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

Non-Proprietary Version

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Revision History

Revision	Page	Description
0	All	Original Issue
1	1-1	Changed sentence.
	1-2	Changed Figure 1.0-1 by having added thermal element(TE).
	2-1	Changed results reflecting re-calculation.
	6-1	Added stress limit “S_m”.
	7-1	Revised revision number of document.
	8-2	Changed description of Design Basis Pipe Break Loads.
	9-4	Delete the first five lines
	9-7 to 9-10	Changed sentence for explanation of Mi
	11-2	Changed results reflecting re-calculation.
	12-1	Revised revision number of document.
	A1-3	Changed schematic diagram by having added thermal element(TE).
	A1-4	Changed piping isometrics reflecting analysis model modification.
	A1-5	Corrected mass of supports.
		Changed name & type of supports.
	A1-6	Changed point number.
		Changed support stiffness.
		Changed supprt direction.
	A1-7 to A1-15	Changed thermal displacement.
	A1-21	Changed schematic diagram by having added thermal element(TE).

Revision History (Contd.)

1	A1-22	Changed schematic diagram by having added thermal element(TE).
	A1-35 to A1-37	Changed point number.
	A1-41	Changed analysis model.
	A1-42 to A1-45	Changed result of eigenvalue analysis reflecting re-calculation.
	A1-46 to A1-48	Changed mode shape reflecting re-calculation.
	A1-57	Changed Figure by having added thermal element(TE).
	A1-58	Changed stress analysis results reflecting re-calculation.
	A2-11	Changed LBB evaluation results reflecting re-calculation.

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Abstract

This report provides a summary of the stress analyses results of Pressurizer Surge Line in accordance with MHI's commitment letter (Reference 10) concerning the content of the Technical Report.

From the results summarized in this report and a review of the component design drawings, it is concluded that the US-APWR Pressurizer Surge Line satisfies all of the requirements of the Design Specification (Reference 1) for structural integrity, operability, and safety.

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List of Acronyms

The following list defines the acronyms used in this document.

ABS	Absolute Sum
APWR	Advanced Pressurized-Water Reactor
ASME	American Society of Mechanical Engineers
BAC	Bounding Analysis Curve
DBPB	Design Basis Pipe Break
FRS	Floor Response Spectrum
IC	Inner Concrete
ISM	Independent Support Motion
LBB	Leak-Before-Break
LOCA	Loss-of-Coolant Accident
LOF	Left-out-Force
MCP	Main Coolant Pipe
MS	Main Steam
NPS	Nominal Pipe Size
N/A	Not Applicable
OBE	Operating Basis Earthquake
PZR	Pressurizer
RCL	Reactor Coolant Loop
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
SAM	Seismic Anchor Motion
SI	Safety Injection
SG	Steam Generator
SRSS	Square Root Sum of the Squares
SSE	Safe-Shutdown Earthquake
UF	Usage Factor

1.0 INTRODUCTION

This Stress Analysis Technical Report is a non-certified version of the ASME Design Report for the US-APWR Pressurizer Surge Line that has been prepared to support the US-APWR DCD Review. The content of this report follows the ASME guidelines for Design Reports (Section III Division 1 Appendix C) (Reference 5).

Design loads (pressure, deadweight and seismic inertia loads including loads associated with thermal expansion anchor motion and Seismic Anchor Motion (SAM),etc) used for pipe stress analysis were computed based on the conditions specified in the Design Specification (Reference 1). As for the thermal stratification described in NRC Bulletin 88-11, structural analysis was carried out by setting the thermal stratification profile based on the thermal flow analysis results.

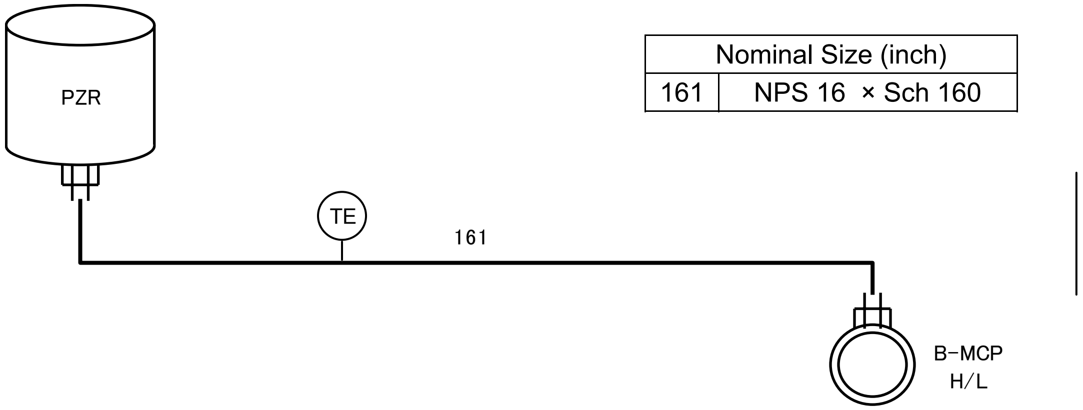
This Technical Report meets the requirements of the ASME Code Section III Division 1 NCA-3551.1 (Reference 5) by providing a summary of results and conclusions based upon detailed analyses that demonstrate the validity of the Pressurizer Surge Line to meet the requirements of the Design Specification (Reference 1).

For the design of Class 1 piping (i.e. NB-3600), the 1992 Edition including the 1992 Addenda of ASME Section III was used as required by 10CFR50.55a (b) (1) (iii).

The scope of this Stress Analysis Report is the piping system of Pressurizer Surge Line whose boundary is identified in Figures 1.0-1. The selection of Pressurizer Surge Line is consistent with MHI’s updated PSC design completion plan (Reference 10).

For Pressurizer Surge Line, The Scope of the Report provides the following:

- A Summary of the Specification
- The Loads and Load Combinations
- The structural model of the piping including supports
- The results of the piping analysis in accordance with the piping Design Specification (Reference 1)
- A review of the calculated stresses including effects of stress intensification, demonstration of ASME III acceptability, and LBB applicability checks



Nominal Size (inch)	
161	NPS 16 × Sch 160

Figure 1.0-1 RC01 : Pressurizer surge line

2.0 SUMMARY OF RESULTS

The structural analysis results for Pressurizer Surge Line are summarized in Section 11 and Appendix-1, 2. The most limiting results are listed in Table 2.0-1 below.

Table 2.0-1 Summary of Most Limiting Results

Evaluated Part	Max Stress / Allowable Ratio	Highest Fatigue Usage Factor	LBB Evaluation
RC01 Pressurizer Surge Line	[		]

3.0 CONCLUSIONS

The US-APWR Pressurizer Surge Line was designed to the requirements of the ASME Boiler and Pressure Vessel Code, 1992 Edition including the 1992 Addenda for the Design, Service Loadings, Operating Conditions, and Test Conditions as specified in the Design Specification (Reference 1).

Based on the results summarized in this report, it is concluded that the US-APWR Pressurizer Surge Line satisfy all of the requirements of the Design Specification (Reference 1) for structural integrity, operability, and safety, and it is confirmed that pressurizer surge line satisfies the LBB criteria using Bounding Analysis Curves (BACs) as described in Appendix 2.

