ANP-10264NP-A
Revision 0

U.S. EPR Piping Analysis and Pipe Support Design Topical Report

November 2008

AREVA NP Inc.

Non-Proprietary

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

August 11, 2008

Mr. Ronnie L. Gardner, Manager
AREVA NP
3315 Old Forrest Road
P.O. Box 10935
Lynchburg, VA 24506-0935

SUBJECT: FINAL SAFETY EVALUATION REPORT REGARDING ANP-10264NP, "U.S. EPR PIPING ANALYSIS AND PIPE SUPPORT DESIGN TOPICAL REPORT" (TAC NO. MD3128)

Dear Mr. Gardner:

By letter dated September 29, 2006 (ML062770021), as supplemented by letters dated July 13, 2007 (ML071990264), November 20, 2007 (ML073300462), and April 18, 2008 (ML081140034), AREVA NP (AREVA) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review Topical Report (TR) ANP-10264NP, "U.S. EPR Piping analysis and Pipe Support Design Topical Report" (ML062770023). By letter dated May 19, 2008 (ML081220154), a draft safety evaluation (SE) regarding our approval of ANP-10264NP was provided for your review and comments. The staff's disposition of AREVA's comments (ML081630037) on the draft SE are discussed in the attachment to the final SE enclosed with this letter.

The staff has found that ANP-10264NP, Revision 0 is acceptable for referencing in licensing applications for U.S. EPR to the extent specified and under the limitations delineated in the TR and in the enclosed SE. The SE defines the basis for acceptance of the TR.

Our acceptance applies only to material provided in the subject TR. We do not intend to repeat our review of the acceptable material described in the TR. When the TR appears as a reference in regulatory applications, our review will ensure that the material presented applies to the specific application involved. Regulatory applications that deviate from this TR will be subject to further review in accordance with applicable review standards.

In accordance with the guidance provided on the NRC website, we request that AREVA publish the accepted version of this TR within three months of receipt of this letter. The accepted version shall incorporate this letter and the enclosed SE after the title page. Also, the accepted version must contain historical review information, including NRC requests for additional information and your responses. The accepted versions shall include a "-A" (designating accepted) following the TR identification symbol.

If future changes to the NRC's regulatory requirements affect the acceptability of this TR, AREVA will be expected to revise the TR appropriately, or justify its continued applicability for subsequent referencing.

If you have any questions, please contact me at Getacher.Tesfaye@nrc.gov or (301) 415-3361.

Sincerely,

Getachew Tesfaye, Sr. Project Manager
EPR Projects Branch
Division of New Reactor Licensing
Office of New Reactors

Docket No. 52-020

Enclosure:
Final Safety Evaluation Report

cc w/encl: See next page

FINAL SAFETY EVALUATION BY THE OFFICE OF NEW REACTORS

TOPICAL REPORT ANP-1026NP, REVISION 0

"EPR PIPING ANALYSIS AND PIPE SUPPORT DESIGN TOPICAL REPORT"

AREVA NP, INC. (AREVA)

DOCKET NO. 52-020

1.0 Introduction and Background

This safety evaluation report (SER) provides the staff's evaluation of design methods and acceptance criteria for the U.S. EPR piping system design documented in the Topical Report (TR) ANP-10264NP (Revision 0), "U.S. EPR Piping Analysis and Pipe Support Design," submitted by AREVA NP Inc. (AREVA). AREVA plans to reference the approved version of this document in its EPR design certification application final safety analysis report (FSAR) [also referred to design control document (DCD)] for the U.S. EPR and will use these criteria to support detailed design activities. To evaluate the piping and pipe support design information given in this TR, the staff used the U. S. Nuclear Regulatory Commission (NRC) acceptance criteria and guidelines documented in the General Design Criteria (GDC), Standard Review Plan (SRP) Sections 3.7.3, 3.9, and 3.12, Regulatory Guides (RGs), and other NRC regulatory guidance documents (e.g., NUREG Reports, NRC Bulletins, etc.). The design criteria related to whip restraints (and pipe break analysis) for the U.S. EPR piping design are not within the scope of this review.

In TR Section 1.0, AREVA states that the reactor coolant loop (RCL) and the pressurizer surge line piping requirements, modeling techniques, analysis approaches and acceptance criteria are not specifically addressed in this document and will be included in the FSAR. In the Request for Additional Information (RAI) EPR-1, the staff requested AREVA to describe any significant differences in the requirements, techniques, approaches and criteria for the RCL and the pressurizer surge piping as against those presented in this TR. In response (dated July 13, 2007), AREVA stated that the RCL loop structural model includes representation of the nuclear island basemat and the interior concrete structure (ICS), to which the RCL supports are attached, as well as very detailed representations of the primary components and their internals. In addition, in most cases, the RCL supports are explicitly represented in the model. In case of typical Class 1 piping analysis, the models do not include representations of the supporting concrete structures or detailed representations of components, and the supports are not typically explicitly modeled. The method of seismic loading is also quite different, with the RCL loop structural model being loaded through application of basemat excitation to the base of the ICS, whereas Class 1 piping models are loaded through the application of attachment point response spectra (or time histories), floor response spectra (or time histories) and seismic anchor motions at the various support locations in the model. Other aspects of RCL structural analysis are the same as those described for Class 1 piping in the TR, such as damping requirements, load combinations, mass distribution requirements, cutoff frequency requirements, and applicable ASME stress and fatigue allowables. AREVA will include a thorough description of the approaches and methods employed in the structural, stress and fatigue analysis of the RCL and the pressurizer piping in Chapter 3 of the FSAR. Based on this the staff concludes that the modeling and analysis of the RCL and the pressurizer surge line piping along with its supporting structures are performed based on the basic principles of the structural analysis, and include all piping criteria presented in the subject TR. Therefore, the staff finds this acceptable and the **RAI EPR-1 is resolved.**

The staff evaluated the adequacy of the structural integrity and functional capability of safety-related piping systems associated with the design of the U.S. EPR standard plant. The review included not only the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (BP&V) Code Class 1, 2, and 3 piping and pipe supports, but also buried piping, instrumentation lines, the interaction of non-seismic and/or seismic Category II piping with seismic Category I piping and any safety-related piping designed to industry standards other than the ASME Code. The following sections of this report provide the staff's evaluation of the adequacy of the U.S. EPR piping and pipe support analysis methods, design procedures, and acceptance criteria. The staff's evaluation includes:

2.0 Regulatory Evaluation
3.1 Codes and Standards
3.2 Piping Analysis Methods
3.3 Modeling of Piping Systems
3.4 Pipe Stress Analysis Criteria
3.5 Pipe Support Design Criteria

The staff must arrive at a final safety determination that, if the combined license (COL) applicant successfully completes the piping design and analyses, and complies with the Inspection, Tests, Analyses and Acceptance Criteria (ITAAC) as required by Part 52 of Title 10 of the *Code of Federal Regulations* (10 CFR), using the design methods and acceptance criteria discussed herein, there will be adequate assurance that the piping systems will perform their safety-related functions under all postulated combinations of normal operating conditions, system operating transients, and seismic and other dynamic events.

2.0 Regulatory Evaluation

The staff reviewed the TR in accordance with NUREG-0800, SRP Section 3.7.3, "Seismic Subsystem Analysis," Rev. 3, Section 3.9.1, "Special Topics for Mechanical Components," Rev. 3; Section 3.9.2, "Dynamic Testing and Analysis of Systems, Components, and Equipment," Rev. 3; Section 3.9.3, "ASME Code Class 1, 2, and 3 Components, Component Supports, and Core Support Structures," Rev. 2; and Section 3.12, "ASME Code Class 1, 2, and 3 Piping Systems, Piping Components and Their Associated Supports," Initial Issuance, March 2007. The applicant's piping and pipe support design criteria, including the analysis methods and modeling techniques, are acceptable if they meet codes and standards, and regulatory guidance documents commensurate with the safety function to be performed. This will ensure that the piping system design criteria meet the relevant requirements of 10 CFR 50.55a, "Codes and Standards," and the GDCs 1, 2, 4, 14, and 15 of Appendix A to 10 CFR Part 50.

The acceptance criteria are based on meeting the relevant requirements of the following regulations for piping system, piping components and their associated supports:

- 10 CFR 50.55a and GDC 1 as they relate to piping system, pipe supports, and components being designed, fabricated, erected, constructed, tested, and inspected

- to quality standards commensurate with the importance of the safety function to be performed.

- GDC 2 and 10 CFR Part 50, Appendix S with regard to design transients and resulting load combinations for piping and pipe supports to withstand the effects of earthquakes combined with the effects of normal or accident conditions.

- GDC 4, with regard to piping systems and pipe supports important to safety being designed to accommodate the effects of, and to be compatible with, the environmental conditions of normal as well as postulated events such as loss-of-coolant accident (LOCA) and dynamic effects.

- GDC 14, with regard to the reactor coolant pressure boundary (RCPB) of the primary piping systems being designed, fabricated, constructed, and tested to have an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross rupture.

- GDC 15, with regard to the reactor coolant systems and associated auxiliary, control, and protection systems being designed with sufficient margin to assure that the design condition of the RCPB are not exceeded during any condition of normal operation, including anticipated operational occurrences.

- 10 CFR 52.47(b)(1), as it relates to ITAAC (for design certification) sufficient to assure that the structures, systems, and components (SSCs) in this area of review will operate in accordance with the certification.

- 10 CFR 52.80(a), as it relates to ITAAC (for combined licenses) sufficient to assure that the SSCs in the area of review have been constructed and will be operated in conformity with the license the provisions of the Atomic Energy Act and the Commission's rules and regulations.

The NRC has established requirements in 10 CFR Part 50 to ensure the pressure boundary leakage integrity of the piping components and structural integrity of the pipe supports in the nuclear power plants. The staff evaluates the design, materials, fabrication, erection, inspection, testing, and in-service surveillance of piping and pipe supports based on the following industry codes and standards, materials specifications, and regulatory guides:

- ASME Boiler and Pressure Vessel Code, Section III, "Rules for Construction of Nuclear Power Plant Components," contains the material specifications, design criteria, fabrication and construction requirements, construction testing and examination techniques, and structural integrity testing of the piping and pipe supports.

- ASME Boiler and Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," contains inservice inspection and testing requirements and repair and replacement criteria for piping and pipe supports.

- RG 1.26, "Quality Group Classifications and Standards for Water-, Steam-, and Radioactive-Waste-Containing Components of Nuclear Power Plants," Revision 4, March 2007.

- RG 1.29, "Seismic Design Classification," Revision 4, March 2007.
- RG 1.61, "Damping Values for Seismic Design of Nuclear Power Plants," Revision 1, March 2007.
- RG 1.92, "Combining Modal Responses and Spatial Components in Seismic Response Analysis," Rev. 2, July 2006.
- RG 1.122, "Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components," Revision 1, February 1978.
- RG 1.199, "Anchoring Components and Structural Supports in Concrete," November 2003.
- RG 1.206, "Combined License Applications for Nuclear Power Plants," June 2007.
- NUREG - 0484, "Methodology for Combining Dynamic Responses," Revision 1, May 1980.
- NUREG - 1061, "Report of the U.S. Nuclear Regulatory Commission Piping Review Committee - Evaluation of Other Loads and Load Combinations," Volume 4, December 1984.
- NUREG - 1367, "Functional Capability of Piping Systems," November 1992.

