3.12 ASME Code Class 1, 2, and 3 Piping Systems, Piping Components, and their Associated Supports

3.12.1 Introduction

This section addresses the design of the piping systems and piping supports used in Seismic Category I, Seismic Category II, and non-safety-related systems. The information in this section is primarily supported by AREVA NP Topical Report ANP-10264(NP) (Reference 1). This topical report focuses on Seismic Category I and Seismic Category II systems, but also addresses the interaction of non-seismic piping with Seismic Category I piping. Further supporting information is provided in Sections 3.7.2, 3.7.3, 3.9.1, 3.9.2, 3.9.3, 3.13, and 5.2.

3.12.2 Codes and Standards

Applicable codes and standards for piping and pipe supports are detailed in Section 2.0 and in Section 6.1 of Reference 1.

3.12.3 Piping Analysis Methods

3.12.3.1 Experimental Stress Analysis Methods

Experimental stress analysis methods are not used in lieu of analytical methods for Seismic Category I piping.

3.12.3.2 Modal Response Spectrum Method

The uniform support response spectrum method used in the analyses for piping systems is addressed in Section 4.2 of Reference 1.

3.12.3.3 Response Spectra Method (or Independent Support Motion Method)

The independent support motion response spectrum method is addressed in Section 4.2 of Reference 1.

3.12.3.4 Time History Method

Section 4.2.3 of Reference 1 addresses the time history methods used in the analyses of piping systems. Additional information is given in FSAR Section 3.7.2.

3.12.3.5 Inelastic Analysis Method

Inelastic analysis will not be used to qualify piping for the U.S. EPR design.

3.12.3.6 Small Bore Piping Method

As noted in AREVA NP letter NRC:07:028 dated July 13, 2007, “Response to a Request for Additional Information Regarding AREVA NP Topical Report, ANP-10264(NP)” (Reference 2), small bore piping is defined as ASME Class 1 piping that is 1 in NPS and smaller and Class 2, Class 3 and QG D piping that is 2 in NPS and smaller. This piping may be analyzed using response spectrum methods described in Section 4.2.2 of Reference 1 or the equivalent static method described in Section 4.2.3 of Reference 1.

3.12.3.7 Nonseismic/Seismic Interaction (II/I)

Section 4.4 of Reference 1 addresses design and analysis considerations for the interaction of non-seismic and seismic piping.

3.12.3.8 Seismic Category I Buried Piping

Section 3.10 of Reference 1 addresses the seismic criteria for buried piping systems.

3.12.4 Piping Modeling Techniques

3.12.4.1 Computer Codes

Section 5.1 of Reference 1 addresses the computer codes used in the analysis of safety-related piping systems (i.e., BWSPAN and SUPERPIPE). Further information on these computer codes is provided in Reference 2.

3.12.4.2 Dynamic Piping Model

Section 5.2 of Reference 1 addresses the dynamic piping modeling techniques. A COL applicant that references the U.S. EPR design certification will perform a review of the impact of contributing mass of supports on the piping analysis following the final support design to confirm that the mass of the support is no more than ten percent of the mass of the adjacent pipe span.

3.12.4.3 Piping Benchmark Program

As indicated in Section 5.3 of topical report ANP-10264(NP), pipe and support stress analysis will be performed by the COL applicant that references the U.S. EPR design certification. If the COL applicant that references the U.S. EPR design certification chooses to use a piping analysis program other than those listed in Section 5.1 of the topical report, the COL applicant will implement a benchmark program using models specifically selected for the U.S. EPR.

3.12.4.4 Decoupling Criteria

Section 5.4.2 of Reference 1 addresses piping decoupling criteria.

3.12.5 Piping Stress Analyses Criteria

3.12.5.1 Seismic Input Envelope versus Site-Specific Spectra

As noted in Section 4.2.1 of Reference 1, the response spectra curves used for seismic analysis cover a range of possible soil conditions with the ground motion anchored to a peak ground acceleration of 0.3 g. The ratio of the vertical design ground motion to the horizontal design ground motion is 1.0

As indicated in Section 2.5.2, the COL applicant will confirm that the site-specific seismic response is within the parameters of Section 2.5.2.

