Summary of Environmental Fatigue Analysis Results for the US-APWR Pressurizer Surge Line

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ABSTRACT

This report provides the environmental fatigue analyses results of Pressurizer Surge line in support of the US-APWR DCD Review process and complies with U.S.NRC Regulatory Guide 1.207 (Reference 2).

Based on the results summarized in this report, it is concluded that the US-APWR Pressurizer Surge line satisfies the recommendations for environmental fatigue contained in U.S.NRC Regulatory Guide 1.207.

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LIST OF ACRONYMS

The following list defines the acronyms used in this document.

ANL	Argonne National Laboratory
ASME	American Society of Mechanical Engineers
CUF	Cumulative Usage Factor
DCD	Design Control Document
DO	Dissolved Oxygen
H/L	Hot Leg
JSME	Japan Society of Mechanical Engineers
LWR	Light Water Reactor
MCP	Main Coolant Piping
PWR	Pressurized Water Reactor
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
TE	Thermal Element
U.S.NRC	U.S. Nuclear Regulatory Commission

1.0 INTRODUCTION

This report summarizes environmental fatigue analysis of Pressurizer Surge line. It has been prepared in support of the US-APWR DCD Review process and complies with U.S.NRC Regulatory Guide 1.207 (Reference 2).

The pressure boundary of the ASME class 1 branch piping in contact with the primary coolant fluid is required to be evaluated for fatigue incorporating the life reduction of the metal components due to the effect of the light-water reactor (LWR) environment.

Environmental fatigue analysis has been performed in accordance with Regulatory Guide 1.207. The methodology includes calculation of the usage factor in air based on ASME Code analysis procedure with the new fatigue design curve developed from the Argonne National Laboratory (ANL) model, and then employing the environmental fatigue correction factor (F_{en}) as described in NUREG/CR-6909 (Reference 3). The fatigue analysis was performed under 60 year plant operation.

This report provides the environmental fatigue analysis method and results of US-APWR Pressurizer Surge line. For the results of the stress analysis in accordance with ASME Code Section III, refer to a summary described in the ASME Stress Report (Reference 6, 9).

2.0 SUMMARY OF RESULTS AND CONCLUSION

2.1 Summary of Results

The most limiting results of environmental fatigue analysis are listed in Table 2.1-1. The detail of analysis condition and results are described in section 8 and 9, respectively.

Table 2.1-1 Summary of Environmental Fatigue Analysis

- Pressurizer Surge Line
- SA-312 (Seamless) TP316 (austenitic stainless steel) material
- Based on more detailed fatigue analysis method

Cumulative usage factor in air based on ASME fatigue design curve, U	Cumulative usage factor in air based on NUREG/CR-6909 fatigue design curve, U	Cumulative usage factor in LWR environment based on NUREG/CR-6909 fatigue design curve, U_{en} (LWR F_{en})

2.2 Conclusion

U.S.NRC Bulletin 88-11 expresses concern for thermal stratification in the Pressurizer Surge line as it relates to fatigue and pipe deformation.

Based on the results of this report, it is concluded that the US-APWR Pressurizer Surge line meets the U.S.NRC Regulatory Guide 1.207 environmental fatigue requirements for 60 years of operation.

The maximum elastic displacement and rotation for all Level A and Level B transients, including insurge and outsurge thermal stratification, is less than 2” and less than 1^{o}, respectively (Reference 6). The pipe support system is appropriately designed to accommodate these movements.

3.0 NOMENCLATURE

Table 3.0-1 (1/2) Symbol and Definition

Symbol	Definition
α	Coefficient of thermal expansion
C_1,C_2,C_3	Secondary stress indices
D_o	Outside diameter of pipe
ε	Strain
$\dot{\varepsilon}$	Strain rate
$\Delta\varepsilon_k$	Increment of strain for the “k” th incremental segment
$\dot{\varepsilon}_k$	Strain rate for the “k” th incremental segment
ε_A	Strain for load case “A”
ε_B	Strain for load case “B”
$\dot{\varepsilon}'$	Transformed strain rate
E	Modulus of elasticity
E_{ab}	Average modulus of elasticity of the two sides of a gross structural discontinuity or material discontinuity at room temperature
$F_{en,nom}$	Nominal environmental fatigue correction factor
$F_{en,i}$	Environmental fatigue correction factor for “i” th load set
$F_{en,k}$	Environmental fatigue correction factor for the “k” th incremental segment
$F_{en,A}$	Environmental fatigue correction factor for load case “A”
$F_{en,B}$	Environmental fatigue correction factor for load case “B”
I	Moment of inertia
K_e	Elastic-plastic correction factor (NB-3228.5 of ASME Code)
K_1,K_2,K_3	Local stress indices
M_i	Resultant moment due to a combination of Design Mechanical Loads
Ni	Allowable number of stress cycles
ni	Number of cycles of load set
ν	Poisson’s ratio
O'	Transformed dissolved oxygen level
P_o	Range of service pressure
Salt	Alternating stress intensity
Sp	Peak stress intensity
$\Delta Sp_{dom,k}$	Increment of dominant stress of Sp for the “k” th incremental segment
T'	Transformed temperature
T_k	Temperature for the “k” th incremental segment

