3.12 Piping Design Review

3.12.1 Introduction

This section covers the design of the APR1400 piping systems and piping supports consisting of seismic Category I, Category II, and Category III (non-seismic). The piping design of the reactor coolant loop (RCL) is described in Subsection 3.9.3. The seismic classifications are described in Subsection 3.2.1.

This section addresses the adequacy of the structural integrity as well as the functional capability of the safety-related piping system, piping components, and their associated supports. The design of piping systems provides reasonable assurance that they will perform their safety-related functions under all postulated normal operating conditions, system operating transients, postulated pipe breaks, seismic events, and combinations.

This design boundary includes pressure retaining piping components and their supports, instruments lines, and the interaction of seismic Category II piping and associated supports with seismic Category I piping and associated supports.

This section also covers the design transients and resulting loads and load combinations with appropriate specified design and service limits for seismic Category I piping and piping supports, including those designated as ASME Class 1, 2, and 3, and those covered by the ASME B31.1 and B31.3 (References 1, 2, and 3).

3.12.2 Codes and Standards

Applicable codes and standards used in the design fabrication, construction, testing, and inservice inspection (ISI) of the piping systems and piping supports are consistent with the codes and standards specified in 10 CFR 50.55a; the applicable General Design Criteria (GDC 1, 2, 4, 14, and 15) for nuclear power plants, 10 CFR 50, Appendix A, as described in Section 3.1; and 10 CFR 50, Appendix S.

3.12.2.1 ASME Boiler and Pressure Vessel Code

*[The safety-related piping system design and analysis for the APR1400 are performed in accordance with the 2007 Edition with 2008 addenda of the ASME Section III (Reference 1).]**

*[However, for socket weld leg dimensions, ASME Section III, Footnote 11 to Figure NC/ND-3673.2(b)-1 in the 1989 Edition is used for socket weld with leg size less than 1.09 t_n instead of Footnote 13 from 2007 Edition and 2008 Addenda to Figures NC/ND-3673.2(b)-1.]**

For ASME Class 1 piping, the material and D_0/t requirements of NB-3656(b) are met for all service limits when service limits include reversing dynamic loads, and alternative rules for reversing dynamic loads are used.

The non-safety-related piping system design and analysis for the APR1400 are performed in accordance with the 2010 Edition of ASME B31.1 (Reference 2) and the 2010 Edition of ASME B31.3 (Reference 3).

As described in Subsection 3.12.6, all pipe supports are designed in accordance with Subsection NF of the 2007 Edition with 2008 addenda of the ASME Section III.

3.12.2.2 ASME Code Cases

ASME Code cases applicable for the piping systems and pipe supports of the APR1400 are Code Cases N-122-2, N-71-18, and N-249-14 (Reference 4).

Other ASME Code cases may be used if they are conditionally or unconditionally approved in NRC RG 1.84 (Reference 5). ASME Code cases listed in NRC RG 1.193 (Reference 6) may be used with the approval of the NRC.

3.12.2.3 Piping System Design Specification and Design Report

The design specification for all ASME Class 1, 2, and 3 piping systems including loading combinations, design data, and other design inputs is to be developed in accordance with ASME Section III. The design specification defines the code and the edition to be applied to the piping system design. In addition, ASME Section III requires that design reports for

all ASME Class 1, 2, and 3 piping systems demonstrating and documenting that as-built piping system and pipe support configurations adhere to the requirements of the design specification (Reference 7). The COL applicant is to prepare design reports for ASME Class 1, 2, and 3 piping system in accordance with ASME Section III (COL 3.12(1)).

3.12.3 Piping Analysis Methods

Seismic analysis methods used for all seismic Category I, seismic Category II, and non-seismic piping systems, as described below, include the response spectrum method, time history method, or where applicable, the equivalent static load method in accordance with Subsection 3.7.3.1.1.

*[This section covers the procedure used for analytical modeling, selection of frequencies, damping criteria, combination of modal responses, the analysis for small bore piping, and interaction of seismic Category I piping systems with other piping systems.]**

3.12.3.1 Experimental Stress Analysis Method

For the APR1400, experimental stress analysis methods are not used for the design of the piping system and its supports.

3.12.3.2 Modal Response Spectrum Method

3.12.3.2.1 General

The modal response spectrum method is a measure of how the piping system with certain natural frequencies responds to an earthquake applied at its pipe supports. To determine the piping system natural frequencies, each piping system is idealized as a mathematical model consisting of lumped masses connected by elastic members.

The response spectra are applied to the piping system at locations of structural attachment, such as pipe supports or equipment for each of the three orthogonal spatial components. The response spectra analysis is performed using either uniform support motion (USM) or independent support motion (ISM) method.

The response spectra analysis for piping systems uses the damping values specified in NRC RG 1.61 (Reference 8). No combination of piping damping values in NRC RG 1.61 is allowed.

3.12.3.2.2 Floor Response Spectrum

As described in Subsection 3.7.2.5, a floor response spectrum is a curve that represents the peak acceleration responses verses frequencies of a series of single degree of freedom spring mass systems, which are excited by an earthquake time history motion.

To account for the uncertainty in the structural frequencies due to uncertainties in the material properties of structures and soil and to approximations in the seismic analysis modeling techniques, the floor response spectra are smoothed with the peak values broadened in accordance with NRC RG 1.122 (Reference 9).

3.12.3.2.3 Uniform Support Motion Method

For analyzing the piping systems or components supported at multiple locations within a single structure or multiple structures, a uniform response spectrum (URS) that envelops all of the individual response spectra at the various support locations is used to calculate the maximum inertial responses of the piping system or component, which is defined as the uniform support motion (USM) method. The enveloped response spectrum is developed and applied in the two mutually perpendicular horizontal directions and in the vertical direction. Typically, the USM method can result in considerable overestimation of seismic responses.

The modal and spatial combination methods using the USM method are described in Subsections 3.12.3.2.4 and 3.12.3.2.5.

The piping system analyses performed using the USM method use damping values specified in Table 3 or the frequency-dependent damping values of Figure 1 of NRC RG 1.61.

3.12.3.2.4 Modal Combination

The response of individual modes is calculated and combined with the other modal responses using the methods as described in NRC RG 1.92 (Reference 10).

For the piping system modes with no closely spaced (two consecutive modes are defined as closely spaced if their frequencies differ from each other by 10 percent or less of the lower frequency), the representative maximum responses are obtained by taking the square root of the sum of the squares (SRSS). This method may not produce conservative results for piping systems with closely spaced modes.

Therefore, to combine the modal responses of the piping system with closely spaced modes, the 10 percent method described in Subsection 3.7.2.7 is applied. The responses of low frequency modes are obtained from all the low frequency modes with frequencies at least up to the ZPA cutoff frequency.

In addition, the residual rigid response of the missing mass modes as described in Regulatory Positions C.1.4.1 and C.1.5.1 of NRC RG 1.92 (Reference 11), and the missing mass correction (MMC) method in the ADLPIPE computer program are considered. The left-out-force (LOF) method in the PIPESTRESS computer program is used for calculating the effect of the high frequency rigid modes. The LOF and MMC methods are described in the PIPESTRESS Theory Manual (Reference 12) and the ADLPIPE Manual (Reference 26).

3.12.3.2.5 Directional Combination

The responses due to each of the three orthogonal spatial components of earthquake motion are combined by SRSS as described in Regulatory Position C.2.1 of NRC RG 1.92 (Reference 10).

3.12.3.2.6 Seismic Anchor Motion Analysis Method

Seismic anchor motion (SAM) analysis is a static analysis and includes the following effects acting on the piping system supported by either a single structure or more than one structure.

a. Building seismic movements

b. Equipment seismic movements as anchor motions on the piping system

c. Header piping seismic movements for decoupled branch lines

The effects of SAM on the piping system are considered for the safe shutdown earthquake (SSE).

