September 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: 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 NRC staff is reviewing the integrated plant assessment reports contained in the application against the requirements of 10 CFR 54.21(a)(1) and 10 CFR 54.21(a)(3). Based on a review of the information submitted, the staff has identified in the enclosure, areas regarding metal fatigue where additional information is needed to complete its review.

Please provide a schedule by letter or telephonically for the submittal of your responses within 30 days of the receipt of this letter. Additionally, the staff would be willing to meet with BGE prior to the submittal of the responses to provide clarifications of the staff's requests for additional information.

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: Request for Additional Information

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Mr. Charles H. Cruse
Baltimore Gas & Electric Company

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REQUEST FOR ADDITIONAL INFORMATION
CALVERT CLIFFS UNITS 1 AND 2 INTEGRATED PLANT ASSESSMENT
ON METAL FATIGUE
DOCKET NOS. 50-317/50-318

Section 5.2, "Chemical and Volume Control System"

1. Section 5.2, page 5.2-14, of the application contains a list of Chemical and Volume Control System (CVCS) subcomponent parts for which fatigue is considered plausible. The application further indicates that the CVCS Charging Inlet Nozzle was identified as the most bounding location. Identify which subcomponents have fatigue analyses. Describe the review process used to evaluate the subcomponent parts for fatigue, including the selection of the bounding location.

2. Section 5.2 of the application indicates that the Fatigue Monitoring Program (FMP) tracks the fatigue usage at the Charging Inlet Nozzle. Describe the parameters that are monitored by the FMP that are applicable to the Charging Inlet Nozzle. Also describe how the monitored parameters are compared to the fatigue analysis of record.

3. Electric Power Research Institute (EPRI) Report TR-107515, "Evaluation of Thermal Fatigue Effects on Systems Requiring Aging Management Review for License Renewal for the Calvert Cliffs Nuclear Power Plant," dated December 1997, provides the results of the fatigue analyses of the CVCS piping. Section 3.2.1.1 of the EPRI report indicates that the existing fatigue analysis of the piping did not account for the auxiliary spray transients. The EPRI report further indicates that revised analyses are under development. Describe the manner by which the time-limited aging analyses (TLAA) for the revised CVCS fatigue analyses will satisfy 10 CFR 54.21(c) considering the existing analysis did not account for the auxiliary spray transients. Also provide the schedule for completion of the revised CVCS fatigue analyses. Also, describe the expected impact of these revised analyses on the evaluation contained in EPRI Report TR-107515.

4. Section 3.2.2.1 of EPRI Report TR-107515 indicates that the charging and auxiliary spray piping were reanalyzed to account for the installation of an orifice for the stop check valve in the bypass line around isolation valve CV-519. Section 3.2.2.3 of the EPRI report describes the back-projection of fatigue usage from FMP data, which was only available for the May through December 1995 time frame. Provide the date of the installation of the orifice in the bypass line. Describe the impact of the modification to the bypass line, if any, on the parameters monitored by the FMP. Also describe the impact of the modification, if any, on the computation of previous fatigue usage and the projection of fatigue usage to 40 and 60 years.

5. Section 3.2.2.5 of EPRI Report TR-107515 summarizes the fatigue cumulative usage factor (CUF) projections for the Charging System piping and Auxiliary Spray piping locations. The projected CUFs in these lines are higher than the projected CUF at the

CVCS Charging Inlet Nozzle. However, as discussed in item 1 above, the CVCS Charging Inlet Nozzle was identified as the most bounding fatigue location. Explain why the projected CUFs are higher in the Charging System and Auxiliary Spray piping locations than at the bounding location.

6. Section 3.2.3 of EPRI Report TR-107515 contains an evaluation of environmental effects on the 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. Attached are comments on the application of the EPRI methodology for environmental fatigue factors to the Calvert Cliffs plant. 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.

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

7. Section 5.2 of the application indicates that Calvert Cliffs Units 1 and 2 have experienced cases of fatigue failures in CVCS piping that were attributed to vibration loads imposed by operation of the Charging Pumps. The application indicates that BGE performed piping design modifications to reduce vibration and improve the CVCS reliability. Describe the modifications that were performed to reduce the vibration. Indicate whether vibration monitoring of the piping was performed subsequent to the modifications. Identify the Codes and Standards used, and summarize the significance of the results for the period of extended operation, if any, of the vibration monitoring.

8. To verify that no significant vibrational fatigue is occurring for the components, Section 5.2 of the application indicates that a new program will be developed to provide requirements for inspections of representative components. The application further indicates that the program details are discussed in the Aging Management Program section for CVCS Group 2. However, the Group 2 program is for managing the effects of corrosion. Discuss the specific elements of the Group 2 corrosion program that are relevant in monitoring vibration fatigue.

Section 4.1, "Reactor Coolant System"

9. Section 4.1 of the application indicates that Calvert Cliffs has shut down on several occasions due to Reactor Coolant System (RCS) leakage associated with the Reactor Coolant Pumps (RCPs). The application also indicates that a vibration monitoring and

reduction program has been implemented for the piping associated with the RCP seal leakoff lines. Describe the parameters that are currently monitored by this program. Also, provide the acceptance criteria for the monitored parameters including the technical basis for the acceptance criteria.

10. Section 4.1 of the application indicates that the FMP monitors and tracks low-cycle fatigue usage for the limiting components of the Nuclear Steam Supply System (NSSS) and Steam Generator (SG) safe-ends-to-reducer welds. Describe the parameters that are monitored by the FMP that are applicable to the NSSS and SG safe-end-to-reducer welds. Also describe how the monitored parameters are compared to the fatigue analysis of record.