Table 3.0-1 (2/2) Symbol and Definition

Symbol	Definition
ΔT_1	Range of the temperature difference between the temperature of the outside surface and the temperature of the inside surface of the piping product assuming moment generating equivalent linear temperature distribution
ΔT_2	Range for that portion of the nonlinear thermal gradient through the wall thickness not included in ΔT_1
T_a-T_b	Range of the temperature difference of the two side of a gross structural discontinuity or material discontinuity
t	Nominal wall thickness
Δt_k	Increment of time for the “k” th incremental segment
U	Cumulative usage factor in air
U_i	Usage factor in air for “i” th load set
U_{en}	Cumulative usage factor in LWR environment
$U_{en,i}$	Usage factor in LWR environment for “i” th load set

4.0 ASSUMPTIONS AND OPEN ITEMS

4.1 Assumptions

The assumptions are as follows.

1) The pipe support and snubber characteristics used in the analysis are based on experience from previous projects. The actual values will not be known until the procurement phase.

2) Pipe welds are assumed to be as-welded girth butt-welds rather than flush girth butt-welds, so conservatively high stress indices are applied.

3) The locations of the pipe weld joints will not be finalized until later in the project but will be placed in low stress regions. The pipe welds are conservatively assumed to be located near the pipe-bends where stresses are elevated.

4) Thermal stratification is modeled assuming the temperature profile of the horizontal portion of the Pressurizer Surge line.

4.2 Open Items

There are no open items in this report.

5.0 ACCEPTANCE CRITERIA

The usage factor is calculated based on the ASME procedure with the new fatigue design curve, which are provided in NUREG/CR-6909, Appendix A, Figure A.3 (Reference 3). The usage factor is multiplied by F_{en} to obtain the cumulative usage factor in the LWR environment. The acceptance criteria is that the cumulative usage factor in the LWR environment U_{en} does not exceed the limit of 1.0.

$$U_{en} = U_1 \cdot F_{en,1} + U_2 \cdot F_{en,2} + U_3 \cdot F_{en,3} + U_i \cdot F_{en,i} ..... + U_n \cdot F_{en,n} \leq 1.0$$

6.0 COMPUTER CODE USED IN CALCULATION

Table 6.0-1 below provides a brief description of each of the computer programs used.

Table 6.0-1 Computer Program Description

No.	Program Name	Version	Description
1	PIPESTRESS	3.6.2	PIPESTRESS is a computer program for the analysis of piping systems. This program is used for the analysis of ASME Code, Section III, Class 1, 2, 3 and ASME B31.1 piping systems under various load conditions.
2	ABAQUS	6.7-1	ABAQUS is a general-purpose finite element computer program that performs a wide range of linear and nonlinear engineering simulations. This program is used for temperature distribution analysis and thermal stress analysis according to piping geometries and design transients such as fluid temperature and coefficient of heat transfer.
3	P4TEDIA	1.3	P4TEDIA is an in-house program to obtain temperature difference between in-side and out-side of pipe ΔT_1, ΔT_2 and temperature difference at structural discontinuous point T_a-T_b. This program uses the thermal distribution analysis results generated by ABAQUS.
4	CEFF-N	1.0	CEFF-N is an in-house program for the fatigue analysis in LWR environment. This program calculates the environmental fatigue correction factor using the fatigue analysis result in air and time history of ΔT_1 and T_a-T_b. These results are generated by PIPESTRESS and P4TEDIA, respectively.

All these computer programs were verified and validated in compliance with the MHI quality assurance program. The computer programs were validated using one of the methods described below. Verification tests demonstrate the capability of the computer program to produce valid results for the test problems encompassing the range of permitted usage defined by the program documentation.

- Hand calculations
- Known solution for similar or standard problem
- Acceptable experimental test results
- Published analytical results
- Results from other similar verified program

7.0 DESIGN INPUT

The design input information contained in the ASME Stress Report (Reference 6, 9) of the Pressurizer Surge line applies to this report. Section 8.4 of this report describes the more detailed condition used to represent the Heatup and Cooldown insurge and outsurge transients.

Additional design input is from the U.S.NRC Regulatory Guide 1.207 (Reference 2) and NUREG/CR-6909 (Reference 3) for performing the environmental fatigue evaluation.

8.0 METHODOLOGY

8.1 Analysis Procedure

U.S.NRC Regulatory Guide 1.207 and NUREG/CR-6909 describe a methodology for evaluating environmental fatigue effects and a “modified rate approach” used to calculate F_{en}.

The calculated F_{en} values are used to incorporate environmental effects into a fatigue evaluation based on use of a fatigue curve in air. The fatigue analysis employs ASME Code analysis procedures with a new fatigue design curve that is provided in NUREG/CR-6909, Appendix A, Figure A.3.

