Therefore, the piping is designed to operate at temperatures less than that for which creep and creep-fatigue is a concern.

3.6.3.3.3 Wall Thinning Induced by the Effects of Erosion/Corrosion

RCL Piping

RCL piping utilizes austenitic stainless steel, which provides a high resistance to wall thinning induced by erosion, erosion/corrosion, and erosion/cavitation. Historically, there have been no recorded cases of erosion-induced wall thinning within the primary loops of operating plants. Since the US-APWR primary loop design maintains a flow velocity of approximately 55 feet per second and water chemistry similar to other pressurized water reactors, degradation of RCL pipe wall thicknesses by erosion, erosion/corrosion, or erosion/cavitation is not considered a credible failure mechanism for RCL piping.

RCL Branch Piping

Similar to the primary loops, RCL branch piping utilizes austenitic stainless steel highly resistant to wall thinning. In addition, no cases of erosion induced wall thinning have been reported for RCL branch piping in operating plants with similar operating parameters. Therefore, wall thinning induced by the effects of erosion is not considered a credible failure mechanism for RCL branch piping.

Main Steam Piping

Although fabricated from SA-106 Grade B~~333 Grade 6~~ carbon steel, wall thinning induced by the effects of erosion is not anticipated within main steam piping. The MSS operates with high quality steam at high temperatures, thereby circumventing the chemical and temperature initiators that erode carbon steel surfaces. Therefore, wall thinning induced by the effects of erosion is not considered a credible failure mechanism for main steam piping. MIC-03-03-00056

3.6.3.3.4 SCC

System operations are maintained that inhibit SCC, primarily through use of materials with low susceptibility, stress limitations, and chemistry control.

RCL Piping

The RCL piping is constructed of austenitic stainless steel materials that are proven through years of successful industry usage to resist SCC. The recommendations of RG 1.44 (Reference 3.6-22) in the use of sensitized stainless steel are applied by the US-APWR.

In addition to stress control in accordance with ASME Code, Section III, Class 1 piping (Reference 3.6-12), fluid chemistry is maintained as low- or no-oxygen environments. While RCL piping tensile stresses are within design allowables, residual tensile stresses also develop within welds. These residual stresses are self-equalizing, and industry experience with other pressurized water reactors has affirmed their acceptability.

Butting nozzles located at safe ends with a stainless steel to carbon steel interface are performed utilizing a high nickel alloy material. An alloy consisting of nickel, chromium, and iron has been selected and qualified based on the non-susceptibility to SCC.

RCL Branch Piping

Similar to the primary loops, RCL branch piping utilizes austenitic stainless steel which is highly resistant to SCC. Therefore, SCC is not considered a credible failure mechanism within both primary and branch RCL piping.

Main Steam Piping

Although fabricated from ferritic SA-106 Grade B~~333 Grade 6~~ carbon steel, SCC is not anticipated within main steam piping. While SCC in main steam piping could result from SG moisture, the secondary side utilizes an all-volatile water treatment chemistry. All volatile treatment resists causticity in the SG bulk liquid environment which resulted in chemical imbalances from SCC of SG tubing previously experienced in some operating plants. No caustic SCC on the ferritic steam lines have occurred with all volatile water treatment. Therefore, SCC is not considered a credible failure mechanism within the main steam piping. MIC-03-03-00056

3.6.3.3.5 Fatigue

Low-Cycle Fatigue

Class 1 piping satisfying the requirements of ASME Code, Section III (Reference 3.6-12) are designed for low-cycle fatigue postulated to occur during normal operation and anticipated transients, including thermal stratification. No significant transients that have the ability to generate low-cycle fatigue are postulated to occur during normal operation of main steam piping. Therefore, low-cycle fatigue is not a potential failure mechanism of piping.

