

# Summary of Stress Analysis Results for the US-APWR Reactor Coolant Loop Piping

**Non-proprietary Version**

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**Revision History**

Revision	Page	Description
0	All	Original Issue
1	i & ii	Add the sections and change the page numbers.
	iii	Add the tables and change the page numbers.
	iv	Add the figures and change the page numbers.
	v	Add the acronyms.
	1-1	Change Figure 1-1.
	2-1	Change Table 2-1.
	4-1	Add the nomenclatures in Table 4-1.
	6-1	Add the sentences.
	6-2	Add "according to NB-3600" to the title of Table 6-1.
	6-3	Add Table 6-2.
	7-2	Add the material of nozzles in Table 7-2.
	7-2	Add the values of $S_u$ in Table 7-3.
	7-3	Change the table numbers and add the sentences.
	7-4	Change the figure number.
	7-5	Add Figure 7-1-2.
	7-6 to 7-10	Change the table numbers.
	7-11 to 7-13	Add Tables 7-5-4 to 7-5-9
	7-14	Change the 1 <sup>st</sup> paragraph.
	7-14 & 7-15	Change the table number.
	7-16	Add Table 7-6-2.
	7-17	Change the table number and title.

**Revision History (Contd.)**

Revision	Page	Description
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	8-1	Add "based on NB-3600" to the title of Section 8.2.
	8-1 & 8-2	Add Section 8.3 and change the sentences in Section 8.4.
	8-3	Change the figure title.
	8-4	Add Figure 8-2.
	9-1	Change the 1 <sup>st</sup> sentence of Section 9.0.
	9-1	Correct the typing error and add the contents to Table 9-1
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	12-1	Update the revision number of References 4 and 10.
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	3-1	Modify sentences.
	6-1	Modify sentences and remove Table 6-2.
	7-1	Change wording in Table 7-1.
	7-2	Change contents of Table 7-2 and Table 7-3.
	7-3	Modify sentences and remove Figure 7-1-2 and Tables 7-5-4 through 7-5-9.
	7-5 to 7-9	Change contents of Tables 7-5-1 through 7-5-3.

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**Revision History (Contd.)**

Revision	Page	Description
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	7-12	Modify sentences and remove Table 7-7-2.
	8-1	Remove Section 8.3 and Figure 8-2.
	9-1	Update contents of Table 9-1.
	10-1	Change sentence.
	10-3	Revise stress analysis result.
	10-4 to 10-19	Remove contents.
	11-1 & 11-2	Change Figure 11-1 through Figure 11-3.
3	12-1	Update and delete reference documents.
	2-1	Add LBB evaluation result.
	3-1	Add description of LBB evaluation result.
	11-1	Add description of LBB evaluation result.
	11-1 & 11-2	Add figures of LBB evaluation result.
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**Abstract**

This report contains a summary of the structural evaluation of the Reactor Coolant Loop (RCL) piping.

The calculations were based on the loading conditions defined in the US-APWR RCL piping Design Specification (Reference 4) and on the procedures per ASME Boiler & Pressure Vessel Code Section III (Reference 1).

The RCL piping satisfies the applicable structural limits of the 1992 Edition of Section III including the 1992 addenda.

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## List of Acronyms

The following list defines the acronyms used in this document.

BAC	Bounding Analysis Curve
FE	Finite Element
LBB	Leak Before Break
RCL	Reactor Coolant Loop
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RV	Reactor Vessel
SG	Steam Generator
SRSS	Square Root Sum of Square
SSE	Safe Shutdown Earthquake
1/3 SSE	Level B Service Loading Earthquake

## 1.0 INTRODUCTION

This Technical Report contains a summary of the stress analysis results for the US-APWR RCL piping. The content of this report follows the ASME guidelines for Design Reports (Section III Division 1 Appendix C).

The RCL piping consists of hot leg, crossover leg and cold leg as shown in Figure 1-1.

This report provides structural evaluations for the three parts of RCL piping.