Figure 8.1-1 shows the general procedure of environmental fatigue analysis for ASME class 1 piping, where P4TEDIA and CEFF-N are MHI proprietary computer code described in Section 6.0.

If the maximum possible F_{en} is applied to the fatigue usage factors in air and the result is less than or equal to 1.0, then no further evaluation is needed. This means that the cumulative usage factor in the LWR environment U_{en} is less than 1.0 and is acceptable. For cases where the maximum F_{en} causes the fatigue usage to exceed the allowable, then a more detailed analysis is required. Refer to Section 9.0 for a description.

The time histories of thermal stress (ΔT_1, ΔT_2, T_a-T_b) and metal temperature that are processed in P4TEDIA are used as an input of CEFF-N for use in modified rate approach. CEFF-N performs the F_{en} calculations and then incorporates the environmental effect.

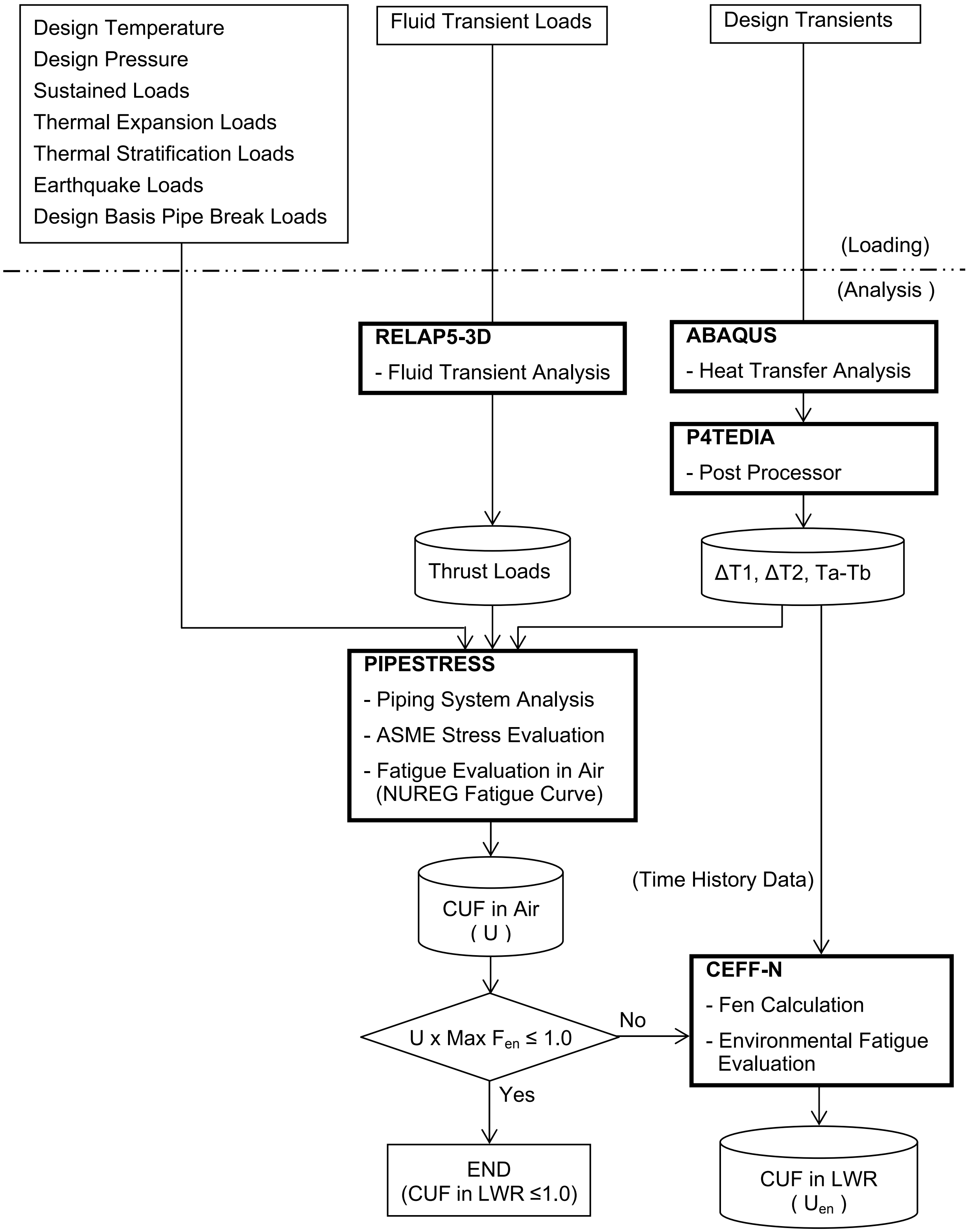


Figure 8.1-1 Environmental Fatigue Analysis Procedure

8.2 Basic Consideration

NUREG/CR-6909, Appendix A provides the guidance to use parameters for determining F_{en} values. However, it is incomplete for calculation of F_{en} under the loading histories.

The following analytic procedures associated with F_{en} are adopted.

1) The effect of elastic-plastic correction factor (Ke) per NB-3228.5 of ASME Code on strain rate is neglected.