In the SAM analysis, the relative displacements at the support are considered. The maximum relative support displacements are obtained from the structural response calculations. The support displacements are then imposed on the supported item in the most unfavorable combination by static analysis procedures.

In case of the seismic analysis using the USM method, the effects of SAMs in each of the three orthogonal spatial components are analyzed separately considering all dynamic pipe supports to be active. These interspatial responses are combined by the SRSS method to obtain cumulative effect of pipe support displacements.

The effects of these seismic anchor motions are then considered by combining with SSE inertia by the absolute summation method.

In case of the seismic analysis using the ISM method, the effects of SAMs are analyzed with the method specified in Section 2 of NUREG-1061, Volume 4 (Reference 13). The responses from SAM of each group for each spatial direction are combined by the absolute summation method. These interspatial responses are combined by the SRSS method to obtain the cumulative effect of pipe support displacements. The effects of these seismic anchor motions are considered by combining with SSE inertia using the SRSS method.

3.12.3.3 Independent Support Motion Method

Independent support motion (ISM) method may be used in lieu of the uniform support motion (USM) method when piping systems are supported by more than one supporting structure or at multiple levels within the same structure because the USM method can result in considerable overestimation of seismic responses.

In the analysis using the ISM method, the supports are divided into support groups. Each support group consists of the supports that have similar time-history inputs. Typically, all supports in each support group are located on the same floor or portions of the floor of a structure.

The responses caused by each support group are combined by the absolute summation method. The modal and directional responses are then combined as described in Section 2 of NUREG-1061 Volume 4 (Reference 13).

Analyses performed using the ISM method are used for damping values identified in Table 3 of NRC RG 1.61 (Reference 8).

3.12.3.4 Time-History Method

The time-history method may be used for other types of dynamic analyses such as hydraulic transient loads caused by water or steam hammer, safety and relief valve discharge actuation loads, jet force loads, postulated pipe breaks, or any other dynamic loading associated with fluid flow transients.

For the dynamic response of the piping system, the time history analysis may be performed using the modal superposition method (Reference 14).

When the modal superposition method is used, the cutoff frequency for the determination of modal properties is selected to account for the principal vibration modes of the piping system based upon mass and stiffness properties, modal participation factors and the frequency content of the input forcing function. As required on a case-by-case basis, the analysis is repeated with more modes in order to verify the cutoff frequency for the determination of modal properties.

The missing mass effects of high frequency modes are included based on the same principles described in Subsection 3.12.3.2.4.

Alternatively, the cutoff frequency is determined so that the calculated number of modes produces dynamic analysis results within 10 percent of the results of the dynamic analysis, including the next higher mode.

Damping values are described in Subsection 3.12.5.4.

3.12.3.5 Inelastic Analysis Method

For the APR1400, inelastic analysis methods are not used for the design of the piping system and its supports.

3.12.3.6 Small-Bore Piping System Method

Small bore piping system is defined as ASME Class 1 piping less than or equal to nominal diameter (DN) 25 (nominal pipe size (NPS) 1) and smaller, and the other classes piping with nominal diameter DN 50 (NPS 2) and smaller. These small bore piping systems are analyzed using the response spectrum method or the equivalent static load method.

The modal response spectrum method is described in Subsections 3.12.3.2 and 3.12.3.3, and used when the equivalent static method cannot be justified.

The equivalent static load method produces conservative results in their responses. The masses of piping, its contents, and any in-line component are considered as lumped masses at their center of gravity locations.

The static forces are determined by multiplying the contributing mass by a seismic acceleration (g factor) at each location. To obtain an equivalent static load of small bore piping system, which is represented by a simple model, a factor of 1.5 is applied to the peak acceleration of the applicable floor response spectrum. This static force analysis is performed for all three spatial components of seismic excitation, and the results of these static analyses are combined by the SRSS method.

3.12.3.7 Non-seismic/Seismic Interaction (II/I)

The APR1400 is designed to minimize the interactions of seismic Category I piping systems with non-seismic Category I piping system and to protect seismic Category I piping system from adverse interactions with a non-seismic Category I piping system. A non-seismic Category I piping system whose continuous function is not required but whose failure could adversely affect the safety function of structures, systems, and components

(SSCs) is seismically designed. The primary method of protecting a seismic Category I piping system is its isolation from a non-seismic Category I piping system. If isolation of the seismic Category I piping system is not feasible or practical, adjacent non-seismic Category I piping is classified as seismic Category II and analyzed in accordance with the same seismic design criteria applicable to the seismic Category I piping and pipe supports.

Similarly, for non-seismic piping attached to seismic piping, the dynamic effects of the non-seismic piping account for the modeling of the seismic piping. The attached non-seismic piping up to the analysis boundary is classified as seismic Category II and designed to preclude causing failure of the seismic piping during a seismic event. Non-seismic piping classified as seismic Category II is isolated from the continuing non-seismic piping by the analysis boundary, such as seismic boundary anchor. The seismic boundary anchor provides reasonable assurance that the seismic response of the seismic Category II is not affected by the dynamic effect from the non-seismic side of the anchor. The seismic boundary anchors are designed considering the plastic hinge moment from the non-seismic piping.

3.12.3.8 Seismic Category I Buried Piping

The seismic design of the buried seismic Category I piping is performed in accordance with the procedures described in Subsection 3.7.3.7.

3.12.4 Piping Modeling Technique

3.12.4.1 Computer Codes

The following computer programs are used in the analysis of seismic Category I piping designated as ASME Class 1, 2, and 3, and non-ASME piping systems. These computer programs are further described in Subsection 3.9.1.2. The applicable computer programs are as follows:

a. PIPESTRESS

PIPESTRESS is a piping analysis program that is used for the analysis of ASME Class 1, 2, and 3 as well as ASME B31.1 and B31.3 piping systems. This program is described in Subsection 3.9.1.2.1.14.

b. ANSYS

ANSYS is used in numerous applications for all components in the areas of structural, fatigue, thermal, and eigenvalue analysis including static and dynamic; elastic, plastic, creep and swelling; small and large deflections; steady-state and transient heat transfer and fluid flow. This program is described in Subsection 3.9.1.2.1.7.

c. ADLPIPE

ADLPIPE is a linear finite element program for the static and dynamic analysis of piping systems. The program performs ASME Class 1 analysis in any manner specified by the user to create the appropriate loading cases applicable for each of the ASME Code stress equations. This program is described in Subsection 3.9.1.2.1.3.

d. RELAP5/MOD3.3

RELAP5/MOD 3.3 is developed by the NRC is for best-estimate transient simulation of light water reactor coolant systems during postulated accidents in the light water reactor (LWR). This program is also used for the analysis of a dynamic behavior, such as water hammer and safety/relief valve discharge, by modeling the fluid flow. This program is described in Subsection 3.9.1.2.1.6.

e. GTSTRUDL

GTSTRUDL is used for structural analysis of pipe supports in compliance with ASME Section III, Subsection NF, and ANSI/AISC 360-05 (Reference 15). This

computer program is a general-purpose structural analysis program including the base plate flexibility, anchor bolts check, and the calculation of weld leg sizes.

3.12.4.2 Dynamic Piping Model

For dynamic analysis, the seismic Category I piping systems and pipe supports are modeled as a three-dimensional space framework using a linear finite element analysis program. The analysis model consists of a series of nodes connected by beam elements with stiffness properties representing the piping and other components. Node points are modeled at points that define piping geometries as well as lumped mass locations, support locations, flange locations, expansion joint locations, or locations of structural or load discontinuities; other appurtenance locations of interest along the piping system are modeled as a node point.