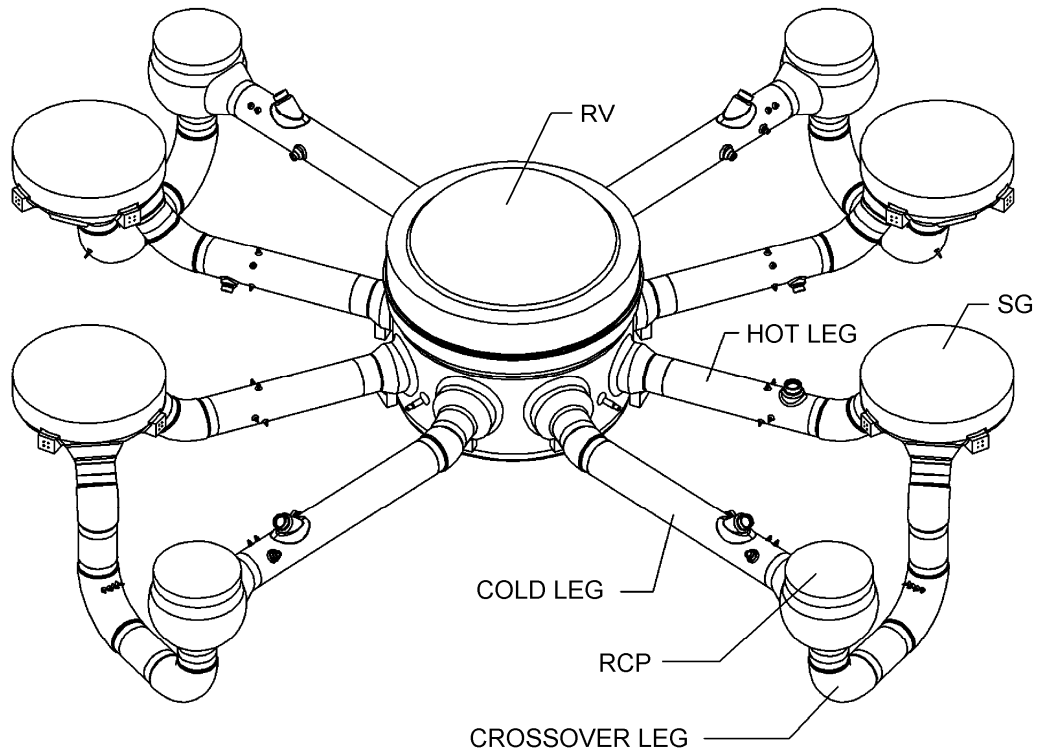


Figure 1-1 Schematic view of the RCL piping

**2.0 SUMMARY OF RESULTS**

The most limiting results of the RCL piping are listed in Table 2-1. The structural analysis results and the LBB evaluation results are summarized in Sections 10 and 11 respectively.

**Table 2-1 Summary of Most Limiting Results**

Section	Evaluated Part	Max Stress / Allowable Ratio (1)	Highest Fatigue Usage Factor (2)	LBB Evaluation
10.1 & 11	Hot Leg			
10.1 & 11	Crossover Leg			
10.1 & 11	Cold Leg			

Note 1: The max stress / allowable ratio is the ratio of the calculated stress intensity (or pressure) to the allowable stress intensity (or allowable pressure). Therefore, any ratio less than or equal to 1.0 is acceptable.

$$\text{Ratio} = \frac{\text{Calculated stress intensity (or Pressure)}}{\text{Allowable stress intensity (or Allowable pressure)}}$$

Note 2: The fatigue calculations performed in this report meet the requirement of the ASME Code of Reference. Environmental fatigue per RG 1.207 will be evaluated separately.

### **3.0 CONCLUSIONS**

The US-APWR RCL piping is designed to the requirements of the ASME Boiler and Pressure Vessel Code, 1992 Edition including the 1992 Addenda for the Design, Service Loadings and Operating Conditions as specified in the Design Specification (Reference 4).

From the results summarized in this report and a review of the piping design drawings, it is concluded that the RCL piping satisfies the requirements of the ASME Code and the LBB requirements.

#### 4.0 NOMENCLATURE

Table 4-1 Symbols and definition

Symbol	Unit	Definition
$S_m$	ksi/psi	Design stress intensity
$S_y$	ksi/psi	Yield stress
$S_u$	ksi/psi	Tensile strength
$P$	psi	Design pressure
$P_a$	psi	Maximum allowable internal pressure defined in NB-3641.1
$P_L$	ksi	General primary membrane stress
$P_b$	ksi	Primary bending stress
$Q$	ksi	Secondary stress
$C_4$	–	Constant number defined in NB-3653.7. (=1.3 for austenitic material)
$E$	psi	Modulus of elasticity
$y'$	–	Constant number defined in NB-3653.7
$\alpha$	1/°F	Coefficient of thermal expansion
$\Delta T_1$	°F	Range of temperature difference between $T_o$ and $T_i$ of the piping assuming equivalent linear temperature distribution
$T_o$	°F	Temperature of the outside surface
$T_i$	°F	Temperature of the inside surface

## **5.0 ASSUMPTIONS AND OPEN ITEMS**

### **5.1 Assumptions**

All dimensions used in the evaluation (diameter, thickness and bend radius of elbow) are nominal values.

### **5.2 Open Items**

There are no open items in this Technical Report.



## **6.0 ACCEPTANCE CRITERIA**

The RCL piping is evaluated in accordance with NB-3600.

Table 6-1 specifies the RCL piping stress limits according to NB-3600.

