50-317/318

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

November 2, 1998

Mr. Charles H. Cruse, Vice President
Nuclear Energy Division
Baltimore Gas and Electric Company
1650 Calvert Cliffs Parkway
Lusby, MD 20657-47027

SUBJECT: CLARIFICATION REGARDING SELECTED REQUEST FOR ADDITIONAL INFORMATION FOR THE REVIEW OF THE CALVERT CLIFFS NUCLEAR POWER PLANT, UNIT NOS. 1 & 2, INTEGRATED PLANT ASSESSMENT ON METAL FATIGUE (TAC NOS. MA0601, MA0602, M99227, MA1016, MA1017, M99223, MA1108, MA1109, AND M99222)

Dear Mr. Cruse:

By letter dated April 8, 1998, Baltimore Gas and Electric Company (BGE) submitted its license renewal application. The application references the industry's evaluation, in part, to address metal fatigue and Generic Safety Issue (GSI) 166, "Adequacy of Fatigue Life of Metal Components." By letter dated September 2, 1998, the staff issued a request for additional information (RAI) regarding metal fatigue. In a public meeting on October 1, 1998, BGE requested clarification on certain RAIs, including five questions in this RAI. BGE designated these questions as numbers 7.6(a) and (b), 7.15, 7.16, 7.17, and 7.22 in the meeting handouts. On October 14, 1998, Mr. Don Shaw of BGE telephoned and indicated that BGE was also requesting the same clarification on question number 7.6(c). Therefore, the subject five questions are designated by BGE as numbers 7.6, 7.15, 7.16, 7.17, and 7.22.

The staff has evaluated BGE's request for clarification and has determined that it is more appropriate to address these questions to the industry. Thus, the staff is redirecting these questions and issuing them to the Nuclear Energy Institute (NEI) for an industry response. Enclosed is a copy of the letter to the NEI transmitting the questions. Note that GSI-166 is closed for operating reactors; however, the staff has opened GSI-190, "Fatigue Evaluation of Metal Components for 60-Year Plant Life," to address fatigue for license renewal. The staff is evaluating GSI-190 to determine an appropriate resolution.

The staff evaluation of GSI-190 will follow the GSI resolution process described in NUREG-0933, "A Prioritization of Generic Safety Issues." Should it be determined that metal fatigue issues will have to be addressed during the period of extended operation, BGE will be required to take appropriate actions in accordance with the existing GSI process. BGE is requested to continue their participation in industry activities related to GSI-190.

In its submittal of April 8, 1998, BGE relies on the evaluations in Electric Power Research Institute (EPRI) reports as the basis for the BGE position regarding GSI-190. BGE is requested to readdress that position for the period until GSI-190 is resolved, in the absence of the staff's endorsement of the EPRI reports. Although we expect timely resolution of GSI-190, your response should address the situation where GSI-190 is not resolved prior to the current

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Sincerely,

David L. Solorio, Project Manager
License Renewal Project Directorate
Division of Reactor Program Management
Office of Nuclear Reactor Regulation

Docket Nos. 50-317 and 50-318
Enclosure: Letter to NEI
cc w/encl: See next page
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DATE	10/27/98	10/27/98	10/27/98	10/28/98	10/ /98	10/ /98

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license term. Specifically, the staff requests that BGE discuss how they satisfy the relevant portion of paragraph 54.29 of the license renewal rule as discussed in the statements of consideration (60 FR 22484, May 8, 1995) and as described in Subsection 6.3.5, "Aging Management for Aging Issues Associated with a Generic Safety Issue (GSI) or Unresolved Safety Issue," of Section 2.0, "Integrated Plant Assessment Methodology," to Appendix A of the BGE application. Consistent with the SOC, it is expected that BGE will "submit a technical rationale which demonstrates that the CLB will be maintained until some later point in time in the period of extended operation, at which time one or more reasonable options (e.g., replacement, analytical evaluation, or a surveillance/maintenance program) would be available to adequately manage the effects of aging... and briefly describe options that are technically feasible during the period of extended operation to manage the effects of aging..."