4.0 NOMENCLATURE

Table 4.0-1 Symbol and Definition

Symbol	Unit	Definition
S_m	psi	Design Stress Intensity
S_y	psi	Yield Stress
S_c	psi	Allowable Stress at minimum (cold) temperature
S_h	psi	Allowable Stress at maximum (hot) temperature
S_A	psi	Allowable Stress Range for Expansion Stress
DL	-	Dead Load (The dead weight consists of the weight of the piping, insulation, and other loads permanently imposed upon the piping)
P	-	Design Pressure
P_R	-	Range of Service Pressure
P_M	-	Maximum Service Pressure
TH_{MTL}	-	ASME Service Level A (Normal) and Service Level B (Upset) Miscellaneous Thermal Loads with Thermal Stratification and Thermal Cycling Effects
TH_{DISCON}	-	Thermal Discontinuity Loads
TH_{GRAD}	-	Thermal Radial Gradient Loads
L_{DM}	-	Design Mechanical Loads
L_{DFN}	-	ASME Service Level A (Normal) Dynamic Fluid Loads associated with hydraulic transients such as relief/safety valve opening or water/steam hammer
L_{DFU}	-	ASME Service Level B (Upset) Dynamic Fluid Loads associated with hydraulic transients such as relief/safety valve opening or water/steam hammer
L_{DFE}	-	ASME Service Level C (Emergency) Dynamic Fluid Loads associated with hydraulic transients such as relief/safety valve opening or water/steam hammer
L_{DFF}	-	ASME Service Level D (Faulted) Dynamic Fluid Loads associated with hydraulic transients such as relief/safety valve opening or water/steam hammer
1/3 SSE	-	Design Condition & Level B Service Loading Earthquake (i.e. OBE)
SSEI	-	Safe-Shutdown Earthquake Inertia Loads
SSEA	-	Safe-Shutdown Earthquake Anchor Loads
BS	-	Building Settlement
DBPB	-	Design Basis Pipe Breaks, including LOCA and non-LOCA
LOCA	-	Loss-of-Coolant Accident

5.0 ASSUMPTIONS AND OPEN ITEMS

5.1 ASSUMPTIONS

The basic modeling assumptions derived from the detailed analyses are as follows:

1. Because the rigidity of supports has not been set by the procurer, the value was set on the basis of a trial design that was consistent with the earlier PWR plant.
2. Because the locations of girth butt welds along straight pipes are to be determined in the detail design phase, local stress indices of girth butt welds are considered in both ends of each bend pipe. If the straight pipe length between a bend pipe and other bend pipe is short enough to manufacture the straight pipe and the bend pipe without welding, the local stress indices at the end of the short straight pipe side of the bend pipe may not be considered.

5.2 OPEN ITEMS

There are no open items in this Technical Report.

6.0 ACCEPTANCE CRITERIA

The stress limits acceptance criteria for class 1 piping are specified in NB-3650 of ASME Section III. Table 6.0-1 lists the stress limits for Pressurizer Surge Line.

Table 6.0-1 Pressurizer Surge Line Stress Limits

Condition	Service Level	Category	Loading	Equation (NB-3650)$^{(4)}$	Stress Limit$^{(4)}$
Design	-	Primary Stress	P, DL, L_{DM} (including L_{DFN})	Eq. 9 NB-3652	1.5 S_m
Normal /Upset	A/B	Primary + Secondary Stress Intensity Range (SIR)	$^{(3)}$ P_R, TH_{MTL}, TH_{DISCON}, L_{DFN}, L_{DFU}, $SSEI$, $SSEA$	Eq. 10 NB-3653.1	3 S_m
		Peak SIR	P_R, TH_{MTL}, TH_{DISCON}, TH_{GRAD}, L_{DFN}, L_{DFU}, $SSEI$, $SSEA$	Eq. 11 NB-3653.2	
		Thermal Bending SIR	$^{(2)}$ TH_{MTL}	Eq. 12 NB-3653.6(a)	3 S_m
		Primary + Secondary Membrane + Bending SIR	$^{(2)}$ P_R, TH_{DISCON}, L_{DFN}, L_{DFU}, $SSEI$, $SSEA$	Eq. 13 NB-3653.6(b)	3 S_m
		Alternating Stress Intensity (Fatigue)	P_R, TH_{MTL}, TH_{DISCON}, TH_{GRAD}, L_{DFN}, L_{DFU}, $SSEI$, $SSEA$	NB-3653.3 NB-3653.4 NB-3653.5 NB-3653.6(c)	
		Thermal Stress Ratchet	TH_{GRAD} (linear)	NB3653.7	
Upset	B	Permissible Pressure	P_M	NB-3654.1	1.1 Pa
		Primary Stress	P_M, DL, L_{DFU}	NB-3654.2	Min(1.8 S_m,1.5 S_y)
Emergency	C	Permissible Pressure	P_M	NB-3655.1	1.5 Pa
		Primary Stress	P_M, DL, L_{DFE}	NB-3655.2	Min(2.25 S_m,1.8 S_y)
Faulted	D	Permissible Pressure	P_M	NB-3656(b)	2 Pa
		Primary Stress	P_M, DL, $L_{DFF}^{(1)}$, $SSEI$, $DBPB^{(1)}$	NB-3656(a) NB-3656(b)	Appendix-F or Min(3 S_m,2 S_y)
Faulted	D	Secondary Stress	$SSEA$	$^{(5)}$	6 S_m , $S_m^{(5)}$

Notes:

1. Dynamic loads are to be combined considering timing and causal relationships. SSE and DBPB are combined

using the SRSS method.

2. The Thermal and Primary plus Secondary Membrane plus Bending Stress Intensity Ranges (Equations 12 and 13) need only be calculated for those load sets that do not meet the Primary plus Secondary Stress Intensity Range (Equation 10) allowable.
3. The earthquake inertial and anchor movement loads used in the Level B Stress Intensity Range and Alternating Stress calculations (Equations 10, 11, 13 and 14) is taken as 1/3 of the peak SSE inertial and anchor movement loads or as the peak SSE inertial and anchor movement loads. If the earthquake loads are taken as 1/3 of the peak SSE loads then the number of cycles to be considered for earthquake loading is to be 300 as derived in accordance with Appendix D of Institute of Electrical and Electronic Engineers Standard 344-2004 (Reference 6) If the earthquake loads are taken as the peak SSE loads then 20 cycles of earthquake loading is considered. Also, see Note 2.
4. ASME Boiler and Pressure Vessel Code, Section III (Reference 7).
5. $$\frac{C_2 D_o M_{AM}}{2I} \leq 6.0S_m \text{ and } \frac{F_{AM}}{A_M} \leq S_m$$

where

D_o = Pipe Outer Diameter
I = Pipe Moment of Inertia
A_M = Area of cross-section of the pipe
M_{AM} = Range of resultant moment due to *SSEA*
F_{AM} = Amplitude of longitudinal force due to *SSEA*
S_m = Allowable design stress intensity value

The use of $6S_m$ limit assumes elastic behavior of the entire piping system. In the case of unbalanced systems, the design is modified to eliminate unbalance or the piping is qualified by using an allowable limit of $3S_m$.

7.0 DESIGN INPUT

The piping was designed based on the design inputs described in the Design Specification (Reference 1) and the documents listed as follows:

1. N0-CF00004 Revision 3 “Piping Design Criteria” (Reference 2)
2. N0-GB00005 Revision 5 ”Input Package of Stress Analysis of Pressurizer Surge Line and Main Steam Piping” (Reference 3)
3. N0-EE12001 Revision 4 ” Class 1 Equipment Design Transients” (Reference 4)

8.0 LOAD AND LOAD COMBINATIONS

8.1 LOADINGS

8.1.1 Design Temperature and Design Pressure

Pressurizer Surge Line Design Temperature and Design Pressure are as shown in Table 8.1-1.

Table 8.1-1 Design Temperature and Design Pressure

Design Temperature (°F)	Design Pressure (psi)
680	2485

8.1.2 Sustained Loads

The weight of the piping system, its contents, any insulation, and any other sustained loads identified in the Design Specification (Reference 1) were considered in the piping analysis. The mass contributed by the support was included in the analysis when it was greater than 10% of the total mass of the adjacent pipe span.