3.0 Technical Evaluation

3.1 Codes and Standards

GDC 1 requires that SSCs important to safety should be designed, fabricated, erected, tested, and inspected to quality standards commensurate with the importance of the safety functions to be performed. Where generally recognized codes and standards are used, they should be identified and evaluated to determine their applicability, adequacy, and sufficiency and shall be supplemented or modified as necessary to assure a quality product in keeping with the required safety function. 10 CFR 50.55a requires that systems and components of boiling and pressurized water-cooled nuclear power reactors must meet the requirements of the ASME Code. It specifies the latest edition and addenda endorsed by the NRC and any limitations. RG 1.84 and RG 1.147 list ASME Code Cases that the NRC staff finds acceptable.

In TR Section 2.0, AREVA identifies all applicable codes and standards that will be used for the U.S. EPR design of ASME Code, Class 1, 2, and 3 pressure retaining components and their supports. Also, this section identifies ASME Code Cases that are applicable to the RCPB components, including piping and pipe supports.

3.1.1 ASME Boiler and Pressure Vessel Code

For the U.S. EPR piping and pipe support design, in TR Section 2.1, AREVA established that the 2001 ASME Boiler and Pressure Vessel (B&PV) Code, Section III, Division 1, 2003 addenda will be used for the design of ASME Code Class 1, 2, and 3 pressure retaining components and their supports. Other TR sections (e.g., 5.1, 6.2) reference the use of ASME B31.1 Code for piping analysis; however, AREVA has not identified which category or group of piping systems that will be analyzed using the ASME B31.1 Code requirements. In addition, AREVA has not identified ASME Code Section XI for testing and inspection of installed pipe components (e.g., pressure testing, weld examinations) that may be used in the design of piping and pipe supports. Therefore, in RAI EPR-2 the staff requested AREVA to clarify if ASME B31.1 Code will be used for Quality Group (QG) D piping systems, as suggested in RG 1.26, and if the ASME Section XI Code requirements are part of this design review.

In response dated July 13, 2007 (ML071990264), AREVA stated that the U.S. EPR piping systems containing radioactive material (outside the RCPB) are classified as QG D and are designed to ASME B31.1, 2004 Edition. This QG D piping will be analyzed to ASME B31.1, 2004 Edition, no addenda. In addition, the U.S. EPR adheres to the requirements of the ASME Section XI, 2001 Edition, 2003 addenda and, at this time of the certification stage, no Section XI code cases are used for the U.S. EPR. The staff finds this acceptable, since both B31.1 Code (2004) for QG D piping design and Section XI along with Section III of the ASME Code (2001 Edition with 2003 Addenda) for Class 1, 2, and 3 piping are consistent with 10 CFR 50.55a requirements. Therefore, **RAI EPR-2 is resolved.**

The ASME Code involves a consensus process to reflect the evolving design and construction practices of the industry. Although the reference to a specific edition of the Code for the design of ASME Code class components and their supports is suitable to reach a safety finding during the design review stage, the construction practices and examination methods of an updated Code that would be effective at the COL application stage must be consistent with the design practices established at the design review stage.

The staff finds that the specific edition and addenda stated in the TR are appropriate, because they would provide the means for the COL applicant to revise or supplement the referenced Code edition with portions of the later Code editions and addenda needed to ensure consistency between the design for the U.S. EPR pressure retaining components and their supports and construction practices. In this manner, the updated reference Code to be used at the time of the COL application is ensured to be consistent with the latest design, construction, and examination practices at that time. However, where the staff finds that there may be a need to specify certain design parameters from a specific Code edition or addenda during its design certification review, particularly when that information is of importance to establish a significant aspect of the design or is used by the staff to reach its final safety determination, such considerations, if necessary, are reflected in the various sections of this safety evaluation.

AREVA states in TR Section 2.1 that for the dynamic loads, including seismic loads, the pipe stress analyses will be performed in accordance with the Subsubarticles NB/NC/ND-3650 of the 1993 Addenda of the ASME Code as required by 10 CFR 50.55a(b)(1)(iii). However, AREVA did not address other limitations and modifications applicable to piping system design as included in 10 CFR 50.55a(b)(1). Therefore, in RAI EPR-3 the staff requested AREVA to explain why all six limitations and modifications specified in 10 CFR 50.55a(b)(1) are not addressed in the TR. In its revised response dated November 20, 2007 (ML070330462), AREVA stated that piping analysis and pipe support design for the U.S. EPR addressed in this TR use the 2001 ASME Code, Section III, Division 1, 2003 Addenda as the base code with limitations identified in the *Code of Federal Regulations*, 10 CFR 50.55a(b)(1). The staff finds this acceptable, since the response included all six limitations listed in 10 CFR 50.55a(b)(1) and the U.S. EPR piping design meets the 2001 ASME Code, Section III, Division 1 through the 2003 Addenda with limitations in 10 CFR 50.55a(b)(1) (ii) Weld Leg, (iii) Seismic, (v) Independence of Inspection, and (vi) Inspection NH, and other limitations (i) Section III-Materials and (iv) Quality Assurance do not apply to U.S. EPR piping design. Therefore, **RAI EPR-3 is resolved.**

AREVA also states in TR Section 2.1 that Class 1 piping one-inch NPS and smaller and Class 1 piping meeting the requirements of Subsubarticle NB-3630(d)(2) may be analyzed to Subarticle NC-3600. The staff notes that this is acceptable for Class 1 piping, provided the specified service loads for which Level A and B Service Limits are designated meet all the requirements stipulated in (a) through (e) of the Subsubarticle NB-3630(d)(2).

Based on the above, all ASME Code Class 1, 2, and 3 pressure retaining components and their supports must be designed in accordance with the requirements of ASME Code, Section III and Section XI using the 2001 Edition and 2003 Addenda as identified in the TR. The QG D piping are analyzed and designed to ASME B31.1, 2004 Edition, no addenda. However, the COL applicant should also ensure that the design is consistent with the construction practices (including inspection and examination methods) of the ASME Code edition and addenda as endorsed in 10 CFR 50.55a in effect at the time of COL application. The portions of the later Code editions and addenda must be identified to the NRC staff for review and approval with the COL application.

3.1.2 ASME Code Cases

The only acceptable ASME Code Cases that may be used for the design of ASME Code Class 1, 2, and 3 piping systems in the U.S. EPR standard plant are those either conditionally or unconditionally approved in RG 1.84 and RG 1.147 in effect at the time of design certification. This review is based on Revision 33 of RG 1.84, dated August 2005, since AREVA did not identify any code cases associated with Section XI of the ASME Code for RG 1.147 at this certification stage. Both RGs include Code Cases listed up to Supplement 6 (or 2003 Addenda) to the 2001 Edition of the ASME B&PV Code. The staff finds this to be acceptable as long as the additional Code Cases are listed in RG 1.84 and RG 1.147 as a conditionally or unconditionally accepted Code Cases at the time of their use.

All ASME Code Cases that are listed in TR Section 2.2 for the RCPB components, which are applicable to the U.S. EPR piping and pipe support design, are listed below.

- ASME Code Case N-122-2[1], "Procedure for Evaluation of the Design of Rectangular Cross Section Attachments on Class 1 Piping, Section III, Division 1." The staff endorses the use of this Code Case in RG 1.84.

- ASME Code Case N-318-5, "Procedure for Evaluation of the Design of Rectangular Cross Section Attachments on Class 2 or 3 Piping, Section III, Division 1." The staff endorses the use of this Code Case in RG 1.84.

- ASME Code Case N-319-3, "Alternate Procedure for Evaluation of Stress in Butt Weld Elbows in Class 1 Piping, Section III, Division 1." The staff endorses the use of this Code Case in RG 1.84.

[1] Code Case N-122-2 is identified as the second revision of Code Case N-122.

- ASME Code Case N-391-2, "Procedure for Evaluation of the Design of Hollow Circular Cross Section Welded Attachments on Class 1 Piping, Section III, Division 1." The staff endorses the use of this Code Case in RG 1.84.

- ASME Code Case N-392-3, "Procedure for Evaluation of the Design of Hollow Circular Cross Section Welded Attachments on Class 2 and 3 Piping, Section III, Division 1." The staff endorses the use of this Code Case in RG 1.84.

Based on the above evaluation of all code cases referenced in the TR for piping and pipe support design, the staff concludes that all of these code cases either meet the guidelines of RG 1.84, or have been reviewed and endorsed by the staff.

3.1.3 Design Specifications

ASME Code, Section III, Subsubarticle NCA-3250 requires that a design specification be prepared for Class 1, 2, and 3 components such as pumps, valves, and piping systems. The design specification is intended to become a principal document governing the design and construction of these components and should specify loadings and their combinations; design, service and test limits; and other design data inputs. Subsubarticle NCA-3260 of the Code also requires a design report for ASME Code, Class 1, 2, and 3 piping and components. In the TR, AREVA committed to construct all safety-related piping systems to applicable requirements of the ASME Code, Section III.

TR Section 2.3 states that COL applicants referencing the U.S. EPR design will make available to the staff design specifications and design reports demonstrating and documenting that as-designed[2] piping and pipe support configurations adhere to the requirements of the design specification as required by the ASME Code. This is identified as the COL-Action Item 2 in TR Table 1-1. This issue will be addressed during the design certification and RCOL application.

3.1.4 Conclusions

On the basis of the evaluation of TR Section 2.0, the staff concludes that the piping systems important to safety are designed to quality standards commensurate with their importance to safety. The staff's conclusion is based on the following:

- AREVA satisfies the requirements of GDC 1 and 10 CFR 50.55a by specifying appropriate codes and standards for the design and construction of safety-related piping and pipe supports, and

- AREVA identified ASME Codes and Code Cases that may be applied to ASME Code, Class 1, 2, and 3 piping and pipe supports.

[2] AREVA, in Attachment B of its second revised response to RAIs dated April 18, 2008, changed "as-built" to "as-designed" in TR Table 1-1, Item 2 and in TR Section 2.3. The staff finds this acceptable, since the design reports and design specifications are generally associated with as-designed piping and support configurations, prior to as-built reconciliation.

3.2 Piping Analysis Methods

GDC 1 requires that SSCs important to safety should be designed, fabricated, erected, tested, and inspected to quality standards commensurate with the importance of the safety functions to be performed. Where generally recognized methods of analysis are used, they shall be identified and evaluated to determine their applicability, adequacy, and margin of safety to withstand the loadings as a result of normal operating, transients, and accident conditions. GDC 2 requires that the piping and pipe supports should withstand the effects of earthquakes combined with the effects of normal or accident conditions.

The staff reviewed the applicable information in TR Section 4.0 related to the methods of analysis to be used for all seismic Category I piping and pipe supports designated as ASME Code Class 1, 2, and 3 under ASME Code, Section III, as well as those not covered by the Code. TR Section 4.2 indicates that the analysis methods described in SRP Section 3.7.3 are applicable to piping systems for all seismic Category I subsystems. Analysis methods to be used for piping systems include the response spectrum (RS) method (both uniform support motion and independent support motion), the time history (TH) method (both modal superposition and direct integration) and the equivalent static load method. Experimental stress analysis methods (as stated in TR Section 4.1) and inelastic analysis methods (as stated in TR Section 4.3) are not planned to be used to design piping for the U.S. EPR standard plant at this design certification stage.

AREVA did not provide details of the seismic analysis methods discussed in TR Section 4.2, which indicate that the analysis methods described in SRP Section 3.7.3 are applicable to piping systems for all seismic Category I subsystems. Therefore, in RAI EPR-4 and RAI EPR-5 the staff requested AREVA to expand the mathematical derivations and associated assumptions to develop a mathematical model of a piping system and to discuss their application procedures and limits.