3.12.5.2 Design Transients

Section 3.9.1 addresses design transients.

3.12.5.3 Loadings and Load Combinations

Section 3.3 and Section 6.3 of Reference 1 address loads and load combinations that are considered in piping analyses. Specifically, Section 3.3 addresses loads and load combinations for piping stress analysis and Section 6.3 addresses loads and load combinations for pipe support stress analysis. Additional information is provided in FSAR Section 3.9.3.

3.12.5.4 Damping Values

Section 4.2.5 of Reference 1 addresses the damping values used in the U.S. EPR piping analyses. Additional information is provided in FSAR Section 3.7.1.

3.12.5.5 Combination of Modal Responses

Section 4.2.2.3 of Reference 1 addresses the modal combination methods used in response spectrum analyses for piping.

3.12.5.6 High-Frequency Modes

Section 4.2.2.3.2 of Reference 1 addresses how high frequency modes are evaluated in seismic response spectrum analyses of the piping systems.

3.12.5.7 Fatigue Evaluation for ASME Code Class 1 Piping

Section 3.4.1 of Reference 1 addresses fatigue evaluation methods used for ASME Code Class 1 piping.

3.12.5.8 Fatigue Evaluation of ASME Code Class 2 and 3 Piping

Section 3.4.2 of Reference 1 addresses fatigue evaluation methods used for ASME Code Class 2 and Code Class 3 piping.

3.12.5.9 Thermal Oscillations in Piping Connected to the Reactor Coolant System

Piping connected to the reactor coolant system (RCS) can experience temperature oscillations resulting from a swirling turbulent flow that has a varying range of axial penetration distance into the attached piping. The axial movement of the vortex penetration may introduce hot water into an otherwise cooler stagnant horizontal line. If the swirling penetration periodically enters a horizontal section and then retreats, the piping conditions will cycle between stratified and non-stratified. Thermal oscillations have caused cracks in non-isolable piping connected to the RCS for several nuclear plants. As a result, NRC Bulletin 88-08 and Supplements 1 through 3 were issued.

A two-step approach was used for the assessment of thermal oscillations in piping connected to the RCS. The first step consisted of following the generic Electric Power Research Institute (EPRI) thermal management guidelines provided in EPRI Reports TR-1011955 (Reference 3) and TR-103581 (Reference 4). The identification, screening, and evaluation of thermal cycling were performed for normally stagnant non-isolable lines attached to the RCS. The second step considered measurements on similar piping arrangements to determine if thermal stratification could occur.

For thermal oscillations to occur in piping connected to the RCS, the following conditions are required:

- For piping that extends vertically upward from the RCS that is followed by a horizontal section, a cold water source must exist in order to have the potential for thermal oscillations.
    - There must be a pressure differential capable of forcing leakage through the pressure retaining component (e.g., valve) into the RCS.
    - There must be a temperature difference between the fluid in the non-isolable piping section and the fluid from the leakage source.
- For piping that extends vertically downward from the RCS that is followed by a horizontal section, vortex penetration distance must reach the horizontal section in order for stratification to occur.
    - Thermal cycling primarily occurs due to cyclic penetration, break down, and retreat of a thermal stratification interface that is formed by the interaction between the swirl penetration and the cooler fluid in the horizontal branch line.
    - A leaking cold water source is not required for this configuration.
- Sections of piping that are less than or equal to one inch nominal pipe size are not susceptible to these thermal fatigue phenomena.
- If a sufficient continuous flow rate exists within the RCS attached piping, thermal oscillations will not occur.

The following piping systems connected to the RCS were identified and evaluated:

- Residual heat removal discharge/safety injection piping/extra borating system (RHR/SIS/EBS).
- Residual heat removal suction/safety injection piping (RHR/SIS).
- Chemical volume control system (CVCS) letdown piping.
- CVCS injection piping.
- Normal and auxiliary pressurizer spray lines.