11. Section 4.1 of the application indicates that a one-time fatigue analysis will be performed for the RCPs, Motor-Operated Valves (MOVs), and pressurizer relief valves to determine if these components are bounded by components and transients currently included in the FMP. Describe the fatigue criteria that were used in the original design of these components. Describe the purpose and criteria for the one-time fatigue analysis described in Section 4.1. Describe the manner by which the time-limited aging analyses (TLAA) for these fatigue analyses will satisfy 10 CFR 54.21(c). Also provide the schedule for completion of these fatigue analyses.

12. Section 4.1 of the application provides the CUFs through 1996 for the critical RCS components. Provide the projected CUFs for the critical RCS components at the end of the period of extended operation.

13. Section 4.1 of the application indicates that in order to remain within the design basis, corrective action is initiated well in advance of the CUF approaching one or the number of cycles approaching design allowable. Describe the specific criteria used to determine when corrective actions will be initiated.

14. EPRI Report TR-107515 provides the results of a fatigue assessment of the Pressurizer Surge Line. Section 3.3.1.1 of the EPRI report provides the results of an ASME Code Section III evaluation of the line that had been performed to address the issue of fatigue due to thermal stratification. The EPRI report lists a Class 1, Equation 12 stress that exceeds the ASME Code allowable limit. No further explanation is provided. Indicate whether the ASME Code stress limits were met for this analysis.

15. Section 4.1 of the application indicates that environmental effects do not apply to the 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).

16. 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).

17. 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.

Section 5.15, "Safety Injection System"

18. Section 5.15 of the application contains a list of Safety Injection (SI) System components for which fatigue is considered plausible. The application indicates that the SI System vent/drain/test hand valves, instrument isolation hand valves, and relief valves connected to the piping are generally "thin-walled" components and, therefore, do not experience the large temperature gradients that would be necessary to cause significant degradation. Provide the technical basis for this conclusion.

19. Section 5.15 of the application indicates that the FMP tracks the fatigue usage at the SI Nozzle. Describe the parameters that are monitored by the FMP that are applicable to the SI Nozzle. Also describe how the monitored parameters are compared to the fatigue analysis of record.

20. Section 5.15 of the application indicates that in order to stay within the design basis, corrective action is initiated well in advance of the CUF approaching one or the number of cycles approaching the design allowable. Describe the specific criteria used to determine when corrective actions will be initiated.

21. Section 5.15 of the application indicates that BGE identified the potential for thermal stratification in the piping between the SI Tank check valves and the loop inlet check valves. The application also indicates that BGE will complete an engineering review of the industry task group reports regarding thermal stratification to determine whether SI piping changes are necessary, and to determine the impact of such changes on fatigue usage parameters used by the FMP. Indicate whether the plans for the engineering review includes reanalysis for thermal stratification. Describe the manner by which the time-limited aging analyses (TLAA) for these fatigue analyses will satisfy 10 CFR 54.21(c). Also provide the schedule for completion of these fatigue analyses.

22. Section 5.15 of the application indicates that environmental effects do not apply to the SI 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 $\quad F_{en} = \exp(0.384 - 0.00133\, T - 0.554\, S^* T^* \dot{\varepsilon}^* O^*)$ (1)

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

$S^* = S \qquad (0 < S \le 0.015 \text{ wt.\%})$

$S^* = 0.015 \qquad (S > 0.015 \text{ wt.\%}) \qquad (3a)$

$T^* = 0 \qquad (T < 150°C)$

$T^* = T - 150 \qquad (T \ge 150°C) \qquad (3b)$

$\dot{\varepsilon}^* = 0 \qquad (\dot{\varepsilon} > 1\%/s)$

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

$\dot{\varepsilon}^* = \ln(0.001) \qquad (\dot{\varepsilon} < 0.001\%/s) \qquad (3c)$

$O^* = 0 \qquad (DO < 0.05 \text{ ppm})$

$O^* = DO \qquad (0.05 < DO \le 0.5 \text{ ppm})$

$O^* = 0.5 \qquad (DO > 0.5 \text{ ppm}) \qquad (3d)$

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

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

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

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

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

$$\begin{aligned} &O^* = 0 && (\mathrm{DO} < 0.05\ \mathrm{ppm}) \\ &O^* = \ln(\mathrm{DO}/0.04) && (0.05 < \mathrm{DO} \le 0.5\ \mathrm{ppm}) \\ &O^* = \ln(12.5) && (\mathrm{DO} > 0.5\ \mathrm{ppm}) \qquad (8d) \end{aligned}$$

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

$$\begin{aligned} &T^* = 0 && (T < 200°\mathrm{C}) \\ &T^* = 1 && (T \ge 200°\mathrm{C}) \qquad (10a) \end{aligned}$$

$$\dot{\varepsilon}^* = 0 \qquad (\dot{\varepsilon} > 0.4\%/s)$$
$$\dot{\varepsilon}^* = \ln(\dot{\varepsilon}/0.4) \qquad (0.0004 \le \dot{\varepsilon} \le 0.4\%/s)$$
$$\dot{\varepsilon}^* = \ln(0.0004/0.4) \qquad (\dot{\varepsilon} < 0.0004\%/s) \qquad (10b)$$

$$O^* = 0.260 \qquad (DO < 0.05\ ppm)$$
$$O^* = 0.172 \qquad (DO \ge 0.05\ ppm) \qquad (10c)$$

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.