon its validation)