**Table 6-1 RCL Piping Stress Limits according to NB-3600**

Condition	Stress Category	Stress Limits	Remarks
Design	Primary Stress	$1.5 S_m$	NB-3652
Level A/B	Primary Plus Secondary Stress	$3 S_m$	NB-3653
	Usage Factor	1.0	NB-3653.5
	Thermal Bending Stress	$3 S_m$	NB-3653.6
	Primary Plus Secondary Membrane Stress Excluding Thermal Bending and Expansion Stress	$3 S_m$	NB-3653.6
	Thermal Stress Ratchet	$\Delta T_1 \text{ range} \leq y' S_y C_4 / (0.7 E \alpha)$	NB-3653.7
Level B	Permissible Pressure	$1.1 P_a$	NB-3654.1
	Primary Stress	Min ( $1.8 S_m, 1.5 S_y$ )	NB-3654.2
Level C	Permissible Pressure	$1.5 P_a$	NB-3655.1
	Primary Stress	Min ( $2.25 S_m, 1.8 S_y$ )	NB-3655.2
Level D	Permissible Pressure	$2 P_a$	NB-3656
	Primary Stress	Min ( $3 S_m, 2 S_y$ )	NB-3656

## 7.0 DESIGN INPUT

### 7.1 Geometry

The RCL piping basic drawings used to supply dimensions for the stress evaluation are listed in Table 7-1.

**Table 7-1 RCL Piping Basic Design Drawing List**

No.	Drawing Title	Reference Number
1	Reactor Coolant Loop Piping Design Drawings	N0-F700L11

## 7.2 Material

The materials for the RCL piping are listed in Table 7-2.

**Table 7-2 Materials of Construction**

Part	Material
Straight pipe	SA-336 Grade F316
Elbows	SA-336 Grade F316

The material strength properties used in the stress are obtained from ASME Section II.

**Table 7-3 Material Properties for SA-336 Grade F316**

Temperature, °F	$S_m$ , ksi	$S_y$ , ksi	$S_u$ , ksi
70	20.0	30.0	70.0
100	20.0	30.0	70.0
200	20.0	25.9	70.0
300	20.0	23.4	68.0
400	19.3	21.4	67.1
500	18.0	20.0	67.0
600	17.0	18.9	67.0
650	16.6	18.5	67.0

### 7.3 Loads, Load Combinations, and Transients

The loads, load combinations and transients are defined in the Design Specification (Reference 4). The following is a summary of those used for the RCL piping structural evaluations.

#### 7.3.1 Pressure Loads and Temperature

**Table 7-4 Pressures and Temperatures**

Parameter	Value
Design pressure	2500 psia (2485 psig)
Design temperature	650 °F
Normal operating pressure	2250 psia (2235psig)
Normal operating temperature (Hot side)	617.0 °F
Normal operating temperature (Cold side)	550.6 °F

#### 7.3.2 Mechanical Loads

Mechanical loads are dead weight, thermal expansion load, seismic load and accident load. These loads are obtained from the Design Specification (Reference 4).

Tables 7-5-1 through 7-5-3 provide the member loads of the RCL piping used in the structural evaluations and Figure 7-1-1 shows the coordinate system of the RCL piping.