8.1.3 Thermal Expansion Loads

The effect of linear thermal expansion range during various operating modes was considered along with thermal movement of terminal equipment nozzles, anchors, or restraints (thermal anchor movements) corresponding to the operating modes. The stress free temperature was taken as 70°F.

8.1.4 Thermal Stratification Loads

The thermal stratification stress was generated by assuming thermal stratification of the pipe fluid and switching from out-surge to in-surge or from in-surge to out-surge.

At the normal condition, thermal stratification does not occur with an initial condition of an 8 gpm out-surge.

When the transient starts with an out-surge condition, thermal stratification will not occur. When the transient starts with an in-surge condition, the thermal stratification will be formed by shifting from the initial condition of an 8 gpm out-surge to in-surge.

When the transient ceases with an in-surge condition, thermal stratification will be formed by shifting to the normal condition of the 8 gpm out-surge. When the transient ceases with an out-surge condition, thermal stratification will not be formed because the out-surge condition is maintained.

The profile of the thermal stratification used in the analysis is shown in Figure 8.1-1.

Figure 8.1-1 Thermal Stratification Profile

8.1.5 Earthquake Loads

The effects of inertial loads and anchor movements due to an SSE are considered as Service Level D loads in the design of piping. Fatigue effects due to earthquake loads are discussed in Section 9.5.

8.1.6 Design Basis Pipe Break Loads

US-APWR has applied the leak-before-break (LBB) methodology. As a result, dynamic evaluations of main coolant piping (MCP) break, surge line break, accumulator line break and main steam line break at the inside CV were eliminated. The postulated pipe break events that were evaluated for the reactor coolant system are as follows.

- Hot Leg Branch Line break at the 10 inch Schedule 160 Residual Heat Removal (RHR)/ Safety Injection (SI) line nozzle
- Cold Leg Branch line break at the 8 inch Schedule 160 RHR return line nozzle
- Feedwater Line break at the SG FW nozzle
- Main Steam Line break at the outside CV

Pressurizer Surge Line must be protected against mechanical loads due to a LOCA or secondary side pipe rupture (MS line break and FW line break).

a. Pressurizer Surge Line must be protected against RCL Branch Line pipe rupture if Pressurizer Surge Line is in the intact loop.

b. Pressurizer Surge Line must be protected against secondary side pipe rupture.

8.1.7 Design Transients

The design transient conditions for Pressurizer surge line are presented in the tables 8.1-2.

Table 8.1-2 Pressurizer surge line design transients (1/3)

Level A

Mark	Transient	Occurrence	Reference		Remark
			Document	Fig. or Table	
I-a	Plant heat-up (100F/h)	120	Ref. 4	Fig. I-1	
I-b-1	Plant cooldown (200F/h, 2235～400psig)	120		Fig. I-2	
I-b-2	Plant cooldown (200F/h, lower than 400psig)	120		Fig. I-2	
I-c-1	Ramp load increase between 15% and 100% of full power (5% of full power per minute)	600		Fig. I-3	
I-c-2	Ramp load increase between 50% and 100% of full power (5% of full power per minute)	19, 200		Fig. I-4	
I-d-1	Ramp load decrease between 15% and 100% of full power (5% of full power per minute)	600		Fig. I-5	
I-d-2	Ramp load decrease between 50% and 100% of full power (5% of full power per minute)	19, 200		Fig. I-6	
I-e	Step load increase of 10% of full power	600		Fig. I-7	
I-f	Step load decrease of 10% of full power	600		Fig. I-8	
I-g	Large step load decrease with turbine bypass	60		Fig. I-9	
I-h	Steady-state fluctuation and load regulation i) Steady-state fluctuation	1×10^{6}		—	P_p±50psi, Tp±3.1F
	ii) Load regulation	1.6×10^{6}		Table 4	
I-i	Main feedwater cycling	2, 100		Fig. I-10	
I-j	Refueling	60		Fig. I-11	Water is replaced in 10 minutes.
I-k	Ramp load increase between 0% and 15% of full power	600		Fig. I-12	
I-l	Ramp load decrease between 0% and 15% of full power	600		Fig. I-13	
I-m	RCP startup	3, 000		Fig. I-14	
I-n	RCP shutdown	3, 000		Fig. I-15	
I-o	Core lifetime extension	60		Fig. I-16	
I-p	Primary leakage test	120		Fig. I-17	
I-q	Turbine roll test	10		Fig, I-18	
I-r	Boron concentration equalization	39, 600		—	P_p+25psi, Tp+1.4F,-0F

Table 8.1-2 Pressurizer surge line design transients (2/3)

Level B						
Mark	Transient		Occurrence	Reference		Remark
				Document	Fig. or Table	
II-a	Loss of load		60	Ref. 4	Fig. II-1	
II-b	Loss of offsite power		60		Fig. II-2	
II-c	Partial loss of reactor coolant flow		30		Fig. II-3	
II-d	Reactor trip from full power	i) With no inadvertent cooldown	60		Fig. II-4	
		ii) With cooldown and no safety injection	30		Fig. II-5	Including the transient of Excessive feedwater flow
		iii) With cooldown and safety injection	10		Fig. II-6	
II-e	Inadvertent RCS depressurization	i) Umbrella case	30		Fig. II-7	
		ii) Inadvertent auxiliary spray	15		Fig. II-12	
II-f	Control rod drop		30		Fig. II-8	
II-g	Inadvertent safeguards actuation		30		Fig. II-9	
II-h	Emergency feedwater cycling		700		Fig. II-10	
II-i	Cold over-pressure		30		Fig. II-11	
II-j	Excessive feedwater flow		—		—	Be covered with the transient of Reactor trip from full power ii)
II-k	Loss of offsite power with natural circulation cooldown		—		—	Be covered with the transient of Plant cooldown
II-l	Partial loss of emergency feedwater		30		—	Please use the figure of the transient of Loss of offsite power.
II-m	Safe shutdown		—		—	Be covered with the transient of Plant cooldown

Table 8.1-2 Pressurizer surge line design transients (3/3)

Mark	Transient	Occurrence	Reference		Remark
			Document	Fig. or Table	
Level C					
III-a	Small loss of coolant accident	5	Ref. 4	Fig. III-1	
III-b	Small steam line break	5		Fig. III-2	
III-c	Complete loss of flow	5		Fig. III-3	
III-d	Small feedwater line break	5		Fig. III-4	
III-e	SG tube rupture	5		Fig. III-5	
Level D					
IV-a	Large loss of coolant accident	1	Ref. 4	Fig. IV-1	
IV-b	Large steam line break	1		Fig. IV-2	
IV-c	RCP locked rotor	1		Fig. IV-3	
IV-d	Control rod ejection	1		Fig. IV-4	
IV-e	Large feedwater line break	1		Fig. IV-5	
Test					
V-a	Primary-side hydrostatic test	10	Ref. 4	—	

8.2 LOAD COMBINATIONS

The loading conditions consist of various combinations of pressure, thermal and external loads.

The loads combinations considered in the analysis are listed in the Table 8.2-1 below.

