UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

In the Matter of NEXTERA ENERGY SEABROOK, LLC (Seabrook Station, Unit 1)	Docket No. 50-443-LA-2 ASLBP No. 17-953-02-LA-BD01

Hearing Exhibit

Exhibit Number: NER014

Exhibit Title: NUREG-2191, “Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR) Report,” Vol. 2 (July 2017) [Cover and Section X.M1]

NUREG-2191, Vol. 2

United States Nuclear Regulatory Commission

Protecting People and the Environment

Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR) Report

Final Report

Office of Nuclear Reactor Regulation

X.M1 FATIGUE MONITORING

Program Description

This aging management program (AMP) provides an acceptable basis for managing structures and components (SCs) that are the subject of fatigue or cycle-based time-limited aging analyses (TLAAs) or other analyses that assess fatigue or cyclical loading, in accordance with the requirements in Title 10 of the *Code of Federal Regulations* (10 CFR) 54.21(c)(1)(iii). Examples of cycle-based fatigue analyses for which this AMP may be used include, but are not limited to: (a) cumulative usage factor (CUF) analyses or their equivalent (e.g., I_t-based fatigue analyses, as defined in specific design codes) that are performed in accordance with American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) requirements for specific mechanical or structural components; (b) fatigue analysis calculations for assessing environmentally-assisted fatigue; (c) implicit fatigue analyses, as defined in the United States of America Standards (USAS) B31.1 design code or ASME Code Section III rules for Class 2 and Class 3 components; (d) fatigue flaw growth analyses that are based on cyclical loading assumptions; (e) fracture mechanics analyses that are based on cycle-based loading assumptions; and (f) fatigue waiver or exemption analyses that are based on cycle-based loading assumptions. This program may be used for fatigue analyses that apply to mechanical or structural components.

Fatigue of components is managed by monitoring one or more relevant fatigue parameters, which include, but are not limited to, the CUF factors, the environmentally-adjusted (CUF_{en}), transient cycle limits, and the predicted flaw size (for a fatigue crack growth analysis). The limit of the fatigue parameter is established by the applicable fatigue analysis and may be a design limit, for example, from an ASME Code fatigue evaluation; an analysis-specific value, for example, based on the number of cyclic load occurrences assumed in a fatigue exemption evaluation; or the acceptable size of a flaw identified during an inservice inspection.

This program has two aspects, one that verifies the continued acceptability of existing analyses through cycle counting and the other that provides periodically updated evaluations of the fatigue analyses to demonstrate that they continue to meet the appropriate limits. In the former, the program assures that the number of occurrences and severity of each transient remains within the limits of the fatigue analyses, which in turn ensure that the analyses remain valid. For the latter, actual plant operating conditions monitored by this program can be used to inform updated evaluations of the fatigue analyses to ensure they continue to meet the design or analysis-specific limit. The program may include stress-based fatigue monitoring, in which operating temperatures, pressures, and other parameters are monitored and used to determine the effects of actual operating transients on the cumulative CUF and CUF_{en} for the analyzed components. Technical specification requirements may apply to these activities.

CUF is a computed parameter used to assess the likelihood of fatigue damage in components subjected to cyclic stresses. Crack initiation is assumed to begin in a mechanical or structural component when the CUF at a point on or in the component reaches the value of 1.0, which is the ASME Code Section III design limit on CUF values. (Note that other values may be used as CUF design limits, for example, values used for high energy line break considerations.) In order not to exceed the design limit on CUF, the AMP may be used to directly monitor the number of transient occurrences (i.e., transient cycles) or else to monitor applicable design transient parameters (e.g., temperatures, pressures, displacements, strains, flow rates, etc.) for components with stress-based fatigue calculations, such that the actual severity of each event is evaluated and used to compute the resulting fatigue usage factors for the impacted component locations.