High-Cycle Fatigue

The reactor coolant pumps generate vibrations capable of causing high-cycle fatigue within the RCL piping. Operational controls are established to minimize vibrations during hot functional testing and normal operation. In addition, pump vibrations that could lead to adverse high-cycle fatigue in piping are also monitored by alarming when the vibrations exceed acceptable limits. These precautions maintain the piping in operational ranges with very low probability of failure.

3.6.3.3.6 Thermal Aging

RCL Piping and RCL Branch Piping

Stainless casting is not used for the RCL and RCL branch piping. The fracture toughness is also not a concern, because the amount of the ferrite contents in welding material is low.

Main Steam Piping

Table 3.6-2 List of High Energy Lines for Pipe Break Hazard Analysis, Including Properties of Internal and External Fluids (Sheet 1 of 4)

No.	System	Subsystem	Line No(s)	Nominal Diameter (Inches)	Outside Diameter (Inches)	Thickness (Inches)	Material	Temp (°F)	Pres-sure (psig)	Inside Pipe	Outside Pipe (°F , psig)
1	RCS	Primary Loop Hot Leg	31"ID-RCS-2501R A,B,C,D	31ID	37.12	3.06	SA182 F316	617	2235	Subcooled liquid	Air (120, 0)
1	RCS	Primary Loop Hot Leg	31"ID-RCS-2501R A,B,C,D	31ID	37.12	3.06	SA182 F316LN	617	2235	Subcooled liquid	Air (120, 0)
2	RCS	Primary Loop Crossover Leg	31"ID-RCS-2501R A,B,C,D	31ID	37.12	3.06	SA182 F316	550.6	2235	Subcooled liquid	Air (120, 0)
3	RCS	Primary Loop Cold Leg	31"ID-RCS-2501R A,B,C,D	31ID	37.12	3.06	SA182 F316	550.6	2235	Subcooled liquid	
2	RCS	Primary Loop Crossover Leg	31"ID-RCS-2501R A,B,C,D	31ID	37.12	3.06	SA182 F316LN	550.6	2235	Subcooled liquid	Air (120, 0)
3	RCS	Primary Loop Cold Leg	31"ID-RCS-2501R A,B,C,D	31ID	37.12	3.06	SA182 F316LN	550.6	2235	Subcooled liquid	
4	RCS	Surge Line	16"-RCS-2501R B	16	16	1.594	SA-312 TP316	653	2235	Saturated liquid	Air (120, 0)
5	RCS	Surge Line	16"-RCS-2501R A	16	16	1.594	SA-312 TP316	449	400	Saturated liquid	Air (120, 0)
6	RCS	Residual Heat Removal System (RHRS) Hot Leg Branch Line off RCS	10"-RCS-2501R A,B,C,D, Hot Leg Side	10	10.75	1.125	SA-312 TP316	617	2235	Subcooled liquid	Air (120, 0)
7	RCS	RHRS Cold Leg Branch Line off RCS	8"- RCS -2501R A,B,C,D (COLD LEG)	8	8.625	0.906	SA-312 TP316	550.6	2235	Subcooled liquid	Air (120, 0)
8	SIS	Accumulator Sys-tem	14"-RCS-2501R A,B,C,D	14	14	1.406	SA-312 TP316	550.6	2235	Subcooled liquid	Air (120, 0)
9	RCS	Pressurizer Spray Line	6"-RCS-2501R B,C	6	6.625	0.719	SA-312 TP316	550.6	2235	Subcooled liquid	Air (120, 0)
10	MSS	Main Steam Line	32"-MSS-1532N A,B,C,D	32	32	1.496	SA-106 Gr.B~~333 Gr.6~~	535	907	Saturated steam	Air (130, 0)
11	CVS	Aux. Spray Line	3"-RCS-2501	3	3.5	0.438	SA-312 TP316	554.6	2266	Subcooled liquid	Air (120, 0)
12	CVS	Aux. Spray Line	3"-CVS-2561	3	3.5	0.438	SA-312 TP316	554.6	2366	Subcooled liquid	Air (120, 0)
13	CVS	Charging Line	4"-CVS-2501	4	4.5	0.531	SA-312 TP316	554.6	2366	Subcooled liquid	Air (120, 0)

