U.S. Nuclear Regulatory Commission Public Meeting Summary

July 14, 2016

Title: Public Meeting to Discuss Fatigue Research and Related ASME Activities

Meeting Identifier: 20160816

Date of Meeting: Thursday, June 30, 2016

Location: Nuclear Regulatory Commission (NRC) Headquarters, Rockville, MD

Type of Meeting: Category 2

Purpose of the Meeting(s):

To discuss current research plans and American Society of Mechanical Engineers (ASME) Code activities related to fatigue of nuclear components and structures.

General Details:

The Nuclear Regulatory Commission (NRC) conducted a public meeting starting at 8:30 am eastern daylight saving time (EDT) where representatives of the commercial nuclear power industry and members of the public met with NRC staff to discuss ongoing and planned research activities related to fatigue evaluation of nuclear components and structures and associated ASME Code actions that may result from this research. The meeting was scheduled from 8:30 - 4:30 p.m. EST. Sixteen NRC staff members participated the meeting along with eleven nuclear industry representatives and one member of the public. The lead industry contact for the meeting was Mr. Nathan Palm from the Electric Power Research Institute (EPRI). The meeting attendance list is attached. The meeting was led by Dr. Robert Tregoning from the NRC's Office of Nuclear Regulatory Research (RES).

The meeting began with an introduction of the meeting participants and a review of meeting ground rules. The meeting agenda was reviewed next. The initial agenda was provided as part of the meeting announcement which is available in the NRC's Agency Documentation and Management System (ADAMS) under accession number ML16160A020. It was identified that the title of the 2:45pm presentation from Dr. Sam Ranganath was changed to "Fatigue Limit of Stainless Steel for Use in Vibration Evaluation." A revised meeting agenda that reflects this change is attached.

Dr. Tregoning next provided opening remarks to welcome the participants and articulate the NRC's meeting objectives which are as follows:

1. Discuss EPRI's research activities related to fatigue,
2. Identify possible areas for NRC collaboration with EPRI on research related to fatigue,
3. Identify other research that may need to be performed,
4. Discuss research activities leading to potential ASME Code actions, and
5. Discuss the strategy for implementing any proposed ASME Code actions,

The remainder of the meeting was dedicated to presentations that were provided by nuclear industry representatives and one presentation from NRC staff. The meeting presentations are available in ADAMS under accession number ML16183A031.

Summary of Presentations:

In the first presentation, Mr. Nathan Palm of EPRI provided an overview of EPRI sponsored research. He first provide a summary of the licensee's requirements related to fatigue and provided his objectives for the meeting which aligned well with those articulated in the beginning of the meeting by Dr. Tregoning from the NRC. The presentation believes that fatigue issues may be important for existing plants that may want to adopt flexible operation (load following), plants considering applying for subsequent license renewal, new plants that wish to operate beyond the initial 40-year license. He next identified guidance documents that EPRI has developed related to fatigue and provided a brief overview of experimental and analytical efforts being sponsored by EPRI to reduce conservatisms in current fatigue analysis requirements. The other industry presentations in the meeting provide more details on these activities.

The next presentation by Mr. David Steininger of EPRI summarized the ongoing and planned experimental activities related to fatigue that are being sponsored by EPRI. A major initiative is testing of a nuclear component under representative environmental and loading conditions. The desire is to start this testing in late 2017. EPRI currently has identified several international partners that will collaborate on this project. EPRI is planning to send out a request for proposal (RFP) on this activity in the near-term to obtain estimates for the needed resources. Once proposals are received, Mr. Steininger anticipates that additional collaborative partners will be needed in order to fund the effort.

Mr. Steininger next summarized work sponsored by EPRI to evaluate the effects of complex, in-phase and out-of-phase temperature and strain transients compared to the same strain transients under isothermal conditions. This work was performed by Mitsubishi Heavy Industries (MHI). The results show that the phase of the temperature and strain transients can affect fatigue life and the transient tested that was most representative of nuclear operations appears to lead to the longest fatigue life. Future work will investigate reasons for this possible effect. Discussion during the presentation led to a question about the method that was used to evaluate the tests using the modified rate approach in NUREG/CR-6909, rev 1 (draft). It was also unclear if the factor on cycles was applied to NUREG/CR-6909, rev 1 (draft) fatigue life predictions. Mr. Steininger will provide answers for both these questions.

Other EPRI-sponsored research has evaluated the effect of hold time on fatigue lives. This work was performed in Korea. Both long (i.e., hundreds of hours) and short (i.e., tens of seconds) hold-times were combined with steady-state fatigue cycling, which is used in classical fatigue tests. No significant hold time effects were observed for the conditions tested. Future work related to this program will focus on the effects of zinc water chemistry on its possible advantageous effect on fatigue lives.