Sincerely,

Original Signed By

David L. Solorio, Project Manager
License Renewal Project Directorate
Division of Reactor Program Management
Office of Nuclear Reactor Regulation

Docket Nos. 50-317 and 50-318

Enclosure: Letter to NEI

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NAME	SLittle	DSolorio	SLee	PTKuo	RWessman	CGrimes
DATE	10/27/98*	10/27/98*	10/27/98*	10/28/98*	10/30/98	11/2/98

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BGE submittal
is of little
use but expedient

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DSolorio (DLS2)
SStewart (JSS1)
JFair (JRF)
KManoly (KAM)
THiltz (TGH)
PDLR Staff
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Mr. Charles H. Cruse
Baltimore Gas & Electric Company

Calvert Cliffs Nuclear Power Plant
Unit Nos. 1 and 2

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

November 2, 1998

Mr. Douglas J. Walters
Nuclear Energy Institute
1776 I Street, N.W., Suite 400
Washington, DC 20006-3708

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION ON THE INDUSTRY'S EVALUATION OF FATIGUE EFFECTS FOR LICENSE RENEWAL

Dear Mr. Walters:

The NRC staff has had ongoing work regarding the fatigue life of metal components for several years, including the consideration of fatigue life in operating reactors, research by the Argonne National Laboratory (ANL) regarding environmentally assisted cracking of light-water reactors, interaction with the American Society of Mechanical Engineers (ASME), and consideration of fatigue effects for license renewal. Generic Safety Issue (GSI) 166, "Adequacy of Fatigue Life of Metal Components," raised questions about the environmental effects on fatigue that were not reflected in design codes and the differences of the fatigue design requirements between newer and older vintage plants. SECY-95-245, "Completion of the Fatigue Action Plan," indicated that a backfit of operating reactors could not be justified; however the staff recommended that additional evaluation be performed considering environmental effects for license renewal. The staff recently revised NUREG-0933, "A Prioritization of Generic Safety Issues." In NUREG-0933, Supplement 2, the staff indicated that GSI-166 was resolved for operating reactors and opened GSI-190, "Fatigue Evaluation of Metal Components for 60-year Plant Life," to address fatigue for license renewal.

The staff is evaluating GSI-190 to determine an appropriate resolution. ANL research indicates that, under some circumstances, the current ASME design curves may be nonconservative. The staff is also interacting with the ASME regarding the ANL results and their relationship to the ASME Boiler and Pressure Vessel Code (ASME Code) criteria. In addition, the staff has been interacting with the Nuclear Energy Institute (NEI) on a generic resolution of GSI-190.

By letter dated February 9, 1998, Electric Power Research Institute (EPRI) submitted two EPRI reports dealing with the fatigue issue. These were TR-107515, "Evaluation of Thermal Fatigue Effects on Systems Requiring Aging Management Review for License Renewal for the Calvert Cliffs Nuclear Power Plant," which contains the industry's evaluation for the Baltimore Gas and Electric Company (BGE), and TR-105759, "An Environmental Factor Approach to Account for Reactor Water Effects in Light Water Reactor Pressure Vessel and Piping Fatigue Evaluations." On March 19, 1998, the staff met with the industry in a public meeting to discuss the status of the industry's evaluation and technical aspects of these two EPRI reports (Meeting Summary, dated March 30, 1998). Certain aspects of these EPRI reports have also been reviewed by ANL, pursuant to the staff's request.

Enclosure

By letter dated June 1, 1998, NEI submitted three additional EPRI reports providing information on the industry's evaluation of metal fatigue effects for license renewal. These were TR-110356, "Evaluation of Environmental Thermal Fatigue Effects on Selected Components in a Boiling Water Reactor Plant," TR-110043, "Evaluation of Environmental Fatigue Effects for a Westinghouse Nuclear Power Plant," and TR-107943, "Environmental Fatigue Evaluations of Representative BWR Components." In the June 1, 1998, letter, the industry contends that these EPRI reports provide (1) a technical basis for closing GSI-166 and (2) a technical basis for license renewal applicants to address GSI-166 in the interim while formal closure is in process. (Since GSI-190 supersedes GSI-166, these statements are considered applicable to GSI-190).