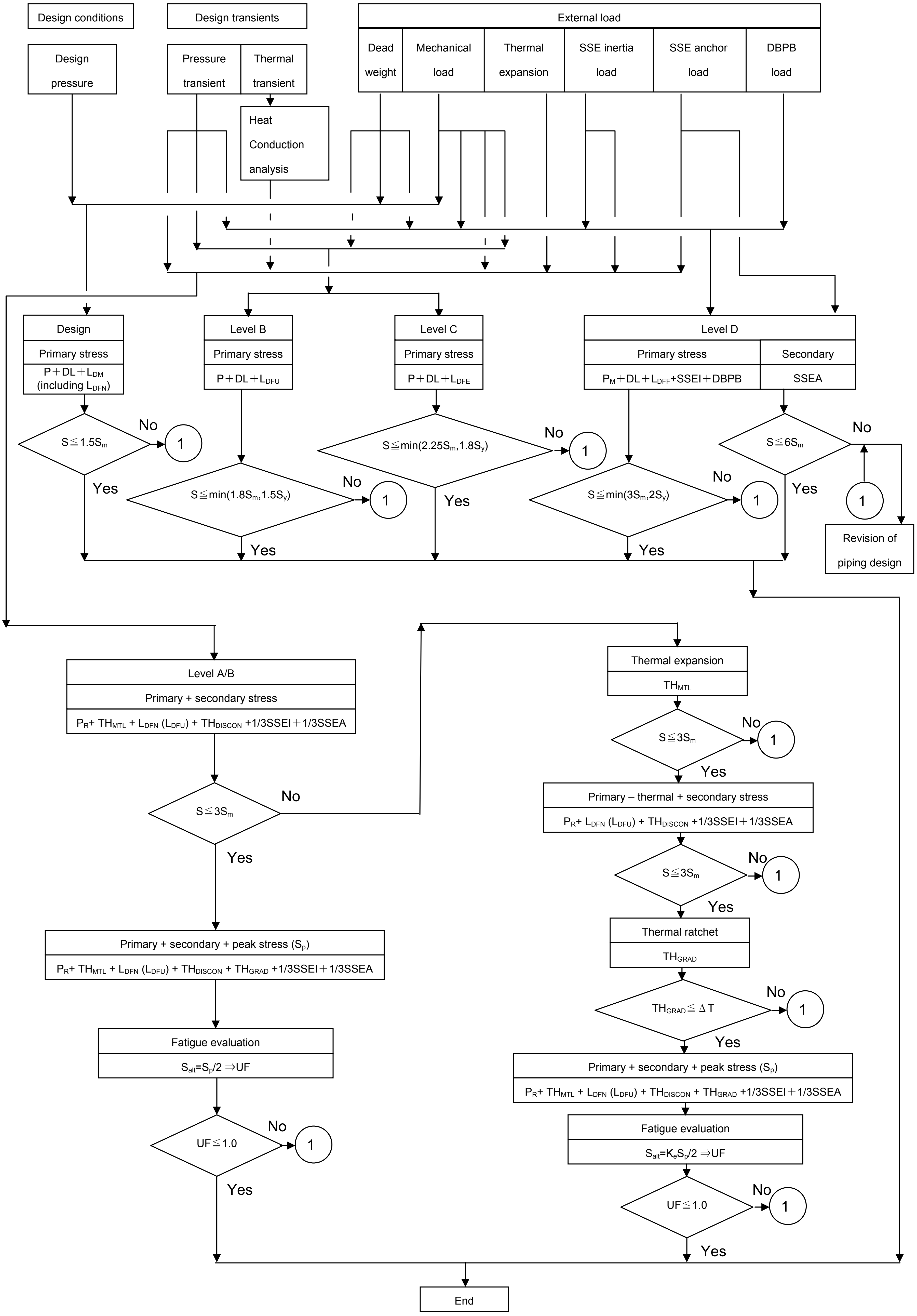
Table 8.2-1 Loadings to be considered for various Load Condition

Loading Conditions	Design	Level A/B	Level C	Level D
Design Pressure	✓			
Maximum Operating Pressure		✓	✓	✓
Dead Load	✓		✓	✓
Level A thermal, pressure transient load		✓		
Level B thermal, pressure transient load		✓		
Level C pressure transient load			✓	
Level D pressure transient load				✓
1/3 SSE Loads		✓		
SSE Loads				✓
Design Basis Pipe Break				✓

9.0 METHODOLOGY

9.1 LOGIC DIAGRAM OF EVALUATION

Pressurizer Surge Line was evaluated according to NB-3650 (Reference 7).The evaluation logic diagrams are shown in Figure 9.1-1.



Note 1: In addition to the logic diagram shown above, permissible pressure was evaluated for Levels B, C, and D.

Figure 9.1-1 Evaluation Logic Diagram

9.2 STRUCTURAL ANALYSIS

A structural analysis was performed with the following conditions according to the Piping Design Criteria (Reference 2).

9.2.1 Analysis model

For dynamic analysis, the piping system is idealized as a three dimensional space frame. The analysis model consists of a sequence of nodes connected by straight pipe elements and curved pipe elements with stiffness properties representing the piping, and other in-line components.

Piping restraints and supports are idealized as zero length springs with appropriate stiffness values for the restrained degrees of freedom.

In the dynamic mathematical model, the distributed mass of the system, including pipe, contents, and insulation weight, is represented as lumped masses located at each node, which is designated as a mass point.

The following formula is used to determine the spacing between two successive mass points. The PIPESTRESS program uses this formula for mass point spacing.

$$L = \sqrt{\left[\frac{K}{F_R}\right]\sqrt{\frac{EI}{W}}}$$

where

K = 0.743

L = Mass point spacing (ft)

F_R = Cut-off frequency (Hz)

E = Modulus of elasticity of pipe material (psi)

I = Moment of inertia of pipe cross-section (in^4)

W = Mass per unit length of piping + insulation + contents (lbm/ft)

The Pressurizer analysis model in reference 3 was coupled with the analysis model of Pressurizer Surge line.

9.2.2 Seismic Analysis Method

9.2.2.1 Damping Values

The damping value used for the SSE was generally 4%, which is consistent with Table 3 of the RG 1.61, Rev.1. In the case when Pressurizer analysis model was coupled with piping analysis model as described above, 3% damping which was used for seismic analysis of Pressurizer was conservatively used.

9.2.2.2 Combination of Modal Responses

For piping systems with no closely spaced modes, the SRSS method was applied to obtain the representative maximum response of each element, for each direction of excitation. A 10% grouping method was used for combining the responses of closely spaced modes.

9.2.2.3 High-Frequency Mode

The PIPESTRESS computer program was used for analyzing the piping systems. This program uses the LOF method to calculate the effect of the high frequency rigid modes. The results obtained were treated as an additional modal result from a non-closely spaced last mode, and were combined with other modal responses by the methods described in Subsection 9.2.2.2.

9.2.2.4 Directional Combination

The collinear responses due to each of the three spatial input components of motion were combined using the SRSS method.

9.2.2.5 Seismic Anchor Motion

The effects of differential displacements of equipment or structures to which the piping system attaches during a SSE were considered.

The analysis of these seismic anchor motions (SAMs) was performed as a static analysis with all dynamic supports active. The results of this analysis were combined with the piping system seismic inertia analysis results by absolute summation.

Where supports were located within a single structure, the seismic motions were considered to be in-phase and the relative displacement between the support locations was considered in the analysis. Where supports were located within different structures, the seismic motions at these locations were assumed to move 180 degrees out-of-phase while performing the analysis.

9.2.2.6 Independent Support Motion Method

ISM method was applied to the seismic analysis model of Pressurizer Surge line, because they were supported by multiple support structures, at multiple levels within a structure, or connected to RCL nozzles.

The supports were divided into support groups. Each support group was made up of supports that had similar time-history input. The responses caused by each support group were combined by the ABS method.

9.2.3 Design Basis Pipe Break Analysis Method

Pressurizer Surge Line must be protected against mechanical loads due to the RCL branch line and secondary side pipe rupture as described in section 8.1.6. In these cases, Pressurizer Surge Line is vibrated by the anchor movements of the RCL nozzle. Therefore, Pressurizer Surge Line response is calculated based on the response spectra of RCL nozzle in these pipe rupture condition using ISM method. The supports were divided into two support groups. For one group, RCL nozzle, response spectra was generated from time history of RCL nozzle vibration. For another support group, other than RCL nozzle, 0 amplitude acceleration was assumed. Static analyses were also performed to evaluate the effects of differential displacements of RCL nozzle.