Dr. Steve Gosselin of Lucius Pitkin, Inc. (LPI) next discussed the development of a fatigue usage life and gradient factor concept for reducing the conservatism in typical fatigue evaluations. ASME Code fatigue rules are based on testing performed on small cylindrical specimens under alternating, uniform membrane loading. However, these rules are typically applied to larger components which are loaded non-uniformly through the component thickness. This is often called through-thickness stress gradient loading. These differences can lead to fatigue life predictions that are much less than in service for such components. The approach, as in NUREG/CR-6909, separates fatigue life into Stage I (i.e., crack depth between 10 μm to 200 μm) and Stage II (i.e., crack depths from 200 μm to depth at a 25% load drop). The gradient factor accounts for the increase in Stage II life associated with through thickness stress gradient loading. The life factor corrects fatigue usage estimates to account for the additional crack growth needed in a component to reach a 25% load drop, compared to a smaller test specimen.

The life and gradient factors were then calculated for the 60-year fatigue usage calculation (CUF) for a schedule 80 10” X 12” reducing elbow in a boiling water reactor (BWR) low pressure core spray system. The original calculations were performed according to Section III of the ASME Code with an environmental correction factor (F_{en}) applied. In this example, the life factor was 0.941 and the gradient factor was 0.752. Therefore, the combined factor reduced the CUF predictions by approximately 30%

Ensuing discussion focused on the next steps. The initial plan is to present the approach during the August 2016 ASME Code meetings and propose the formation of a small task group to develop an ASME Code Case for the method. This approach may propose a single Code Case or separate the life and gradient factor methods into two separate Code Cases. The industry has asked that NRC staff participate closely on the development of the Code Case to ensure that NRC questions and issues are addressed before the Code Case is balloted. The ensuing action is for EPRI (Palm) to develop a strategy for implementing the life and gradient factor method within the ASME Code using a process that engenders early and frequent participation from NRC staff.

The next talk was provided by Dr. Sam Ranganath of XGEN on an alternative, simplified approach for performing elastic-plastic (EP) analysis with the ASME Code fatigue evaluation. The current simplified EP analysis within the ASME Code is often the largest source of conservatism in a fatigue analysis. The ASME Code currently allows an updated EP analysis to be used, but the disadvantages are that this analysis is expensive because it requires a new finite element analysis, there are no explicit rules for performing the analysis, and it is difficult to apply for piping evaluations. The presentation next summarized the development of the current EP method in the ASME Code and discusses alternative approaches in international codes and standards. These approaches are often complex and may require new stress analyses.

Dr. Ranganath’s objective is to develop an approach which uses existing information in current ASME Code stress reports, retains the simplicity of the current Code approach without the excessive conservatism, applies to both pressure vessel components and piping, and covers all common structural materials. The new method considers temperature-induced bending as the only thermal load and conservatively assumes all other loading to be mechanical, pressure-type loading. As in other methods, the EP reduction factor, K_e*, is the addition of the thermal load ratio multiplied by the Poisson reduction factor, K_v, and the mechanical load ratio multiplied by the plasticity reduction factor, K_e. Dr. Ranganath used simplifying, yet conservative expressions for K_v and K_e compared to other methods. Dr. Ranganath also developed a notch factor, K_n, that could be applied to account for localized effects on the deformation fields.

The proposed method was next applied to four example problems: the Bettis stepped pipe test, a notched beam, an axial groove in a pipe with mechanical and thermal loading, and a pipe taper. In all cases, the simplified method (without the notch factor) proposed by Dr. Ranganath was less conservative than the current ASME Code approach while still bounding the results from more rigorous EP finite element calculations. Based on the example problem results and other considerations, Dr. Ranganath recommends that the K_n factor not be applied with his approach, as the results are unnecessarily conservative.

Ensuing discussion focused on the next steps associated with this work. Dr. Ranganath will present this method during the August ASME Code meetings and will then propose to initiate a Code Case for the method. He provided an initial draft of this Code Case (CC) as part of his presentation. It was identified that the draft CC does not appear to cover piping components. Dr. Ranganath took the action to revise the draft CC to ensure that it applies to both piping and reactor vessel components.