   The Ke factor causes a higher strain that increase the strain rate, which in turn lowers the F_{en}. Thus neglecting Ke is conservative.

2) For load pairs in an environmental usage factor calculation that are based on seismic loading, F_{en}=1.0.

   Seismic loading occurs too quickly for environmental effects.

3) For the transformed temperature, the highest metal temperature for each incremental segment in the strain history is used.

   NURG/CR-6909 supports this approach in that the maximum temperature can be used to perform the most conservative evaluation.

4) For strain calculation, the modulus of elasticity (E) at the room temperature is used.

5) For determination of strain rate by combination of pressure, moment, ΔT_1, ΔT_2, and T_a-T_b, the guidance by JSME (Reference 4) is used.

$$S_P = \underbrace{K_1 C_1 \frac{P_o D_o}{2t}}_{\text{Pressure term}} + \underbrace{K_2 C_2 \frac{D_o}{2I} M_i}_{\text{Moment term}} + \underbrace{\frac{1}{2(1-\nu)} K_3 E \alpha |\Delta T_1|}_{\Delta T_1 \text{term}} + \underbrace{K_3 C_3 E_{ab} \times |\alpha_a T_a - \alpha_b T_b|}_{T_a\text{-}T_b \text{ term}} + \underbrace{\frac{1}{1-\nu} E \alpha |\Delta T_2|}_{\Delta T_2 \text{ term}}$$

   That is, when ΔT_1, ΔT_2, or T_a-T_b is dominant, the strain rate is calculated from the time history of the dominant strain.

8.3 Environmental Fatigue Analysis Method

1) Environmental fatigue correction factor

Environmental fatigue analysis is performed in accordance with NUREG/CR-6909 (Reference 3), using the environmental fatigue correction factor. The environmental cumulative usage factor U_{en} is calculated by multiplying the cumulative usage factor in air U (fatigue design curve is from NUREG/CR-6909) and the environmental fatigue correction factor F_{en}. The F_{en} is calculated by using the parameters described in NUREG/CR-6909, Appendix A.

Environmental cumulative usage factor

$$U_{en} = \sum_{i=1}^{n} U_i \times F_{en,i} \quad (1)$$

Environmental fatigue correction factor

・Austenitic stainless steel

$$F_{en,nom} = \exp(0.734 - T'O'\dot{\varepsilon}') \quad (2)$$

$$T' = 0 \qquad (T < 150\ ℃)$$
$$T' = (T - 150)/175 \qquad (150 \le T < 325\ ℃)$$
$$T' = 1 \qquad (T \ge 325\ ℃)$$
$$\dot{\varepsilon}' = 0 \qquad (\dot{\varepsilon} > 0.4\%/s)$$
$$\dot{\varepsilon}' = \ln(\dot{\varepsilon}/0.4) \qquad (0.0004 \le \dot{\varepsilon} \le 0.4\%/s)$$
$$\dot{\varepsilon}' = \ln(0.0004/0.4) \qquad (\dot{\varepsilon} < 0.0004\%/s)$$
$$O' = 0.281 \qquad (all\ \ DO\ \ levels)$$

2) Threshold strain amplitude

A threshold strain amplitude (one-half of the strain range) is considered, below which LWR coolant environment have no effect on fatigue life. The threshold strain amplitude is 0.10% (28.3 ksi (195 MPa) stress amplitude) for austenitic stainless steel.

For the alternating stress intensity Salt below 28.3 ksi, the environmental fatigue correction factor F_{en} is 1.0.

$$F_{en,nom} = 1.0 \qquad (S_{alt} \le 28.3 ksi (195 MPa)) \quad (3)$$

3) Modified rate approach

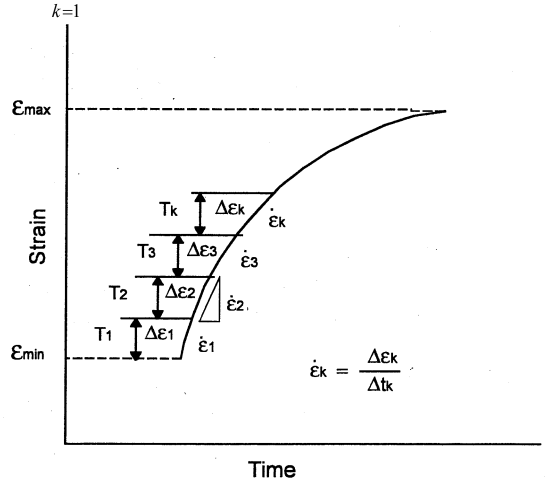
When the terms ΔT_1, ΔT_2, and T_a-T_b are dominant, the time histories of the inner surface temperature and the strain rate are obtained from the results of temperature distribution analysis (output of P4TEDIA). Therefore, the environmental fatigue correction factor F_{en} is calculated using the modified rate approach.