In the dynamic mathematical model, the distributed mass of the piping system, including pipe, contents, and insulation weight, is represented as lumped masses placed at each node.

To provide reasonable assurance that there are a sufficient number of mass points for an accurate dynamic model in the PIPESTRESS program (Reference 16), the length, L (ft), is determined by the following formula based on a simply supported pipe element with fundamental natural frequency.

$$L^4 = (\alpha^2 / f_R^2)\,(EI / W)$$

Where:

E	=	modulus of elasticity [psi]
I	=	moment of inertia [in^4]
W	=	mass per unit length [lbm/ft]
f_R	=	fundamental natural frequency [Hz]
α	=	0.743

If the distance between mass points exceeds L/2 when the automatic mass modeling is used, then additional mass points are generated.

Concentrated weights of the components, such as valves, flanges, and other appurtenances, are also modeled as lumped masses. The torsional effect due to eccentricity of an eccentric mass, such as a valve operator, is considered.

In general, pipe supports are modeled as rigid with the rigidity verified by checking support deflection in the restrained direction, if springs with actual stiffness values for the restrained degrees of freedom. Pipe support hardware weight for snubbers, struts, and spring hangers supported by piping system is considered in the piping analysis. The weight added by the component support is included in the piping analysis when it is greater than 10 percent of the total mass of the adjacent pipe span including pipes, contents, insulations, and in-line components.

In general, an entire piping system cannot be modeled and analyzed as a single model; the piping system is therefore conveniently divided into multiple, smaller piping subsystems that satisfy the analysis size limitations of the computer program used for the piping system analysis. Branch piping that does not have a significant effect on the run piping is decoupled from the run pipe analysis based on the branch decoupling criteria defined in Subsection 3.12.4.4. Intermediate pipe anchors such as wall or slab penetration sleeve anchors and structural anchor supports may also be used for subdividing the piping systems.

3.12.4.3 Piping Benchmark Program

The computer programs used for the piping system analysis are verified in accordance with NRC benchmark problems.

The piping benchmark problems prescribed in NUREG/CR-1677, Volumes 1 and 2 (Reference 17), are used to validate the PIPESTRESS and ADLPIPE computer programs used in piping system analysis.

3.12.4.4 Decoupling Criteria

Small branch lines including instrument connections may be decoupled from the analysis model of the larger run pipe provided that either the ratio of the branch pipe mean diameter to the run pipe mean diameter (D_b/D_r) is less than or equal to 1/3 or the ratio of the moments of inertia of the two lines (I_b/I_r) is less than or equal to 1/25.

In the run pipe analysis, the applicable stress intensification factors (SIF) and/or stress indices are incorporated. The mass effects of the branch line, where the mass of half the span of the branch pipe is greater than 10 percent of the mass of the pipe run span, are also considered at the run pipe connection point. If a large valve or other large concentrated mass is located within the first span of the branch piping, the torsional effects of the eccentric mass is considered. In these cases, the branch pipe is included in the run pipe model up to the first anchor or four seismic supports in each of the three perpendicular directions to consider eccentric mass effect.

In the decoupled branch pipe analysis, the run pipe connection point is modeled as an anchor with the same SIF and/or stress indices as the run pipe and the effect of seismic excitation from run pipe is considered as follows. The analysis of the branch line considers run pipe movements greater than 1/16 inch at the header connection. The movements of the run pipe due to the thermal, seismic anchor motion (SAM), or pipe break analyses at the header connection are applied as anchor motions in the branch line analysis. In addition, seismic inertial movement from the run pipe analysis is also considered at header connection. The inertial effects of the run pipe on the branch line are considered in the branch piping analysis in order to capture the possible amplification of inertial input from the run pipe. The effects of seismic excitations from the two seismic supports in each of the three perpendicular directions to the branch connections in the run pipe are included in the branch piping analysis.

3.12.5 Piping Stress Analysis Criteria

3.12.5.1 Seismic Input Envelope vs. Site-Specific Spectra

Seismic input envelope and site-specific spectra of the APR1400 are described in Subsection 3.7.2.5.

3.12.5.2 Design Transients

RCS design transients used for the design and fatigue analysis of ASME Class 1 piping systems and support components are addressed in Table 3.9-1.

3.12.5.3 Loadings and Load Combination

3.12.5.3.1 Pressure

*[Internal design pressure, P, is used in the design and analysis of ASME Class 1, 2, and 3 piping (Reference 1). Minimum pipe wall thicknesses are determined using the formulations of NB/NC/ND-3640 and the design pressure. The applicable design and maximum service level pressures are used in load combinations as identified in Tables 3.12-1 and 3.12-2.]**

3.12.5.3.2 Mechanical Loads

*[The weight of the piping system, its contents, any insulation and in-line equipment, and any other mechanical loads identified in the design specification are considered in the piping analysis. The weight of water during hydrostatic testing is considered for steam or air-filled piping systems.]**

3.12.5.3.3 Thermal Expansion

*[The effect of linear thermal expansion range during various operating modes is considered along with thermal movements of terminal equipment nozzles, anchors, or restraints (thermal anchor movements) corresponding to the operating modes. The stress free temperature is taken as 21 ℃ (70 ℉). The piping systems operating at a temperature of 65 ℃ (150 ℉) (Reference 1) and below are not analyzed for the effects of linear thermal expansion.]**

*[Thermal anchor movements less than or equal to XX mm (1/16 in) may be excluded from analysis since this represents the industry practice for acceptable gaps in pipe supports (Reference 30).]**

3.12.5.3.4 Seismic

[The effects of seismic inertial loads and anchor movements are included in the design analysis. The ground motion of the operating basis earthquake (OBE) for the APR1400 is equal to one-third of the ground motion of the SSE. Per Appendix S to 10 CFR Part 50, the OBE load case does not require explicit design analysis. In the event of an earthquake that meets or exceeds the OBE ground motion, plant shutdown is required and seismic

*Category I piping and supports are inspected to provide reasonable assurance that no functional damage has occurred. The design of the APR1400 seismic Category I piping and supports includes analysis of the inertial and anchor movement (greater than 1/16 inch) effects of the SSE event. These loads are Service Level D loads.]**

*[Fatigue effects due to earthquake loads are addressed in Table 3.12-1. Tables 3.12-1 and 3.12-2 identify SSE inertial and displacement loads in various load combinations for ASME Class 1, 2, and 3 piping and piping supports.]**

3.12.5.3.5 Fluid Transient Loads

*[The relief/safety valve thrust loads for open or closed systems are functions of valve opening, flow rate, flow area, and fluid properties. The analysis of these loads is usually accomplished using static loads as input to the piping analysis with appropriate dynamic load factors. Dynamic analysis of relief valve thrusts is used when static analysis produces undesirably conservative results. These loads are considered in Service Level B, C, or D load combinations.]**

*[The water hammer phenomenon involves the rapid change in fluid flow creating a "shock wave" effect in the piping system. They are usually set in motion by rapid actuation of control valves, relief valves, and check valves. Rapid start or trip of a pump or turbine can also initiate such a phenomenon. The water hammer phenomenon is analyzed using dynamic analysis methods. The water hammer loads are considered in Level B, C, or D service load combinations.]**

3.12.5.3.6 Wind/Tornado Loads

*[ASME Class 1, 2, and 3 piping for the APR1400 within the DC scope is not exposed to wind or tornado loads. The COL applicant is to design those piping exposed to wind and/or tornado, if any, to the plant design basis loads (COL 3.12(2)).]**