In response (dated July 13, 2007), AREVA stated that the seismic response of a piping system is determined by developing a mathematical model of the system suitable for calculating the response of the system to the seismic input. Dynamic equilibrium equations are formulated for the system using the direct stiffness method. In this method, the element stiffness matrices are formed according to virtual work principles and assembled to form a global stiffness matrix for the system relating external forces and moments to nodal displacements and rotations. Once the mathematical model has been established, dynamic equilibrium equations are solved to determine the seismic response of the system by performing a modal analysis using either the RS method or TH methods. Alternatively, the direct integration TH method and, where applicable, the equivalent static load method may be used.

AREVA also stated that factors considered when choosing the analysis method to be used for a given piping configuration include complexity of the system, type of loads to be included in the analysis, class of piping (ASME Class 1, 2, 3 or non-seismic) and analysis tools available. In general, for seismic load cases, RS and TH methods of analysis will produce similar results with TH producing acceptable results that are not as conservative as RS. Class 1 piping analysis which requires considerably more detail may be analyzed by TH methods, although RS will yield acceptable results. The TH method is also used when transient loads due to pipe break, water hammer, or other dynamic events are anticipated and static analysis produces a high level of conservatism. Class 2 and 3 and non-seismic piping analysis is generally analyzed using the RS method. Equivalent static analysis can only be used on

Class 2 and 3 and non-seismic piping two inches NPS[3] and smaller where the piping configuration can be reduced to simple models. In its revised response (dated November 20, 2007), AREVA stated that non-seismic piping that interacts with seismic systems and seismic Category II piping will be analyzed by the RS or the equivalent static load methods. In Attachment A to the RAI response dated July 13, 2007, AREVA provided step by step computations for response spectra analysis to be included in the revised TR Section 4.2.2.

AREVA further, in its revised response (November 20, 2007), stated that the modal superposition method of time history analysis is used for seismic piping analyses with acceleration time history seismic input. This method is based on decoupling of the differential equations of motion, considering a linear elastic system, using the same method as that described in TR Section 4.2.2 (see Attachment A to the RAI response dated July 13, 2007). The direct integration TH analysis method may be used as an alternative to the modal superposition TH analysis. In this method, the differential equation of motion, as provided in Section 4.2.2 (see Attachment A to the RAI response dated July 13, 2007), is solved directly on the uncoupled equations without a coordinate transformation. Rayleigh damping, or mass and stiffness damping, is used when direct integration TH analysis is performed.

All of the above seismic analysis methods (including those described in TR Section 4.2 and Attachment A to the RAI response dated July 13, 2007) are consistent with the SRP 3.7.3, and therefore, the staff finds this acceptable. Thus, **RAI EPR-4 and RAI EPR-5 are resolved.**

3.2.1 Experimental Stress Analysis

In TR Section 4.1 AREVA states that U.S. EPR piping system design will not use the experimental stress analysis method. The staff finds this acceptable.

3.2.2 Response Spectrum Method with Uniform Support Motion

TR Section 4.2.2 describes the dynamic analysis procedure using the RS method with uniform support motion (USM) using enveloped floor response spectra or independent support motion (ISM) using multiple floor response spectra.

AREVA states that the effects of the ground motion during a safe shutdown earthquake (SSE) event are transmitted through structures to the piping system at support and equipment anchorage locations. The floor response spectra are developed which represent the maximum acceleration responses of idealized single-degree-of-freedom damped oscillators as a function of natural frequency to the vibratory input motion of the structure. These floor response spectra are applied to the piping system at locations of structural attachment, such as support or equipment locations in each of three (3) orthogonal directions. The total seismic response of the system is determined by combining the modal and spatial results.

In TR Section 4.2.2.2.1, AREVA also states that for a piping system supported at points with different dynamic excitations, an enveloped response spectrum of all attachment points is used in the USM method of analysis. Typically, from the mode shapes, participation factors and spectral accelerations of each mode, the modal responses are calculated. They include the modal forces, stresses and deflections. For a given direction, the modal responses are

[3] NPS – Nominal Pipe Size

combined in accordance with the methods described in TR Section 4.2.2.3. Following the modal combinations, the responses due to each of the three orthogonal earthquake motion inputs (two horizontal and vertical) are combined using the SRSS method as stated in TR Section 4.2.2.4. AREVA did not provide a criterion for ensuring that adequate number of modes are included in a piping model nor define the cutoff frequency that will be used in piping dynamic analysis. Therefore, in RAI EPR-6 the staff requested AREVA to define the number of modes to be included in the dynamic range of the input spectra.

In response (dated July 13, 2007), AREVA stated that the criterion for the inclusion of sufficient number of modes in accordance with SRP 3.9.2, Item II.2.A(i)(3) is that the inclusion of additional modes does not result in more than a 10-percent increase in responses. For U.S. EPR piping analyses, all modes with frequencies below the zero period acceleration (ZPA) frequency (i.e., cutoff frequency) are included. Above this frequency, in the rigid range, the effects of all additional modes are also included by the application of the missing mass correction as discussed in TR Sections 4.2.2.3.2 and 4.2.3. The cutoff frequency for a given spectra is the frequency at which the response curves for all damping values converge to the same acceleration value ZPA and remain at this value for all frequencies above this cutoff frequency. In its revised response (dated November 20, 2007), AREVA stated that for the U.S. EPR the cutoff frequency is 40 Hertz or as defined by Figures 2 and 3 in RG 1.92, Rev 2. Since this approach is consistent with the industry practice and SRP 3.9.2, the staff finds this acceptable. Therefore, **RAI EPR-6 is resolved.**

The staff notes that, for piping systems that are anchored and restrained to floors and walls of structures that have differential movements during a seismic event, additional forces and moments due to the differential supporting structure movements are induced in the system. Additional static analyses are performed to determine responses to these structure movements as described in TR Section 4.2.2.5. The support displacements are imposed in a conservative manner using the static analysis method for each orthogonal direction with all dynamic supports active. This is known as seismic anchor movement (SAM) analysis. For USM method of analysis, the results of the SAM analysis are combined with the results of the dynamic analysis by absolute sum method in accordance with SRP Section 3.9.2.

AREVA discusses in TR Section 4.2.2 how to determine the input spectra and input displacement when the piping system is attached to structures or at equipment connections, but did not discuss how the input response spectra and SAM displacements will be defined for a flexible equipment connection or branch piping of a smaller size when decoupled from a large pipe run. Therefore, in RAI EPR-7 the staff requested AREVA to describe the procedures to be used in defining the inputs for the analysis of a branch pipe when decoupled from a large pipe run or flexible equipment.

In its revised response (dated November 20, 2007), AREVA described the response for Class 1 branch lines from the reactor coolant loop (RCL) and for those decoupled from other large pipe runs. The model of a decoupled Class 1 branch line includes an anchor where the branch line connects to the RCL. The seismic inertial analysis of the RCL yields THs at branch connections and equipment nozzles. The inertial seismic analysis results then become input into the Class 1 branch line seismic analysis in the form of THs or response spectra which are generated from the THs using classical response spectra generation techniques. If response spectra are used, they are peak broadened by ±15 percent in accordance with RG 1.122, Rev. 1, before application to the Class 1 branch line model. The analysis of the Class 1 branch line also considers seismic movements generated from the RCL (seismic anchor motions), which are applied as static displacements at the branch-to-RCL anchor. This analysis captures the effects of run pipe or equipment amplification on the branch pipe.

AREVA also stated that for the remaining decoupled branch lines (not connected to the RCL), the model of a decoupled branch line includes an anchor at the run to branch intersection. The analysis of the branch line includes all anchor movements greater than 1/16 inch from the run pipe applied at the run to branch anchor for all load cases. AREVA stated that the branch pipe analysis will include more consideration for the effect of the run piping. The branch point is considered as an anchor in the analysis of the branch pipe with the appropriate stress intensity factor (SIF) and/or stress indices for the branch connection. The movements (displacements and rotations) of the run pipe at the branch intersection due to statically applied loads in the run pipe analysis (such as thermal and SAM) shall be applied as anchor movements with their respective load cases in the branch line analysis. Additionally, in the branch analysis, the applied SAMs at the decoupled location shall also include the run pipe movements from the run pipe SSE inertia analysis. The inertial effects of the run pipe (other than RCL) on the branch line are considered in one of the following methods:

- The fundamental frequency of the run pipe at the branch location will be determined. If this frequency is at or above the ZPA cutoff frequency, the run pipe is considered as rigid and there will be no amplification of the building response spectra. Therefore, the applied inertial excitation at the branch-to-run pipe anchor shall include the envelope of building excitations for the nearest supports on both the branch and run pipes.

- If the fundamental frequency of the run pipe at the branch location is below the ZPA cutoff frequency, the run pipe at this location is considered to be flexible and, therefore, may amplify the input inertial effects. Where practical, in these cases, amplified response spectra will be developed from the run pipe analysis and applied at the branch-to-run pipe anchor in the branch pipe analysis.

- As an alternative to a decoupled analysis, for branch lines connected to flexible run piping where amplified response spectra are not generated, the branch line analysis may include a portion of the run pipe meeting one of the model isolation methods described in Section 5.4.3 in order to capture the possible amplification of inertial input from the run pipe. Therefore, the applied inertial excitation shall include the envelope of building excitations for the nearest supports on both the branch and run pipes. In these cases, the run pipe analysis remains qualified by the decoupled analysis.

Since the above methods of analysis to be used in the U.S. EPR piping design are consistent with the current industry practices and will account for the effects of run pipe or flexible equipment responses on the decoupled branch piping, the staff finds this acceptable. Therefore, **RAI EPR-7 is resolved.**

The staff reviewed the TR description of the RS method with USM and found that it is consistent with the applicable guidelines in SRP Section 3.9.2, Subsection II.2. Therefore, the staff finds this acceptable.

3.2.3 Response Spectrum Method with Independent Support Motion

As an alternative to the enveloped response spectrum method, the RS method with ISM may be used. The theory and development of the governing equations of motion for this method are basically the same as the USM RS method. Additional requirements associated with the application of this method are described in the TR Section 4.2.2.2.2. This section states that when the ISM method of analysis is used, the following conditions must be met. First, a support group is defined by supports which have the same time history input. This usually means all supports located on the same floor, or portions of a floor, of a structure. Second, the responses from motions of supports in two or more different groups are combined by the absolute sum procedure. The modal and directional responses are then combined similar to those discussed for the USM RS method and as discussed in TR Sections 4.2.2.3 and 4.2.2.4, respectively.

In addition to the inertial response, the effects of relative support displacements, similar to that discussed in the USM method above, are performed to obtain the SAM responses, as discussed in TR Section 4.2.2.5.

The current staff position for modal and group combinations in the ISM method of analysis is presented in Volume 4, Section 2 of NUREG-1061. For inertial or dynamic components, group responses are combined by the absolute sum method. Both modal and directional responses are combined by the square-root-of-the-sum-of-the-square (SRSS) method; the modal combination is performed without considering the effects of closely spaced frequencies. For SAM components, the maximum absolute responses from each directional input for each group are combined by the absolute sum method, and the directional responses are combined by the SRSS method. Finally, the dynamic and SAM responses are combined by the SRSS method, unlike the case for the USM method of analysis where the combination uses the absolute sum method as required by SRP Section 3.9.2.

