UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

February 22, 2017

Mr. Victor M. McCree
Executive Director for Operations
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: REVISION OF REGULATORY GUIDANCE FOR EVALUATING THE EFFECTS OF LIGHT-WATER REACTOR WATER ENVIRONMENTS IN FATIGUE ANALYSES OF METAL COMPONENTS

Dear Mr. McCree:

During the 640th meeting of the Advisory Committee on Reactor Safeguards, February 9-11, 2017, we reviewed Revision 1 of Regulatory Guide (RG) 1.207, “Guidelines for Evaluating the Effects of Light-Water Reactor [LWR] Water Environments in Fatigue Analyses of Metal Components” and associated NUREG/CR-6909, Revision 1, “Effect of LWR Water Environments on the Fatigue Life of Reactor Materials.” Our Subcommittee on Metallurgy and Reactor Fuels also reviewed this matter during meetings on December 2, 2014 and December 15, 2016. During these meetings, we had the benefit of discussions with representatives of the NRC staff. We also had the benefit of the referenced documents.

RECOMMENDATIONS

1. Revisions 1 of Regulatory Guide 1.207 and NUREG/CR-6909 should be issued.

2. The staff should continue to participate in American Society of Mechanical Engineers Code Committee efforts to incorporate environmental fatigue effects through Code Case N-792.

BACKGROUND

In the late 1960s and early 1970s, the American Society of Mechanical Engineers (ASME) developed design fatigue curves for Section III of the ASME Boiler and Pressure Vessel Code based on tests conducted in laboratory air environments at room temperature. At that time, the developers lacked sufficient data to explicitly address the effects of exposure to high temperature reactor coolant environments on fatigue. The original ASME Code fatigue curves incorporated substantial safety factors (a factor of two on stress or twenty on cycles, whichever predicts earlier failure). However, current versions of the ASME Code caution that the design fatigue curves do not include tests in the presence of corrosive environments that might accelerate fatigue failure, and that provisions for such effects should be included in the design or specified life of components.

Laboratory fatigue testing in simulated reactor water environments published in the 1990s indicated that, safety factors notwithstanding, the ASME design curves may not adequately bound fatigue life for materials exposed to water environments. The staff initiated a “Fatigue Action Plan” to address this concern. Closing out this plan in 1995, the staff concluded that “the risk of core damage from fatigue failure of reactor coolant system components is very small for current plant design lives of 40 years, but that environmental fatigue issues should be evaluated for new plants and for periods of extended operation under license renewal for operating plants.”

The current staff guidance on this issue is documented in RG 1.207, Revision 0, “Guidelines for Evaluating Fatigue Analyses Incorporating the Life Reduction of Metal Components Due to the Effects of the Light-Water Reactor Environment for New Reactors,” March 2007, and in NUREG-1801, Revision 2, “Generic Aging Lessons Learned (GALL) Report,” December 2010, for operating plants in periods of extended operation. The technical basis for this guidance is NUREG/CR–6909, Revision 0, “Effect of LWR Coolant Environments on the Fatigue Life of Reactor Materials – Final Report,” February 2007.

More recent fatigue test data from NRC and international research activities are documented in NUREG/CR-6909, Revision 1. This report provides an extensive update to the fatigue data from testing results available over the decade since publication of Revision 0. It also incorporates updates to address technical issues with the environmental fatigue factor (F_{en}) equations in the original report, as well as a validation of the revised methodology through comparison to experimental datasets that simulated actual plant conditions. The staff has prepared Revision 1 to its environmental fatigue guidance, RG 1.207, addressing the new data and methodology. The revised RG was issued for public comment as Draft Regulatory Guide DG-1309 in November 2014.

In addition, based on NUREG/CR-6909, Revision 0, ASME Boiler and Pressure Vessel Code Case N-792, “Fatigue Evaluations Including Environmental Effects Section III, Division 1,” was prepared for performing fatigue evaluations of LWR coolant system and primary pressure boundary components when the effects of reactor coolant environment on fatigue life are judged to be significant. ASME is awaiting the publication of the revised NUREG, after which they will consider updating this code case.