The next presentation was also provided by Dr. Ranganath and detailed an approach to use mean stress correction at the actual temperature to define the high cycle fatigue limit to be used in vibration fatigue analyses for stainless steels. The presentation first provided background on the evolution of the high-cycle fatigue limits within the ASME Code. Dr. Ranganath next discussed the work contained in several different studies, all using slightly different methods, to determine the fatigue limit for stainless steels. In all cases, the fatigue limit is approximately 31.5 ksi. When a factor of 2 margin is applied, this estimate is close to the current ASME Code design fatigue limit of 13.6 ksi. The remaining question is how to account for temperature effects in both the elastic modulus, E, needed to convert the fatigue strain life curve to a fatigue stress life curve, and the mean stress correction.

There is no consensus among practitioners on the approach to correct the high cycle fatigue portion of the S-N curve based on changes in E with respect to temperature. However, the variation between room temperature and commercial nuclear operating temperature (approximately 300^{o}C) is less than 10%. There is a bigger difference in the material constitutive properties (yield and ultimate stress) between room temperature and 300^{o}C such that the mean stress correction using the modified Goodman approach leads to a bigger benefit that more than offsets the reduction for E-correction. Based on this result, Dr. Ranganath has proposed that a constant fatigue limit value of 13.6 ksi independent of temperature can be justified for vibration analysis of stainless steel components.

The next step is this work is to propose a CC to allow a constant value of 13.6 ksi be used as the design fatigue limit of austenitic stainless steel for use in vibration evaluation for temperatures up to 343°C. During the ensuing discussion, it was asked if a CC for performing mean stress correction as a function of temperature would have more general use than simply using the method as the technical basis for supporting the use of the fatigue limit of 13.6 for stainless steels up to 343°C. Dr. Ranganath took an action to consider if developing such a broader CC would be a preferable approach.

The next agenda topic discussed irradiation effects on fatigue life. Dr. Tregoning of the NRC made the first presentation on this topic. He summarized past fatigue crack growth rate and fatigue life testing programs and also discussed microstructural changes induced by irradiation that could affect fatigue life. There is a paucity of data under representative light water reactor (LWR) conditions and therefore conclusive trends cannot be established. The data that does exist do not exhibit a significant effect of irradiation on fatigue crack growth rates (FCGRs).

However, some consistent effects of irradiation on fatigue life have been observed in the existing data. This data shows decreases in fatigue life at higher (i.e., > 0.35 to 0.6%) strain levels and increases in fatigue life at low (i.e., < 0.35 to 0.6%) strain levels. These trends appear consistent with material changes caused by irradiation. Radiation hardening causes increased tensile strength, which has long been correlated to increased high cycle fatigue resistance. Conversely, reduced ductility due to irradiation could lead to decreases in low-cycle fatigue life where the role of plastic strain is more important. These initial results can be used to prioritize any subsequent testing. Any such testing should evaluate representative materials under LWR conditions to characterize the effects of irradiation. Initial testing should focus on evaluating the effects on low-cycle fatigue life, where irradiation may have a detrimental effect, and identifying the transition strain between low-cycle and high-cycle fatigue regimes.

Mr. Palm of EPRI made the next presentation on this topic. Mr. Palm summarized work being led by Dr. Raj Pathania of EPRI that is evaluating the effect of irradiation on FCGRs. Dr. Pathania is using data collected under testing to evaluate irradiated-assisted stress corrosion cracking (IASCC) rates. While IASCC testing is conducted under constant loading, these tests contain periods where fatigue loading is use to grow and prepare the crack for the constant load stage. Dr. Pathania is evaluating the fatigue portions of these tests and comparing them with unirradiated material under the same conditions to evaluate the irradiation effects. Based on analysis of data collected in a pilot study, Dr. Pathania has preliminarily concluded that irradiation increases FCGRs and that the FCGR increases as the irradiation level increases. This conclusion contradicts what Dr. Tregoning reported earlier in his presentation.

The basis of this preliminary conclusion was a pilot study performed in 2014. Plots from that pilot study compared crack growth rates in LWR environments, both with and without irradiation, with crack growth rates in laboratory air. These results show increases due to irradiation. However, the plots presented appear to be for constant loading and not fatigue loading. Therefore, the basis for concluding that the FCGRs are affected based on these plots is not clear. Mr. Palm took an action to ask Dr. Pathania to provide a brief description of these plots that identifies how the loading conditions are relevant to fatigue and how the results show that FCGRs are increased by fatigue compared with constant load CGRs.

Since the completion of the pilot study in 2014, additional data has been obtained which approximately doubles the existing data set and is more representative of LWR environments. Analysis and modeling of this expanded, more representative data is in progress. Interim results will be presented at the August 2016 EPRI LWR Materials Reliability Conference in Chicago. A final report identifying gaps in data coverage and research needs will be completed in December 2016. After this report has been completed, EPRI and the NRC will meet with the Department of Energy (DOE) to determine the next steps, including the need for further research in this area. NRC has the lead in setting up this meeting.