The staff noted some differences between the ISM method of response combinations presented in TR Section 4.2.2.2.2 and the method given in NUREG-1061 (e.g., the modal combination methods). In RAI EPR-8, the staff requested AREVA to indicate whether all of the rules contained in NUREG-1061 for the ISM method of analysis will be followed or AREVA should provide the technical justification for the methods described in TR Section 4.2.2.2.2. In response (dated July 13, 2007), AREVA stated that all of the provisions of NUREG-1061, Volume 4, for using the ISM method of analysis will be followed for U.S. EPR piping design. AREVA will revise various subsections of TR Section 4.2.2 in order to include all provisions of NUREG-1061, including the combination of the missing mass effects with the low frequency modal responses, as committed in its revised responses of November 20, 2007, and April 18, 2008. Since this will satisfy the current staff position on ISM method of analysis, the staff finds this acceptable. Therefore, **RAI EPR-8 is resolved.**

3.2.4 Time History Method

Typically, a TH analysis may be performed using either the modal superposition method, direct integration method in the time domain, or the complex frequency response method in the frequency domain. AREVA described the modal superposition method in TR Section 4.2.3, which is the only method that will be used for the U.S. EPR plants. However, as discussed in Section 3.2 of this report, AREVA may use the direct integration TH analysis method as an alternative to the modal superposition TH analysis. The modal superposition method involves the calculation and utilization of the natural frequencies, mode shapes, and appropriate damping factors of the particular system toward the solution of the equations of dynamic equilibrium. The orthogonality of the mode shapes is used to effect a coordinate transformation of the displacements, velocities, and accelerations such that the response in each mode is independent of the response of the system in any other mode. Through this transformation, the problem becomes one of solving a set of "n" independent differential equations rather than simultaneous differential equations. As long as the system is linear, the principle of superposition holds and the total response of the system oscillating simultaneously in "n" modes may be determined by direct addition of the responses of the individual modes.

In TR Section 4.2.3 AREVA states that the cutoff frequency for the determination of modal properties is selected to account for the principal vibration modes of the system based upon mass and stiffness properties, modal participation factors and the frequency content of the input forcing function. The missing mass effects of high frequency modes are included based on the same principle for the response spectrum method described in TR Section 4.2.2.3.2. Alternatively, the cutoff frequency is determined such that the number of modes calculated will produce dynamic analysis results within 10 percent of the results of the dynamic analysis including the next higher mode. AREVA will use guidance for including the missing mass effects as provided in Appendix A of SRP Section 3.7.2, as well as RG 1.92, Rev.2, as stated in TR Section 4.2.2.3.2. However, Appendix A of the RG 1.92, Rev. 2 has some differences in the calculation of the missing mass contribution to total response in its Step 2 when compared to the Appendix A of the SRP Section 3.7.2. In addition, RG 1.92 Section 1.4.1 states that in recently-published literature it is shown that the missing mass contribution needs to be considered only if the fraction of the missing mass at any degrees of freedom exceeds 0.1 is non-conservative and should not be used. Rather, the missing mass contribution should be calculated in all RS analyses because its potential effect on support reactions is difficult to judge based on the fraction of missing mass. This is discussed further in Section 3.4.6 (under high-frequency modes) of this report.

In addition to seismic analysis, the modal superposition TH method will be used for the dynamic analysis of water/steam hammer loads; relief/safety valve thrust loads; jet force loads or other hydraulic transient loadings. Since many of these loads are for a short duration and may contain very high frequency content, all modes up to the appropriate cutoff frequency must be considered. As in RS analysis, the modal superposition TH method must also consider the missing mass contribution. RG 1.92, Rev. 2, Section 1.4.1 describes an acceptable methodology in which the missing mass contribution is scaled to the instantaneous acceleration and then algebraically summed with the transient solution at the corresponding time to obtain the total solution. In RAI EPR-9, the staff requested AREVA to explain the methods to include the high frequency content including the missing mass contribution when applying the modal superposition TH method.

In its revised response (dated November 20, 2007), AREVA stated that missing mass will be accounted for in TH modal superposition analyses in accordance with Appendix A of RG 1.92, Rev. 2. The mode shapes and frequencies are determined as they are in the RS analysis. The cutoff frequency for the determination of modal properties is 40 Hz or as defined by Figures 2 and 3 in RG 1.92, Rev 2, as this is expected to encompass all of the important response frequencies of the system.

Missing mass effects of the high frequency modes beyond the cutoff frequency are included via the missing mass method described in Regulatory Position C.1.4.1 and Appendix A of RG 1.92, Rev. 2. Since, by including the missing mass effects of the high frequency modes beyond the cutoff frequency would include the piping response to any high frequency transient loadings, the staff finds this acceptable. Therefore, **RAI EPR-9 is resolved.**

In TR Section 4.2.3 AREVA also states that the time step to be used in the TH analysis is no larger than one-tenth of the period of the cutoff frequency. Generally, the numerical integration time step, Δt, must be sufficiently small to accurately define the dynamic excitation and to render stability and convergence of the solution up to the highest frequency of significance. For most of the commonly used integration methods, the maximum time step is limited to one-tenth of the smallest period of interest selected initially, which is generally the reciprocal of the cutoff frequency. In accordance with industry practice and as described in Section 3.2.2.1(c) of ASCE 4-98, an acceptable approach for selecting the actual time step (Δt) is that the Δt used shall be small enough such that the use of one-half of Δt does not change the response by more than 10 percent. In RAI EPR-10, the staff requested AREVA to clarify whether this criterion is used as part of the piping analysis requirements using time history analysis method in addition to the 10 percent of the period of the cutoff frequency as the initial selection or AREVA should provide a technical justification for not considering this criterion for seismic and other dynamic loading analyses.

In its revised response (dated November 20, 2007), AREVA stated that a time step study has been performed for the direct integration TH analysis of the reactor pressure vessel (RPV) isolated model considering seismic loading. This model contains a representation of the reactor coolant system (RCS) piping, components and supports, including the pressurizer and surge line, as well as a representation of the reactor building internal structure. In this study, a representative seismic case was analyzed using two integration time steps: 1) 0.0005 seconds and 2) 0.0025 seconds. Comparison of results (accelerations, displacements and forces) at several locations within the RPV and its internals indicates that the solution has converged (the maximum difference in response was identified as 5.5 percent). Based on this study, AREVA is confident that a 0.0001 second integration time step would be more than sufficient to achieve convergence. However, recognizing that there are inherent differences between the dynamic characteristics of the RPV isolated model and models of pure piping systems, AREVA will perform time step studies for three of the Class 1 attached piping problems for the U.S. EPR. This represents a sample of greater than 10 percent of the Class 1 piping problems that AREVA will analyze. The smallest integration time step required for convergence in these sample analyses will be used for all of the Class 1 piping analyses. It is currently not anticipated that TH analysis will be used for Class 2 and 3 piping, but if it is, the integration time step will be established in the same manner, i.e., through time step studies on a representative sample of Class 2 and 3 piping problems. The intent of these time step studies is to identify a practical lower bound integration time step that provides adequate assurance of convergence. Convergence will be determined by halving the integration time step until it can be shown that halving it further will not increase the response of the system by more than 10 percent. Since this approach is consistent with the current industry practices and will ensure convergence of the solution, the staff finds this acceptable. Therefore, **RAI EPR-10 is resolved.**

In TR Section 4.2.3, AREVA states that the total seismic response is predicted by combining the responses from the three orthogonal components (two horizontal and one vertical) of the earthquake. The combined response is obtained by algebraically adding the codirectional responses from each analysis at each time step or the total response may be obtained directly by applying the three component motions simultaneously in one analysis. Whenever these methods are used, the three component input motions must be mutually statistically independent. As an alternative, when separate TH analyses are performed for each directional component, the combined response may be obtained by taking the SRSS of the maximum codirectional responses caused by each component.

To account for uncertainties in the structural analysis using the TH method, in TR Section 4.2.3 AREVA states that similar to peak shifting in the response spectrum method of analysis, three separate input TH with modified time steps may be analyzed. Alternatively, the THs at the attachment points may be derived considering variations in the concrete stiffness. An acceptable method to vary the frequency content of the in-structure acceleration TH to account for uncertainties in the analysis is either by expanding and shrinking the TH within 1/(1± 0.15) so as to change the frequency content of the TH within ±15 percent or by varying building stiffness (Note that for AP1000, NRC accepted building stiffness variation within ±30 percent). In RAI EPR-11, the staff requested AREVA to provide additional details on their procedure for accounting for these uncertainties in a TH analysis of piping systems when subjected to seismic and other dynamic loadings.

In its revised response (dated November 20, 2007), AREVA stated that to account for uncertainties in the structural analysis for seismic loading, a peak shifting approach, similar to that described in TR Section 4.2.2.1.2 for RS analysis, is used. This is accomplished by first converting the seismic TH excitations into response spectra, and then proceeding through the methodology outlined in Section 4.2.2.1.2. Note that shifting of the input excitation peaks is accomplished by adjusting the time step of the THs which represent the excitations. Further supporting information for the above revision to the TR is provided below:

(1) The seismic design basis of the U.S. EPR includes twelve different seismic analysis cases (twelve different combinations of soil conditions and seismic control motion); all twelve cases are anchored to a PGA of 0.3g. Therefore, there will be three translational THs (one in each of the three orthogonal directions) at each anchor point and at each support\restraint in the piping system. AREVA intends to analyze each of the twelve seismic cases individually, though enveloping them is a conservative option.

(2) There will be sets of three translational THs at each terminal point\support\ restraint in the piping systems being analyzed. There are two options available regarding how to treat these different sets of THs that are applicable to the various terminal points\supports\restraints in the piping systems:

   i. The THs at terminal points/supports/restraints can be enveloped by: a) turning them into response spectra, b) developing the enveloping terminal point/support/restraint response spectra, and then c) generating an artificial TH (and resulting response spectra) which envelopes the enveloping terminal point/support/restraint response spectra within the guidance of SRP 3.7.1.

   ii. For Class 1 piping systems, the piping system in question can be coupled to the model used to perform RCL analysis, which has a representation of the reactor building interior structure (RBIS) in it and a representation of the containment building can be added (if necessary, because one or more of the supports/restraints are attached to the containment building). The resulting model has one point of excitation (the nuclear island basemat) and, therefore, only one set of earthquake THs per seismic case.

(3) Once the peak shifting factors are determined by the procedure described in Section 4.2.2.1.2 of the TR, the time steps of the translational THs (either the enveloping THs described in 2(i) above, or the basemat THs described in 2(ii) above) are reduced, or increased, in order to move the peak input accelerations to the desired frequencies. Note that each orthogonal direction is treated separately. The piping model is then analyzed separately for the resulting THs (N+3 for each orthogonal direction, see Section 4.2.2.1.2 of the TR, where N is the number of piping modes within the broadened frequency range). The maximum piping system response (accelerations, displacements

and loads in the x, y, and z directions) among the global X direction excitations, among the global Y direction excitations, and among the global Z direction excitations are combined at each time point.

AREVA also, in its response (July 13, 2007), stated that methods used to account for uncertainties will only be used in seismic analysis as the intent is to approximate the effect of the application of peak broadened spectra in a RS analysis. The time step compression/expansion approach to account for these uncertainties will be demonstrated by equating its results to the peak shifting method used in RS analysis as described in TR Section 4.2.2.1.2. As stated in TR Section 4.2.3, the approach of considering variations in concrete stiffness to account for uncertainties in seismic time history analysis will be removed from the TR.