DISCUSSION

RG 1.207, Revision 1 describes methods and procedures that the NRC staff considers acceptable for use in determining fatigue lives of components evaluated by a cumulative usage factor calculation in accordance with the fatigue design rules in Section III of the ASME Boiler and Pressure Vessel Code, to account for the effects of LWR water environments. This revision consolidates, updates, and replaces previous staff guidance on the subject in the following areas:

- The title was revised to remove “New Reactors” (i.e., the regulatory guide was made applicable to all LWRs).
- The guidance was clarified to apply to all metal components exposed to LWR environments that have a cumulative usage factor calculation required by a plant’s current licensing basis. The previous guidance was applicable to pressure boundary components.
- The background section was revised to incorporate the relevant content for operating reactors and license renewal, as well as for new reactors.
- The equations for environmental fatigue factor, F_{en}, were revised based on stakeholder feedback and the updated research documented in NUREG/CR-6909, Revision 1.

Revision 1 of NUREG/CR-6909 summarizes, reviews, and quantifies the effects of LWR environments on the fatigue lives of reactor materials, including carbon steels, low-alloy steels, nickel-chromium-iron (Ni-Cr-Fe) alloys, and austenitic stainless steels. The primary purpose of RG 1.207 is to provide guidance on use of NUREG/CR-6909.

The method chosen by the staff to address environmental fatigue effects utilizes the factor, F_{en}, which is the ratio of the component fatigue life in a room temperature air environment to its fatigue life in a LWR water environment at operating temperature. F_{en} equations are provided in NUREG/CR-6909, and referenced in RG 1.207, for each of the above materials. F_{en} is a function of a number of parameters that were found in the tests to have significant effects. These parameters include coolant temperature, dissolved oxygen in the coolant, strain rate of the loading, and specific alloying content for some materials. F_{en} typically ranges from 1 to 4. In unusual circumstances F_{en} can be as high as 15 or 20.

The F_{en} equations in the original NUREG contained some technical issues, not the least of which was that they yielded an F_{en} greater than 1 even when the input parameters were such that environmental effects would not occur. Revision 1 of NUREG/CR-6909 provides a more technically consistent set of F_{en} equations for carbon and low-alloy steels, and wrought and cast austenitic stainless steels. It also provides a material-specific F_{en} equation for Ni-Cr-Fe alloys (Alloys 600, 690, and 800, excluding Alloy 718) and their associated weld metals.

The updated F_{en} expressions were validated in NUREG/CR-6909, Revision 1 by comparing calculated results from six experimental datasets with estimates of fatigue lives based on the updated F_{en} expressions. The experimental datasets included tests on small specimens with various types of realistic service loading (e.g. temperature and strain rates that changed within each strain cycle, spectrum loading, and thermal shock loading), as well as laboratory thermal fatigue tests of a stepped pipe of differing thicknesses exposed to temperature cycles between 100 and 650°F. In all cases, the results indicated that the predicted fatigue lives were in good agreement with the experimental values; the differences between the experimental and predicted fatigue lives were within a factor of 2, which is well within the observed data scatter.

The staff received numerous comments during the public comment period on draft versions of both NUREG/CR-6909, Revision 1 and RG 1.207, Revision 1 (DG-1309). The comments came from a wide variety of knowledgeable subject matter experts. The staff addressed each comment and incorporated numerous changes to the two documents.

The additional data and revised methodology for environmental fatigue effects contained in Revision 1 of NUREG/CR-6909 represent a significant improvement. The NUREG plus RG 1.207, Revision 1, which is based upon it, should be issued.

Material harvested from decommissioned reactors may provide additional data and information to support validation of the methodology. The staff should remain cognizant of this potential opportunity in their research planning.

Sincerely,

/RA/

Dennis Bley
Chairman

REFERENCES

1. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.207, “Guidelines for Evaluating the Effects of Light-Water Reactor Water Environments in Fatigue Analyses of Metal Components,” Revision 1, December 2016 (ML16315A130).

2. U. S. Nuclear Regulatory Commission, Draft Report, NUREG/CR-6909, Revision 1, “Effect of LWR Water Environments on the Fatigue Life of Reactor Materials,” March 2014 (ML14087A068).

3. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III, “Rules for Construction of Nuclear Power Plant Components,” 2013 Edition.

4. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.207, “Guidelines for Evaluating Fatigue Analyses Incorporating the Life Reduction of Metal Components Due to the Effects of the Light-Water Reactor Environment for New Reactors,” Revision 0, March 2007 (ML070380586).

5. U.S. Nuclear Regulatory Commission, NUREG-1801, “Generic Aging Lessons Learned (GALL) Report,” Revision 2, December 2010 (ML103490041).

6. U.S. Nuclear Regulatory Commission, NUREG/CR-6583, “Effects of LWR Coolant Environments on Fatigue Design Curves of Carbon and Low-Alloy Steels,” March 1998 (ML031480391).

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