By letter dated April 8, 1998, BGE submitted its license renewal application which references the industry's evaluation, in part, to address GSI-166 (GSI-190). Specifically, one of the EPRI reports, TR-107515, addresses Calvert Cliffs fatigue issues. The staff reviewed EPRI TR-107515 and by letter dated September 2, 1998, the staff issued a request for additional information (RAI) to BGE on metal fatigue which contains several questions regarding this EPRI report. In a public meeting with BGE on October 1, 1998, BGE requested clarification on certain RAIs, including five questions dealing with metal fatigue. It was agreed that the subject questions involve generic information regarding EPRI reports submitted by the industry.

Based on the foregoing, the staff has determined that these five questions on fatigue, identified by BGE at the October 1, 1998, public meeting, relate to current industry and staff activities and should be more appropriately addressed by the industry. Thus, the staff is redirecting these five questions from the BGE RAIs and is transmitting them to NEI in the enclosure to this letter for an industry response. The staff also expanded Question 1(b) (from the language originally provided to BGE) by adding one more sentence at the end.

Because of the staff's ongoing work with GSI-190 and the importance of this issue to license renewal, a timely resolution to these issues is desirable. If you have any questions regarding this matter, please contact Sam Lee at (301) 415-3109.

Sincerely,

CI Grimes

Christopher I. Grimes, Director
License Renewal Project Directorate
Division of Reactor Program Management
Office of Nuclear Reactor Regulation

Project No. 690

Enclosure: Request for Additional Information

cc w/encl: See next page

Project No. 690

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REQUEST FOR ADDITIONAL INFORMATION
ON INDUSTRY'S EVALUATION OF FATIGUE EFFECTS FOR LICENSE RENEWAL
NUCLEAR ENERGY INSTITUTE
PROJECT NO. 690

1. Section 3.2.3 of Electrical Power Research Institute (EPRI) Report TR-107515 contains an evaluation of environmental effects on the Chemical and Volume Control System (CVCS) Charging Inlet Nozzle using methodology developed in EPRI Report TR-105759, "An Environmental Factor Approach to Account for Reactor Water Effects in Light Water Reactor Pressure Vessel and Piping Fatigue Evaluations," dated December 1995. The attached evaluation summarizes the staff's technical concerns regarding the methodology in EPRI Report TR-105759. Based on these comments, provide the following:

   (a) Discuss the impact of the current Argonne National Laboratory (ANL) statistical correlations of environmental test data on the Calvert Cliffs fatigue evaluation.

   (b) The technical basis for the assertion that the American Society of Mechanical Engineers (ASME) Code stainless steel fatigue design curve contains sufficient margin to accommodate moderate environmental effects. Include a discussion of the factor required to adjust the laboratory test data for size and surface finish effects and the margin necessary to account for scatter of the test data. Also include a discussion of the effect on the margin due to potential inconsistencies between the ASME mean curve and the ANL air environment data.

   (c) The technical justification for the strain threshold values.

2. Section 4.1 of the Baltimore Gas and Electric Company (BGE) application indicates that environmental effects do not apply to the Reactor Coolant System (RCS) components because of the low oxygen concentrations and because the RCS carbon steel interior surfaces are clad with stainless steel. Discuss the applicability and impact of the latest stainless steel fatigue correlation from ANL on this conclusion (see attachment).

3. Section 3.3.3 of EPRI Report TR-107515 contains an evaluation of the Surge Line using methodology developed in EPRI Report TR-105759. Discuss the applicability and impact of the latest stainless steel fatigue correlation from ANL on this evaluation (see attachment).

Enclosure

4. Section 3.3.3.2 of EPRI Report TR-107515 indicates that the procedure in Section 3.1.3.2 of the EPRI report was used to develop the environmental factor used in the evaluation. Indicate whether the factor was calculated based on a "standard" treatment or "weighted average" approach as discussed in a June 1, 1998, letter from the Nuclear Energy Institute to the NRC regarding EPRI Report TR-105759. If the "weighted average" approach was used, provide the test data used to develop the approach. Include a statistical assessment of the test data scatter. Compare the results of the statistical assessment with the ANL assessment contained in NUREG/CR-6335, "Fatigue Strain-Life Behavior of Carbon and Low-Alloy Ferritic Steels, Austenitic Stainless Steels, and Alloy 600 in LWR Environments." On the basis of this comparison, indicate whether the use of the "weighted average" approach will produce an adequate margin to account for test data scatter.