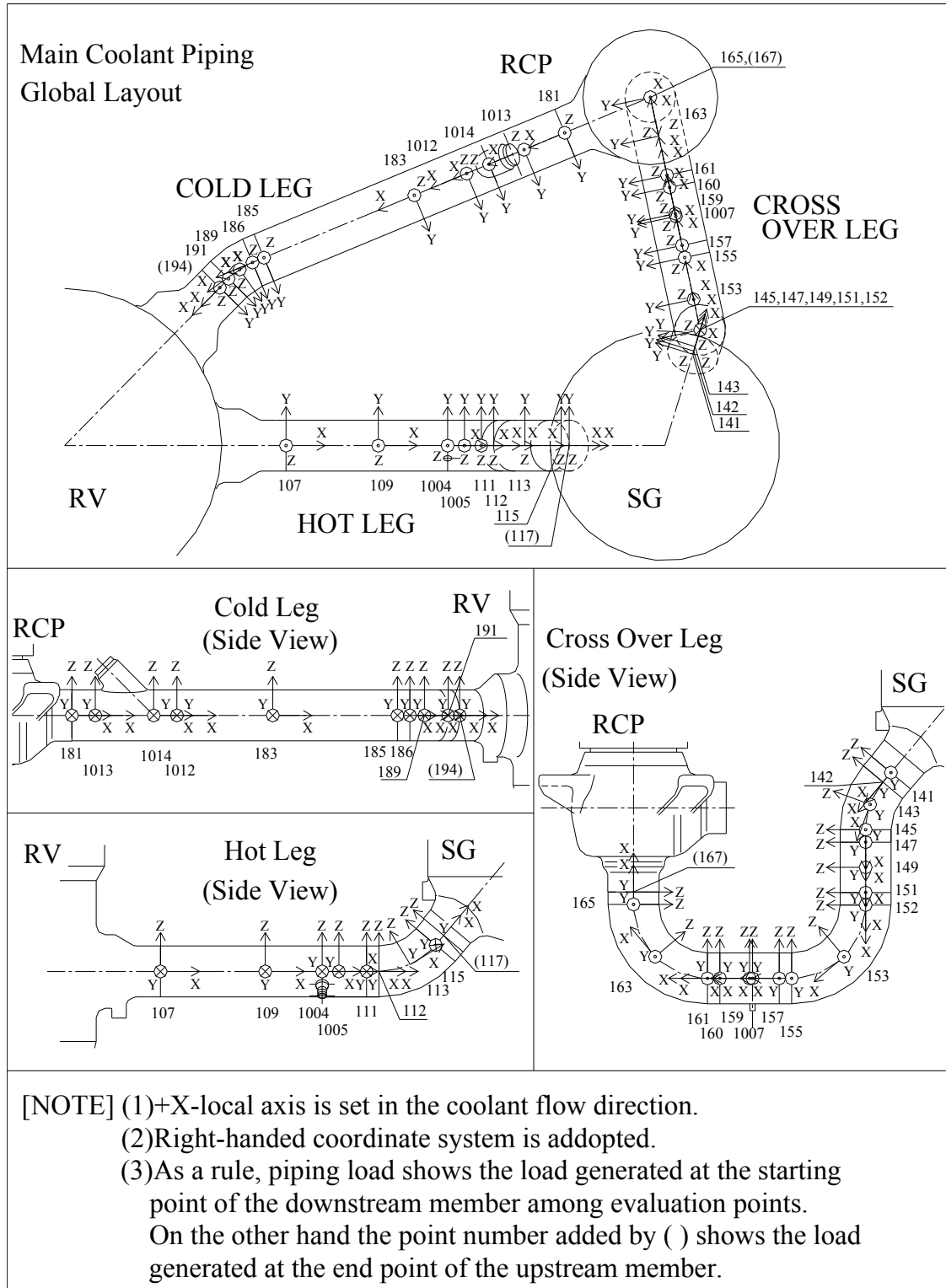


Figure 7-1-1 Coordinate System for RCL piping

Table 7-5-1 Member Load of Hot Leg

Node No.	Loading	Fx (kips)	Fy (kips)	Fz (kips)	Mx (kips · in)	My (kips · in)	Mz (kips · in)
107	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
109	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
111	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
112	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
113	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
115	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
117	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						

Table 7-5-2 Member Load of Crossover Leg (1/3)

Node No.	Loading	Fx (kips)	Fy (kips)	Fz (kips)	Mx (kips · in)	My (kips · in)	Mz (kips · in)
141	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
142	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
143	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
145	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
147	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
149	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
151	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						



Table 7-5-2 Member Load of Crossover Leg (2/3)

Node No.	Loading	Fx (kips)	Fy (kips)	Fz (kips)	Mx (kips · in)	My (kips · in)	Mz (kips · in)
152	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
153	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
155	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
157	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
159	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
160	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
161	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						

Table 7-5-2 Member Forces of Crossover Leg (3/3)

Node No.	Loading	Fx (kips)	Fy (kips)	Fz (kips)	Mx (kips · in)	My (kips · in)	Mz (kips · in)
163	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
165	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
167	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						

Table 7-5-3 Member Load of Cold Leg

Node No.	Loading	Fx (kips)	Fy (kips)	Fz (kips)	Mx (kips · in)	My (kips · in)	Mz (kips · in)
181	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
183	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
185	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
186	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
189	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
191	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						
194	Dead Weight						
	Thermal						
	Seismic (1/3 SSE)						
	Seismic (SSE)						
	Accident						

7.3.3 Thermal and Pressure Transient Loads

The design transients used in the structural evaluations are listed in Table 7-6-1.

These transients were determined based on a 60-year plant operating period and are classified into the ASME Level A, Level B, Level C, Level D service conditions, or Test condition, depending on the expected frequency of occurrence and severity of the event.

Table 7-6-1 Design Transients (1/2)

Mark	Transient	Occurrence	Remark
<b>Level A Service Condition</b>			
I-a	Plant heat-up (50F/h)	120	
I-b	Plant cooldown (100F/h)	120	Includes Transient for Loss of offsite power with natural circulation cooldown (10 times) and Safe shutdown (1 time)
I-c-1	Ramp load increase between 15% and 100% of full power (5% of full power per minute)	600	
I-c-2	Ramp load increase between 50% and 100% of full power (5% of full power per minute)	19,200	
I-d-1	Ramp load decrease between 15% and 100% of full power (5% of full power per minute)	600	
I-d-2	Ramp load decrease between 50% and 100% of full power (5% of full power per minute)	19,200	
I-e	Step load increase of 10% of full power	600	
I-f	Step load decrease of 10% of full power	600	
I-g	Large step load decrease with turbine bypass	60	
I-h(i)	Steady-state fluctuations and load regulation (Steady state fluctuations)	$1 \times 10^6$	$P_P \pm 50\text{psi}$ , $T_{\text{hot}}, T_{\text{cold}}$ , $T_{\text{ave}} \pm 3.1\text{F}$
I-h(ii)	Steady-state fluctuations and load regulation (Load regulation)	$8 \times 10^5$	
I-i	Main feedwater cycling	2,100	
I-j	Refueling	60	Water is replaced in 10minutes
I-k	Ramp load increase between 0% and 15% of full power	600	
I-l	Ramp load decrease between 0% and 15% of full power	600	
I-m	RCP startup	3,000	
I-n	RCP shutdown	3,000	
I-o	Core lifetime extension	60	
I-p	Primary leakage test	120	
I-q	Turbine roll test	10	

Table 7-6-1 Design Transients (2/2)