3.12.5.3.7 Design Basis Pipe Break Loads

[High-energy line breaks cause loads in the form of pipe whip, jet impingement, and changes in environmental conditions. Design basis pipe break (DBPB) loads include the

*impact of the RCPB piping break, main steam and feedwater line breaks except for piping breaks that meet the leak-before-break (LBB) criteria (see Subsection 3.6.3) or inside the pipe break exclusion area. DBPB loads are considered in Level D service load combinations.]**

3.12.5.3.8 Thermal and Pressure Transient Loads

*[Thermal and pressure transients are evaluated in the analysis of ASME Class 1 piping by calculating the range of primary plus secondary stress intensities. For ASME Class 2 and 3 piping, these transients are included as load cases in the appropriate ASME Code equations.]**

3.12.5.3.9 Hydrostatic Pressure Tests

*[Piping systems are tested for leaks by filling the system with the test fluid and pressurizing to test pressures specified in the design specification. Piping systems that normally carry operating fluids, such as steam or gas, have stops placed in spring hangers and temporary supports added as needed. The effects of the test pressure and fluid weight are considered in satisfying the appropriate ASME Class 1, 2, and 3 stress equations. The effects of hydrostatic pressure tests on ASME Class 1 piping fatigue are in accordance with NB-3226.]**

3.12.5.3.10 Load Combinations

*[Using the methodology and equations from the ASME Code, pipe stresses are calculated for various load combinations. The ASME Code includes design limits for design conditions; Service Levels A, B, C, and D; and testing. Load combinations for ASME Class 1 piping are given in Table 3.12-1. ASME Class 2 and 3 load combinations are given in Table 3.12-2.]**

3.12.5.4 Damping Values

Damping values in Table 3 of NRC RG 1.61 (Reference 8) are used for dynamic response spectra and time-history analyses.

Frequency-dependent damping values identified in Figure 1 of NRC RG 1.61 may also be used for uniform support motion (USM) response spectra analysis provided the five restrictions identified in C.2 of NRC RG 1.61 (Reference 8).

3.12.5.5 Combination of Modal Responses

Seismic responses to each mode are calculated in accordance with the method described in NRC RG 1.92 (Reference 10) and combined with other responses. Seismic responses to periodic modal response with sufficiently separated frequencies are combined by SRSS. Closely spaced frequencies are combined by the ten percent method.

3.12.5.6 High-Frequency Modes

PIPESTRESS and ADLPIPE computer programs use left-out-force (LOF) and missing mass correction (MMC) methods to calculate the effect of high-frequency rigid modes (References 12 and 19). The result obtained from this method is multiplied by scalar amplitude that is equivalent to the highest spectral acceleration for frequencies, which is greater than the last natural frequency being calculated by LOF and MMC methods regarding the corresponding directional spectrum.

3.12.5.7 Fatigue Evaluation of ASME Code Class 1 Piping

Fatigue evaluation of ASME Class 1 piping systems is performed for loadings caused by thermal and pressure transients, thermal stratification, and other cyclic events including earthquakes. *[Fatigue evaluation of ASME Class 1 piping greater than DN 25 (NPS 1) is performed per ASME Section III, Subsection NB-3653.]** The COL applicant is to perform fatigue evaluation of ASME Class 1 piping except for the RCS primary loop (COL 3.12(3)).

The fatigue evaluation considering the effects of the reactor coolant environment in ASME Class 1 piping follows the guidance in NRC RG 1.207 (Reference 20).

3.12.5.8 Fatigue Evaluation of ASME Code Class 2 and 3 Piping

The calculation for the cumulative usage factors of ASME Class 2 and 3 piping is not required. Fatigue evaluation of ASME Class 2 and 3 piping is not performed in accordance with the requirements in NC/ND-3653.2(a). Acceptable cyclic stress is reduced by applying stress range reduction factor, f, to thermal expansion stress ranges in accordance with Table NC/ND-3611.2(e)-1. The stress intensification factors that are applicable to piping components and joints are based on fatigue testing. The COL applicant is to perform stress evaluations for ASME Class 2 and 3 piping (COL 3.12(4)).

3.12.5.9 Thermal Oscillations in Piping Connected to the Reactor Coolant System

Unisolable sections of piping connected to the reactor coolant system (RCS) that could be subjected to stresses from thermal stratification caused by valve leakages or turbulent penetrations are reviewed to provide reasonable assurance of the structural integrity of the lines.

APR1400 conforms to the requirements in U.S. NRC Bulletin 88-08 (Reference 21) for all piping connected to the reactor coolant system. Data available from the reference plant have been evaluated and incorporated into the design of the APR1400.

Based on the temperature distributions in the piping between the direct vessel injection (DVI) nozzle and the first isolation valve, and the piping between shutdown cooling system (SCS) nozzle and the first isolation valve, which were evaluated using commercial thermal hydraulic analysis code, it is determined that the temperature difference in stratified flow is so small that the thermal stratification effects will be negligible for SCS suction line.

Thermal stratification is anticipated in the horizontal section of the piping between the DVI nozzle at the reactor vessel and the first isolation valve.

The effect of thermal stratification on the piping system is analyzed in two parts:

a. Global stratification, which causes bending

b. Local stratification, which causes stresses similar to thermal gradient stresses

To consider the global stratification, the global bending stress due to a vertical temperature distribution in horizontal and non-horizontal members is mathematically defined in the computer program PIPESTRESS (Reference 16) as follows:

$$g_u = \frac{\int_{\Omega} T(v) v \, d\Omega}{I_u}$$

Where:

Ω	=	the pipe wall region
$T(v)$	=	a vertical temperature distribution on pipe cross-section
I_u	=	the moment of inertia
v	=	vertical direction against axis of a horizontal pipe

Then, αg_u is the load on the pipe due to the temperature distribution $T(v)$, where α is the coefficient of thermal expansion of the pipe. The unit of αg_u is rotation-per-unit-length.

Local stresses due to thermal stratification are confined to thermal stratification zone. The boundary conditions are such that local thermal stresses are due only to temperature distribution across the pipe wall. The local stress intensity due to thermal stratification is calculated for the fatigue analysis of the ASME Class 1 piping system. The steps for piping fatigue analysis are as follows:

a. Thermal hydraulic analysis

b. Conversion of thermal hydraulic analysis data

c. Direct application of temperature distribution data into three-dimensional piping model

d. Extraction of the maximum stress intensity (local stress)

e. Evaluation of code requirements in accordance with ASME Section III, NB-3600

The reactor vessel and piping segments away from the stratified zone are not affected by thermal stratification and are not considered in local stress determination. The maximum stress intensity extracted from three-dimensional finite element analysis is added to the ΔT_2 term of ASME Section III, NB-3653.2 Equation (11) without considering stress index.

3.12.5.10 Thermal Stratification

NRC Bulletin 79-13 (Reference 22) addresses the effect of thermal stratification that leads to the cracking of the feedwater line. The APR1400 feedwater lines are designed to minimize the thermal stratification. The feedwater lines are angled downward from the horizontal to minimize the potential for thermal stratification. This is also described in Subsection 5.4.2.1.2.1.3.

NRC Bulletin 88-11 (Reference 23) was issued in response to the results of an inspection of the surge line at Trojan that showed large, unexpected movements that closed available gaps between the line and pipe whip restraints. NRC Bulletin 88-11 requires that holders of operating licenses or construction permits establish and implement a program to provide reasonable assurance of the structural integrity of the surge line when subjected to thermal stratification in the pressurizer surge line.

The APR1400 conforms to NRC Bulletin 88-11 pressurizer surge line requirements. Available data from construction plants have been evaluated and incorporated into the design of the APR1400. The design will continue to be assessed as new data become available and will be evaluated for applicability to the APR1400.