The strain ε , the denominator of weighting factor in equation (4), is the sum of the strain increments $\Delta\varepsilon_k$. Then, if the strain history does not show a monotonic increase, the strain ε is the sum of the strain increments in the F_{en} calculation segment to be described later. So, the calculated strain ε may not be match the value calculated from the peak stress.

Modified rate approach

$$F_{en} = \sum_{k=1}^{n} F_{en,k}\left(\dot{\varepsilon}_k, T_k\right)\frac{\Delta\varepsilon_k}{\varepsilon} \quad (4)$$

$$\varepsilon = \sum_{k=1}^{n} \Delta\varepsilon_k \quad (5)$$



4) Combination of load set

The environmental fatigue correction factor F_{en} for a combination of load set is calculated by the following equation using the environmental fatigue correction factors $F_{en,A}$ and $F_{en,B}$ calculated for load case A and B:

F_{en} for a combination of load set

$$F_{en} = \frac{F_{en,A} \times \varepsilon_A + F_{en,B} \times \varepsilon_B}{\varepsilon_A + \varepsilon_B} \quad (6)$$

5) Temperature

6) Strain rate

7) F_{en} calculation segment

Figure 8.3-1 Illustration of F_{en} Calculation Segment

Figure 8.3-2(1/2) Example of F_{en} Calculation Segment

Figure 8.3-2(2/2) Example of F_{en} Calculation Segment

8.4 Analysis Condition

8.4.1 Temperature Fluctuation

8.4.2 More Detailed Descriptions for Insurge and Outsurge Transients

Figure 8.4.2-1 Image of Load Cycle During Plant Heat-up Transient

Figure 8.4.2-2 Image of Load Cycle for More Detailed Loading Condition (Plant Heat-up Transient)

8.5 Analysis Cases

In the ASME Stress Report (Reference 6) four load cases are set to involve insurge / outsurge events. The most limiting of these four cases isn't easy to determine before performing the fatigue evaluation. So, all four cases are carried through this report to assure the most limiting case is evaluated. Table 8.5-1 describes the four cases.

Table 8.5-1 Analysis Case

Parameter	Case 1	Case 2	Case 3	Case 4
Full power assumption	Steady-state fluctuation	Steady-state fluctuation	Load regulation	Load regulation
Insurge / outsurge cycles				
Insurge flow rate, gpm				
Outsurge flow rate, gmp				
Insurge / outsurge hot-cold temperature difference, ^{o}F				
Thermal stratification Transient combination	Table A2-1	Table A2-2	Table A2-3	Table A2-4

9.0 ANALYSIS RESULTS

This section summarizes the results of the environmental fatigue analysis under more detailed loading condition.

Maximum Fen is 14.514 for austenitic stainless steel for T $\geq$ 325°C and $\dot{\varepsilon} < 0.0004$%/s. Therefore, the environmental fatigue analysis was performed for all points of Pressurizer Surge line in the case when the cumulative usage factor based on the NUREG/CR-6909 new fatigue design curve was equal to or greater than 0.0689 (=1/14.514). All the calculated cumulative usage factors in LWR environment (U_{en}) are listed in Table 9.0-1. The location of the environmental fatigue evaluation points are shown in Figure 9.0-1.

The details of the first two most severe environmental fatigue analysis results are shown in section 9.1 and 9.2.

Table 9.0-1 Results of Environmental Fatigue Analysis

Point	Location	NUREG (air) $U^{1)}$				NUREG (LWR) $U_{en}{}^{2)}$			
		Case1	Case2	Case3	Case4	Case1	Case2	Case3	Case4

Note:
1) Cumulative usage factor in air based on NUREG/CR-6909 fatigue design curve.
2) Cumulative usage factor in LWR environment.

Figure 9.0-1 Location of Environmental Fatigue Evaluation Points

9.1 Detailed Result of TE Nozzle

**Table 9.1-1 (1/2) Usage Factor Based on NUREG/CR-6909 Fatigue Design Curve
TE Nozzle (Point 8100) Group1 (Case2)**

Load Set[1)]		Salt (psi)	ni	NUREG(air) Ni	NUREG(air) U_i
A [2)]	B [2)]				

**Table 9.1-1 (2/2) Usage Factor Based on NUREG/CR-6909 Fatigue Design Curve
TE Nozzle (Point 8100) Group1 (Case2)**

Load Set[1)]		Salt (psi)	ni	NUREG(air) Ni	NUREG(air) U_i
A [2)]	B [2)]				

Note:
1) All other load sets produce zero U_i with the NUREG/CR-6909 design fatigue curve in air.
2) Load Set number A and B mean Load No. of design transient shown in Appendix 1, Table A1.

Table 9.1-2 Usage Factor Based on NUREG/CR-6909 Fatigue Design Curve TE Nozzle (Point 8100) Group2 (Case2)

Load Set[1)]		Salt (psi)	ni	NUREG(air) Ni	NUREG(air) U_i
A [2)]	B [2)]				

Note:
1) All other load sets produce zero U_i with the NUREG/CR-6909 design fatigue curve in air.
2) Load Set number A and B mean Load No. of design transient shown in Appendix 1, Table A1.