5. Section 5.15 of the BGE application indicates that environmental effects do not apply to the Safety Injection components because of the low oxygen concentrations and the stainless steel components materials used in fabrication of the affected piping and valve subcomponents. Discuss the applicability and impact of the latest stainless steel fatigue correlation from ANL on this conclusion (see attachment).

COMMENTS ON THE APPLICATION OF THE EPRI ENVIRONMENTAL FATIGUE FACTOR TO THE CALVERT CLIFFS PLANTS

The environmental factor approach described in the report is a convenient and acceptable method to incorporate the effects of LWR coolant environments on fatigue life of pressure vessel and piping steels. However, the correlations for calculating the fatigue life correction factors F_{en} should be updated. For carbon and low–alloy steels, the dependence of F_{en} on dissolved oxygen (DO) is not consistent with experimental data. For austenitic stainless steels, the correlations do not include the effects of DO content and temperature; particularly the effects of DO content are important because environmental effects are more pronounced in low–DO PWR environments than in high–DO water.

Another minor point, the report makes several references to the fact that environmental factor approach gives a lower usage factor than the interim fatigue design curves of NUREG/CR-5999, implying that this difference is due to the methodology, i.e., graphical versus mathematical representation of the best–fit curve of the experimental data. The methodology will introduce a difference if the best–fit curves used in developing the current Code design fatigue curves are different than the best–fit curves of the present fatigue S–N data, because the design curves not only account for the effects of environment but also small differences that might exist between the ASME mean curve and the best–fit curve of existing fatigue data.

For carbon and low–alloy steels, because the ASME mean curves are either comparable or somewhat conservative, the two methods should yield similar results as long as the same correlations are used in developing the design curve and the correction factors. Minor differences between the two mentioned in this report are due to the correlations used for the interim curves. For austenitic stainless steels, it is well known (Jaske & O'Donnell, 1978) that the ASME mean curve is inconsistent with the existing fatigue data. Experimental fatigue lives are a factor of up to 3 lower than those predicted by the ASME mean curve. Consequently, usage factors based on interim design curves may be significantly higher because they account for this difference. However, for austenitic stainless steels, the margin factors on life are lower than 20 and closer to 10 or 8, i.e., there is little or no safety margin to account for environmental effects. Some specific comments on the report are as follows.

SECTIONS 2.2.3 & 3.1.3: ENVIRONMENTAL EFFECTS

The report follows the methodology of EPRI TR–105759, "An Environmental Factor Approach to Account for Reactor Water Effects in Light Water Reactor Pressure Vessel and Piping Fatigue Evaluations," to account for the effects of reactor coolant environment on the fatigue life of components. This approach was initially proposed by Higuchi and Iida (1991). The effects of coolant environment on fatigue life are expressed in terms of a fatigue life correction factor F_{en}, which is the ratio of the life in air at room temperature to that in water at the service temperature. This method is also being proposed as a non–mandatory Appendix.

To incorporate environmental effects into the ASME Code fatigue evaluation, a fatigue usage for a specific load pair based on the current Code design curve is multiplied by the correction factor. The correlations for F_{en} are based on the statistical models developed by ANL (NUREG/CR-6335, 1995). The statistical models have since been updated. The models for carbon and low-alloy steels were first modified (Gavenda et. al. PVP-Vol. 350, 1997) because it was determined that in the range of 0.05 to 0.5 ppm, the effect of DO was more logarithmic than linear. Recently, these models have been further optimized with a larger data base (Chopra & Shack PVP 98; also NUREG/CR-6583, 1998). The models in NUREG/CR-6335 for austenitic stainless steels were based on very limited data, and have also been updated to incorporate the effects of DO, temperature, and strain rate on fatigue life (Chopra & Smith, PVP 98). These updated models should be used to estimate F_{en} in LWR environments.