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Table 3.6-2 List of High Energy Lines for Pipe Break Hazard Analysis, Including Properties of Internal and External Fluids (Sheet 4 of 4)

No.	System	Subsystem	Line No(s)	Nominal Diameter (Inches)	Outside Diameter (Inches)	Thickness (Inches)	Material	Temp (°F)	Pres-sure (psig)	Inside Pipe	Outside Pipe (°F , psig)
47	FWS	Feedwater Line	6"-FWS-1805	6	6.625	0.562	SA-335 Gr.P22	471	1850	Subcooled liquid	Air (130, 0)
48	FWS	Feedwater Line	16"-FWS-1525	16	16	0.844	SA-335 Gr.P22	471	1185	Subcooled liquid	Air (130, 0)
49	FWS	Feedwater Line	3"-FWS-1802	3	3.5	0.438	SA-106 Gr.B	471	1850	Subcooled liquid	Air (130, 0)
50	MSS	Main Steam Line	32"-MSS-1532	32	32	1.500	SA-106 Gr.B ~~333 Gr.6~~	539	938	Saturated steam	Air (130, 0)
51	MSS	Main Steam Line	6"-MSS-1532	6	6.625	0.432	SA-106 Gr.B	539	938	Saturated steam	Air (130, 0)
52	MSS	Main Steam Drain Line	2"-MSS-1532	2	2.375	0.218	SA-106 Gr.B	539	938	Saturated liquid	Air (130, 0)
53	MSS	Main Steam Drain Line	4"-MSS-1532	4	4.5	0.337	SA-106 Gr.B	539	938	Saturated liquid	Air (130, 0)
54	SGS	SGBD Line	3"-SGS-1532	3	3.5	0.300	SA-106 Gr.B	539	938	Saturated liquid	Air (120, 0)
55	SGS	SGBD Line	4”-SGS-1532 (Inside CV)	4	4.5	0.337	SA-106 Gr.B	539	938	Saturated liquid	Air (120, 0)
56	SGS	SGBD Line	4”-SGS-1532 (Outside CV)	4	4.5	0.337	SA-106 Gr.B	539	938	Saturated liquid	Air (105, 0)
57	SGS	SGBD Line	3/8”-SGS-2521	3/8	-	-	-	539	938	Saturated liquid	Air (120, 0)
58	SGS	SGBD Line	3/8”-SGS-25CA	3/8	-	-	-	539	938	Saturated liquid	Air (105, 0)

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Security-Related Information – Withheld Under 10 CFR 2.390

Figure 3.6-1 Break Exclusion Region-Main Steam Pipe Room

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2c = is the remaining circumferential ligament of the cracked portion of the pipe

where, *T* is expressed as a difference equation, Equation B2.2.2.3-12 changes as follows:

$$T = \frac{E}{\left(\sigma_f\right)^2}\frac{dJ}{da} = \frac{E}{\left(\sigma_f\right)^2}\frac{\Delta J}{\Delta a} \qquad (3B.2.2.2\text{-}16)$$

Since the EPRI/GE J-estimation procedures are for tension or bending, the critical crack length for a combination of membrane and tensile stress are determined by a linear interaction rule as depicted in Figure 3B-3 and is expressed as the following:

$$a_c = \frac{\sigma_t}{\left(\sigma_t + \sigma_b\right)} a_{c,t} + \frac{\sigma_b}{\left(\sigma_t + \sigma_b\right)} a_{c,b} \qquad (3B.2.2.2\text{-}17)$$

where

a_c = critical crack length in a combination of tension and bending

σ_t = applied membrane stress

σ_b = applied bending stress

$a_{c,t}$ = critical crack length for a tension stress of $\sigma_t + \sigma_b$

$a_{c,b}$ = critical crack length for a bending stress of $\sigma_t + \sigma_b$

In the case of loading control condition, lower stress-strain curve gives larger applied *J* (J_{APP}). On the other hand generally larger strength material has lower fracture toughness. This relation is suitable for base metal and weld metal of carbon steel. Therefore, in the evaluation, stress-strain curve of the base metal and the J-R curve of the weld metal are applied for conservativeness.