Table 9.1-3 (1/2) Detail of Usage Factor in LWR Environment
TE Nozzle (Point 8100) Group1 (Case2)

Load Set [1]		Salt (psi)	Sp (psi)	Component of Sp					Dominant Stress	NUREG (air) U_i	$F_{en,i}$	NUREG (LWR) $U_{en,i}$	[3]
A [2]	B [2]			Pressure (psi)	Moment (psi)	ΔT_1 (psi)	ΔT_2 (psi)	T_a-T_b (psi)					

Table 9.1-3 (2/2) Detail of Usage Factor in LWR Environment
TE Nozzle (Point 8100) Group1 (Case2)

Load Set [1]		Salt (psi)	Sp (psi)	Component of Sp					Dominant Stress	NUREG (air) U_i	$F_{en,i}$	NUREG (LWR) $U_{en,i}$	[3]
A [2]	B [2]			Pressure (psi)	Moment (psi)	ΔT_1 (psi)	ΔT_2 (psi)	T_a-T_b (psi)					

Note:
1) All other load sets produce zero U_i with the NUREG/CR-6909 design fatigue curve in air.
2) Load Set number A and B mean Load No. of design transient shown in Appendix 1, Table A1.
3) The mark " * " shows relatively large values of $U_{en,i}$.

Table 9.1-4 Detail of Usage Factor in LWR Environment
TE Nozzle (Point 8100) Group2 (Case2)

Load Set 1)		Salt (psi)	Sp (psi)	Component of Sp					Domi-nant Stress	NUREG (air) U_i	$F_{en,i}$	NUREG (LWR) $U_{en,i}$	3)
A 2)	B 2)			Pressure (psi)	Moment (psi)	ΔT_1 (psi)	ΔT_2 (psi)	T_a-T_b (psi)					

Note:
1) All other load sets produce zero U_i with the NUREG/CR-6909 design fatigue curve in air.
2) Load Set number A and B mean Load No. of design transient shown in Appendix 1, Table A1.
3) The mark " * " shows relatively large values of $U_{en,i}$.

Figure 9.1-1 Time History Chart of the Parameters used for F_{en} Calculation
TE Nozzle (Point 8100) Group1

9.2 Detailed Result of End of MCP Nozzle

Table 9.2-1 (1/2) Usage Factor Based on NUREG/CR-6909 Fatigue Design Curve
End of MCP Nozzle (Point 9001) Group1(Case2)

Load Set[1]		Salt (psi)	ni	NUREG(air) Ni	NUREG(air) U_i
A [2]	B [2]				

Table 9.2-1 (2/2) Usage Factor Based on NUREG/CR-6909 Fatigue Design Curve
End of MCP Nozzle (Point 9001) Group1 (Case2)

Load Set[1]		Salt (psi)	ni	NUREG(air) Ni	NUREG(air) U_i
A[2]	B[2]				

Note:
1) All other load sets produce zero U_i with the NUREG/CR-6909 design fatigue curve in air.
2) Load Set number A and B mean Load No. of design transient shown in Appendix 1, Table A1.

Table 9.2-2 Usage Factor Based on NUREG/CR-6909 Fatigue Design Curve End of MCP Nozzle (Point 9001) Group2 (Case2)

Load Set[1)]		Salt (psi)	ni	NUREG(air) Ni	NUREG(air) U_i
A [2)]	B [2)]				

Note:
1) All other load sets produce zero U_i with the NUREG/CR-6909 design fatigue curve in air.
2) Load Set number A and B mean Load No. of design transient shown in Appendix 1, Table A1.

Table 9.2-3 (1/2) Detail of Usage Factor in LWR Environment
End of MCP Nozzle (Point 9001) Group1 (Case2)

Load Set 1)		Salt (psi)	Sp (psi)	Component of Sp					Dominant Stress	NUREG (air) U_i	$F_{en,i}$	NUREG (LWR) $U_{en,i}$	3)
A 2)	B 2)			Pressure (psi)	Moment (psi)	ΔT_1 (psi)	ΔT_2 (psi)	T_a-T_b (psi)					

Table 9.2-3 (2/2) Detail of Usage Factor in LWR Environment
End of MCP Nozzle (Point 9001) Group1 (Case2)

Load Set [1]		Salt (psi)	Sp (psi)	Component of Sp					Dominant Stress	NUREG (air) U_i	$F_{en,i}$	NUREG (LWR) $U_{en,i}$	[3]
A [2]	B [2]			Pressure (psi)	Moment (psi)	ΔT_1 (psi)	ΔT_2 (psi)	T_a-T_b (psi)					

Note:
1) All other load sets produce zero U_i with the NUREG/CR-6909 design fatigue curve in air.
2) Load Set number A and B mean Load No. of design transient shown in Appendix 1, Table A1.
3) The mark " * " shows relatively large values of $U_{en,i}$.