In addition, a set of threshold values of strain amplitude, strain rate, temperature, dissolved oxygen (DO), and sulfur content are defined for environmental effects to occur. In NUREG/CR-6335, these threshold values were defined on the basis of experimental observations and trends in the existing fatigue S-N data. With the exception of strain amplitude, the same threshold values have been included in the non-mandatory Appendix. A threshold strain amplitude of 0.1% is proposed for both carbon and low-alloy steels as well as austenitic stainless steels in the Appendix; the basis for this value is not provided. The threshold strain should be related to the rupture strain of the surface oxide film; there is little data to establish this value. Limited data suggest that for carbon and low-alloy steels, the threshold strain is ≈20% higher than the fatigue limit of the steel (i.e., ≈0.11 and 0.15%, respectively, for carbon steels and low-alloy steels). A threshold strain amplitude of 0.16% has been observed for austenitic stainless steels. Unless it can be demonstrated otherwise, these values must be adjusted for the effects of mean stress and uncertainties due to material and loading variability, which yields threshold strain amplitude of 0.07% (21 ksi or 145 MPa) for carbon and low-alloy steels and 0.097% (27.5 ksi or 189 MPa) for stainless steels.

The EPRI report TR-105759 gives a different set of threshold values that represent the strain rate, temperature, and DO level which results in "moderate" or "acceptable" effects of environment, i.e., a factor of up to 4 decrease in fatigue life. For example, environmental effects on life for 0.1 ppm DO level are considered acceptable, and F_{en} is considered to be 1. Although a factor of 3 or even 4 on life appears reasonable for carbon and low-alloy steels (Chopra & Shack, PVP 98), the EPRI report does not provide a technical basis for selecting a factor of 4 as a working definition of acceptable effects. However, this approach results in a discontinuity at the threshold value, e.g., F_{en} is 1 at 0.1 ppm DO and may jump to 10 or higher at 0.105 ppm. To avoid such discontinuities, experimental threshold values (e.g., NUREG/CR-6583) should be used to determine F_{en}; then to take advantage of the conservatism in design fatigue curves, the calculated values may be divided by 3. In other words, up to a factor of 3 decrease in life due to environment is ignored in the evaluations. This approach is being considered by EPRI.

Please note that the above approach (factor of 3 decrease in life being acceptable) is applicable only for carbon and low-alloy steels and not for austenitic stainless steels. The reason being that the current ASME Code mean curve for low-alloy steels is consistent with the existing fatigue S-N data and that for carbon steels is somewhat conservative. Thus, a factor 3 margin on life may be used to account for acceptable effects of environment. However, the current ASME Code mean curve for austenitic stainless steels are not consistent with the existing fatigue S-N data; a margin of only 10 on life and 1.5 on stress exists between the Code design curve and the mean curve (Chopra & Smith, PVP 98). Consequently, a factor of less than 1.5 margin on life may be used to account for acceptable effects of environment.

EXECUTIVE SUMMARY (PAGE 2, "RESULTS")

".... application of the effects of reactor water environments, ... produces worst–case environmental multipliers that are already compensated for by two existing conservatisms in Class 1 ASME Code fatigue analysis procedures – (1) the low–cycle portion of the design fatigue curve margin factor of 20 that is appropriately ascribed to moderate environmental effects, and .... "

Please note that the factors of 20 on life and 2 on stress should not be considered as safety margins but rather conversion factors that must be applied to the experimental data to obtain reasonable estimates of the lives of actual reactor components. Although in a benign environment some fraction of the factors, e.g., a factor of 3 on life, may be available as a safety margin.

Also, fatigue tests conducted on 0.914 m (36 in.) diameter vessels with 19 mm (0.75 in.) wall in room–temperature water at Southwest Research Institute for the Pressure Vessel Research Council (Kooistra, et al., 1964) show that ≈5 mm deep cracks can form in carbon and low–alloy steels very close to the values predicted by the ASME Code design curve. These results demonstrate clearly that the Code design fatigue curves do not necessarily guarantee any margin of safety.

MEETING WITH ELECTRIC POWER RESEARCH INSTITUTE ON METAL FATIGUE, MARCH 19, 1998

The methodology and results from four studies on Environmental Fatigue Evaluations, e.g., Calvert Cliffs, Older Westinghouse Plants, Representative BWR Components, and Newer Vintage BWR Plants, were presented at the meeting. All studies essentially follow the environmental factor approach described in the EPRI report TR-105759, and used in the EPRI report TR-107515 on evaluation of thermal fatigue effects for Calvert Cliffs Nuclear Power Plant.