Meeting Discussion

Next, participants discussed future engagement on metal fatigue issues. All parties agreed that NRC and EPRI should meet periodically to discuss research and ASME Code activities related to metal fatigue. It was agreed that a standing agenda item on metal fatigue will be added to the quarterly call to discuss of NRC and industry activities related to materials issues. The objective of adding this agenda item is to provide a brief status on progress and identify the need and time-frame for future in-depth meetings on the topic. It was also agreed that the next in-depth meeting should be targeted for early 2017, after Dr. Pathania's work on irradiation effects has been completed.

Action Items/Next Steps:

The following action items were identified during the meeting

- Mr. Steininger of EPRI will provide the details of the analysis using the modified rate approach in NUREG/CR-6909 rev. 1 to predict the results of the complex strain transient tests conducted at MHI.

- Mr. Steininger of EPRI will determine if the factor on cycles was applied to the NUREG/CR-6909, rev 1 (draft) predictions of the complex strain transient tests conducted at MHI.
- Mr. Nathan Palm of EPRI will develop a strategy for implementing the life and gradient factor method within the ASME Code using a process that engenders early and frequent participation from NRC staff.
- Dr. Ranganath of XGEN will revise the draft Code Case on alternative rules for simplified elastic-plastic analysis to ensure that it applies to both piping and reactor vessel components.
- Dr. Ranganath of XGEN will determine if a draft Code Case for performing mean stress correction as a function of temperature would be more beneficial than simply using the method as the technical basis for supporting the use of the fatigue limit of 13.6 for stainless steels up to 343°C. Next, if appropriate, Dr. Ranganath will also develop a draft of such a Code Case.
- Mr. Palm of EPRI will ask Dr. Pathania of EPRI to provide a brief description of the plots comparing crack growth in LWR environments, both with and without irradiation, with crack growth rates in laboratory air. This description will identify how the loading conditions are relevant to fatigue and how the results demonstrate that FCGRs are increased by fatigue compared with constant load CGRs.
- Dr. Tregoning will arrange a meeting among NRC, EPRI, and DOE to discuss possible research to address irradiation effects on fatigue after EPRI's study on irradiation effects on FCGRs is completed. This report is planned for completion in December 2016.
- In concert with previous action item, the next in-depth meeting on fatigue activities will be planned by Dr. Tregoning for early 2017. The exact date will be determined, after Dr. Pathania's work on irradiation effects has been completed.
- Mr. Robin Dyle of EPRI will create a standing agenda item on metal fatigue to the quarterly call to discuss of NRC and industry activities related to materials issues. The objective of this agenda item is to provide a brief status on progress and identify the need and time-frame for future in-depth meetings on the topic.

Public Comment

No comments or questions were provided by members of the public during the public comment portion of the meeting.

Attachments:

- Attendance list
- Meeting announcement - ML16160A020
- Revised agenda
- Meeting presentations - ML16183A031

Attendance List

Public Meeting on Fatigue Research and Related ASME Activities

NRC Headquarters, Rockville, MD
Thursday, June 30, 2016
8:30 AM to 4:30 PM

Name	Organization	Email Address
Rob Tregoning	Nuclear Regulatory Commission	robert.tregoning@nrc.gov
Alexander Tsirigotis	Nuclear Regulatory Commission	axt4@nrc.gov
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PUBLIC MEETING AGENDA

Fatigue Research and Related ASME Activities

June 30, 2016, 08:30 AM to 04:30 PM

NRC One White Flint North, 9 B4
11555 Rockville Pike
Rockville, MD

Time	Topic	Speaker
8:30 am	Introductory Remarks	R. Tregoning, NRC
8:40 am	Overview of EPRI Fatigue Efforts and Roadmap	N. Palm, EPRI
9:10 am	EPRI Environmentally Assisted Fatigue Testing Efforts	D. Steininger, EPRI
10:10 am	Break	
10:25 am	Fatigue Usage Gradient and Life Factor Concept	S. Gosselin, LPI
12:00 pm	Lunch	
1:00 pm	Alternative Approaches for Simplified Elastic-Plastic Analysis	S. Ranganath, XGEN
2:30 pm	Break	
2:45 pm	Fatigue Limit of Stainless Steel for Use in Vibration Evaluation	S. Ranganath, XGEN
3:45 pm	Effects of Irradiation on Fatigue Life	R. Tregoning/N. Palm
4:15 pm	Public Comment Period	R. Tregoning, NRC
4:30 pm	Adjourn	