CUF_{en} is CUF adjusted to account for the effects of the reactor water environment on component fatigue life. For a plant, the effects of reactor water environment on fatigue are evaluated by assessing a set of sample critical components for the plant. Examples of critical components are identified in NUREG/CR–6260; however, plant-specific component locations in the reactor coolant pressure boundary may be more limiting than those considered in NUREG/CR–6260, and thus should also be considered. Environmental effects on fatigue for these critical components may be evaluated using the guidance in Regulatory Guide (RG) 1.207, Revision 1[1]; alternatively, the bases in NUREG/CR–6909, Revision 0 (with "average temperature" used consistent with the clarification that was added to NUREG/CR–6909, Revision 1); or other subsequent U.S. Nuclear Regulatory Commission (NRC)-endorsed alternatives. Similar to monitoring of CUF limits, the AMP monitors and tracks the number of occurrences and severity of each of the critical thermal and pressure transients for the selected components in order to maintain the CUF_{en} below the design limit of 1.0. This program also relies on the Generic Aging Lessons Learned for Subsequent License Renewal Report (GALL-SLR) Report AMP XI.M2, "Water Chemistry," to provide monitoring of appropriate environmental parameters for calculating environmental fatigue multipliers (F_{en} values).

Some of the design fatigue analyses are implicit evaluations or fatigue waivers. Both of these analyses provide the basis for not requiring detailed fatigue analyses (e.g., CUF, CUF_{en}). Implicit evaluations specify allowable stress levels based on the number of anticipated full thermal range transient cycles. As an example, piping components designed to USAS American National Standards Institute (ANSI) B31.1 requirements and ASME Code Class 2 and 3 components designed to ASME Code Section III design requirements include implicit cycle-based maximum allowable stress range calculations. Fatigue waivers are based on transient cycle limits. Fatigue waivers may have been permitted such that a detailed fatigue calculation was not required if a component conformed to certain criteria, such as those established in ASME Code, Section III, NB-3222.4(d). The AMP monitors and tracks the number of critical thermal and pressure transient occurrences for the selected components and verifies that the severity of the monitored transients is bounded by the design transient definitions in order to ensure these implicit fatigue evaluations or fatigue waivers remain valid.

In some cases, flaw tolerance evaluations are used to establish inspection frequencies for components that, for example, exceed CUF or CUF_{en} fatigue limits. As an example, ASME Code, Section XI, Nonmandatory Appendix L provides guidance on the performance of fatigue flaw tolerance evaluations to determine acceptability for continued service of reactor coolant system and primary pressure boundary components and piping subjected to cyclic loadings. In flaw tolerance evaluations, the predicted size of a postulated fatigue flaw, whose initial size is typically based on the resolution of the inspection method, is a computed parameter that is used to determine the appropriate inspection frequency. The AMP monitors and tracks the number of occurrences and severity of critical thermal and pressure transients for the selected components that are used in the fatigue flaw tolerance evaluations to verify that the inspection frequencies remain appropriate.

When a flaw is identified by inservice inspection, ASME Code, Section XI, Nonmandatory Appendices A and C provide guidance on the performance of fatigue flaw crack growth evaluations to determine acceptability for continued service of reactor coolant system pressure boundary components and piping subjected to cyclic loadings. In such a case, the predicted size of an identified flaw is a computed parameter suitable for determining the appropriate inspection

[1] If and when published as RG 1.207, Revision 1 Final.

frequency through a fatigue crack growth evaluation. The AMP monitors and tracks the number of occurrences and severity of each of the critical thermal and pressure transients for the selected components that are used in the crack growth evaluations to verify that the inspection frequencies remain appropriate.

Evaluation and Technical Basis

1. ***Scope of Program***: The scope includes those mechanical or structural components with a fatigue TLAA or other analysis that depends on the number of occurrences and severity of transient cycles. The program monitors and tracks the number of occurrences and severity of thermal and pressure transients for the selected components, to ensure that they remain within the plant-specific limits. The program ensures that the fatigue analyses remain within their allowable limits, thus minimizing the likelihood of failures from fatigue-induced cracking of the components caused by cyclic strains in the component's material. In addition, the program can be used to monitor actual plant operating conditions for component locations with stress-based fatigue calculations (i.e., stress-based CUF calculations) to perform updated evaluations of the fatigue analyses to ensure they continue to meet the design limits.