Since these methods to account for uncertainties in the structural analysis are industry-accepted practices, the staff finds this acceptable. Therefore, **RAI EPR-11 is resolved.**

It should be noted that, as an alternative to the spectral broadening procedure, the staff has accepted the peak shifting method for specific plant applications on a case-by-case basis pending revision of RG 1.122, as indicated in RG 1.84 for the Code Case N-397. Since the peak shifting method applicable to floor spectrum generation has now been included in the Appendix N (Section N-1226.3) of the ASME Code Section III, ASME has currently annulled this Code Case that was conditionally accepted by the staff. In addition, ASCE 4-98 Section 3.4.3.2(b) for TH analysis and Section 3.4.2.3(c) for RS method of analysis provide acceptable methods of peak shifting. The applicability of the peak shifting method for developing floor response spectra is also discussed in Section 3.4.1 of this report. Based on this, the staff finds the peak shifting method to account for analysis uncertainties is acceptable.

3.2.5 Equivalent Static Load Method

In TR Section 4.2.4, AREVA discusses an alternative method of analysis that allows a simpler technique, but is known to yield more conservative results. The equivalent static load analysis method is used when a simplified analysis is considered with the mass of the piping and components as lumped masses at their center of gravity locations. The seismic response forces due to these masses are then statically determined by multiplying the contributing mass by an appropriate seismic acceleration coefficient at each location. This method does not require frequency calculation of the system and the loads are statically applied at each mass point by a multiplying a static coefficient equal to 1.5 times the maximum spectral acceleration at appropriate damping value of the input floor response spectrum. The static coefficient of 1.5 is intended to account for the effect of both multi-frequency excitation and multi-mode response for piping systems which have multiple degrees of freedom and have a number of significant modal frequencies in the amplified region of the RS curve (i.e., below the ZPA).

In accordance with SRP Section 3.9.2, II.2.A (ii), TR discusses the following conditions that should be met prior to using this method of analysis:

- Justification is provided that the system can be realistically represented by a simple model and the method produces conservative results in terms of responses.

- The design and associated simplified analysis account for the relative motion between all points of support.

- To obtain an equivalent static load of equipment or component which can be represented by a simple model, a factor of 1.5 is applied to the peak acceleration of the applicable floor response spectrum.

This analysis is performed for all three directions of the seismic input motion. The results of these three analyses are then combined using the SRSS method. The SAM analysis is performed similar to that for RS analysis methods as discussed in TR Section 4.2.2.5.

In general, if the system behaves essentially as a single degree of freedom system and the fundamental frequency of this system is known, a factor of 1.0 of the spectral acceleration at the highest spectral acceleration value at or beyond, the fundamental frequency may be used. Also, when the system is rigid, the ZPA instead of the maximum spectral acceleration of the input spectra may be used. A component is considered to be rigid when its fundamental frequency is equal to or greater than the frequency at which the input RS returns to approximately the ZPA. In RAI EPR-12, the staff requested AREVA to confirm that as stated in the TR, the equivalent static load is determined by multiplying 1.5 to the peak acceleration for all cases including a single degree of freedom system and a rigid system.

In response (dated July 13, 2007), AREVA stated that for multiple degree of freedom systems, the peak acceleration of the appropriate floor response spectra will be multiplied by 1.5. However, in response to RAI EPR-5, AREVA states that for cases where a piping configuration can be demonstrated to respond as a single degree of freedom system with a known fundamental frequency or rigid system with a fundamental frequency beyond the cutoff frequency, a factor of 1.0 may be used with the highest spectral acceleration at that frequency or any higher frequency (as may be the case for multiple peak input spectra). Since these criteria typically provide conservative piping response, the staff finds this acceptable. Therefore, **RAI EPR-12 is resolved.**

3.2.6 Inelastic Analysis Method

In TR Section 4.3, AREVA states that inelastic analysis will not be used to qualify piping for the U.S. EPR design certification. The staff finds this acceptable.

3.2.7 Small Bore Piping Analysis Methods

Small bore piping is typically defined as piping 50 mm (two inches) and less nominal pipe size. In many cases, small bore piping systems are field run and qualified based on in-house developed design criteria by architect engineering firms. The TR did not define the small bore piping for the U.S. EPR piping design. Also, the TR did not provide any design methods, analysis techniques or acceptance criteria for small bore piping. In RAI EPR-13, the staff requested AREVA to provide the design criteria applicable to small bore piping in the U.S. EPR piping design.

In its revised response (dated November 20, 2007), AREVA defined the small bore piping (including instrumentation lines) for the U.S. EPR as ASME Class 1 piping that is one inch NPS and smaller and Class 2, and 3 and QG D that is two inches NPS and smaller. AREVA suggested adding a new TR Section 4.5 on small bore piping and this piping may be analyzed using RS methods described in TR Section 4.2.2 or the equivalent static method described in

TR Section 4.2.4. Since the classification and analysis of small bore piping are consistent with industry practices, the staff finds this acceptable. Therefore, **RAI EPR-13 is resolved.**

3.2.8 Non-Seismic/Seismic Interaction (II/I)

All non-seismic Category I piping (or other systems and components) should be isolated from seismic Category I piping. This isolation may be achieved by designing a seismic constraint or barrier or by locating the two sufficiently apart to preclude any interaction. If it is impractical to isolate the seismic Category I piping system, the adjacent non-seismic Category I system should be evaluated to the same criteria as the seismic Category I system.

In TR Section 4.4, AREVA states that, for non-seismic Category I piping systems attached to seismic Category I piping systems, the dynamic effects of the non-seismic Category I system are considered in the analysis of the seismic Category I piping. In addition, the non-seismic Category I piping from the attachment point to the first anchor is evaluated to ensure that, under all loading conditions, it will not cause a failure of the seismic Category I piping system (per RG 1.29, Regulatory Position C.3).

In TR Section 4.4, AREVA also states that the primary method of protection for seismic piping is isolation (by physical separation or physical barrier as discussed in TR Section 4.4.1) from all non-seismically analyzed piping. AREVA clarified in its response to RAI EPR-14 for isolation criteria (dated July 13, 2007), that in cases where it is not possible, or practical, to isolate the seismic piping, isolation of a non-seismic piping is achieved when two piping systems in the same room (one seismic and one non-seismic) are physically located away from each other as much as possible, such that there will be little chance of the non-seismic piping adversely interacting with the seismic piping, potentially causing damage to the seismic piping during a seismic event. Otherwise, the adjacent non-seismic piping is classified as seismic Category II and analyzed and supported such that an SSE event will not cause an unacceptable interaction with the seismic Category I piping. Alternatively, an interaction evaluation (as discussed in TR Section 4.4.2) may be performed to demonstrate that the interaction will not prevent the seismic Category I piping system from performing its safety-related function. Furthermore, in its revised response (dated November 2007), AREVA agreed to remove the following interaction criteria given in TR Section 4.4.2:

- If the non-seismic piping is supported by seismic restraints within the ASME B31.1 Code suggested pipe support spacing shown in Table 4-1, it is considered to lose its pressure boundary integrity, but not fall.

- All moderate energy piping should be assumed to fall vertically downward from its original position. Side motion should be assumed to be ±six inches (centerline to centerline) from the original pipe position. Pipe whip should be considered for high energy piping.

- Safety-related piping with NPS and thickness equal to or greater than that of the non-seismic piping may be assumed to stop the downward motion of the non-seismic piping without failure of the safety-related piping."

All other non-seismic/seismic interaction criteria discussed in TR Sections 4.4.1 and 4.4.2 are found reasonable and acceptable to the staff. Therefore, **RAI EPR-14 is resolved.**

3.2.9 Buried Piping

In TR Section 3.10, AREVA states that Class 2 and 3 seismic Category I buried piping systems in the U.S. EPR will be analyzed for pressure, weight, thermal expansion and seismic loads using dynamic or equivalent static load methods. The acceptance criteria are the same as those used for non-buried piping systems described in TR Table 3-2 with additional consideration of the following differences:

- Deformations imposed by either seismic waves traveling through the surrounding soil or by differential deformations between the soil and anchor points and lateral earth pressures acting on buried piping will be considered.
- The effects of static resistance of the surrounding soil on piping deformations or displacements, anchor movements and pipe geometry will be considered using the theory of structures on elastic foundations.
- The effects of local soil settling will be considered when applicable.
- It is also assumed that soil liquefaction and fault displacement will be avoided.
- Seismic loads experienced by buried piping are primarily generated by soil strains and, therefore, are self-limiting and considered secondary in nature.

Design conditions, load combinations and stress criteria to be used in the qualification of buried piping are addressed in TR Table 3-4.

AREVA also states that these criteria conform to the applicable guidelines in SRP Section 3.9.2. However, AREVA did not give any details on how these criteria are to be applied in the design of buried piping. Therefore, in RAI EPR-15, the staff requested AREVA to discuss the design criteria for buried pipes. In Attachment B to the RAI responses (July 13, 2007), AREVA provided a revised new TR Section 3.10 on seismic Category I Buried Piping. In this section, AREVA defined all applicable loads, methods of analysis, and acceptance criteria for various load combinations. However, the staff review of this new section found several errors and inconsistencies in the governing equations and definitions of various load parameters in loads and load combinations given in TR Table 3-4. In Attachment B to the RAI revised responses (November 20, 2007), AREVA provided a revised TR Section 3.10 addressing the buried piping design. The staff review of this revised section also found several errors and inconsistencies. Finally, on April 18, 2008 AREVA provided a new TR Section 3.10 in Attachment B of its second revised response to the RAIs, which the staff finds acceptable. **Therefore, the RAI EPR-15 is resolved.**

3.2.10 Conclusions

On the basis of the evaluations, the staff concludes that the analysis methods to be used for all seismic Category I piping systems as well as non-seismic Category I piping systems that are important to safety are acceptable. The analysis methods utilize piping design practices that are commonly used in the industry and provide an adequate margin of safety to withstand the loadings as a result of normal operating, transient, and accident conditions. The staff concludes that AREVA satisfies the requirements of GDC 2 by specifying appropriate analysis methods for designing piping and pipe supports against seismic loads.

3.3 Modeling of Piping Systems

GDC 2 requires that components important to safety should be designed to withstand effects of natural events including earthquakes. 10 CFR Part 50, Appendix B requires that design quality should be controlled for ensuring structural and functional integrity of seismic Category I components. For determining design adequacy, each piping system is idealized as a mathematical model and dynamic analysis is performed using computer programs. Modeling techniques should be in conformance with generally recognized engineering practices, and computer programs should be verified in accordance with one or more methods suggested in SRP Section 3.9.1.

TR Section 5.0 describes piping modeling techniques and discusses the computer programs and their applications in the U.S. EPR piping design.

3.3.1 Computer Codes

In TR Section 5.1 AREVA provides short descriptions of the major computer programs to be used in the analysis and design of safety-related piping systems. These computer programs include: SUPERPIPE, BWSPAN, BWHIST, BWSPEC, COMPAR2, CRAFT2, P91232, and RESPECT. AREVA states that SUPERPIPE has been thoroughly verified and validated to NRC standards. For all other computer codes, AREVA did not indicate whether these programs are verified for their application by appropriate methods, such as hand calculations, or comparison with results from similar programs, experimental tests, or published literature, including analytical results or numerical results to the benchmark problems and validated as the piping program SUPERPIPE. Moreover, AREVA did not mention how the quality of these programs and computer results is controlled.