Mark	Transient	Occurrence	Remark
<b>Level B Service Condition</b>			
II-a	Loss of load	60	
II-b	Loss of offsite power	60	
II-c	Partial loss of reactor coolant flow	30	
II-d(i)	Reactor trip from full power With no inadvertent cooldown	60	
II-d(ii)	Reactor trip from full power With cooldown and no safety injection	30	Includes Transient for excessive feedwater flow
II-d(iii)	Reactor trip from full power With cooldown and safety injection	10	
II-e	Inadvertent RCS depressurization	30	
II-f	Control rod drop	30	
II-g	Inadvertent safeguards actuation	30	
II-h	Emergency feedwater cycling	700	
II-i	Cold over-pressure	30	
II-j	Excessive feedwater flow	—	Covered by Transient for reactor trip from full power ii)
II-k	Loss of offsite power with natural circulation cooldown	—	Covered by Transient for plant cooldown
II-l	Partial loss of emergency feedwater	30	Use Figure for Transient of loss of offsite power
II-m	Safe Shutdown	—	Covered by Transient for plant cooldown
<b>Level C Service Condition</b>			
III-a	Small loss of coolant accident	5	
III-b	Small steam line break	5	
III-c	Complete loss of flow	5	
III-d	Small feedwater line break	5	
III-e	SG tube rupture	5	
<b>Level D Service Condition</b>			
IV-a	Large loss of coolant accident	1	
IV-b	Large steam line break	1	
IV-c	RCP locked rotor	1	
IV-d	Control rod ejection	1	
IV-e	Large feedwater line break	1	
<b>Test Condition</b>			
V-a	Primary side hydrostatic test	10	

**7.3.4 Load Combinations**

The load combinations specified in Reference 4 were used in the structural evaluations. The combinations of pressure, temperatures and member loads are provided in Table 7-7-1.

The names used for member loads refer directly to the names specified in Tables 7-5-1 through 7-5-3.

**Table 7-7-1 Load Combinations for the design based on NB-3600**

System Operating Condition	Service Stress Limit	Service Loading Combination
Design	Design	Design pressure <sup>(1)(2)</sup> Dead weight loads <sup>(2)</sup>
Normal	Level A	Level A thermal & pressure transients Thermal loads
Upset	Level B	Level B maximum pressure <sup>(1)(2)</sup> Level B thermal & pressure transients Dead weight loads <sup>(2)</sup> Thermal loads Seismic (1/3 SSE) loads
Emergency	Level C	Level C maximum pressure <sup>(1)(2)</sup> Dead weight loads <sup>(2)</sup>
Faulted	Level D	Level D maximum pressure <sup>(1)(2)</sup> Dead weight loads <sup>(2)</sup> $\pm$ SRSS(Seismic(SSE) loads + Accident loads) <sup>(2)</sup>

Note 1: Applied to permissible pressure evaluations.

Note 2: Applied to primary stress evaluations.

## **8.0 METHODOLOGY**

### **8.1 Heat Transfer Coefficients and Thermal Analysis**

The ABAQUS computer program was used to determine temperature distributions of the RCL piping. ABAQUS is a general purpose finite element computer program used by MHI in the design and analysis of nuclear components. ABAQUS is available in the public domain and has been used by MHI for U.S. replacement steam generator and replacement reactor vessel closure head projects.

Heat transfer coefficients on the inner and outer surfaces of the piping are required to define the temperature distributions during transients. Classical Handbook heat transfer equations (References 6, 7 and 8) were used to calculate the heat transfer coefficients.

Finite element thermal analyses were performed for all Level A and Level B transients to define the time-dependent temperature distributions of the piping. The primary coolant temperature versus time curves were applied to all wetted surfaces with appropriate heat transfer coefficients as discussed above. The outside surfaces under the piping insulation were considered adiabatic.

### **8.2 Stress Calculation based on NB-3600**

Stress calculation was performed in accordance with NB-3650 using the MCPEVALSI. This program uses input of dimensions, pressure, temperature and load data of the piping, and calculates primary, secondary and peak stress according to the equations described in Appendix 1.

Figure 8-1 shows the stress calculation process.

### **8.3 (Deleted)**

#### **8.4 Fatigue Analysis Method**

The fatigue analysis was based on the rules of NB-3650. This rule requires calculation of the total stress, including the peak stress, to determine the allowable number of stress cycles for the specified Service Loadings. In the RCL piping analysis, the MCPEVALSI was used to calculate fatigue usage factors.

The design transients for Level A and B service conditions (Table 7-6-1) were used in the evaluation of cyclic fatigue. The effect of 300 cycles of a 1/3 SSE seismic event was also included in the evaluation of cyclic fatigue, treated as a Level B service condition. The number of cycles assumed for the 1/3 SSE seismic event was based on a fatigue usage factor equivalent to that for a single SSE event of 20 cycles.





**Figure 8-1 Stress Evaluation Process (NB-3600)**

**9.0 COMPUTER PROGRAMS USED**

Refer to Figure 8-1 for a visual description of the stress evaluation process. The table below provides a brief description of each of the computer programs used.