   For the purposes of ascertaining the effects of the reactor water environment on fatigue, applicants include CUF_{en} calculations for a set of sample reactor coolant system components. This sample set includes the locations identified in NUREG/CR–6260 and additional plant-specific component locations in the reactor coolant pressure boundary if they may be more limiting than those considered in NUREG/CR–6260. Plant-specific justification can be provided to demonstrate that calculations for the NUREG/CR–6260 locations do not need to be included. Environmental effects on fatigue for these critical components may be evaluated using the guidance in RG 1.207, Revision 1[2]; NUREG/CR–6909, Revision 0 (with "average temperature" used consistent with the clarification that was added to NUREG/CR–6909, Revision 1); or other subsequent NRC-endorsed alternatives. Component locations within the scope of this program are updated based on operating experience (OE), plant modifications, and inspection findings.

2. ***Preventive Actions***: This program does not involve preventive actions.

3. ***Parameters Monitored or Inspected***: The program monitors all applicable plant transients that cause cyclic strains and contribute to fatigue, as specified in the fatigue analyses, and monitors or validates appropriate environmental parameters that contribute to F_{en} values. The number of occurrences and the severity of the plant transients that contribute to the fatigue analyses for each component are monitored. For environmentally-assisted fatigue calculations, chemistry parameters that provide inputs to F_{en} factors used in CUF_{en} calculations are monitored and tracked in accordance with this program or alternatively through implementation of the applicant's water chemistry program. More detailed monitoring of pressure, thermal, and water chemistry conditions at the component location may be performed to allow the fatigue analyses to be assessed for the specified critical locations.

4. ***Detection of Aging Effects***: The program uses applicant defined activities or methods to track the number of occurrences and severity of design basis transient conditions, and any

---

[2] If and when published as RG 1.207, Revision 1 Final.

applicable plant operating conditions used to inform updated evaluations of the fatigue analyses. Monitoring of water chemistry parameters that are inputs to environmentally-assisted fatigue calculations may be performed in accordance with the implementation of this AMP or an applicant's Water Chemistry Program. Technical specification requirements may apply to these activities.

5. ***Monitoring and Trending***: Monitoring and trending of the number of occurrences of each of the transient cycles and their severity is used to track the occurrences of all transients needed to ensure the continued acceptability of the fatigue analyses, or to update the analyses. Monitoring of plant operating conditions or water chemistry parameter conditions (i.e., as inputs for components with stress-based fatigue calculations or environmental fatigue calculations) is used to either verify the validity of the evaluations against their applicable design limits or else to update the evaluations, when necessary, of the fatigue analyses to ensure they continue to meet the design or analysis-specific limit. Trending is performed to ensure that the fatigue analyses are managed and that the fatigue parameter limits will not be exceeded during the subsequent period of extended operation, thus minimizing the possibility of fatigue crack initiation of metal components caused by cyclic strains or water chemistry conditions. The program provides for revisions to the fatigue analyses or other corrective actions (e.g., revising augmented inspection frequencies) on an as-needed basis, if the values assumed for fatigue parameters are approached, transient severities exceed the design or assumed severities, transient counts exceed the design or assumed quantities, transient definitions have changed, unanticipated new fatigue loading events are discovered, or the geometries of components are modified.

6. ***Acceptance Criteria***: The acceptance criterion is maintaining the value of all relevant fatigue parameters to values less than or equal to the limits established in the fatigue analyses, with consideration of reactor water environmental effects, where appropriate, as described in the program description and scope of program.

7. ***Corrective Actions***: Results that do not meet the acceptance criteria are addressed in the applicant's corrective action program under those specific portions of the quality assurance (QA) program that are used to meet Criterion XVI, "Corrective Action," of 10 CFR Part 50, Appendix B. Appendix A of the GALL-SLR Report describes how an applicant may apply its 10 CFR Part 50, Appendix B, QA program to fulfill the corrective actions element of this AMP for both safety-related and nonsafety-related SCs within the scope of this program.

   The program also provides for corrective actions to prevent the appropriate limits of the fatigue analyses from being exceeded during the subsequent period of extended operation. Acceptable corrective actions include repair of the component, replacement of the component, and a more rigorous analysis of the component to demonstrate that the design limit will not be exceeded during the subsequent period of extended operation. In addition, a flaw tolerance analysis with appropriate (e.g., inclusion of environmental effects) crack growth rate curves and associated inspections performed in accordance with Appendix L of ASME Code Section XI is an acceptable correction action. For CUF_{en} analyses, scope expansion includes consideration of other locations with the highest expected CUF_{en} values.