In response to NRC Bulletin 88-11, a test in a Korean nuclear power plant was performed to obtain operating plant data that were needed to characterize thermal stratification in the surge line. Data obtained at operating plants showed that temperature differences in the surge line walls due to thermal stratification were related to the mode of plant operation. These data confirmed that the maximum temperature differences in the surge line were bounded by the difference in temperature between the pressurizer and the hot leg. The APR1400 surge line is designed for the maximum temperature difference that is experienced between the pressurizer and the hot leg.

Piping systems subjected to stratified flow are evaluated for additional thermal stresses due to thermal stratification. Stratified flow exists when a hotter fluid flows over a colder one.

This condition induces a vertical thermal gradient, resulting in increased overall bending stresses and localized thermal gradient stresses. Stratified flow effects consist of (1) local stresses due to temperature gradients in the pipe wall and (2) additional thermal pipe bending moments generated by the restraining effect of supports on the stratified-flow-induced curvature of the piping. The extent of stratification is reduced by sloping generally horizontal pipe runs and is mitigated by carefully selecting designs and operating procedures.

Structural evaluations are performed using elastic and/or simplified elastic-plastic analyses in accordance with the ASME Code, considering the applicable loadings in addition to the stratified flow loadings.

The stratified-flow-induced curvature of the piping and local stresses due to a temperature gradient are obtained from finite element analyses. These analyses provide the local effects and pipe rotations for an unsupported pipe segment. A stratified flow thermal hydraulic model with the top half of the fluid at hotter temperature and the lower half of the fluid at colder temperature is used to determine the pipe wall temperature based on the thermal hydraulic conditions. Heat transfer and structural thermal stress analyses are performed using the ANSYS computer program to determine the rotations and local stresses. Rotations are considered to act over all horizontal portions of the pipe. The resulting bending moments are calculated in the piping analysis with the ADLPIPE computer program by allowing the pipe to thermally expand unconstrained and by then applying a set of equal and opposite displacements at the rigid support points. Local stress effects due to top-to-bottom thermal gradients are also considered to act over all horizontal sections of pipe. For ASME Class 1 piping, gross bending stresses due to stratification are considered as secondary stresses, while local stresses due to thermal gradients are considered as peak stresses.

3.12.5.11 Safety Relief Valve Design, Installation, and Testing

The design and installation of the safety valves and relief valves for overpressure protection are performed per the requirements in Appendix O of the ASME Code (Reference 24).

A static method with a conservative dynamic loading factor is used to calculate the discharge forces of safety valves and relief valves that use open vent stacks for discharging fluid directly into the air. Dynamic transient loads of fluid discharged from safety/relief

valve to vessels or headers are considered as forces acting on the changes in direction such as elbows or branch connections. Piping stresses and support/restraint loads resulting from these discharge forces of safety and relief valves are assessed by dynamic time-history analysis or by an equivalent static force analysis in piping systems.

See Subsection 3.12.4.1.d for the computer program used in the analysis.

3.12.5.12 Functional Capability

Functional capability of all ASME Class 1, 2, and 3 piping systems essential for safe shutdown of the plant is reasonably assured in accordance with NUREG-1367 (Reference 25) to provide sufficient fluid flow path under Service Level D loading conditions.

3.12.5.13 Combination of Inertial and Seismic Anchor Motion Effects

The inertial and seismic anchor motion (SAM) effects are analyzed separately. The results of SAM analysis are combined with those of seismic inertial analysis by absolute summation when an enveloped USM method is used, per SRP 3.7.3, and by the SRSS when ISM method is used for the dynamic analysis per NUREG-1061, Volume 4 (Reference 13).

3.12.5.14 Operating Basis Earthquake as a Design Load

The applicable earthquake load in the design of APR1400 piping systems is described in Section 3.7. The operating basis earthquake (OBE) ground motion has been set as one-third of SSE and, therefore, is not considered in the seismic design in accordance with 10 CFR 50.

3.12.5.15 Welded Attachments

If integral welded attachments are used to attach supports on piping systems, they are evaluated by the nonmandatory Appendix Y of ASME Section III, "Evaluation of the Design of Rectangular and Hollow Circular Cross Section Welded Attachments on Class 1, 2, and 3 Piping."

3.12.5.16 Modal Damping for Composite Structures

The composite modal damping for coupled building and piping systems is used for piping systems that are coupled to concrete building structures, if applicable. The procedure used to determine the composite modal damping value for the piping system is described in Subsection 3.7.2.15.

3.12.5.17 Minimum Temperature for Thermal Analyses

The stress-free state temperature for a piping system is typically defined as 21 °C (70 °F). The analysis for a piping system with an operational temperature of greater than 65 °C (150 °F) or less than 4 °C (40 °F) is performed for the effect of thermal expansion/contraction.

3.12.5.18 Intersystem Loss-of-Coolant Accident

Minimum wall thickness of piping systems that are influenced by pressure of reactor coolant pressure boundary (RCPB) and connected to part of the RCS components is calculated according to the requirements of ASME Section III NB-3640.

3.12.5.19 Effects of Environment on Fatigue Design

The fatigue evaluation considering the effects of the reactor coolant environment in ASME Class 1 piping follows the guidance in NRC RG 1.207 (Reference 20). The COL applicant is to perform a fatigue evaluation of environmental impact on ASME Class 1 piping, except in the RCS primary loop, using methods acceptable to the NRC at the time of evaluation (COL 3.12(5)).

3.12.6 Piping Support Design Criteria

This section provides piping support design methods, procedures and criteria, and piping support design criteria provided in Subsection 3.9.3 are used as references.

3.12.6.1 Applicable Codes

Seismic Category I pipe supports are designed in accordance with ASME Section III, NF for Service Levels A, B, C, and D, and the acceptance limits of Appendix F of ASME Section III for Service Level D.

Standard component supports are designed, manufactured, installed, and tested pursuant to Subsection NF of the ASME Section III.

For non-seismic category pipe supports supporting piping analyzed to ASME B31.1, the requirements of ASME B31.1 for supports (Sections 120 and 121) are met, where applicable. In addition, the structural elements are designed using guidance from the AISC 360-05 (Reference 15).

In addition to the pipe support design codes mentioned above, expansion anchors and other steel embedments in concrete are designed in accordance with Subsection 3.12.6.4.

3.12.6.2 Jurisdictional Boundaries

The jurisdictional boundary between the pipe and its support structure follows the guidance of NB-1132, NC-1132, or ND-1132, as appropriate for the ASME Section III Class of piping involved.

The jurisdictional boundary between the pipe support and the building structure follows the guidance of *[ASME Section III, NF-1130.]** In general, for attachments to building steel, the boundary is taken at the interface with the building steel, with the weld being designed to the rules of NF. For attachments to concrete building structures, the boundary is generally at the weld of the support member to a baseplate or embedded plate, with the weld again being designed to the rules of NF.

3.12.6.3 Loads and Load Combinations

Subsection 3.12.5.3 describes loads, loading combinations including system operating transients, and stress criteria for piping supports, including margins of safety.

Seismic self-weight excitations (Subsection 3.12.6.8) for Service Level D and friction loads (Subsection 3.12.6.10) for Service Level A are considered in addition to the above-mentioned guidances. Table 3.9-10 is also referenced.