AREVA did not specifically identify the computer programs associated with other than linear type of pipe support designs, welding of lugs or stanchions to pipe, or other piping analysis related calculations (e.g., nozzle load and analysis, broadening of spectra or time history). However, in TR Section 3.6, AREVA states that support and restraint designs using such welded attachments will adhere to industry practices and ASME Code Cases identified in TR Section 2.2. Based on the TR Section 5.1, the following are short descriptions of each of the computer codes addressed at this certification stage:

- <u>SUPERPIPE</u> - Analyzes piping for both static and dynamic loads, performs design checks for ASME Class 1, 2, and 3 and B31.1 piping. Dynamic analysis methods include both RS and TH analysis using either modal superposition or direct integration methods.

- <u>BWSPAN</u> - Performs structural analysis of piping and structural systems. Also, performs pipe stress and fatigue calculations to a variety of design codes including B31.1, B31.7 and the ASME Code, and calculates stresses for linear type supports according to Subsection NF of the ASME Code.

- <u>BWHIST</u> - Converts pressure THs generated by CRAFT2 or COMPAR2 into force THs by integrating the pressure over the area to which it is being applied.

- BWSPEC - Tabulates displacements, pipe and structure loads, support loads and spring loads using output from a BWSPAN analysis.

- COMPAR2 - Performs hydraulics analysis of fluid systems (generally containment cavities).

- CRAFT2 - Performs hydraulics analysis of fluid systems (generally piping or components).

- P91232 - Calculates through-wall gradient temperatures and stresses given pipe or nozzle geometry and thermal characteristics.

- RESPECT - Generates amplified response spectra (ARS) given the frequency and mode characteristics of the system in question (from BWSPAN) and the acceleration TH applicable to the base of the structure. Also, generates seismic ARS at the branch nozzle locations in a model of a piping system.

Since AREVA did not provide any validation and verification of any of these computer codes, in RAI EPR-16 the staff requested AREVA to provide the status and quality control aspects of these computer programs. In response (dated July 13, 2007), AREVA stated that BWSPAN and SUPERPIPE are the only two computer codes currently in use during the certification stage. BWSPAN is being used for analysis of the RCL piping during the design certification phase. While the other codes given in the initial version of the TR are also being used for RCL analysis in the design certification phase, they are not strictly piping analysis codes (they are general purpose hydraulic and post processing codes) and so their description will be removed from the TR. Also, SUPERPIPE is being used during design certification for the analysis of ASME Class 2 and 3 piping. It may be used for Class 1 piping. The following is the status of the two computer codes requiring design certification:

- BWSPAN: The use of BWSPAN for Class 1 RCL analysis has previously been approved by the NRC, see letter David E. LaBarge (NRC) to W.R. McCollum, Jr. (Duke Energy Corporation), Oconee Nuclear Station, Units 1, 2 and 3 Re: Reactor Coolant Loop Analysis Methodology for Steam Generator Replacement (TAC Nos. MA9886, MA9887, and MA9888), dated September 6, 2001. Earlier versions of BWSPAN have been successfully benchmarked to the piping problems given in NUREG/CR-1677. Later versions have been benchmarked to a prior version of BWSPAN by running selected sample problems which demonstrate that the changes made in moving from one version to the next have been correctly implemented. BWSPAN is controlled and maintained per AREVA NP, Inc. administrative procedures. The files which document the verification, validation, maintenance and control of BWSPAN are available. These files will provide the author, source, dated version, program description, the extent and limitation of the program application; and the computer solutions to the test problems described above.

- SUPERPIPE: The use of SUPERPIPE, in previous versions, has been approved by the NRC for a number of previous license applications including the Catawba Nuclear Station (CNS UFSAR, Rev. 12, Table 3-68) and the System 80+ Design Certification (NUREG-1462, Section 3.12.3). Current versions of SUPERPIPE have been subsequently verified under the AREVA software QA program by comparison of results to the results of previously accepted versions. SUPERPIPE is controlled and maintained per AREVA NP Inc. administrative procedures. The files which document the verification, validation, maintenance and control of SUPERPIPE are available. These files will provide the author, source, dated version, program description, the extent and limitation of the program application; and the computer solutions to the test problems described above.

As discussed in Section 3.5.7 of this report, in response to RAI EPR-36 AREVA is also committed to add the computer code GT STRUDL at this phase of the design certification. This would require changes to the TR Section 5.1.

The information on the first two computer codes is available for NRC inspection. These files will provide the author, source, dated version, program description, the extent and limitation of the program application; and the computer solutions to the test problems described above. **However, in its revised response (dated November 20, 2007) to RAI EPR-36, AREVA is committed to include the computer code GT STRUDL for design certification of pipe supports.** Since the BWSPAN and SUPERPIPE computer codes satisfy the requirements of SRP 3.9.1, the staff finds this acceptable. Therefore, **RAI EPR-16 is resolved.**

3.3.2 Dynamic Piping Model

In TR Section 5.2, AREVA describes the procedures used for analytical modeling of piping systems. For dynamic analysis, the piping system is idealized as a three dimensional model using finite element analysis programs. The analysis model consists of a sequence of nodes connected by pipe elements (both straight and bend elements) with stiffness properties representing the piping and other inline components. Nodes are typically modeled at points required to define the piping system geometry as well as lumped mass locations, support locations, locations of structural or load discontinuities and at other locations of interest along the piping. System supports are idealized as springs with appropriate stiffness values for the restrained direction.

In the dynamic mathematical model, AREVA also states that the distributed mass of the system, including pipe, contents (fluid or gas) and insulation weight, is represented either as a consistent (distributed) mass or as lumped masses placed at each node. For the latter case, in order to adequately determine the dynamic response of the system, elements may be subdivided and additional mass points added. The minimum number of degrees of freedom in the model is to be equal to twice the number of modes with frequencies below the ZPA frequency. Maximum mass point spacing may be no greater than one half of the span length of a simply supported beam with stiffness properties and distributed mass equal to that of the piping cross-section and the first fundamental frequency equal to the cutoff frequency. AREVA further states that concentrated weights of in-line components, such as valves, flanges and instrumentation, are also modeled as lumped masses. Torsional effects of eccentric masses are included in the analysis. For rigid components (those with natural frequencies greater than the ZPA cutoff frequency) the lumped mass is modeled at the center of gravity of the component with a rigid link to the pipe centerline. Flexible components (those with natural frequencies less than the ZPA cutoff frequency) are included in the model using beam elements and lumped mass locations to represent the dynamic response of the component.

Additionally, a portion of the weight of component type supports (such as snubbers, struts, spring hangers, etc.) is supported by the pipe and is considered in the piping analysis model. The mass contributed by the support is included in the analysis when it is greater than

10 percent of the total mass of the adjacent pipe span (including pipe, contents, insulation and concentrated masses). The adjacent span is defined as the piping including the applicable support and bounded by the adjacent restraint on each side of this support in each direction. AREVA also states that because the mass of a given support will not contribute to the piping response in the direction of the support, only the unsupported directions need to be considered. It is not clear why the mass of the support will not contribute to the piping response in the direction of a flexible support. Therefore, in RAI EPR-17, the staff requested AREVA to provide conditions under which this statement is applicable. In response (dated July 13, 2007), AREVA stated that the mass contributed by the support is included in the analysis when it is greater than 10 percent of the total mass of the adjacent pipe span (including pipe contents, insulation and concentrated masses). It is agreed that if the support is determined to be flexible in the direction of the restraint, the support mass should also be included in this direction, as well as for the unrestrained directions. Since this will simulate the actual response of the piping and its supports, the staff finds this acceptable. Therefore, **RAI EPR-17 is resolved.**

A review of the impact of contributing mass of supports on the piping analysis will need to be performed by the COL applicant(s) following the final support design to confirm that the mass of the support is no more than 10 percent of the mass of the adjacent pipe span. This is identified as the COL-Action Item 5 in TR Table 1-1.

In TR Section 5.4, AREVA discusses the model boundaries based on defining terminal points. Piping system analysis models are typically terminated by one of three techniques: 1) structural boundaries, 2) termination based on decoupling criteria, or 3) termination by model isolation methods. Structural boundaries and the use of decoupling criteria are the preferred methods. However, after applying these first two methods, further division of the piping system may be desired to create more manageable models for analysis. This may be accomplished using the model isolation methods. The structural boundary and the model isolation methods are discussed here. The decoupling criteria are discussed later in Section 3.3.4 of this report.

AREVA states that structural model boundaries, such as equipment nozzles or penetrations, provide isolation of the effects of the piping on one side of the boundary to the piping on the opposite side. For large piping systems, AREVA also describes three different ways to create model boundaries for separating a large piping model into smaller models: 1) an in-line physical anchor, 2) restrained elbows, and 3) restrained tees. The addition of an in-line anchor generally creates stiffer piping systems and may cause significant increases in stress and support loads on lines with high thermal movements. Additionally, the use of in-line anchors on high energy lines adds additional postulated terminal end pipe rupture locations. Therefore, additional in-line anchors are only added if they are determined to be practical.

In TR Sections 5.4.1.2 and 5.4.1.3, AREVA describes two other alternate approaches when a single full anchor support is not feasible. A pair of guide supports placed around an elbow or a tee may be used to separate analysis models. In this method, an elbow or a tee is restrained by a pair of guide supports in each leg at a certain distance apart from the pipe component. This creates a structurally rigid zone around the elbow or the tee in which the piping effects from one end of the restrained section are not transmitted beyond the other end. AREVA did not provide any technical justifications or references to any available literature for the restrained elbow or tee method of piping model terminations. Therefore, in RAI EPR-18, the staff requested AREVA to provide technical justifications with sample calculations to create a structurally rigid zone around an elbow or a tee.

In response (dated July 13, 2007), AREVA stated that the configurations shown in Figures 5-1 and 5-2 produce boundaries which, over a relatively short distance, provide effective restraint for the six degrees of freedom. The configuration creates a rigid zone of pipe with natural frequencies well above the ZPA and provides four restraints in the out-of-plane direction. The location of the two in-plane restraints on each side of the elbow or each segment of the tee provides a very short, stiff segment of piping from the intersect point and therefore create an effective axial restraint for the piping in the in plane direction. This configuration meets the recommendations for an overlap zone presented in NUREG/CR-1980.

In accordance with NUREG/CR-1980 recommendations, first the overlap region should have enough rigid restraints and include enough bends (or tees) in three directions to prevent the transmission of motion due to modal excitation from one end to the other and to reduce to a negligible level of the sensitivity of the structure to the direction of excitation. For this to achieve the NUREG/CR-1980 recommends four (4) rigid restraints in each of the mutually perpendicular directions in the overlap region (including the ends). For axial restraints only this requirement may be relaxed to a single restraint in any straight segment. The second condition to this rigidity in each of the three mutually perpendicular directions includes a demonstration of the fundamental frequency of the overlap region to be at least 25 percent higher than the highest significant forcing frequency. Since AREVA states that both the restrained elbows and/or restrained tees configuration meet the recommendations for an overlap zone presented in NUREG/CR-1980, the staff could not conclude from TR Figures 5-1 and 5-2 how these configurations meet the two conditions of NUREG/CR-1980 discussed above. However, on April 18, 2008, AREVA provided revised pages of the TR in Attachment B of its second revised response, where both Subsections 5.4.1.2 on Restrained Elbows and 5.4.1.3 on Restrained Tees (including their corresponding TR Figures 5-1 and 5-2) are deleted from the TR. **Since AREVA has deleted these TR Subsections, the staff finds that RAI EPR-18 is no longer needed. Thus, RAI EPR-18 is withdrawn.**

In TR Section 5.4.3, AREVA describes two model isolation methods, namely, overlap region method and influence zone method, to divide large seismic piping systems that cannot be separated by structural methods or decoupling criteria. Both these methods are similar in technique in that a section of the piping system is used as the boundary of the models. This section of the system is defined such that the effects of the piping beyond one end of the region do not significantly affect the piping beyond the opposite end of the region. In TR Section 5.4.3.1, AREVA suggests for the overlap region method that, as a minimum, an overlap region must contain at least four (4) seismic restraints in each of three perpendicular directions and at least one change in direction. The overlap region should be selected in a rigid area of the piping system and is modeled in two or more piping analyses. A dynamic analysis of the overlap region shall be made with pinned boundaries extended beyond the overlap region either to the next actual support or to a span length equal to the largest span length within the region. The fundamental frequency determined from this analysis shall be greater than the frequency corresponding to the ZPA.