**Table 9.2-4 Detail of Usage Factor in LWR Environment
End of MCP Nozzle (Point 9001) Group2 (Case2)**

Load Set 1)		Salt (psi)	Sp (psi)	Component of Sp					Domi-nant Stress	NUREG (air) U_i	$F_{en,i}$	NUREG (LWR) $U_{en,i}$	3)
A 2)	B 2)			Pressure (psi)	Moment (psi)	ΔT_1 (psi)	ΔT_2 (psi)	T_a-T_b (psi)					

Note:
1) All other load sets produce zero U_i with the NUREG/CR-6909 design fatigue curve in air.
2) Load Set number A and B mean Load No. of design transient shown in Appendix 1, Table A1.
3) The mark “ * “ shows relatively large values of $U_{en,i}$.

Figure 9.2-1 Time History Chart of the Parameters used for F_{en} Calculation
End of MCP Nozzle (Point 9001) Group2

10.0 REFERENCES

1) ASME Boiler and Pressure Vessel Code, Section III NB-3600, 1992 Edition including 1992 Addenda
2) 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” March 2007
3) NUREG/CR-6909 ANL-06/08 ”Effect of LWR Coolant Environments on the Fatigue Life of Reactor Materials Final Report”, U.S. Nuclear Regulatory Commission, Washington, DC, February 2007
4) JSME S NF1-2006 “Codes for Nuclear Power Generation Facilities, Environmental Fatigue Evaluation Method for Nuclear Power Plants”, March 2006
5) N0-EE12001 Rev.4 “US-APWR Standard Design Class 1 Equipment Design Transient”
6) N0-GB00202 Rev.2 “US-APWR Standard Design Pressurizer Surge Line Stress Analysis Report”
7) N0-GB00219 Rev.0 “US-APWR Standard Design Temperature Distribution Analysis Report for Pressurizer Surge Line”
8) N0-GB00002 Rev.4 “US-APWR Standard Design Class 1 Piping ASME Design Specification (Excluding Reactor Coolant Loop Piping)”
9) MUAP-11003-P Rev.1 “Summary of Stress Analysis Results for the US-APWR Pressurizer Surge Line “

Appendix 1

Design Transients

Table A1 (1/10) Pressurizer Surge Line Design Transients

Level A					
Mark	Transients	Occurrence	Load No. 1)		Load Group 2)
			Case1 Case3	Case2 Case4	

Table A1 (2/10) Pressurizer Surge Line Design Transients

Level A					
Mark	Transients	Occurrence	Load No. 1)		Load Group 2)
			Case1 Case3	Case2 Case4	

Table A1 (3/10) Pressurizer Surge Line Design Transients

Level A					
Mark	Transients	Occurrence	Load No. 1)		Load Group 2)
			Case1 Case3	Case2 Case4	

Table A1 (4/10) Pressurizer Surge Line Design Transients

Level A					
Mark	Transients	Occurrence	Load No. 1)		Load Group 2)
			Case1 Case3	Case2 Case4	

Table A1 (5/10) Pressurizer Surge Line Design Transients

Level A					
Mark	Transients	Occurrence	Load No. 1)		Load Group 2)
			Case1 Case3	Case2 Case4	

Table A1 (6/10) Pressurizer Surge Line Design Transients

Level A					
Mark	Transients	Occurrence	Load No. 1)		Load Group 2)
			Case1 Case3	Case2 Case4	

Table A1 (7/10) Pressurizer Surge Line Design Transients

Level A					
Mark	Transients	Occurrence	Load No. 1)		Load Group 2)
			Case1 Case3	Case2 Case4	

Table A1 (8/10) Pressurizer Surge Line Design Transients

Level B					
Mark	Transients	Occurrence	Load No. 1)		Load Group 2)
			Case1 Case3	Case2 Case4	

Table A1 (9/10) Pressurizer Surge Line Design Transients

Level B					
Mark	Transients	Occurrence	Load No. [1]		Load Group [2]
			Case1 Case3	Case2 Case4	

Table A1 (10/10) Pressurizer Surge Line Design Transients

Level B					
Mark	Transients	Occurrence	Load No. 1)		Load Group 2)
			Case1 Case3	Case2 Case4	

Appendix 2

Fatigue Analysis Input

Table A2-1 (1/9) Level A,B Fatigue Analysis Input (Case1)

	Transient	Load No.	Occurrence	Temp. (°F)	Thermal Stratification [1] (°F)	Pressure (psi)	Case1		Load Group
							ΔT1 (°F)	ΔT2 (°F)	

Table A2-1 (2/9) Level A,B Fatigue Analysis Input (Case1)

	Transient	Load No.	Occurrence	Temp. (°F)	Thermal Stratification [1] (°F)	Pressure (psi)	Case1		Load Group
							ΔT1 (°F)	ΔT2 (°F)	

Table A2-1 (3/9) Level A,B Fatigue Analysis Input (Case1)

	Transient	Load No.	Occurrence	Temp. (°F)	Thermal Stratification [1] (°F)	Pressure (psi)	Case1 ΔT1 (°F)	Case1 ΔT2 (°F)	Load Group

Table A2-1 (4/9) Level A,B Fatigue Analysis Input (Case1)