9.3 THERMAL STRESS ANALYSIS

A heat conduction analysis was performed to obtain the piping temperature distribution during a thermal transient. For heat conduction analysis, the ABAQUS (Reference 9) general finite element method program was used.

In the heat conduction analysis, the temperature distribution was obtained in the piping plate thickness direction during the transient. The temperature differences of the inner and outer pipe surfaces, ΔT1 and ΔT2, were computed using our independently developed P4TEDIA program (see section 10).

The heat transfer coefficient used was the value obtained from the equation, described below (Gnielinski's equation), for turbulent flow within a cylindrical pipe. The outer surface of the piping was considered as a heat-retaining insulator.

$$Nu = \frac{(f/2)(Re - 1000)Pr}{1 + 12.7(f/2)^{1/2}(Pr^{2/3} - 1)}$$

$$0.5 \le Pr \le 2000$$

$$2300 \le Re \le 5 \times 10^6$$

$$1/f^{0.5} = 1.5635\ell n(Re/7) \qquad (4 \times 10^3 \le Re \le 1 \times 10^7)$$

$$\alpha = Nu \cdot \lambda / d$$

$$Re = u \cdot d / \nu$$

Nu : Nusselt number
Re : Reynolds number
Pr : Prandtl number
α : Heat transfer coefficient
λ : Thermal conductivity of fluid
ν : Kinematic viscosity of fluid
u : Flow velocity
d : Inner diameter of pipe

9.4 STRESS EVALUATION

Stress limits for design and service loadings are as follows.

(1) Design limit

(a) Primary stress evaluation (eq.9)

$$B_1 \frac{PD_0}{2t} + B_2 \frac{D_0}{2I} M_i \leq 1.5 S_m$$

B_1, B_2: Stress indices
P: Design pressure
D_0: Outside diameter
t: Wall thickness
I: Moment of inertia
M_i: Dead weight

(2) Level A/B service limits

(a) primary plus secondary stress evaluation (eq.10)

$$S_n = C_1 \frac{P_0 D_0}{2t} + C_2 \frac{D_0}{2I} M_i + C_3 E\alpha \left| T_a - T_b \right| \leq 3 S_m$$

C_1, C_2: Stress indices
P_0: Pressure range
M_i: Moment ranges for following loads. Thermal expansion, Thermal stratification, seismic inertia load (1/3SSE), seismic anchor load (1/3SSE)
E: modulus of elasticity (room temperature)
α: Coefficient of thermal expansion (room temperature)
Ta-Tb: Structural discontinuity temperature difference range

(b) Primary plus secondary plus peak stress evaluation (Eq.11)

$$S_p = K_1 C_1 \frac{P_0 D_0}{2t} + K_2 C_2 \frac{D_0}{2I} M_i + \frac{1}{2(1-\nu)} K_3 E\alpha \left| \Delta T_1 \right| + K_3 C_3 E\alpha \left| T_a - T_b \right| + \frac{1}{1-\nu} E\alpha \left| \Delta T_2 \right|$$

K_1, K_2, K_3: Stress indices
ΔT_1:Absolute value of the range of the temperature difference between the temperature of the outside T_0 and the temperature of the inside surface T_1 of the piping product assuming moment generating equivalent linear temperature distribution
ΔT_2: Absolute value of the range for that portion of the nonlinear thermal gradient through the wall thickness not included in ΔT_1.
v: Poisson's ratio (=0.3)

Sp is computed to obtain the stress intensity Salt for the fatigue analysis described later. Sp does not have any allowable stress.

(c) Fatigue evaluation

For $S_n \leq 3S_m$

$$S_{alt} = \frac{S_p}{2},$$

$$UF \leq 1.0$$

(d) Simplified elastic-plastic discontinuity analysis

For $S_n > 3S_m$

1)

$$S_e = C_2 \frac{D_0}{2I} M_i^{*} \leq 3S_m \quad \text{(eq.12)}$$

M^*_i: Thermal expansion (including anchor movements) moment range

2)

$$C_1 \frac{P_0 D_0}{2t} + C_2 \frac{D_0}{2I} M_i + C_3' E\alpha \left| T_a - T_b \right| \leq 3S_m \quad \text{(eq.13)}$$

M_i: Moment ranges for following loads, seismic inertial load (1/3SSE), seismic anchor load (1/3SSE)

C_3': Stress index

3) Fatigue Evaluation

$$S_{alt} = K_e \frac{S_p}{2} \quad \text{(eq.14)}$$

$$UF \leq 1.0$$

where

$$K_e = 1.0 \quad \cdots \; S_n \leqq 3S_m$$

$$K_e = 1.0 + \frac{1-n}{n(m-1)} \left(\frac{S_n}{3S_m} - 1 \right) \quad \cdots \; 3S_m < S_n < 3mS_m$$

$$K_e = \frac{1}{n} \quad \cdots \; S_n \geqq 3mS_m$$

$n=0.3$, $m=1.7$ ･･･ for austenitic stainless steel

4)

$$\Delta T_1 range \leq_e \frac{y'S_y}{0.7E\alpha}C_4$$

x	0.3	0.5	0.7	0.8
y´	3.33	2.00	1.20	0.80

$$x = \frac{PD_0}{2t}\frac{1}{S_y}$$

P: maximum pressure for the set of conditions under consideration
C4: 1.3 (austenitic stainless steel)
Sy: Yield point at the average fluid temperature of the load set

(3) Level B service limits

(a) Permissible pressure

$$P_M \leq 1.1P_a$$

$$P_a = \frac{2S_m t}{D_0 - 2yt}$$

P_m: maximum pressure for Level B
y:0.4

(b) Primary stress evaluation (eq.9)

$$B_1\frac{PD_0}{2t} + B_2\frac{D_0}{2I}M_i \leq \min(1.8S_m, 1.5S_y)$$

P: Maximum pressure for Level B
M_i: Moment amplitude for dead weight

(4) Level C service limits

(a) Permissible pressure

$$P_M \leq 1.5P_a$$

$$P_a = \frac{2S_m t}{D_0 - 2yt}$$

P_m: maximum pressure for Level C
y:0.4

(b) Primary stress evaluation (eq.9)

$$B_1\frac{PD_0}{2t} + B_2\frac{D_0}{2I}M_i \leq \min(2.25S_m, 1.8S_y)$$

P: Level C maximum pressure

M_i: Moment amplitude for dead weight

(5) Level D service limits

(a) Permissible pressure

$$P_M \leq 2.0P_a$$

$$P_a = \frac{2S_m t}{D_0 - 2yt}$$

P_m: maximum pressure for Level D
y:0.4

(b) Primary stress evaluation (eq.9)

$$B_1 \frac{PD_0}{2t} + B_2 \frac{D_0}{2I} M_i \leq \min(3S_m, 2S_y)$$

P: maximum pressure for Level D
M_i: Moment amplitude for following loads. Dead weight, SSE seismic inertia load, DBPB load
Note that the SSE seismic inertia load and DBPB load were combined using the SRSS method.

(c) Secondary stress evaluation

$$\frac{C_2 D_0 M_{AM}}{2I} \leq 6.0S_m$$

$$\frac{F_{AM}}{A_M} \leq S_m$$

M_{AM}: Range of resultant moment due to SSEA
F_{AM}: Amplitude of longitudinal force due to SSEA
A_M: Piping cross-sectional area

9.5 FATIGUE EVALUATION

The fatigue analysis was based on the rules of NB-3653 of ASME Section III. These rules require calculation of the total stress, including the peak stress, to determine the allowable number of stress cycles for the specified Service Loadings.

The design transients for ASME Level A and B service conditions (Table 8.1-2) were used in the evaluation of cyclic fatigue. The effect of 300 cycles of a 1/3 SSE seismic event was included in the evaluation of cyclic fatigue, treated as a Level B service condition. The number of cycles was based on equivalent fatigue usage for 20 cycles of a single SSE event.