**Table 9-1 Computer Program Description**

No.	Program Name	Version	Description
1	ABAQUS	6.7-1	ABAQUS is a general purpose finite element computer code that performs a wide range of linear and nonlinear engineering simulations.  ABAQUS is used for thermal analysis in RCL piping evaluation.
2	MCPFEM	2.0	MCPFEM is an MHI Code that makes ABAQUS input files for thermal analysis.
3	MCPEVALPRI	2.0	MCPEVALPRI is an MHI Code that extracts temperature data from ABAQUS output files.
4	MCPEVALSI	5.0	MCPEVALSI is an MHI Code that calculates the stresses and usage factors in accordance with NB-3600.

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

## **10.0 STRUCTURAL ANALYSIS RESULTS**

This section summarizes the results of the analyses for the RCL piping.

The stress calculation was performed using computer programs and hand calculations.

The reported results are generally conservative and larger than the actual values if more detailed calculations were performed; but since they all meet the ASME Code allowable limits, further analysis is not necessary.

### **10.1 RCL piping**

#### **10.1.1 Evaluated Part Dimensions**

The RCL piping dimensions are listed in Table 10-1-1.

Table 10-1-1 RCL piping dimensions

Evaluated Part	Node No.	Outer Diameter (in)	Thickness (in)	Bend Radius of Elbow (in)
Hot Leg	107			
	109			
	111			
	112			
	113			
	115			
	117			
Crossover Leg	141			
	142			
	143			
	145			
	147			
	149			
	151			
	152			
	153			
	155			
	157			
	159			
	160			
	161			
	163			
165				
167				
Cold Leg	181			
	183			
	185			
	186			
	189			
	191			
	194			

**10.1.2 Stress Results**

The stress-to-allowable ratios (calculated stress divided by allowable value), the fatigue cumulative usage factors for the most limiting locations are summarized in Table 10-1-2.

**Table 10-1-2 RCL Piping Stress Result Summary**

Condition	Stress Category	ASME Ref.	Stress-to-Allowable Ratio		
			Hot Leg	Cross-over Leg	Cold Leg
Design	Primary Stress	NB-3652			
Level A/B	Primary Plus Secondary Stress	NB-3653.1			
	Usage Factor	NB-3653.5			
	Thermal Bending Stress	NB-3653.6			
	Primary Plus Secondary Membrane Stress Excluding Thermal Bending and Expansion Stress	NB-3653.6			
	Thermal Stress Ratchet	NB-3653.7			
Level B	Permissible Pressure	NB-3654.1			
	Primary Stress	NB-3654.2			
Level C	Permissible Pressure	NB3655.1			
	Primary Stress	NB-3655.2			
Level D	Permissible Pressure	NB-3656			
	Primary Stress	NB-3656			

## 11.0 LEAK-BEFORE-BREAK EVALUATION

This section describes the leak-before-break (LBB) evaluation results for the RCL piping.

### 11.1 Evaluation Method

The bounding analysis curve (BAC) approach, which is summarized in Appendix 2 of MUAP-09011 (Reference 12), was applied to the evaluation.

### 11.2 Evaluation Results

The BACs for the RCL piping were taken from Reference 11.

The RCL piping stress calculation results were plotted in Figures 11-1 through 11-3.

These figures show that the stress calculation results range below the BACs and the RCL piping satisfies the LBB requirements.