  - The pressurizer, surge line, and spray lines are evaluated in Section 3.12.5.10.
- Pressurizer surge line.
  - The pressurizer, surge line, and spray lines are evaluated in Section 3.12.5.10.

The EPRI generic methodology indicates that thermal stratification will not occur in these systems with the exception of the following lines:

- RHR/SIS/EBS injection piping (for all four trains).
- RHR/SIS suction piping (for two of four trains).

However, specific measurements taken at AREVA NP designed foreign plants on piping configurations that are representative of U.S. EPR piping systems indicate smaller range and shorter vortex penetrations than the EPRI methodology. Thus, testing information shows that thermal stratification does not occur in any horizontal segment of the aforementioned RCS attached piping.

The differences in swirling penetration distances between the generic EPRI methodology and AREVA NP measurements indicate the inherent uncertainty in predicting detailed thermal phenomena for piping systems and the need to instrument/monitor conditions during initial plant operation. The RCS attached piping will be instrumented and monitored during first cycle of the first U.S. EPR initial plant operation to verify that operating conditions have been considered in the design unless data from a similar plant's operation demonstrates that thermal oscillation is not a concern for piping connected to the RCS.

3.12.5.10 Thermal Stratification

The term "thermal stratification" applies to any condition where fluid is thermally layered due to buoyancy differences between the layers. Thermal stratification occurs in horizontal piping when flow and boundary conditions result in two layers of fluid at different temperatures without appreciable mixing. In cases where the top of pipe temperature is higher than the bottom of pipe temperature, pipe stresses occur due to pipe deflection and changes in support loads.

3.12.5.10.1 Pressurizer Surge Line Stratification (NRC Bulletin 88-11)

NRC Bulletin 88-11 recommended that pressurized water reactors (PWR) establish and implement a program to verify the structural integrity of the pressurizer surge line when subjected to thermal stratification.

The U.S. EPR design addresses the concerns of NRC Bulletin 88-11 with several features and operational procedures that minimize surge line stratification:

- The pressurizer surge line piping layout minimizes stratification. The pressurizer surge line has a continuous centerline elevation decrease from the pressurizer to the hot leg. Also, the pressurizer surge line connects to the top of the hot leg with a vertical take-off. The surge line is sloped at approximately five degrees between the vertical take-off at the hot leg and the vertical leg at the pressurizer which promotes mixing of the colder and hotter fluid layered in the line. There are no horizontal sections of pressurizer surge line piping.

- The take-off from the hot leg is upward vertical and of sufficient length such that when coupled with continuous bypass spray flow it will prevent the cooler hot leg fluid from entering the surge line beyond the take-off.

- During normal at-power operation, a continuous bypass spray flow of sufficient magnitude is maintained to further suppress turbulent penetration from the hot leg flow.

- The pressurizer versus RCS temperature differential is controlled during heatup to limit the pressurizer-to-hot leg temperature difference. Also, the pressurizer on/off heaters are energized during initial RCS heatup to maintain a constant outsurge of fluid from the pressurizer reducing the number of insurges and the thermal cycles between pressurizer and hot leg temperature.

The pressurizer surge line temperatures will be monitored during the first cycle of the first U.S. EPR initial plant operation to verify that the design transients for the surge line are representative of actual plant operations unless data from a similar plant's operation determines that monitoring is not warranted. The monitoring program, if required, includes temperature measurements at several locations along the pressurizer surge line and plant parameters including pressurizer temperature, pressurizer level, hot leg temperature, and reactor coolant pump status.

3.12.5.10.2 Pressurizer Stratification

Insurges due to momentary fluctuations in RCS inventory occur during normal operation. These fluctuations result in a stratified thermal front of cooler fluid (near hot leg temperature) being moved up into the lower section of the pressurizer. These insurges result in a step change in the pressurizer bottom fluid temperature. Consideration of these temperature changes is included in the design basis of the pressurizer.