10.0 COMPUTER PROGRAMS

The Table below provides a brief description of each of the computer programs used.

Table 10.0-1 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 ΔT1, ΔT2 and temperature difference at structural discontinuous point Ta-Tb. This program uses the thermal distribution analysis results generated by ABAQUS.
4	PICEP	06/30/87	PICEP is a program developed by the Electric Power Research Institute. This program is used for predicting leakage rate from assumed through-wall cracks in the leak-before-break evaluation of piping.

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 programs

11.0 ANALYSIS RESULTS

The calculated stress-to–allowable ratio (calculated stress divided by allowable value), the cumulative fatigue usage factor, and the thermal stress ratchet results for the most limiting locations are summarized in the Table 11.0-1. The ASME Code allowable limits were satisfied in all cases.

The detailed analysis models and results are described in the Appendix 1.

LBB evaluation was applied and it was confirmed that Pressurizer Surge Line satisfies the LBB criteria using BAC as described in Appendix 2.

Table 11.0-1 Pressurizer Surge Line Result Summary

Condition	Service Level	Category	Loading	Equation (NB-3650)	Stress Limit	Stress-to-Allowable Ratio
Design	-	Primary Stress	P, DL, L_{DM} (including L_{DFN})	Eq. 9 NB-3652	1.5 S_m	
Normal /Upset	A/B	Primary + Secondary Stress Intensity Range (SIR)	P_R, TH_{MTL}, TH_{DISCON}, L_{DFN}, L_{DFU}, $SSEI$, $SSEA$	Eq. 10 NB-3653.1	3 S_m	
		Thermal Bending SIR(1)	TH_{MTL}	Eq. 12 NB-3653.6(a)	3 S_m	
		Primary + Secondary Membrane + Bending SIR(1)	P_R, TH_{DISCON}, L_{DFN}, L_{DFU}, $SSEI$, $SSEA$	Eq. 13 NB-3653.6(b)	3 S_m	
		Alternating Stress Intensity (Fatigue)	P_R, TH_{MTL}, TH_{DISCON}, TH_{GRAD}, L_{DFN}, L_{DFU}, $SSEI$, $SSEA$	NB-3653.3 NB-3653.4 NB-3653.5 NB-3653.6(c)	Allowable Value 1	
		Thermal Stress Ratchet(1)	TH_{GRAD} (linear)	NB3653.7	Allowable Temperature	
Upset	B	Permissible Pressure	P_M	NB-3654.1	1.1 Pa	
		Primary Stress	P_M, DL, L_{DFU}	NB-3654.2	Min(1.8 S_m,1.5 S_y)	
Emergency	C	Permissible Pressure	P_M	NB-3655.1	1.5 Pa	
		Primary Stress	P_M, DL, L_{DFE}	NB-3655.2	Min(2.25 S_m,1.8 S_y)	
Faulted	D	Permissible Pressure	P_M	NB-3656(b)	2 Pa	
		Primary Stress	P_M, DL, L_{DFF} $SSEI$, $DBPB$	NB-3656(a) NB-3656(b)	Appendix-F or Min(3 S_m,2 S_y)	
Faulted	D	Secondary Stress	$SSEA$		6 S_m	

Note:
1. Evaluation performed for when Eq.10 was not satisfied.
2. Eq.10 was satisfied.

12.0 REFERENCES

1. N0-GB00002 Revision 4 “Class 1 Piping ASME Design Specification (excluding Reactor Coolant Loop Piping)”
2. N0-CF00004 Revision 3 “Piping Design Criteria”
3. N0-GB00005 Revision 5 ”Input Package of Stress Analysis of Pressurizer Surge Line and Main Steam Piping”
4. N0-EE12001 Revision 4 ”Class 1 Equipment Design Transients”
5. ASME Boiler and Pressure Vessel Code, Section II, Division 1, 2001 Edition through 2003 Addenda
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7. ASME Boiler and Pressure Vessel Code, Section III, Division 1, 1992 Edition through 1992 Addenda
8. DST Computer Services. S.A.,“PIPESTRESS User’s Manual”,Version3.6.2
9. SIMURIA,“ABAQUS Analysis User’s Manual”,Version6.7,2007
10. “Updated Design Completion Plan for US-APWR Piping Systems and Components” UAP-HF-10207, July, 2010.

Appendix 1

RC01
Pressurizer Surge Line

Piping Analysis Results

Table A1-1-1 Block division and piping specifications

Table A1-1-2 Concentrated mass

Table A1-1-3 Support point rigidity

Table A1-1-4 Level A/B thermal displacement input data (1/9) (Point: 9010)

Table A1-1-4 Level A/B thermal displacement input data (2/9) (Point: 9010)

Table A1-1-4 Level A/B thermal displacement input data (3/9) (Point: 9010)

Table A1-1-4 Level A/B thermal displacement input data (4/9) (Point: 9010)

Table A1-1-4 Level A/B thermal displacement input data (5/9) (Point: 9010)

Table A1-1-4 Level A/B thermal displacement input data (6/9) (Point: 9010)

Table A1-1-4 Level A/B thermal displacement input data (7/9) (Point: 9010)

Table A1-1-4 Level A/B thermal displacement input data (8/9) (Point: 9010)

Table A1-1-4 Level A/B thermal displacement input data (9/9) (Point: 9010)

Table A1-1-5 Level A, B temperature and pressure input data (1/6) (Section I)

Table A1-1-5 Level A, B temperature and pressure input data (2/6) (Section I)

Table A1-1-5 Level A, B temperature and pressure input data (3/6) (Section I)

Table A1-1-5 Level A, B temperature and pressure input data (4/6) (Section I)

Table A1-1-5 Level A, B temperature and pressure input data (5/6) (Section I)

Table A1-1-5 Level A, B temperature and pressure input data (6/6) (Section I)

Table A1-1-6 Level C, D maximum temperature and pressure input data

Figure A1-1-2 Seismic floor response curve (1/12)
Pressurizer Surge Line (RC01) FRS for Piping support
X(EW) direction (damping 3.0%)

Figure A1-1-2 Seismic floor response curve (2/12)
Pressurizer Surge Line (RC01) FRS for Piping support
Y (NS) direction (damping 3.0%)

Figure A1-1-2 Seismic floor response curve (3/12)
Pressurizer Surge Line (RC01) FRS for Piping support
Z (Vert.) direction (damping 3.0%)

Figure A1-1-2 Seismic floor response curve (4/12)
Pressurizer Surge Line (RC01) FRS for MCP nozzle
X (EW) direction (damping 3.0%)

Figure A1-1-2 Seismic floor response curve (5/12)
Pressurizer Surge Line (RC01) FRS for MCP nozzle
Y (NS) direction (damping 3.0%)

Figure A1-1-2 Seismic floor response curve (6/12)
Pressurizer Surge Line (RC01) FRS for MCP nozzle
Z (Vert.) direction (damping 3.0%)

Figure A1-1-2 Seismic floor response curve (7/12)
Pressurizer Surge Line (RC01) FRS for Pressurizer skirt
X (EW) direction (damping 3.0%)

Figure A1-1-2 Seismic floor response curve (8/12)
Pressurizer Surge Line (RC01) FRS for Pressurizer skirt
Y (NS) direction (damping 3.0%)

Figure A1-1-2 Seismic floor response curve (9/12)
Pressurizer Surge Line (RC01) FRS for Pressurizer skirt
Z (Vert.) direction (damping 3.0%)

Figure A1-1-2 Seismic floor response curve (10/12)
Pressurizer Surge Line (RC01) FRS for Pressurizer upper support
X (EW) direction (damping 3.0%)