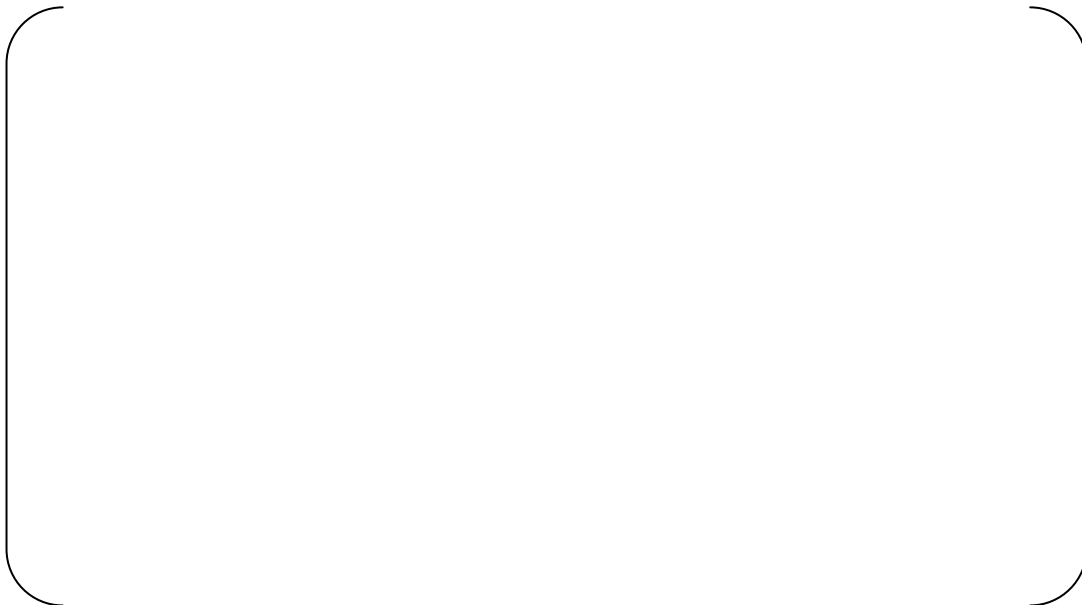


Figure 11-1 Hot Leg LBB Evaluation Result



**Figure 11-2 Crossover Leg LBB Evaluation Result**



**Figure 11-3 Cold Leg LBB Evaluation Result**

## **12.0 REFERENCES**

1. ASME Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components, 1992 Edition including 1992 Addenda
2. ASME Boiler and Pressure Vessel Code, Section II Material Specification, 2001 Edition through 2003 Addenda
3. N0-FB10L01 Rev.3, "US-APWR Standard Design General Design Specification for Class 1 Components"
4. N0-F700L01, Rev.5, "US-APWR Reactor Coolant Loop Piping Design Specification"
5. SIMULIA, "ABAQUS Analysis User's manual", Version 6.7, 2007.
6. Warren M. Rohsenow, James P. Hartnett and Yung I. Cho, "Handbook of Heat Transfer", Third Edition, McGraw Hill, 1998.
7. Eckert and Drake, "Heat & Mass Transfer", Second Edition, 1959.
8. Frank Kreith, Principles of HEAT TRANSFER third edition, 1976.
9. (Deleted)
10. N0-F700L11 Rev.4, "US-APWR Reactor Coolant Loop Piping Design Drawings"
11. N0-CG00005 Rev.2, "US-APWR Bounding Analysis Curves for Leak Before Break Evaluation"
12. MUAP-09011-P Rev.2, "Summary of Stress Analysis Results for the US-APWR Reactor Coolant Loop Branch Piping"
13. (Deleted)
14. (Deleted)
15. (Deleted)
16. (Deleted)



**Appendix 1**  
**Reactor Coolant Loop Piping**  
**Stress Calculation Formula**

## 1. Introduction

This Appendix describes the stress calculation formula used in the RCL piping evaluation.

## 2. Design condition

### 2.1 Primary stress [NB-3652, Eq.(9)]

$$B_1 \frac{PD_o}{2t} + B_2 \frac{D_o}{2I} M_i \leq 1.5S_m$$

- $B_1, B_2$  : Stress indices  
 $P$  : Design pressure, psi  
 $D_o$  : Outside diameter, in  
 $t$  : Wall thickness, in  
 $I$  : Moment of inertia, in<sup>3</sup>  
 $M_i$  : Resultant moment due to dead weight (The other mechanical load is equal to zero for the RCL piping.), in-lb  
 $S_m$  : Allowable design stress intensity value at the design temperature, psi

## 3. Level A/B service condition

### 3.1 Primary plus secondary stress [NB-3653.1, Eq.(10)]

$$S_n = C_1 \frac{P_o D_o}{2t} + C_2 \frac{D_o}{2I} M_i + C_3 E_{ab} |\alpha_a T_a - \alpha_b T_b| \leq 3S_m$$

- $C_1, C_2, C_3$  : Stress indices  
 $P_o$  : Range of pressure, psi  
 $M_i$  : Resultant range of moment due to the followings, in-lb  
 - Thermal expansion load  
 - Mechanical load (equal to zero for the RCL piping)  
 - Seismic load (only included in 1/3 SSE seismic event)  
 $E_{ab}$  : Average modulus of elasticity of the two sides at room temperature, psi  
 $\alpha_a, \alpha_b$  : Coefficient of thermal expansion at room temperature, 1/°F  
 $T_a, T_b$  : Range of average temperature of structural discontinuity, °F  
 $S_m$  : Allowable design stress intensity value at the temperature of normal operation, psi

The other symbols are same as Section 2.1.

### 3.2 Peak stress [NB-3653.2, Eq.(11)]

$$S_p = K_1 C_1 \frac{P_o D_o}{2t} + K_2 C_2 \frac{D_o}{2I} M_i + \frac{1}{2(1-\nu)} K_3 E \alpha |\Delta T_1|$$

$$+ K_3 C_3 E_{ab} |\alpha_a T_a - \alpha_b T_b| + \frac{1}{1-\nu} E \alpha |\Delta T_2|$$

$K_1, K_2, K_3$  : Stress indices

$E$  : Modulus of elasticity at room temperature, psi

$\alpha$  : Coefficient of thermal expansion at room temperature,  $1/^\circ\text{F}$

$\Delta T_1$  : Range of the temperature difference between the temperature of the outside  $T_o$  and the temperature of the inside surface  $T_i$  of the piping product assuming moment generating equivalent linear temperature distribution,  $^\circ\text{F}$

$\Delta T_2$  : Range of the nonlinear thermal gradient through the wall thickness not included in  $\Delta T_1$ ,  $^\circ\text{F}$

$\nu$  : Poisson's ratio (=0.3)

The other symbols are same as Section 3.1.