The effects of coolant environment on fatigue life are expressed in terms of a fatigue life correction factor or environmental factor F_{en}, which is the ratio of the life in air to that in water. A fatigue usage for a specific load pair based on the current Code design curve is multiplied by the correction factor. The correlations for F_{en} are based on the statistical models developed by ANL (NUREG/CR-6335, 1995), which also include a set of threshold values of strain amplitude, strain rate, temperature, and dissolved oxygen beyond which environmental effects on fatigue life are significant. A detailed description of the EPRI methodology is given below.

Correlations Based on NUREG/CR-6335

F_{en} for carbon steels (CSs) and low-alloy steels (LASs) is expressed as

CSs $F_{en} = \exp(0.384 - 0.00133\,T - 0.554\,S^*\,T^*\,\dot{\varepsilon}^*\,O^*)$ (1)

LASs $F_{en} = \exp(0.766 - 0.00133\,T - 0.554\,S^*\,T^*\,\dot{\varepsilon}^*\,O^*)$, (2)

where the threshold and saturation values (the value beyond which the effect of environment saturates) of sulfur content S, temperature T, strain rate $\dot{\varepsilon}$, and DO content in water are defined as

$S^* = S$ $(0 < S \leq 0.015$ wt.%)
$S^* = 0.015$ $(S > 0.015$ wt.%) (3a)

$T^* = 0$ $(T < 150°C)$
$T^* = T - 150$ $(T \geq 150°C)$ (3b)

$\dot{\varepsilon}^* = 0$ $(\dot{\varepsilon} > 1\%/s)$
$\dot{\varepsilon}^* = \ln(\dot{\varepsilon})$ $(0.001 \leq \dot{\varepsilon} \leq 1\%/s)$
$\dot{\varepsilon}^* = \ln(0.001)$ $(\dot{\varepsilon} < 0.001\%/s)$ (3c)

$O^* = 0$ (DO <0.05 ppm)
$O^* = DO$ (0.05 <DO ≤0.5 ppm)
$O^* = 0.5$ (DO >0.5 ppm) (3d)

F_{en} for Types 304 and 316 stainless steels (SSs) is expressed as

$$F_{en} = \exp(0.359 - 0.134\ \dot{\varepsilon}^*) \qquad (4)$$

where the threshold and saturation values of strain rate $\dot{\varepsilon}$ are defined as

$$\dot{\varepsilon}^* = 0 \qquad (\dot{\varepsilon} > 1\%/s)$$
$$\dot{\varepsilon}^* = \ln(\dot{\varepsilon}) \qquad (0.001 \le \dot{\varepsilon} \le 1\%/s)$$
$$\dot{\varepsilon}^* = \ln(0.001) \qquad (\dot{\varepsilon} < 0.001\%/s) \qquad (5)$$

Updated Correlations for Fatigue Life in LWR Environments

The models for CSs and LASs were later updated (PVRC Meeting, Orlando, April 1996) because the existing fatigue S–N data indicate that in the range of 0.05–0.5 ppm, the effect of DO on life (Eq. 3d) was more logarithmic than linear. Thus, updated correlations of F_{en} for CSs and LASs are expressed as

CSs $$F_{en} = \exp(0.384 - 0.00133\ T - 0.1097\ S^*\ T^*\ \dot{\varepsilon}^*\ O^*) \qquad (6)$$

LASs $$F_{en} = \exp(0.766 - 0.00133\ T - 0.1097\ S^*\ T^*\ \dot{\varepsilon}^*\ O^*), \qquad (7)$$

where the threshold and saturation values of sulfur content S, temperature T, and strain rate are the same as those defined in Eqs. 3a–3c, and those of DO content are defined as

$$O^* = 0 \qquad (DO < 0.05\ ppm)$$
$$O^* = \ln(DO/0.04) \qquad (0.05 < DO \le 0.5\ ppm)$$
$$O^* = \ln(12.5) \qquad (DO > 0.5\ ppm) \qquad (8d)$$

These correlations (Eqs. 6 and 7) have been further optimized with a larger data base (Chopra & Shack, PVP 1998). The differences between the optimized correlations and Eqs. 6 and 7 are minimal; the differences are essentially in estimates of life in low–DO environments.