The stress limits for pipe support designs meet the criteria of *[ASME Section III, Subsection NF.]**

3.12.6.4 Pipe Support Baseplate and Anchor Bolt Design

Although the use of baseplates with expansion anchors is expected to be minimized in the APR1400 design, baseplate designs are likely to be needed. For these designs, the concrete is evaluated using *[ACI 349-97,]** Appendix B (Reference 26), subject to the conditions and limitations of NRC RG 1.199 (Reference 34). This guidance accounts for the proper consideration of anchor bolt spacing and distance to a free edge of concrete. In addition, all aspects of the anchor bolt design, including baseplate flexibility and factors of safety, will be used in the development of anchor bolt loads, as addressed in NRC Bulletin Letter 79-02 (Reference 28).

3.12.6.5 Use of Energy Absorbers and Limit Stops

Energy absorbers and limit stops for pipe supports are not used for the APR1400 design.

3.12.6.6 Use of Snubbers

Snubbers for piping systems are used for situations requiring free thermal movements, while restraining movements due to dynamic loadings. Typical snubber components are manufactured standard hardware, and may be either hydraulic or mechanical in operation.

Snubbers are not capable of supporting gravity loads. Under certain circumstances, the weight of the snubber bearing on the pipe is included in the piping stress analysis. Snubbers in general are not to be used where thermal movements are small. Also, use of snubbers is minimized to the extent that is reasonable due to the maintenance and testing requirements for these components. As such, accessibility of any snubbers that are used is considered in the design of the piping system.

The functional requirements and design specifications provided to the supplier of snubbers contain the information described in Subsection 3.9.3.4.

3.12.6.7 Pipe Support Stiffness

Rigid stiffness is used for the piping supports in the piping analysis model with a check on support deflection in the restrained directions to verify the rigidity. The actual stiffness is

modeled for variable spring supports. If the actual support stiffness is used for any support other than variable spring supports, all supports within the piping model use the actual support stiffness.

Each support modeled as rigid is checked with the deflection in the restrained directions to a maximum of 1.6 mm (1/16 in) for SSE loadings, and a maximum of 3.2 mm (1/8 in) for other loadings.

3.12.6.8 Seismic Self-Weight Excitation

The excitation of the support structure to SSE loadings is to be included in the pipe support analysis. Damping values for welded and bolted structures are given in Revision 1 to NRC RG 1.61 (Reference 8). This support self-weight SSE response and the piping inertial load SSE response are to be combined by absolute summation.

3.12.6.9 Design of Supplementary Steel

This subsection provides design information on any supplementary steel required to connect the main support structure to the building structure.

As addressed in Subsection 3.12.6.1, all seismic Category I pipe supports for the APR1400 are designed to ASME Section III, NF. For non-seismic pipe supports, AISC 360-05 (Reference 15) is used for the supplementary steel, as it is for the main support structure.

3.12.6.10 Consideration of Friction Forces

Friction forces are developed in the pipe support when a pipe slides across the surface of a support member in the unrestrained directions under thermal expansion conditions. Because friction is due to the gradual movement of the pipe, loads from friction are only calculated using the deadweight and thermal loads normal to the applicable support member.

Specifically, the friction forces need to be calculated only if the thermal movement in the applicable unrestrained directions is greater than 1.6 mm (1/16 in). The coefficient of friction is taken as 0.3 for steel-to-steel conditions and 0.1 for low friction slide/bearing plates.

3.12.6.11 Pipe Support Gaps and Clearances

For guide type pipe supports modeled as rigid restraints in the piping analysis, the typical industry design practice is to provide small gaps between the pipe and its surrounding structural members. These small gaps allow radial thermal expansion of the pipe as well as allow rotation of the pipe at the support. The normal design practice for the APR1400 is to use a nominal cold condition gap of 1.6 mm (1/16 in) on each side of the pipe in the restrained direction.

3.12.6.12 Instrumentation Line Support Criteria

The design and analysis loadings, load combinations, and acceptance criteria to be used for instrumentation line supports are similar to those used for pipe supports. The applicable design loads include deadweight, thermal expansion, and seismic loadings where appropriate. The applicable loading combinations similarly follow those used for the ASME Section III Levels in Table 3.9-10 using the design loadings mentioned above. The acceptance criteria are in accordance with ASME Section III, Subsection NF for seismic Category I instrumentation lines, AISC 360-05 (Reference 15) for non-seismic instrumentation lines.

3.12.6.13 Pipe Deflection Limits

For standard component pipe supports using standard manufactured hardware components, the manufacturer’s recommendations for limitations in its hardware are followed. The limitations are travel limits for spring hangers, stroke limits for snubbers, swing angles for rods, struts, and snubbers, alignment angles between clamps or end brackets with their associated struts and snubbers, and the variability check for variable spring supports. In addition to the manufacturer’s recommended limits, allowances are made in the initial designs for tolerances on such limits. This is especially important for snubber and spring design in which the function of the support may be changed by an exceeded limit.

3.12.7 Combined License Information

COL 3.12(1) The COL applicant is to prepare design reports for ASME Class 1, 2, and 3 piping system in accordance with ASME Section III.

COL 3.12(2) The COL applicant is to design the piping exposed to wind and/or tornado, if any, to the plant design basis loads.

COL 3.12(3) The COL applicant is to perform fatigue evaluations of ASME Class 1 piping except for the RCS primary loop.

COL 3.12(4) The COL applicant is to perform stress evaluations for ASME Class 2 and 3 piping.

COL 3.12(5) The COL applicant is to perform fatigue evaluations of environmental impact on ASME Class 1 piping, except for the RCS primary loop, using methods acceptable to the NRC at the time of evaluation.

3.12.8 References

1. American Society of Mechanical Engineers, “ASME Boiler and Pressure Vessel Code,” Section III, Division 1, 2007 Edition with 2008 addenda.

2. American Society of Mechanical Engineers, “Code for Pressure Piping, Power Piping,” ASME B31.1, 2010 Edition.

3. American Society of Mechanical Engineers, “Code for Pressure Piping, Process Piping,” ASME B31.3, 2010 Edition.

4. American Society of Mechanical Engineers, “Code Cases: Nuclear Components, Boiler and Pressure Vessel Code,” 2007 Edition.

5. NRC RG 1.84, “Design, Fabrication, and Materials Code Case Acceptability,” Rev. 35, U.S. Nuclear Regulatory Commission, October 2010.

6. NRC RG 1.193, “ASME Code Cases Not Approved For Use,” Rev. 3, U.S. Nuclear Regulatory Commission, October 2010.

7. Electric Power Research Institute, “Guidelines for Piping System Reconciliation,” EPRI NP-5639, Palo Alto, CA, USA, May 1988.

8. NRC RG 1.61, “Damping Values for Seismic Design of Nuclear Power Plants,” Rev. 1, U.S. Nuclear Regulatory Commission, March 2007.

9. NRC RG 1.122, “Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components,” Rev. 1, U.S. Nuclear Regulatory Commission, February 1978.

10. NRC RG 1.92, “Combining Modal Responses and Spatial Components in Seismic Response Analysis,” Rev. 1, U.S. Nuclear Regulatory Commission, February 1976.

11. NRC RG 1.92, “Combining Modal Responses and Spatial Components in Seismic Response Analysis,” Rev. 3, U.S. Nuclear Regulatory Commission, October 2012.

12. DST Computer Services. S.A., PIPESTRESS Theory Manual, Geneva, Switzerland.

13. U.S. Nuclear Regulatory Commission, “Evaluation of Other Loads and Load Combinations,” NUREG-1061, Volume 4, Washington DC, USA, December 1984.

14. K. Gordis, “Outline of Dynamic Analysis for Piping Systems,” Nuclear Engineering and Design, Volume 52, No. 1, March 1979.

15. ANSI/AISC 360-05, “Specification for Structural Steel Buildings,” March 2005, American Institute of Steel Construction.