Figure A1-1-2 Seismic floor response curve (11/12)
Pressurizer Surge Line (RC01) FRS for Pressurizer upper support
Y (NS) direction (damping 3.0%)

Figure A1-1-2 Seismic floor response curve (12/12)
Pressurizer Surge Line (RC01) FRS for Pressurizer upper support
Z (Vert.) direction (damping 3.0%)

Table A1-1-7 Seismic anchor displacement input data(1/3)

Table A1-1-7 Seismic anchor displacement input data(2/3)

Table A1-1-7 Seismic anchor displacement input data(3/3)

Figure A1-1-3 DBPB floor response curve (1/3)
Pressurizer Surge Line (RC01) FRS for MCP nozzle
X (EW) direction (damping 3.0%)

Figure A1-1-3 DBPB floor response curve (2/3)
Pressurizer Surge Line (RC01) FRS for MCP nozzle
Y (NS) direction (damping 3.0%)

Figure A1-1-3 DBPB floor response curve (3/3)
Pressurizer Surge Line (RC01) FRS for MCP nozzle
Z (Vert.) direction (damping 3.0%)

Figure A1-2-1 PIPESTRESS analysis model diagram

Table A1-2-1 Natural frequency analysis results (1/4)

Table A1-2-1 Natural frequency analysis results (2/4)

Table A1-2-1 Natural frequency analysis results (3/4)

Table A1-2-1 Natural frequency analysis results (4/4)

Figure A1-2-2 Frequency mode diagram (primary)

Figure A1-2-2 Frequency mode diagram (secondary)

Figure A1-2-2 Frequency mode diagram (tertiary)

Table A1-2-2 Thermal analysis results (ΔT1, ΔT2, Ta-Tb) (1/9) (Section I)

Table A1-2-2 Thermal analysis results (ΔT1, ΔT2, Ta-Tb) (2/9) (Section I)

Table A1-2-2 Thermal analysis results (ΔT1, ΔT2, Ta-Tb) (3/9) (Section I)

Table A1-2-2 Thermal analysis results (ΔT1, ΔT2, Ta-Tb) (4/9) (Section I)

Table A1-2-2 Thermal analysis results (ΔT1, ΔT2, Ta-Tb) (5/9) (Section I)

Table A1-2-2 Thermal analysis results (ΔT1, ΔT2, Ta-Tb) (6/9) (Section I)

Table A1-2-2 Thermal analysis results (ΔT1, ΔT2, Ta-Tb) (7/9) (Section I)

Table A1-2-2 Thermal analysis results (ΔT1, ΔT2, Ta-Tb) (8/9) (Section I)

Table A1-2-2 Thermal analysis results (ΔT1, ΔT2, Ta-Tb) (9/9) (Section I)

Table A1-2-3 Piping stress and fatigue evaluation results

(Piping that exceeds 1 inch NB–3650 evaluation)

Appendix 2

LEAK BEFORE BREAK EVALUATION

TABLE OF CONTENTS

A2 LEAK BEFORE BREAK EVALUATION

A2.1 Introduction

The leak-before-break (LBB) evaluation of the US-APWR follows the methodology in accordance with General Design Criteria (GDC) 4 of 10CFR50, Appendix A (Ref. 1), NUREG-0800, Standard Review Plan (SRP) 3.6.3, Rev. 1, (Ref. 2), and NUREG-1061, Volume 3 (Ref. 3). The evaluation includes an assessment of all potential failure mechanisms, and development of bounding analysis curves (BACs) that define the allowable maximum stress as a function of the normal operating stress for each piping systems or subsystem with different materials.

The LBB analysis is described in detail in Section 3.6.3 of the US-APWR Design Control Document (DCD), with details in Appendix 3B. That appendix provides the development of the BACs for the piping.

This appendix shows the LBB evaluation method and based on DCD and LBB evaluation results.

A2.2 LBB Evaluation Method

A2.2.1 Bounding analysis curve approach

Work has currently been completed to update the BAC analysis for Appendix 3B of the DCD, Rev.1. The following methods will be used for the LBB evaluation:

(1) Calculation of a leakage rate and determination of leakage flaw sizes as a function of normal operating conditions

(2) Calculation of critical flaw sizes as a function of applied stress

(3) Development of the BACs from the above

A2.2.1.1 Leak Rate Determination

The DCD described the thermal-hydraulics model used to develop the DCD curves. The fundamental equations for calculation of flow through a circumferential crack in a pipe are described. For the revised leakage rate calculations, the following revisions have been made:

(1) The EPRI-developed PICEP computer program (Ref. 4) was used to calculate leakage. PICEP incorporates the thermal-hydraulic model described in the DCD but has improved methods for calculation of the crack opening area based on the EPRI-developed methods for elastic plastic fracture mechanics (Ref. 5).

(2) For conservatism, the crack opening area was calculated without taking credit for the plastic opening. This is consistent with the approach in the DCD. In addition, the plastic zone correction factor was conservatively based on a flow stress (not yield stress) of 51 ksi (consistent with the maximum flow stress in SRP 3.6.3), minimizing

the effects of plastic zone correction on the crack opening area increase due to plasticity effects.

(3) The coefficient of discharge (C_D) was taken as 0.61. Consistent with testing conducted at the time of the PICEP development and verification that it would adequately calculate leakage, the crack roughness for assumed fatigue cracks was taken as 0.000197 inches and no turns were included. These assumptions are consistent with those made at the time that SRP 3.6.3 and NUREG-1061 Volume were published that required a factor of 10 between the calculated leakage and the plant leakage detection system to cover various uncertainties (Ref. 6).

(4) Based on a review of revisions to Regulatory Guide 1.45 (Ref. 7), it was determined that the sensitivity of the US-APWR leakage detection system can be reduced to 0.5 gpm, allowing the leakage flaw sizes to be based on a leak of 5 gpm.

A2.2.1.2 Fracture Mechanics Analysis

Because austenitic stainless steel has high fracture toughness, limit load methodology can be applied to evaluate the fracture behavior of the piping. The methods for limit load evaluation as described in SRP 3.6.3 and in the DCD are used. The flow stress used in the analysis is based on ASME Code minimum values at temperature, conservatively applying these same values for SMAW weldments, since this is less than the specified value of 51 ksi in SRP 3.6.3. Since stresses for the various loadings will be combined by absolute sum methods, the factor of safety for maximum load is 1.0, such that the critical flaw size was determined to be twice the leakage flaw size.

A2.2.1.3 Generation of BAC

The BAC methodology uses a LBB assessment diagram to show that LBB requirements are met for all weld locations in each piping system. In the BAC diagram $\sigma_{nor} = |P_m| + |P_b|$, the sum of the membrane stress and the bending stress under normal operation, is plotted along the abscissa, and $\sigma_{max} = |P_{m\_max}| + |P_{b\_max}|$, the absolute sum of the membrane stress and the bending stress under the maximum load, is plotted along the ordinate. The procedure used in developing the BAC diagram was as follows:

(1) Determine the leakage crack length for a crack with a leak rate 10 times as large as the detectable leak rate by applying the abscissa's normal stress σ_{nor}.

(2) Based on a critical crack size of twice the leakage crack length, determine the maximum stress σ_{max} that is required to produce this critical crack size.

(3) Perform the above steps at a sufficient number of points of normal operating stress to develop of smooth curve of the maximum stress σ_{max} as a function of the abscissa's normal stress σ_{nor}.

(4) For the modified BACs, the normal operating stress was varied from that due to pressure up to a limit of 50 ksi. This upper bound is arbitrary and is a stress greater than will be limited by the ASME Code stress limits for the piping that also must be satisfied.

Per the requirements in SRP 3.6.3, the maximum stress is a combination of the effects of pressure + dead weight + maximum seismic stress if the weld is TIG. If the weld is SMAW or SAW, the maximum stress is a combination of the effects of pressure + dead weight + thermal expansion + maximum seismic stress.