In TR Section 5.4.3.2, AREVA states that the main difference between the influence zone and the overlap region is that in using the influence zone, all piping and supports are qualified by a single model. This is achieved by first determining the qualification boundary between models. Each model is then extended to a termination point such that the response of the piping at the termination of the model will not influence the response of the piping within the qualification boundary. The influence zone is then defined by the section of piping between the qualification boundary and the model termination point. However, when using this methodology versus the overlap region method, a significantly larger section of piping may be required to be included in two or more models.

AREVA did not provide any technical justifications or references to any available literature for these two methods of model isolation. Therefore, in RAI EPR-19, the staff requested AREVA to provide technical justifications with sample calculations to demonstrate the isolation of two piping problems using either the overlap region method or the influence zone method.

In response (dated July 13, 2007), AREVA stated that the overlap methodology provided in TR Section 5.4.3.1 is consistent with the recommendations of NUREG/CR 1980. The zone of influence (ZOI) method is provided as an option when the requirement for a rigid section of piping can not be met in order to use the overlap methodology. In this method, all piping must be modeled to a point where boundary conditions and loadings no longer impact the piping being qualified. This will typically be more piping than is required by the overlap method and the validity of the boundary is required to be demonstrated during the analysis. Since these methods use four (4) seismic restraints in each of three perpendicular directions and at least one change in direction consistent with the recommendations in NUREG/CR-1980, the staff finds this acceptable. **Therefore, RAI EPR-19 is resolved.**

3.3.3 Piping Benchmark Program

In TR Section 5.3, AREVA states that pipe stress and support analysis will be performed by the COL applicant. If the COL applicant chooses to use a piping analysis program other than those listed in TR Section 5.1, the applicant will implement the NRC benchmark program using models specifically selected for the U.S. EPR. This is identified as COL-Action Item 6 in TR Table 1-1.

The staff requires the COL applicants who will complete the piping analysis and finalize the piping designs to verify their computer programs in accordance with the NRC benchmark program specific to the standardized plant design. Under a piping benchmark program, the COL applicant applies his computer program to construct a series of selected piping system mathematical models that are representative of the standard plant piping designs. The results of the analyses must be compared with the results of independent benchmark problem analyses developed by the staff. The COL applicant must document and submit any deviations from these values, as well as justification for such deviations, to the NRC staff for review and approval before initiating final piping analyses. The benchmark program provides assurance that the computer program used to complete the piping design and analyses produces results that are consistent with results considered acceptable to the staff.

In TR Section 5.3, AREVA indicated that, if the COL applicant chooses to use a piping analysis program other than those listed in TR Section 5.1, the applicant will implement the NRC benchmark program using models specifically selected for the U.S. EPR. However, AREVA did not indicate if such a piping benchmark program for the EPR standardized plant exists for its own use or the use by the COL applicants. Furthermore, it did not indicate that its piping analysis computer code described in Section 5.1 was verified using models representative of the U.S. EPR. Therefore, in RAI EPR-20 the staff requested AREVA to provide the status of a piping benchmark program for the U.S. EPR piping design.

In its revised response (dated November 20, 2007), AREVA identified three (3) representative calculations from the analyses currently being completed for the U.S. EPR design certification to be used in the benchmark program. These calculations will utilize the piping analysis codes identified in Section 5.1 of the TR. The COL applicant will implement this benchmarking program if he chooses to use programs other than those stated in TR Section 5.1. This requirement is COL- Action Item 6 of Table 1-1.

Additionally, AREVA will revise TR Section 5.3 and Item 6 of TR Table 1-1 to change the term "NRC benchmark program" to "U.S. EPR benchmark program." Since this is consistent with the current staff position on Advanced Light Water Reactor (ALWR) design certifications, the staff finds this acceptable. Therefore, **RAI EPR-20 is resolved.**

3.3.4 Decoupling Criteria

In TR Section 5.4.2, AREVA defines smaller branch lines as those lines that can be decoupled from the analytical model used for the analysis of the main run piping to which the branch lines are attached. Branch lines can be decoupled when the ratio of run to branch pipe diameter is 3 to 1, or greater, or moment of inertia is 25 to 1, or greater; and with sufficient flexibility to prevent restraint of movement of the main run pipe. The decoupling criteria may also be applied for in-line pipe size changes (such as at a reducer or reducing insert). In addition to the pipe diameter or the pipe moment of inertia criterion for acceptable decoupling, AREVA did not specify that these smaller branch lines shall be designed with no concentrated masses, such as valves, in the first one-half span length from the main run pipe. Therefore, in RAI EPR-21, the staff requested AREVA to technically justify how the effect of a large eccentric concentrated mass near the branch connection is considered in the decoupling criteria.

In its revised response (dated November 20, 2007), AREVA stated that large concentrated masses should not be located within the first span of the branch pipe. 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 must be considered. In these cases, the branch piping will be modeled and analyzed with the run pipe, or a portion of the branch line shall be included in the run pipe analysis to adequately include the torsional effects of the eccentric mass. Since this is consistent with the industry practice associated with this situation, the staff finds this acceptable. Therefore, **RAI EPR-21 is resolved.**

AREVA also states that the small branch line is considered to have adequate flexibility if its first anchor or restraint to movement is at least one-half pipe span in a direction perpendicular to the direction of relative movement between the pipe run and the first anchor or restraint of the branch piping. A pipe span is defined as the length tabulated in Table NF-3611-1, Suggested Piping Support Spacing, ASME B&PV Code Section III, Subsection NF. For branches where the preceding criteria for sufficient flexibility cannot be met, the applicant will demonstrate acceptability by using an alternative criterion for sufficient flexibility, or by accounting for the effects of the branch piping in the analysis of the main run piping.

AREVA also stated that the branch pipe analysis includes more consideration for the effects of the run piping. The branch point is considered as an anchor in the analysis of the branch pipe with the same stress intensity factor (SIF) and/or stress indices as the run pipe at this point. The movements (displacements and rotations) of run pipe from the thermal, seismic anchor movement (SAM) or pipe break analyses shall be applied as anchor movements with their respective load cases in the branch line analysis. For the SSE inertia load case, each individual run pipe movement shall be analyzed as a separate anchor movement load case on the branch line and combined with its respective load case by absolute summation. The meaning of this static analysis for the inertia load case was not clear. Therefore, in RAI EPR-22 the staff requested AREVA to provide further clarification of this procedure.

In its revised response (dated November 20, 2007), AREVA referred to the response of RAI EPR-7 and the suggested changes in TR Section 5.4.2 by this response. This is discussed in detail in Section 3.2.2 of this report and the criteria presented by AREVA are consistent with the industry practices. Therefore, the staff finds this acceptable. Thus, **RAI EPR-22 is resolved.**

In TR Section 5.5, AREVA provides the criteria for analyzing the decoupled seismic Category I piping from the non-seismic piping affecting the seismic Category I piping, which typically occurs at the seismic Category I transition valve(s). The model boundary at a non-seismic/seismic piping interface may consist of structural isolation, decoupling or model isolation methods similar to those discussed in TR Section 5.4. However, additional considerations are required to ensure that the dynamic effects of the non-seismic piping on the seismic Category I piping are considered.

AREVA states that the seismic Category I design requirements extend to the first seismic restraint beyond the seismic system boundary. The non-seismic piping and supports beyond this location that impact the dynamic analysis of the seismic Category I piping are reclassified as seismic Category II and included in the model. The extent of piping classified as seismic Category II may be bounded by the same three methods discussed in TR Section 5.4 and the staff evaluation of these sections is discussed in this section as well as in section 3.3.2 of this report. AREVA states that, when structural boundaries are used to terminate the seismic Category II region, all piping and supports between the seismic Category I design boundary and the structural anchor, or the final restraint of a restrained elbow or tee, are classified as seismic Category II. When the decoupling criteria are used, all piping and restraints beyond the seismic Category I boundary up to the decoupled location are classified as seismic Category II. Finally, when the isolation method is used, isolation of dynamic effects is provided by three (3) seismic restraints in each of the three orthogonal directions beyond the seismic Category I design boundary. The staff notes that in TR Section 5.4.3.1 AREVA uses four (4) such restraints in each orthogonal direction for the isolation method in the overlap region. In RAI EPR-23A, the staff requested AREVA to explain this discrepancy. In response (dated July 13, 2007), AREVA corrected to use four (4) seismic restraints in each of the three orthogonal directions for separation criteria beyond the seismic Category I system boundary, consistent with NUREG/CR-1980 recommendations. Also, AREVA will revise the TR Section 5.5 to reflect this correction.

In all three cases cited in TR Section 5.5, the seismic Category II portion of the system is analyzed with the seismic Category I piping for the SSE load case as well as loads resulting from the potential failure of the non-seismic piping and pipe supports. This is accomplished by the application of a plastic moment in each of three orthogonal directions at the termination of the model. Each moment is applied and evaluated in a separate analysis and the results of the three analyses are enveloped. To clarify the method of applying a plastic moment at the termination point, the staff, in RAI EPR-23B, requested AREVA to describe the calculation of the loads resulting from the potential failure of the non-seismic piping and pipe supports and to discuss the step-by-step procedure for applying this load to the seismic Category I piping analysis.

In response (dated July 13, 2007), AREVA provided details for the plastic moment to be calculated as:

$$M_P = S_Y Z_P \quad \text{and} \quad Z_P = (D^3 - d^3) / 6$$

Where, M_P = Plastic moment to be applied
S_Y = Material Yield Strength at 70°F
Z_P = Plastic section modulus of the pipe
D = Outside diameter of the pipe
d = Inside diameter of the pipe

Each moment is applied and evaluated in a separate analysis and the results of each analysis are individually combined with the seismic inertia results by absolute summation methods. The results of these three analyses are then enveloped to obtain the design loads for the piping and supports. Since the criteria presented are consistent with the industry practices to include the worst effects of a failed non-seismic piping on a seismic Category I piping, the staff finds this acceptable. Therefore, **RAI EPR-23 is resolved.**

Since all methods described in the TR provide assurance that the seismic Category I piping is adequately designed to include the effects from the non-seismic piping during an earthquake, the staff finds them acceptable.

3.3.5 Conclusions

On the basis of the discussions in the above subsections and evaluation of TR Section 5.0, the staff concludes that design control measures are acceptable to ensure quality of computer programs and piping modeling methods. The staff's conclusion is based on the following:

- AREVA satisfies the requirements of GDC 2 by providing criteria for the seismic design and analysis of all seismic Category I piping and pipe supports using prescribed modeling techniques and design methods that are in conformance with generally recognized engineering practice.