Material of the main steam pipe is planned as SA-106 Grade B~~333 Gr.6~~. The material data is to be obtained from the same material to be used, but has not been produced yet. Thus, a conservative approach is used to perform the analysis, and required fracture toughness properties will be provided to suppliers to assure that material properties will meet the requirements described herein. MIC-03-03-00056

In performing the fracture mechanics analysis, the stress strain curve can be fit based on ASME Code minimum properties to determine the Ramberg-Osgood material parameters using the approach:

$$\frac{\varepsilon}{\varepsilon_0} = \frac{\sigma}{\sigma_0} + \alpha \left[\frac{\sigma}{\sigma_0} \right]^n \qquad (3B.2.2.2\text{-}18)$$

Here σ and ε are the true stress and true strain, σ_o and ε_o are the reference stress and reference strain (that may be taken as yield stress and yield strain or any other consistent values) and α and n are the Ramberg-Osgood (R-O) parameters.

If a stress-strain curve at the temperature of interest were available, the R-O parameters could be obtained by curve fitting over the strain range of interest. In the absence of the actual stress-strain curve of the material, a methodology for determining the R-O parameters based on ASME Code minimum-specified mechanical properties is used (Reference 3B-10). The parameters are determined by using a material 0.2% offset yield strength as σ_o and the following equations:

$$\alpha \approx \frac{0.002}{e_y} \qquad (3B.2.2.2\text{-}19)$$

$$n = \frac{\ell n \left[\frac{1}{\alpha} \left(\frac{\ell n(1+e_u)}{\ell n(1+e_y)} \right) - \frac{S_u(1+e_u)}{S_y(1+e_y)} \right]}{\ell n \left[\frac{S_u(1+e_u)}{S_y(1+e_y)} \right]} \qquad (3B.2.2.2\text{-}20)$$

where S_u and S_y represent Code minimum ultimate stress and yield stress, respectively, that can be obtained from Section II of the ASME Code (Reference 3B-2) as a function of temperature. The yield strain (e_y) is determined as:

$$e_y = \frac{S_y}{E} \qquad (3B.2.2.2\text{-}21)$$

where *E* (modulus of elasticity) can also be obtained from the ASME Code. The ultimate strain (e_u) is not specified as a function of temperatures in the ASME Code, hence the room temperature minimum elongation value from the ASME Section II properties for SA-106 Grade B~~333 Grade 6~~ is assumed for all temperatures, since the methodology is not very sensitive to the choice of e_u when determining α and n by using the equations above. MIC-03-03-00056

The choice of the R-O parameters based on either yield strength or flow stress does not change the prediction of the plastic portion of the J-Integral using the EPRI/GE EPFM estimation equations (References 3B-5 and 3B-9) since the stress strain curve is identical in either case. This is why a reference stress nomenclature is used. The elastic portion of the J-Integral is affected however, with lower values of reference stress increasing the computed elastic J-Integral since a plastic zone correction is made. In NUREG/CR-6540 (Reference 3B-11) and NUREG/CR-6235 (Reference 3B-12), it was stated that more recent work by Battelle had not used the plastic zone correction at all, since the effect of the plastic zone correction is inherently included in the plastic J-Integral calculation. Thus, it is acceptable to use the higher flow stress in determining the RO parameters as there is still some contribution due to the elastic J-integral. The Ramberg-Osgood parameters based on the flow stress (α_{flow}, ε_{flow}) may be determined from those above based on the yield stress (α_y, ε_y) by using the following equations:

R-O Coefficient: $\alpha_{flow} = \alpha_y (\sigma_{flow}/ \sigma_y)^{n-1}$

R-O Exponent: $n_{flow} = n_{yield}$

Material of the main steam pipe is planned to be SA-106 Grade B~~333 Gr.6~~. The specific material data to be used for the fracture mechanics evaluations, as specified in SRP 3.6.3, are not yet available. Thus, ASME Code minimum properties based on ASME Section II, Part D were used. An approach has been developed whereby the fracture properties for the base metal and welding will be specified to the piping supply vendor and welding contractor to assure that the BAC provided herein will be met. This is a suitable alternate to testing of typical material that may or may not be similar to that procured. MIC-03-03-00056

As part of this evaluation, a set of material properties have been assumed that will provide sufficient margin for determination of the main steam line BAC, and that can be obtained in the procurement process. The required material property is the J-resistance (JR) curve ($J = C\Delta a^m$) for the base metal and the weld metal. The test procedure requires the following as a supplemental requirement for material procurement and welding material/proccess qualification:

1. Testing shall be conducted to determine the JR curve for the base material and weld material. All testing shall be conducted at a test temperature between 535ºFand 550ºF to bound the main steam line temperature. The test specimens will be slightly less than the pipe material thickness, to accommodate specimen machining. The number of tests will depend on the heats of material to be provided and will be consistent with NUREG-1061 Volume 3 Appendix A Table A-1.

2. Using material tensile testing at the same temperature, the yield strength and ultimate tensile strength shall be determined. The flow stress shall be determined as the average of the yield and ultimate tensile strength. The ratios of the yield strength and flow stress to those based on minimum Code values at this temperature shall be determined. The minimum of the ratios so determined for the flow stress and the yield stress for the base material shall be denoted as the stress factor (SF).

Table 3B-2 List of BACs for LBB Evaluation

No.	System	Subsystem	Line No(s)	Nominal Diameter (Inches)	Outside Diameter (Inches)	Thickness (Inches)	Material	Temp (°F)[1]	Pressure (psig)[1]	Inside Pipe		BAC Figure No.
										Water	Vapor	
1	RCS	Primary Loop Hot Leg	31"ID-RCS-2501R A,B,C,D	31ID	37.12	3.06	SA182 F316	615	2248	X		Figure 3B-6
2	RCS	Primary Loop Hot Leg	31"ID-RCS-2501R A,B,C,D	31ID	37.12	3.06	SA182 F316LN	615	2248	X		Figure 3B-7
3	RCS	Primary Loop Crossover Leg	31"ID-RCS-2501R A,B,C,D	31ID	37.12	3.06	SA182 F316	551	2204	X		Figure 3B-8
4	RCS	Primary Loop Cold Leg	31"ID-RCS-2501R A,B,C,D	31ID	37.12	3.06	SA182 F316	551	2296	X		Figure 3B-9
5	RCS	Primary Loop Crossover Leg	31"ID-RCS-2501R A,B,C,D	31ID	37.12	3.06	SA182 F316LN	551	2204	X		Figure 3B-10
6	RCS	Primary Loop Cold Leg	31"ID-RCS-2501R A,B,C,D	31ID	37.12	3.06	SA182 F316LN	551	2296	X		Figure 3B-11
7	RCS	Surge Line[2]	16"-RCS-2501R B	16	16	1.594	SA-312 TP316	653	2248[2]	X		Figure 3B-12
8												Figure 3B-13 (deleted)
9	RCS	Residual Heat Removal System (RHRS) Hot Leg Branch Line off RCS	10"-RCS-2501R A,B,C,D, Hot Leg Side	10	10.75	1.125	SA-312 TP316	615	2248	X		Figure 3B-14
10	RCS	RHRS Cold Leg Branch Line off RCS	8"- RCS -2501R A,B,C,D (COLD LEG)	8	8.625	0.906	SA-312 TP316	551	2296	X		Figure 3B-15
11	SIS	Accumulator System	14"-RCS-2501R A,B,C,D	14	14	1.406	SA-312 TP316	551	2296	X		Figure 3B-16
12	RCS	Pressurizer Spray Line[3]	6"-RCS-2501R B,C	6	6.625	0.719	SA-312 TP316	551	2296[3]	X		Figure 3B-17
13	MSS	Main Steam Line	32"-MSS-1532 A,B,C,D	32	32	1.496	SA-106 Gr.B~~333 Gr.6~~	535	907		X	Figure 3B-18