3.12.5.10.3 Spray Line Stratification

The normal spray lines contain stratified liquid and steam during the initial part of the heatup as the horizontal sections in each of the two lines are filled from the cold leg at the same time that the pressurizer is being filled. The normal spray line temperatures will be monitored during the first cycle of the first U.S. EPR initial plant operation to verify that the design transients for the normal spray are representative of actual plant operations unless data from a similar plant's operation determines that monitoring is not warranted.

The auxiliary spray line is not used during normal or upset operations. The potential for stratification exists only during initiation for emergency and faulted transients where auxiliary spray is used.

3.12.5.10.4 Feedwater Line Stratification (NRC Bulletin 79-13)

NRC Bulletin 79-13 was issued as a result of a feedwater line cracking incident and the subsequent inspections resulting in discovery of cracks in the feedwater lines of several nuclear power plants. The primary cause of the cracking was determined to be thermal fatigue loading due to thermal stratification during low flow emergency feedwater and main feedwater injections.

The U.S. EPR main feedwater lines are designed to minimize thermal stratification. The main feedwater nozzle (located in the conical shell of the steam generator) and the adjacent feedwater line is angled downward from the horizontal to minimize the potential for thermal stratification. During steady-state operations, thermal stratification is prevented because of a continuous flow in the feedwater lines. During low flow actuation and flow shutdown, thermal stratification in the main feedwater line near the steam generator occurs. The temperature of the main feedwater lines will be monitored during the first cycle of the first U.S. EPR initial plant operation to verify that the design transients for the main feedwater lines are representative of actual plant operations unless data from a similar plant's operation determines that monitoring is not warranted.

The emergency feedwater system (EFWS) is not actuated during normal or upset operations. The EFWS piping layout minimizes thermal stratification during emergency and faulted plant operation.

3.12.5.11 Safety Relief Valve Design, Installation, and Testing

Section 3.8 of Reference 1 addresses the design and installation of pressure relief devices. Additional information is provided in FSAR Section 3.9.3.

3.12.5.12 Functional Capability

Section 3.5 of Reference 1 addresses conformance with NUREG-1367, "Functional Capability of Piping Systems" (Reference 5).

3.12.5.13 Combination of Inertial and Seismic Anchor Motion Effects

As noted in Section 3.3.1.4 of Reference 1, the design of Seismic Category I piping and supports includes analysis of the inertial and anchor movement effects of the safe shutdown earthquake (SSE) event. Additional information is provided in Table 3-1 and Table 3-2 of Reference 1. Discussion of seismic anchor motion effects is provided in Section 4.2.2.5 of Reference 1. Additional information regarding anchor supports is provided in Section 5.4 of Reference 1.

3.12.5.14 Operating Basis Earthquake as a Design Load

As noted in Section 3.7, and also in Section 3.3.1.4 of Reference 1, the ground motion of the operating basis earthquake (OBE) for the U.S. EPR is equal to one third of the ground motion of the SSE. As noted in Section 3.7, the OBE load case does not require explicit design analysis. Section 3.7.4 notes that, in the event of an earthquake which meets or exceeds the OBE ground motion, plant shutdown is required and requires the

COL applicant to have a post-earthquake shutdown response program to inspect designated SSCs for functional damage. The design of Seismic Category I piping and supports includes analysis of the inertial and anchor movement effects of the SSE event.

3.12.5.15 Welded Attachments

Section 3.6 of Reference 1 provides information on the design of welded attachments.

3.12.5.16 Modal Damping for Composite Structures

Section 4.2.5 of Reference 1 addresses modal damping considered in the seismic analysis of composite structures.

3.12.5.17 Minimum Temperature for Thermal Analyses

Section 3.3.1.3 of Reference 1 addresses the minimum operating temperature for which thermal expansion analyses are performed for piping systems.

3.12.5.18 Intersystem Loss-of-Coolant Accident

Section 3.9 of Reference 1 addresses intersystem LOCA. Additional information is provided in FSAR Section 19.2.