For the BAC curves, the membrane stresses were calculated based on the axial force divided by the metal area. For the piping evaluated in this report, the axial loads due to loads other than pressure are not significant. The axial pressure force was based on the internal pipe pressure times the internal area of the weld. For convenience, the bending stresses included in the BAC curves were based on the piping moment divided by the weld section modulus, effectively using the stress at the outside of the piping. All of the BACs were developed using the nominal thickness and diameter of the welds.

If the actual stresses in the piping system, calculated using the same methods as above, fall in the regions below the BAC, then LBB requirements are satisfied.

A2.2.2 Calculation of LBB Evaluation Points

The assessment of LBB acceptability was performed based on the calculated stresses at each weld in the piping system being evaluated. For each weld, stresses for normal operation and the maximum stress conditions were calculated from the piping stress analysis.

The stress for normal operation along the abscissa of the BAC was calculated for each weld in the piping system as follows.

1) For all types of welds, calculate the algebraic sum of the axial force, the bending and torque moment due to deadweight, the internal pressure, and the thermal expansion. Thermal expansion is always included since it will contribute to the crack opening area.

$$F = F_{DW} + F_{Th} + F_P$$

$$M = \sqrt{\left((M_X)^2 + (M_Y)^2 + (M_Z)^2\right)}$$

$$M_X = (M_X)_{DW} + (M_X)_{Th}$$

$$M_Y = (M_Y)_{DW} + (M_Y)_{Th}$$

$$M_Z = (M_Z)_{DW} + (M_Z)_{Th}$$

Where *F* = Axial force
M = Bending moment

Subscripts indicate the loads shown below
DW = Deadweight
Th = Thermal expansion

P = Internal pressure

x, y and *z* = Component of x,y and z direction.

2) Calculate the cross sectional area *A* and the section modulus *Z* assuming the minimum wall thickness.
3) Calculate the stress σ_{nor} at the evaluation point under normal operation.

$$\sigma_{nor} = P_m + P_b = F/A + M/Z$$

The maximum stress for each weld in the piping system was evaluated as follows:

1) For SMAW and SAW welds, calculate the absolute sum of the axial force, the bending and torque moment due to deadweight, the internal pressure, the thermal expansion, and earthquake using the following equations:

$$|F| = |F_{DW}| + |F_{Th}| + |F_P| + |F_{SSE}| + |F_{SAM}|$$
$$|M| = \sqrt{\left((M_X)^2 + (M_Y)^2 + (M_Z)^2\right)}$$
$$M_X = |(M_X)_{DW}| + |(M_X)_{Th}| + |(M_X)_{SSE}| + |(M_X)_{SAM}|$$
$$M_Y = |(M_Y)_{DW}| + |(M_Y)_{Th}| + |(M_Y)_{SSE}| + |(M_Y)_{SAM}|$$
$$M_Z = |(M_Z)_{DW}| + |(M_Z)_{Th}| + |(M_Z)_{SSE}| + |(M_Z)_{SAM}|$$

Where subscripts indicate the following loads.

SSE = Inertia load due to SSE

SAM = Seismic anchor motion load due to SSE.

2) If the weld is a TIG weld, the loads due to thermal expansion and seismic anchor movements may be excluded per SRP 3.6.3.

3) Calculate stress under the maximum load σ_{max} at the weld joint.

$$|\sigma_{\max}| = |P_{m\_\max}| + |P_{b\_\max}| = \left(|F|/A + |M|/Z\right)$$

The BAC assessment points were then plotted on the BAC to determine LBB acceptance. In some cases, the welds may not be acceptable if the assessment is based on the assumption of a SMAW weld joint. In this case, the weld joint can be qualified as a TIG weld, and this can be implemented in the piping system fabrication/construction on a location-unique basis.

A2.2.3 BAC for Pressurizer Surge Line LBB Evaluation

Table A2-1 lists the piping property of Pressurizer surge line selected for setting the BAC. The detailed BACs are shown in Figure A2-1. Table A2-2 is the tabulated BAC points.

A2.3 LBB Evaluation Results

The BAC assessment points for Pressurizer Surge Line is plotted based on the structural analysis results described in appendix A1.

LBB evaluation results for Pressurizer Surge Line are shown in Figure A2-2.

A2.5 References

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7. Regulatory Guide 1.45, “Guidance On Monitoring And Responding To
Reactor Coolant System Leakage.” U. S. Nuclear Regulatory Commission, May 2008.

Table A2-1 List of piping property for setting the BAC

Subsystem	OD, inches	t, inches	Material	Temp, °F (1)	Pressure, psig (1)	Axial. Stress, ksi	BAC Figure No.	BAC Table No.
Surge Line (2)	16	1.594	SA-312 TP316	653	2,248 (2)	4.017	A2-1	A2-2

Note:

1. Conditions from Reactor Coolant System DCD, Table 5.1-2
2. Used conservative lower 2243 psig for leakage which is the pressurizer end pressure.

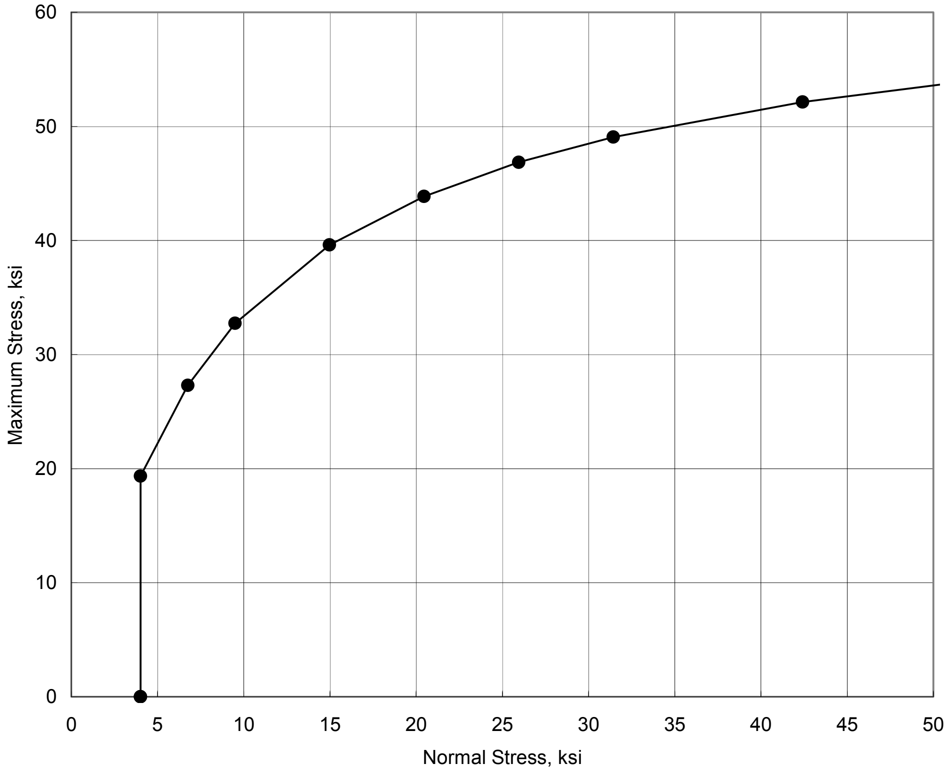

Figure A2-1 BAC for Surge Line

Table A2-2 The tabulated BAC points

Normal Stress, ksi	Maximum Stress, ksi
4.008	0
4.008	19.355
6.751	27.288
9.494	32.738
14.98	39.619
20.466	43.873
25.952	46.847
31.438	49.059
42.411	52.148
53.383	54.242

Figure A2-2 LBB evaluation results