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Notes: 1. Conditions from Reactor Coolant System DCD, Table 5.1-2.
2. Use conservative lower 2243 psig for leakage which is the pressurizer end pressure.
3. Use conservative higher 2296 psig condition of cold leg for critical flaw sizing and 2235 psig for leakage based on upper portion connected to pressurizer steam space

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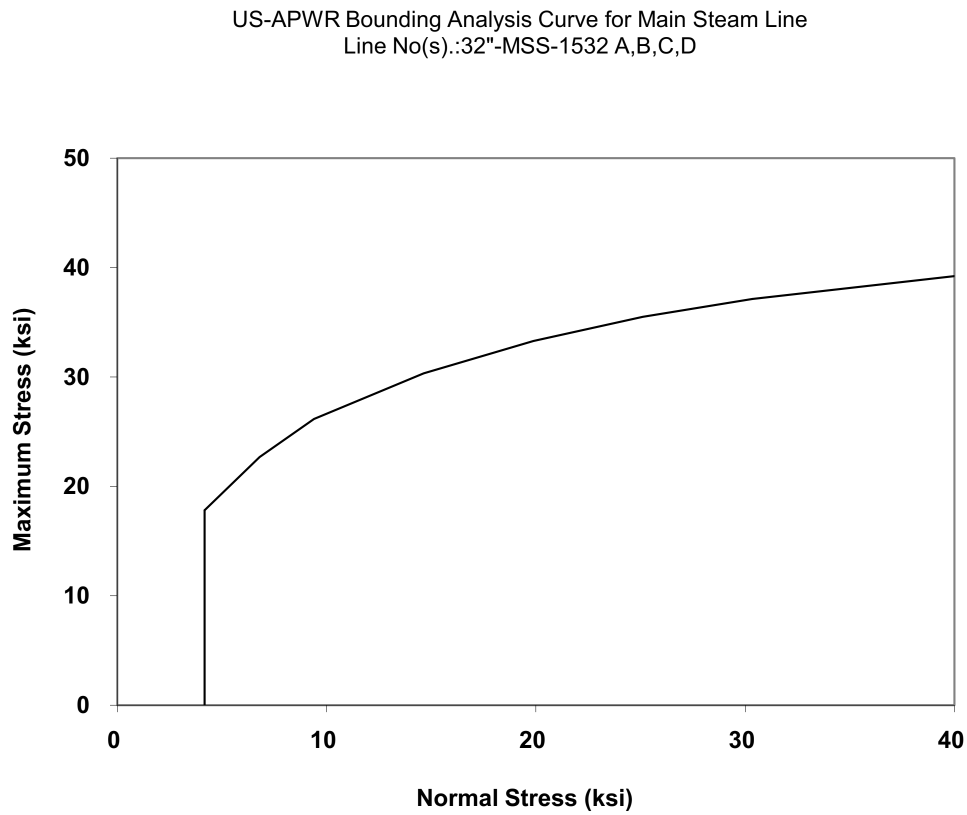

System:	MSS	
Nominal Diameter:	32"	
Outside Diameter:	32.000 inch	
Nominal Thickness:	1.496 inch	
Pipe Material:	SA-106 Grade B	Critical Flaw Size = 2 x Leakage Flaw Size
Normal Operating Pressure:	907 psig	Load Margin = 1.0
Normal Operating Temperature:	535 °F	Leak Rate = 10 x Leak Detection Capability

Figure 3B-18 US-APWR BAC for Main Steam Line