16. DST Computer Services. S.A., PIPESTRESS User’s Manual, version 3.7.0, Geneva, Switzerland, 2012.

17. U.S. Nuclear Regulatory Commission, “Piping Benchmark Problems. Vol. 1 and Vol. 2,” NUREG/CR-1677, Washington DC., USA, August 1980.

18. NUREG-0484, “Methodology for Combining Dynamic Responses,” Revision 1, May 1980.

19. ADLPIPE, Inc., ADLPIPE Static and Dynamic Pipe Design and Stress Analysis, Input Preparation Manual, March 1987.

20. NRC RG 1.207, Rev. 0, “Guidelines for Evaluating Fatigue Analyses incorporating the Life Reduction of Metal Components Due to the Effects of the Light Water Reactor Environment for New Reactors,” Washington, DC, March 2007.

21. U.S. Nuclear Regulatory Commission, “Thermal Stresses in Piping Connected to Reactor Coolant System,” Bulletin 88-08, Washington DC., USA, June 1988.

22. U.S. Nuclear Regulatory Commission, "Cracking in Feedwater System Piping," Bulletin 79-13, Washington DC., USA, August 1979.

23. U.S. Nuclear Regulatory Commission, "Pressurizer Surge Line Thermal Stratification," Bulletin 88-11, Washington DC., USA, December 1988.

24. The American Society of Mechanical Engineers, "ASME Boiler and Pressure Vessel Code," Section III, Division 1 – Appendices, Nonmandatory Appendix O, 2007 Edition.

25. U.S. Nuclear Regulatory Commission, "Functional Capability of Piping Systems," NUREG-1367, Washington DC., USA, November 1992.

26. *[ACI-349-97, Appendix B,]** "Code Requirements for Nuclear Safety Related Concrete Structures," February 2001, American Concrete Institute.

27. NRC RG 1.199, "Anchoring Components and Structural Supports in Concrete," U.S. nuclear Regulatory Commission, November 2003.

28. U.S. Nuclear Regulatory Commission, "Pipe Support Base Plate Designs Using Concrete Expansion Anchor Bolts," Bulletin 79-02, Revision 2, March 1979.

29. IEEE Std. 344-2004 (Reaffirmed 2009), "Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations," Institute of Electrical and Electronics Engineers (IEEE), June 2005.

30. Welding Research Council Bulletins 353, "Position Paper on Nuclear Plant Pipe Support," May 1990.

31. SECY-93-087, "Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water (ALWR) Designs," July 21, 1993.

Table 3.12-1 (1 of 4)

Loading Combinations and Acceptance Criteria for ASME Section III, Class 1 Piping

Service Condition	Service Level	Category	Loading	Acceptance Criteria [1]	
				Equation (NB-3650)	Stress Limit
Design	-	Primary Stress	Design Pressure, Deadweight, Steady State Flow Load and Dynamic Fluid Load [2] specified as Level A	Eq. 9 NB-3652	1.5 S_m
Normal /Upset	A/B	Primary plus Secondary Stress Intensity Range (S.I.R.)	Service Pressure, Steady State Flow Load, Dynamic Fluid Load [2], Thermal Expansion Load [3], Thermal Expansion Anchor Motion Load[3], Cyclic Thermal Load [4], Material Discontinuity Stress, Earthquake Inertial Load [7]	Eq. 10 NB-3653.1	3 S_m
		Peak S.I.R.	Service Pressure, Steady State Flow Load, Dynamic Fluid Load [2], Thermal Expansion Load [3], Thermal Expansion Anchor Motion Load [3], Cyclic Thermal Load [4], Material Discontinuity Stress, Earthquake Inertial Load [7], Thermal Radial Gradient Stress (linear and non-linear)	Eq. 11 NB-3653.2	
		Thermal S.I.R. [5]	Thermal Expansion Load [3], Thermal Expansion Anchor Motion Load [3], Cyclic Thermal Load [4]	Eq. 12 NB-3653.6(a)	3 S_m
		Primary plus Secondary Membrane plus Bending S.I.R. [5]	Service Pressure, Steady State Flow Load, Dynamic Fluid Load [2], Material Discontinuity Stress, Earthquake Inertial Load [7]	Eq. 13 NB-3653.6(b)	3 S_m
		Alternating Stress Intensity (S.I.) (Fatigue Usage) [6]	Service Pressure, Steady State Flow Load, Dynamic Fluid Load [2], Thermal Expansion Load [3], Thermal Expansion Anchor Motion Load[3], Cyclic Thermal Load [4], Material Discontinuity Stress, Earthquake Inertial Load [7], Thermal Radial Gradient Stress (linear and non-linear)	NB-3653.3 NB-3653.4 NB-3653.5 NB-3653.6(c)	
		Thermal Stress Ratchet	Linear Thermal Radial Gradient	NB3653.7	

Table 3.12-1 (2 of 4)

Service Condition	Service Level	Category	Loading	Acceptance Criteria	
				Equation (NB-3650)	Stress Limit
Upset	B	Permissible Pressure	Maximum Level B Service Pressure	NB-3654.1	1.1 Pa
		Primary Stress	Coincident Level B Service Pressure, Deadweight, Steady State Flow Load, Dynamic Fluid Load (2)	NB-3654.2	Min (1.8 S_m, 1.5 S_y)
		Deformation Limits	As Set Forth in the Design Specification	NB-3653.7	
Emergency (9)	C	Permissible Pressure	Maximum Level C Service Pressure	NB-3654.1	1.1 Pa
		Primary Stress	Coincident Level C Service Pressure, Deadweight, Steady State Flow Load, Dynamic Fluid Load (2)	NB-3654.2	Min (1.8 S_m,, 1.5 S_y,)
		Deformation Limits	As Set Forth in the Design Specification	NB-3654.3	
Faulted	D	Permissible Pressure	Maximum Level D Service Pressure	NB-3656(a)(1)	2 P_a
		Primary Stress (10)	Coincident Level D Service Pressure, Deadweight, Steady State Flow Load, Dynamic Fluid Load (2), (11), Earthquake Inertial Load (11), High Energy Line Break Load (11) (Loss-of-Coolant Accident or Secondary Side Pipe Rupture)	NB-3656(a)(2)	Min (3 S_m, 2 S_y)
		Secondary Stress (12)	MAX [Range of (Bending Moments due to Thermal Expansion Load (3) plus Thermal Expansion Anchor Motion Load (3) plus ½ Earthquake Anchor Motion Load) OR Range of Earthquake Anchor Motion Load]	NC/ND-3665(b)(4)	6 S_m (13)
Pressure Testing (14)	-	Primary Membrane S.I.	Test Pressure, Deadweight	NB-3657 NB-3226(b)	0.9 S_y, 0.8 S_y
		Primary Membrane plus Bending S.I	Test Pressure, Deadweight	NB-3657 NB-3226(c)	1.35S_y, Min (2.15 S_y-1.2P_m)

Table 3.12-1 (3 of 4)

(1) Acceptance criteria are taken from the referenced section in Section III of the ASME Boiler and Pressure Vessel Code or are as noted.

(2) Dynamic fluid loads are occasional loads associated with hydraulic transients caused by events such as valve actuation (safety or relief valve discharge, rapid valve opening/closing), water hammer, or steam hammer.

(3) Thermal expansion and thermal expansion anchor motion loads are not calculated for those operating conditions where the piping system does not exceed 65 °C (150 °F).

(4) Cyclic thermal load includes loads due to thermal stratification, and stresses due to high cycle thermal striping and thermal penetration (i.e., thermal mixing).

(5) The thermal bending and primary plus secondary membrane plus bending stress intensity ranges (Equations 12 and 13) are only calculated for those load sets that do not meet the primary plus secondary stress intensity range (Equation 10) allowable.