The NUREG/CR–6335 models for austenitic SSs (Eqs. 4 and 5) were based on very limited data. For example, nearly all of the data in water were obtained at high temperatures (280–320°C) and high levels of DO (0.2–8 ppm). The data were inadequate to establish the dependence of life on strain rate, temperature, or DO content, or to define the threshold and saturation values of these parameters. These models have now been updated with a larger data base (Chopra & Smith, PVP 1998). The updated correlation of F_{en} for Types 304 and 316 SS is expressed as

$$F_{en} = \exp(0.935 - T^*\ \dot{\varepsilon}^*\ O^*) \qquad (9)$$

where the threshold and saturation values of temperature T, strain rate $\dot{\varepsilon}$, and DO content in water are defined as

$$T^* = 0 \qquad (T < 200°C)$$
$$T^* = 1 \qquad (T \ge 200°C) \qquad (10a)$$

$\dot{\varepsilon}^* = 0$ $(\dot{\varepsilon} > 0.4\%/s)$

$\dot{\varepsilon}^* = \ln(\dot{\varepsilon}/0.4)$ $(0.0004 \le \dot{\varepsilon} \le 0.4\%/s)$

$\dot{\varepsilon}^* = \ln(0.0004/0.4)$ $(\dot{\varepsilon} < 0.0004\%/s)$ (10b)

$O^* = 0.260$ (DO <0.05 ppm)

$O^* = 0.172$ (DO ≥0.05 ppm) (10c)

Please note that F_{en} is greater in low–DO PWR than in high–DO environments.

The EPRI Environmental Factor Approach

1) Because the current fatigue design curves are based on data obtained in room–temperature air, an environmental correction factor should be determined with respect to room–temperature air, i.e., F_{en} should be defined as ratio of the life in air at room temperature to that in water at the service temperature. It will retain the margins of 20 on life and 2 on stress that are used to develop design fatigue curves from the best–fit experimental curves. In the EPRI approach, F_{en} is defined as ratio of the life in air to that in water both at the service temperature. The premise being that the effect of environment alone needs to be incorporated in F_{en}; margins of 20 and 2 in the current design curves are adequate to account for the uncertainties that arise due to other factors.

2) The correlations for F_{en} are based on the statistical models of NUREG/CR–6335 (Eqs. 1, 2, and 4). As discussed above, F_{en} should be determined from the updated correlations (Eqs. 6, 7, and 9).

3) In EPRI report TR–105759, a different set of threshold values (other than Eqs. 3, 8, and 10) are defined such that they result in "moderate" or "acceptable" effect of environment (i.e., they result in up to a factor of 3 decrease in fatigue life). For example, when all other threshold conditions are satisfied, a DO level of 0.1 ppm may result in a factor of 3 decrease in life. Therefore, a threshold value of 0.1 ppm DO is used in the evaluations, i.e., F_{en} is 1 for all load pairs with ≤0.1 ppm DO. Although a factor of 3 on life appears reasonable for defining moderate or acceptable effects of environment on life of CSs and LASs, it can not be used for austenitic SSs. The existing fatigue S–N data for austenitic SSs indicate that the difference between the ASME Code design curve and best–fit experimental curve is closer to margins of 10 on life and 1.5 on stress than the 20 and 2 originally intended. Also, care should be taken to avoid taking credit for this factor twice, e.g., after eliminating all load pairs that do not satisfy the modified thresholds, a factor of up to 3 increase in CUF may be considered as "acceptable" effect of environment.

4) The existing fatigue S–N data can not justify a threshold value of 0.1% for strain amplitude, particularly for CSs and LASs.

$\dot{\varepsilon}^* = 0$ ($\dot{\varepsilon}$ >0.4%/s)

$\dot{\varepsilon}^* = \ln(\dot{\varepsilon}/0.4)$ ($0.0004 \le \dot{\varepsilon} \le 0.4$%/s)

$\dot{\varepsilon}^* = \ln(0.0004/0.4)$ ($\dot{\varepsilon}$ <0.0004%/s) (10b)

$O^* = 0.260$ (DO <0.05 ppm)

$O^* = 0.172$ (DO ≥0.05 ppm) (10c)

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