### 3.3 Alternating stress and cumulative usage factor [NB-3653.3 to NB-3653.5]

$$S_{ait} = \frac{S_p}{2} \quad \text{for} \quad S_n \leq 3S_m$$

Cumulative usage factor ( $UF$ ) is evaluated in accordance with NB-3222.4(e)(5).

$$UF \leq 1.0$$

### 3.4 Simplified elastic-plastic discontinuity analysis

In case of  $S_n > 3S_m$ , the simplified elastic-plastic discontinuity analysis is used.

#### (a) Thermal bending stress [NB-3653.6(a)]

$$S_e = C_2 \frac{D_o}{2I} M_i^* \leq 3S_m$$

$M_i^*$  : Range of moment due to thermal expansion load, in-lb

The other symbols are same as Section 3.1

(b) Primary plus secondary stress excluding thermal bending and thermal expansion stresses [NB-3653.6(b)]

$$C_1 \frac{P_o D_o}{2t} + C_2 \frac{D_o}{2l} M_i + C_3' E_{ab} |\alpha_a T_a - \alpha_b T_b| \leq 3S_m$$

$C_3'$  : Stress index

The other symbols are same as Section 3.1

(c) Alternating stress and cumulative usage factor [NB-3653.6(c)]

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

$$K_e = 1.0, \text{ for } S_n \leq 3S_m$$

$$K_e = 1.0 + \frac{1-n}{n(m-1)} \left( \frac{S_n}{3S_m} - 1 \right), \text{ for } 3S_m < S_n < 3mS_m$$

$$K_e = \frac{1}{n}, \text{ for } S_n \geq 3mS_m$$

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

Cumulative usage factor ( $UF$ ) is evaluated in accordance with NB-3222.4(e)(5).

$$UF \leq 1.0$$

(d) Thermal stress ratchet [NB-3653.7]

$$\Delta T_{1 \text{ range}} \leq \frac{y' S_y}{0.7 E \alpha} C_4$$

$y'$  : Refer to the table below.

$x$	0.3	0.5	0.7	0.8
$y'$	3.33	2.00	1.20	0.80

$x$  : Equal to  $(PD_o/2t)(1/S_y)$

$P$  : Maximum pressure for the set of conditions under consideration, psi

$C_4$  : Equal to 1.3 for austenitic stainless steel

$S_y$  : Yield point at the average fluid temperature of the load set, psi

#### 4. Level B service condition

##### 4.1 Permissible pressure [NB-3654.1]

$$P_M \leq 1.1P_a$$

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

$P_M$  : Maximum pressure in Level B service condition, psi

$P_a$  : Maximum allowable internal pressure defined in NB-3641.1, psi

$y$  : Equal to 0.4

The other symbols are same as Section 2.1.

##### 4.2 Primary stress [NB-3654.2]

$$B_1 \frac{P_M D_o}{2t} + B_2 \frac{D_o}{2I} M_i \leq \text{Min}(1.8S_m, 1.5S_y)$$

$P_M$  : Maximum pressure in Level B service condition, psi

$M_i$  : Resultant moment due to dead weight (Mechanical load is equal to zero for the RCL piping.), in-lb

$S_m$  : Allowable design stress intensity value at the maximum temperature in Level B service condition, psi

$S_y$  : Yield strength at the maximum temperature in Level B service condition, psi

The other symbols are same as Section 2.1.

## 5. Level C service condition

### 5.1 Permissible pressure [NB-3655.1]

$$P_M \leq 1.5P_a$$

$P_M$  : Maximum pressure in Level C service condition, psi  
The other symbols are same as Section 4.1.

### 5.2 Primary stress [NB-3655.2]

$$B_1 \frac{P_M D_o}{2t} + B_2 \frac{D_o}{2I} M_i \leq \text{Min}(2.25S_m, 1.8S_y)$$

$P_M$  : Maximum pressure in Level C service condition, psi  
 $M_i$  : Resultant moment due to dead weight (Mechanical load is equal to zero for the RCL piping.), in-lb  
 $S_m$  : Allowable design stress intensity value at the maximum temperature in Level C service condition, psi  
 $S_y$  : Yield strength at the maximum temperature in Level C service condition, psi

The other symbols are same as Section 4.1.

## 6. Level D service condition

### 6.1 Permissible pressure [NB-3656 (b)]

$$P_M \leq 2P_a$$

$P_M$  : Maximum pressure in Level D service condition, psi  
The other symbols are same as Section 4.1.

### 6.2 Primary stress [NB-3655.2]

$$B_1 \frac{P_M D_o}{2t} + B_2 \frac{D_o}{2l} M_i \leq \text{Min}(3S_m, 2S_y)$$

$P_M$  : Maximum pressure in Level D service condition, psi

$M_i$  : Resultant moment due to the followings, in-lb  
- Dead weight  
- Mechanical load (equal to zero for the RCL piping.)  
- Seismic load (SSE)  
- Accident load

$S_m$  : Allowable design stress intensity value at the maximum temperature in Level D service condition, psi

$S_y$  : Yield strength at the maximum temperature in Level D service condition, psi