(6) The cumulative fatigue usage factor is calculated by summing the Level A and Level B fatigue usage. If applicable, fatigue usage from Level C and pressure testing conditions is also included in the calculation of the cumulative usage factor (see Notes 9 and 14).

(7) The earthquake inertial load considered in the Level B primary plus secondary stress intensity range, peak stress intensity range and alternating stress intensity calculations (Equations 10, 11, and 14) is taken as one-third of the peak SSE inertial load or as the peak SSE inertial load. If the earthquake inertial load is taken as the peak SSE inertial load, then 20 cycles of earthquake loading are considered. If the earthquake inertial load is taken as one-third of the peak SSE inertial load, then the number of cycles to be considered for earthquake loading is as described in Subsection 3.7.3.1.2 (the equivalent number of 20 full SSE cycles as derived in accordance with Appendix D of IEEE Standard 344-2004 (Reference 29)).

(8) The resultant moment calculated is the maximum of the resultant moment due to the full range of earthquake inertial load or the resultant moment due to the consideration of half of the range of earthquake inertial load with all other applicable loads.

(9) If a piping system is subjected to more than 25 emergency condition transient cycles that result in an alternating stress intensity (S_a) value greater than that for 106 cycles, as determined from the applicable fatigue design curves of Figures I-9.0 in Section III of the ASME Boiler and Pressure Vessel Code, then those cycles in excess of 25 are included in the fatigue calculation that determines the cumulative usage factor. See Section NB-3113(b) in Section III of the ASME Boiler and Pressure Vessel Code.

(10) The rules given in Appendix F of the ASME Boiler and Pressure Vessel Code may be used in lieu of those given in NB-3656(a) and NB-3656(b) when evaluating Level D primary stress.

(11) Loads due to dynamic events other than high energy line break (i.e., loss-of-coolant accident and secondary side pipe rupture) and SSE are combined considering the time phasing of the events (i.e., whether the loads are coincident in time). When the time phasing relationship can be established, dynamic loads may be combined by the square-root-sum-of-the-squares (SRSS) method, provided it is demonstrated that the non-exceedance criteria given in NUREG-0484 (Reference 18) is met. When the time phasing relationship cannot be established, or when the non-exceedance criteria in NUREG-0484 are not met, dynamic loads are combined by absolute sum. SSE and high energy line break loads are always combined using the SRSS method.

Table 3.12-1 (4 of 4)

(12) This secondary stress check is only necessary if the stresses (including those due to earthquake inertial load) exceed the Equation 10 (primary plus secondary stress intensity range for the upset service condition) allowable stress. See Section NB-3656(b)(4) in Section III of the ASME Boiler and Pressure Vessel Code.

(13) S_m = Allowable design stress intensity value from Part D of Section II of the ASME Boiler and Pressure Vessel Code.

(14) If a piping system is subjected to more than 10 pressure test cycles that result in an alternating stress intensity (S_a) value greater than that for 106 cycles, as determined from the applicable fatigue design curves of Figures I-9.0 in Section III of the ASME Boiler and Pressure Vessel Code, then those cycles in excess of 10 are included in the fatigue calculation that determines the cumulative usage factor. See Sections NB-3657 and NB-3226(e) in Section III of the ASME Boiler and Pressure Vessel Code.

Table 3.12-2 (1 of 2)

Loading Combinations for Acceptance Criteria for ASME Section III Class 2 and 3 Piping

Service Condition	Service Level	Loading	Acceptance Criteria[4]	
			Equation (NB-3650)	Stress Limit
Design	-	Pressure, Weight, Other Sustained Mechanical Loads	Eq. 8 NC/ND-3652[3]	1.5 S_h [3]
Normal /Upset	A/B	Pressure, Weight, Other Sustained Mechanical Loads, Dynamic Fluid Loads (DFL)[1], Wind [7]	Eq.9 NC/ND-3653.1 (Level B Only) [6]	Min (1.8 S_h, 1.5 S_y)
		Thermal Expansion, Thermal Anchor Movement (TAM)	Eq.10 NC/ND-3653.2(a)[2]	S_A[2]
		Building Settlement	Eq. 10a NC/ND-3653.2(b)	3S_c
		Pressure, Weight, Other Sustained Mechanical Loads, Thermal Expansion, TAM	Eq. 11 NC/ND- 3653.2(c)[2]	S_h +S_A [2]
Emergency	C	Pressure, Weight, DFL[1], Tornado[7]	Eq. 9 NC/ND-3654.2(a)[5]	Min(2.25 S_h,1.8 S_y)
Faulted	D	Pressure, Weight , DFL[1], SSE Inertia, Design Basis Pipe Break	Eq. 9 NC/ND-3655(a)[5]	Min(3 S_h, 2 S_y)
		Thermal Expansion, TAM, Seismic Anchor Motion (SAM)	NC/ND-3665(b)[4]	6S_h[6] [8]
Design	-	Pressure, Weight, Other Sustained Mechanical Loads	Eq. 8 NC/ND-3652[3]	1.5 S_h [3]
Normal /Upset	A/B	Pressure, Weight, Other Sustained Mechanical Loads, Dynamic Fluid Loads (DFL)[1], Wind [7]	Eq.9 NC/ND-3653.1 (Level B Only) [6]	Min(1.8 S_h, 1.5 S_y)
		Thermal Expansion, Thermal Anchor Movement (TAM)	Eq.10 NC/ND-3653.2(a)[2]	S_A[2]
		Building Settlement	Eq. 10a NC/ND-3653.2(b)	3S_c
		Pressure, Weight, Other Sustained Mechanical Loads, Thermal Expansion, TAM	Eq. 11 NC/ND- 3653.2(c)[2]	S_h +S_A [2]
Emergency	C	Pressure, Weight, DFL[1], Tornado[7]	Eq. 9 NC/ND-3654.2(a)[5]	Min(2.25 S_h,1.8 S_y)

Table 3.12-2 (2 of 2)

Service Condition	Service Level	Loading	Acceptance Criteria[4]	
			Equation (NB-3650)	Stress Limit
Faulted	D	Pressure, Weight , DFL[1], SSE Inertia, Design Basis Pipe Break	Eq. 9 NC/ND-3655(a)[5]	Min ($3\ S_h$, $2\ S_y$)
		Thermal Expansion, TAM, Seismic Anchor Motion (SAM)	NC/ND-3665(b)(4)	$6S_h$[6, 8]

(1) Dynamic fluid loads (DFL) are occasional loads such as safety/relief valve thrust, steam hammer, water hammer, or other loads associated with plant upset, emergency, or faulted conditions as applicable.

(2) Stresses are to meet the requirements of either Equation 10 or 11, not both.

(3) If, during operation, the system normally carries a medium other than water (air, gas, steam), sustained loads are to be checked for weight loads during hydrostatic testing as well as normal operation weight loads.

(4) ASME Boiler and Pressure Vessel Code, Section III.

(5) When causal relationships can be established, dynamic loads may be combined by the square-root-sum-of-the-squares (SRSS), provided it is demonstrated that the non-exceedance criteria given in NUREG-0484 are met. When the causal relationship cannot be established, or when the non-exceedance criteria given in NUREG-0484 are not met, dynamic loads are to be combined by absolute sum. SSE and high energy line break loads are always combined using the SRSS method.

(6) OBE inertia and SAM loads are not included in the design of Class 2 and 3 piping (Reference 31).

(7) Wind and tornado loads are not combined with earthquake loading.

(8) ASME Code equations and paragraph numbers refer to the 2007 Edition through 2008 Addenda of the ASME Code.