8. ***Confirmation Process***: The confirmation process is addressed through those specific portions of the QA program that are used to meet Criterion XVI, "Corrective Action," of

10 CFR Part 50, Appendix B. Appendix A of the GALL-SLR Report describes how an applicant may apply its 10 CFR Part 50, Appendix B, QA program to fulfill the confirmation process element of this AMP for both safety-related and nonsafety-related SCs within the scope of this program.

9. ***Administrative Controls***: Administrative controls are addressed through the QA program that is used to meet the requirements of 10 CFR Part 50, Appendix B, associated with managing the effects of aging. Appendix A of the GALL-SLR Report describes how an applicant may apply its 10 CFR Part 50, Appendix B, QA program to fulfill the administrative controls element of this AMP for both safety-related and nonsafety-related SCs within the scope of this program.

10. ***Operating Experience***: The program reviews industry experience relevant to fatigue cracking. Applicable OE relevant to fatigue cracking is to be considered in selecting the locations for monitoring. As discussed in the NRC Regulatory Issue Summary (RIS) 2008-30, the use of certain simplified analysis methodology to demonstrate compliance with the ASME Code fatigue acceptance criteria could be nonconservative; therefore, a confirmatory analysis is recommended, if such a methodology is used. Furthermore, as discussed in NRC RIS 2011–14, the staff has identified concerns regarding the implementation of computer software packages used to calculate fatigue usage associated with plant transient operations.

    The program is informed and enhanced when necessary through the systematic and ongoing review of both plant-specific and industry OE including research and development such that the effectiveness of the AMP is evaluated consistent with the discussion in Appendix B of the GALL-SLR Report.

References

10 CFR Part 50, Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants.” Washington, DC: U.S. Nuclear Regulatory Commission. 2016.

ANSI. ANSI/ASME B31.1, “Power Piping.” New York, New York: American National Standards Institute. 2014.

ASME. ASME Code, Section III, “Rules for Construction of Nuclear Power Plant Components.” New York, New York: American Society of Mechanical Engineers. 2015.

_____. ASME Code, Section XI, Nonmandatory Appendix A, Analysis of Flaws, “Rules for Construction of Nuclear Power Plant Components.” New York, New York: American Society of Mechanical Engineers. 2015.

_____. ASME Code, Section XI, Appendix C, Evaluation of Flaws in Austenitic Piping, “Rules for Inservice Inspection of Nuclear Power Plant Components.” New York, New York: American Society of Mechanical Engineers. 2015.

_____. ASME Code, Section XI, Nonmandatory Appendix L, Operating Plant Fatigue Assessment. “Rules for Inservice Inspection of Nuclear Power Plant Components.” New York, New York: American Society of Mechanical Engineers. 2013.

NRC. NUREG/CR–6260, “Application of NUREG/CR-5999 Interim Fatigue Curves to Selected Nuclear Power Plant Components.” Washington, DC: U.S. Nuclear Regulatory Commission. March 1995.

_____. NUREG/CR–6909, “Effect of LWR Coolant Environments on the Fatigue Life of Reactor Materials.” Revision 1. Washington, DC: U.S. Nuclear Regulatory Commission. March 2014.

_____. Regulatory Guide 1.207, “Guidelines for Evaluating the Effects of Light Water Reactor Coolant Environments in Fatigue Analyses of Metal Components.” Revision 1[3]. Washington, DC: U.S. Nuclear Regulatory Commission.

_____. Regulatory Issue Summary 2008-30, “Fatigue Analysis of Nuclear Power Plant Components.” Washington, DC: U.S. Nuclear Regulatory Commission. December 16, 2008.

_____. Regulatory Issue Summary 2011-14, “Metal Fatigue Analysis Performance by Computer Software.” Washington, DC: U.S. Nuclear Regulatory Commission. December 29, 2011.

[3] If and when published as RG 1.207, Revision 1 Final.