	Transient	Load No.	Occurrence	Temp. (°F)	Thermal Stratification 1) (°F)	Pressure (psi)	Case1		Load Group
							ΔT1 (°F)	ΔT2 (°F)	

Table A2-1 (5/9) Level A,B Fatigue Analysis Input (Case1)

	Transient	Load No.	Occurrence	Temp. (°F)	Thermal Stratification [1)] (°F)	Pressure (psi)	Case1 ΔT1 (°F)	Case1 ΔT2 (°F)	Load Group

Table A2-1 (6/9) Level A,B Fatigue Analysis Input (Case1)

	Transient	Load No.	Occurrence	Temp. (°F)	Thermal Stratification 1) (°F)	Pressure (psi)	Case1		Load Group
							ΔT1 (°F)	ΔT2 (°F)	

Table A2-1 (7/9) Level A,B Fatigue Analysis Input (Case1)

	Transient	Load No.	Occurrence	Temp. (°F)	Thermal Stratification [1)] (°F)	Pressure (psi)	Case1		Load Group
							ΔT1 (°F)	ΔT2 (°F)	

Table A2-1 (8/9) Level A,B Fatigue Analysis Input (Case1)

	Transient	Load No.	Occurrence	Temp. (°F)	Thermal Stratification [1] (°F)	Pressure (psi)	Case1 ΔT1 (°F)	Case1 ΔT2 (°F)	Load Group
[redacted]									

Table A2-1 (9/9) Level A,B Fatigue Analysis Input (Case1)

	Transient	Load No.	Occurrence	Temp. (°F)	Thermal Stratification 1) (°F)	Pressure (psi)	Case1 ΔT1 (°F)	Case1 ΔT2 (°F)	Load Group

Table A2-2 (1/9) Level A,B Fatigue Analysis Input (Case2)

	Transient	Load No.	Occurrence	Temp. (°F)	Thermal Stratification [1)] (°F)	Pressure (psi)	Case2		Load Group
							ΔT1 (°F)	ΔT2 (°F)	

Table A2-2 (2/9) Level A,B Fatigue Analysis Input (Case2)

	Transient	Load No.	Occurrence	Temp. (°F)	Thermal Stratification [1)] (°F)	Pressure (psi)	Case2		Load Group
							ΔT1 (°F)	ΔT2 (°F)	

Table A2-2 (3/9) Level A,B Fatigue Analysis Input (Case2)

	Transient	Load No.	Occurrence	Temp. (°F)	Thermal Stratification 1) (°F)	Pressure (psi)	Case2		Load Group
							ΔT1 (°F)	ΔT2 (°F)	
	[redacted]								

Table A2-2 (4/9) Level A,B Fatigue Analysis Input (Case2)

	Transient	Load No.	Occurrence	Temp. (°F)	Thermal Stratification [1] (°F)	Pressure (psi)	Case2		Load Group
							ΔT1 (°F)	ΔT2 (°F)	

Table A2-2 (5/9) Level A,B Fatigue Analysis Input (Case2)

	Transient	Load No.	Occurrence	Temp. (°F)	Thermal Stratification 1) (°F)	Pressure (psi)	Case2		Load Group
							ΔT1 (°F)	ΔT2 (°F)	

Table A2-2 (6/9) Level A,B Fatigue Analysis Input (Case2)

	Transient	Load No.	Occurrence	Temp. (°F)	Thermal Stratification 1) (°F)	Pressure (psi)	Case2		Load Group
							ΔT1 (°F)	ΔT2 (°F)	

Table A2-2 (7/9) Level A,B Fatigue Analysis Input (Case2)

	Transient	Load No.	Occurrence	Temp. (^oF)	Thermal Stratification 1) (^oF)	Pressure (psi)	Case2		Load Group
							ΔT1 (^oF)	ΔT2 (^oF)	

Table A2-2 (8/9) Level A,B Fatigue Analysis Input (Case2)

	Transient	Load No.	Occurrence	Temp. (°F)	Thermal Stratification [1)] (°F)	Pressure (psi)	Case2		Load Group
							ΔT1 (°F)	ΔT2 (°F)	

Table A2-2 (9/9) Level A,B Fatigue Analysis Input (Case2)

	Transient	Load No.	Occurrence	Temp. (°F)	Thermal Stratification [1] (°F)	Pressure (psi)	Case2		Load Group
							ΔT1 (°F)	ΔT2 (°F)	

Table A2-3 Level A,B Fatigue Analysis Input (Case3)

	Transient	Load No.	Occurrence	Temp. (^oF)	Thermal Stratification 1) (^oF)	Pressure (psi)	Case3		Load Group
							ΔT1 (^oF)	ΔT2 (^oF)	

Table A2-4 Level A,B Fatigue Analysis Input (Case4)

	Transient	Load No.	Occurrence	Temp. (°F)	Thermal Stratification [1] (°F)	Pressure (psi)	Case4		Load Group
							ΔT1 (°F)	ΔT2 (°F)	
[redacted]									