3.12.5.19 Effects of Environment on Fatigue Design

The effects of reactor coolant environment, using the methodology described in RG 1.207, are considered when performing fatigue analyses for Class 1 piping. If there are locations in the Class 1 systems where the cumulative usage factor (CUF) cannot be shown to be less than 1.0, based on the methodology described in RG 1.207, alternative methods for addressing environmental fatigue will be applied. Examples of alternative methods are:

- Redefinition of the normal and upset transients affecting the location in question to reduce the severity of the transients or to reduce the number of cycles associated with the transients.

- Redefinition of the in-air design fatigue curves and/or F_{en} environmental penalty factors using data obtained from testing of samples representative of U.S. EPR materials, configurations, and environment.

- Fatigue monitoring of the affected locations.

- Augmented inspection (beyond ten year inservice inspection requirements) of the affected locations.

3.12.6 Piping Support Design Criteria

3.12.6.1 Applicable Codes

Section 2.0 and Section 6.1 of Reference 1 address the applicable codes, code cases, and standards for the U.S. EPR piping supports.

3.12.6.2 Jurisdictional Boundaries

Section 6.2 of Reference 1 addresses the jurisdictional boundaries for pipe supports.

3.12.6.3 Loads and Load Combinations

Section 3.12.5.3 addresses loads and load combinations for pipe supports.

3.12.6.4 Pipe Support Baseplate and Anchor Bolt Design

Section 6.4 of Reference 1 addresses the design of pipe support baseplates and anchor bolts.

3.12.6.5 Use of Energy Absorbers and Limit Stops

Section 6.5 of Reference 1 addresses energy absorbers for pipe supports and gapped rigid supports (limit stops).

3.12.6.6 Use of Snubbers

Section 6.6 of Reference 1 addresses the use of snubbers in the piping design.

3.12.6.7 Pipe Support Stiffnesses

Section 6.7 of Reference 1 addresses the consideration of pipe support stiffnesses in the piping analyses and also provides support deflection criteria.

3.12.6.8 Seismic Self-Weight Excitation

Section 6.8 of Reference 1 addresses the consideration of seismic excitation of pipe supports in the analyses of the supports.

3.12.6.9 Design of Supplementary Steel

Section 6.9 of Reference 1 addresses the design of supplemental steel used in piping supports.

3.12.6.10 Consideration of Friction Forces

Section 6.10 of Reference 1 addresses consideration of pipe-to-pipe support friction forces in the analyses of pipe supports.

3.12.6.11 Pipe Support Gaps and Clearances

Section 6.11 of Reference 1 addresses pipe support gaps and clearances used in the design of pipe supports.

3.12.6.12 Instrumentation Line Support Criteria

Section 6.12 of Reference 1 addresses instrumentation line support design criteria.

3.12.6.13 Pipe Deflection Limits

Section 6.13 of Reference 1 addresses the allowable deflections for standard pipe support components (e.g., snubbers, struts, spring hangars) that are used in the design of piping.

3.12.7 References

1. ANP-10264(NP) Revision 0, "U.S. EPR Piping Analysis and Pipe Support Design," September 2006.

2. Ronnie L. Gardner (AREVA NP Inc.) to Document Control Desk (NRC), AREVA NP letter NRC:07:028 dated July 13, 2007, "Response to a Request for Additional Information Regarding AREVA NP Topical Report, ANP-10264(NP), 'U.S. EPR Piping Analysis and Support Design,' (TAC No. MD3128)," NRC:07:028, July 13, 2007.

3. EPRI Technical Report 1011955, "Management of Thermal Fatigue in Normal Stagnant Unisolable Reactor Coolant System Branch Lines (MRP 146)," EPRI Proprietary Licensed Material, June 2005.

4. EPRI Technical Report 103581, "Thermal Stratification, Cycling, and Striping (TASCS)," EPRI Proprietary Licensed Material, March 1994.

5. NUREG-1367, "Functional Capability Of Piping Systems," November 1, 1992.