- AREVA meets Appendix B to 10 CFR Part 50 by demonstrating the applicability and validity of the computer programs for performing piping seismic analysis.

- Computer programs to be used by the COL applicant to complete its analyses of the U.S. EPR piping systems will be verified and validated.

3.4 Pipe Stress Analysis Criteria

GDC 1 requires that the piping and pipe supports should be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. 10 CFR Part 50, Appendix B requires that design quality should be controlled for ensuring structural and functional integrity of seismic Category I components. GDC 2 requires that the piping and pipe supports should withstand the effects of earthquake loads. GDC 4 requires that the piping and pipe supports should withstand the dynamic effects of equipment failures including missiles and blowdown loads associated with the loss-of-coolant accident. The basis for design of ASME Code Class 1, 2, and 3 piping components sufficiently defines the design and service load combinations, including the system operating transients, and associated design and service stress limits considered for all normal, abnormal and accident conditions.

GDC 14 requires that the RCPB components should be designed, fabricated, erected, and tested to have an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross failure. GDC 15 requires that the reactor coolant system should be designed with sufficient margin to assure that the design conditions are not exceeded. In accordance with NUREG-1367, the Code rules assure that violation of the pressure boundary will not occur if the design specification satisfactorily addresses protection against catastrophic failure, and against initiation and propagation of a crack or propagation of a Section III acceptable flaw through the pressure boundary (i.e., fatigue failure).

3.4.1 Seismic Input

In TR Section 4.2.1, AREVA states that the response spectra curves for the U.S. EPR are being developed to cover an appropriate range of possible soil conditions with the ground motion anchored to peak ground acceleration (PGA) of 0.3g. The PGA in the vertical design ground motion is equal to the horizontal design ground motion PGA. Since the input design ground motion response spectra for the U.S. EPR standard plant is being developed, the review of this section cannot be performed at this design certification stage.

The staff recognizes that the site enveloping response spectra for the U.S. EPR plant would contain conservatisms that may be excessive for certain specific site conditions. If amplified building response spectra are generated using site-dependent properties, then the approach and method used must be submitted to the staff for review and approval as part of the COL application. The staff notes that the method to generate the amplified building floor response spectra should be consistent with the methods accepted by the staff as given in RG. 1.122 and SRP Section 3.7.3.

In TR Section 4.2.2.1, AREVA describes the method of analysis to be used in developing the floor response spectra for the structures using the guidelines provided in RG 1.122, Rev. 1. In addition, AREVA states in TR Section 4.2.3 that, to account for uncertainties in the structural analysis using the TH method, similar to peak shifting in the response spectrum method of analysis discussed in TR Section 4.2.2.1.2, three separate input time histories with modified time steps may be analyzed. Alternatively, the THs at the attachment points may be derived considering variations in the concrete stiffness, which is later withdrawn by AREVA in response to RAI EPR-11 as discussed in Section3.2.4 of this report. The issue pertaining to the validity of using the peak shifting method is also discussed in Section 3.2.4 of this report. This section also discusses the method of adjusting the peak responses in the time history method of analysis that will be used for generating floor response spectra applicable to U.S. EPR structures to account for variations in soil/structure and modeling techniques. The staff will assess the development of seismic input and floor response spectra in the FSAR. Therefore, the staff finds this acceptable.

3.4.2 Design Transients

TR Section 3.1 defines the classification of SSCs for seismic and non-seismic categories in accordance with RG 1.29. Piping required to be designed to withstand the effects of a SSE and remain functional during and after the event is classified as seismic Category I. These components must meet the requirements of Appendix B to 10 CFR Part 50. Piping that is not required to function during or after an SSE event, but its structural failure could reduce the functioning of seismic Category I SSCs is classified as seismic Category II piping by AREVA in TR Section 4.4. To prevent adverse impact to seismic Category I SSCs, seismic Category II piping will be designed to the same requirements as seismic Category I piping. Finally, piping that does not meet the criteria for seismic Category I or II is considered non-seismic. When it is not practical to route non-seismic pipe away from seismic Category I and II piping, the non-seismic piping will be upgraded to seismic Category II. Since the categorization of SSCs is consistent with the industry, the staff finds this acceptable.

In TR Section 3.2, AREVA defines the four service levels and test conditions used in the ASME Code. The plant operating conditions are:

- ASME Service Level A: normal condition - loading during plant startup, operation, refueling and shutdown.

- ASME Service Level B: upset condition - incidents of moderate frequency - occasional, infrequent loadings without sustaining any damage or reduction in function.

- ASME Service Level C: emergency condition - incidents of low frequency - infrequent loadings causing no significant loss of integrity.

- ASME Service Level D: faulted condition - incidents of extremely low frequency - loadings associated with design basis accidents such as SSE, design basis pipe break and LOCA.

- testing conditions.

Based on the guidance in SRP 3.9.3, AREVA states that loading combinations of the various potential analysis load cases will be developed for the defined levels.

AREVA identifies in very general terms the load combinations of transients and other loads in TR Tables 3-1 through 3-4. However, the specific transients and number of events or cycles resulting from each of these design transients applicable to ASME Code Class piping system design are not yet developed for fatigue analysis at this certification stage. In accordance with SRP Section 3.9.1, Item II.1, all transients to be used in the design and fatigue analysis of all Code Class 1 piping and pipe supports within the RCPB must be submitted for staff review. Therefore, in RAI EPR-24 the staff requested AREVA to list all applicable design transients and the number of events associated with each of these design transients that will be used in the design and fatigue analysis of all Code Class 1 piping and pipe supports within the reactor coolant pressure boundary. In response (dated July 13, 2007), AREVA states that the list of transients will be included in Chapter 3 of the FSAR. The staff finds this acceptable. Therefore, **RAI EPR-24 is resolved.**

3.4.3 Loadings and Load Combinations

In TR Section 3.3, AREVA identifies the loadings and load combinations that are applicable to the design of U.S. EPR piping system. Loadings applicable to the U.S. EPR piping design include:

- pressure
- deadweight
- thermal expansion (includes thermal anchor movements)
- seismic (includes seismic anchor movements)
- fluid transients (includes relief valve thrust, valve closure and water/steam hammer)
- wind/tornado (identified as the COL-Action Item 3 in TR Table 1-1)
- design basis pipe breaks (includes pipe whip, jet impingement, dynamic effects)
- thermal and pressure transients
- hydro tests

AREVA states that the zero thermal load temperature is 70°F, and that piping systems with an operating temperature equal to or less than 150°F do not require a thermal analysis. In addition, thermal anchor movements less than or equal to an industry acceptable 1/16th of an inch may be excluded from the analysis. Since these criteria are typically used by the industry, the staff finds this acceptable.

AREVA also states that the ground motion of the operating basis earthquake (OBE) for the U.S. EPR is equal to one-third of the ground motion of 0.3g for the SSE. In case of a seismic event greater than the OBE ground motion, in accordance with Appendix S to 10 CFR Part 50 plant shut down is required and seismic Category I piping and supports are required to be inspected to ensure no loss of function or physical damage has occurred. Both inertial and SAM effects are considered as Service Level D loads, since U.S. EPR is not designed to an OBE loading. This is consistent with SECY 93-087 and therefore, acceptable to the staff.

AREVA states in TR Section 3.3.1.7 for piping and Section 6.3.7 for pipe supports that design basis pipe break loads must be evaluated for the appropriate service condition. However, pipe breaks in the RCL, main steam and pressurizer surge lines which meet the leak-before-break (LBB) size criteria are eliminated from consideration based on LBB analysis. The impact of smaller attached lines and other lines outside the LBB analyzed zone will be considered. Per SECY 93-087 (ML003708021), the staff has approved the LBB approach on a case-by-case basis for austenitic stainless steel and carbon steel with stainless steel clad piping inside the primary containment and pipe size of at least 6-inch NPS. Based on this document, appropriate bounding limits are to be established using preliminary analysis results during the design certification phase and verified during the COL phase by performing the appropriate ITAAC discussed in it. In RAI EPR-25A, the staff requested AREVA to discuss the technical basis for exclusion of pipe break analysis for the above three lines, with the LBB criteria to be used for the U.S. EPR piping design. In response (dated July 13, 2007), AREVA stated that LBB criteria for the U.S. EPR will be addressed in Chapter 3 of the FSAR. It was not included in the TR because it was not addressed in SRP 3.12. The staff finds this acceptable. Therefore, **RAI EPR-25A is resolved.**

AREVA further stated in TR Section 3.3.2 that 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. Design conditions, load combinations and stress criteria for ASME Class 1 piping are given in TR Table 3-1 and that for ASME Class 2 and 3 piping in TR Table 3-2. In reviewing the TR Section 3.3 and Tables 3-1 and 3-2, the staff identified a need for clarification of several items associated with this TR section and its tables. The staff requested AREVA for these clarifications in RAI EPR-25B through E.

The staff notes that SSE and design basis pipe break (including LOCA) shall be combined using the SRSS method. This is acceptable in accordance to NUREG 0484, Rev. 1. However, for dynamic responses resulting from the same initiating events (other than SSE), when time phase relationship between the responses cannot be established, the absolute summation of these dynamic responses should be used. On this subject area, AREVA responded to RAI EPR-25B in its revised response (November 20, 2007) that it expects to be able to establish the timing and causal relationships between dynamic events such as pipe rupture and valve actuation for U.S. EPR piping design. When the causal relationship between two dynamic events can be established, the results from the two events will be combined by SRSS, provided it is demonstrated that the non-exceedance criteria provided in NUREG-0484 is met, or by absolute summation. However, if this relationship cannot be established between two dynamic events, the responses from these events will be combined by absolute summation. Since this is consistent with the recommendations in NUREG-0484, the staff finds this acceptable. Therefore, **RAI EPR-25B is resolved.**

The staff position on the use of a single-earthquake design in SECY-93-087 states that the effects of anchor displacements in the piping caused by an SSE be considered with the Service Level D limits. For simplified elastic-plastic discontinuity analysis, if Eq.10 of the ASME Code cannot be satisfied for all pairs of load sets, then the alternative analysis per ASME Subparagraph NB-3653.6 for Service Level D should be followed. In addition, the combined moment range for either the resultant thermal expansion and thermal anchor movements plus one-half the SSE seismic anchor motion or the resultant moment due to the full SSE anchor motion alone, whichever is greater, must satisfy the equation (known as Eq. 12a) given in Subsubparagraph NB-3656(b)(4). AREVA stated in its response to RAI EPR-25C (dated July 13, 2007) that at the time the TR was written, portions of Section III NB-3600 in the 2004 Edition of the ASME Boiler and Pressure Code were not endorsed by the NRC, per the version of 10 CFR 50.55a in effect at that time. However, AREVA will now, therefore, reference the equations from Subsubparagraph NB-3656(b)(4) for the treatment of SSE anchor motions and revise Table 3-1 for this reason. The staff finds this not acceptable, since AREVA stated in its response that, in the upset loading condition for primary plus secondary stress intensity range (equations 10 and 11), the loads will include the SSE. However, AREVA removed the SSE load from the equation 11U in Table 3-1 in its revised response in Attachment C (dated November 20, 2007). On April 18, 2008, AREVA provided in Attachment B of its second revised response, a revision to the TR Table 3-1 for load combinations and acceptance criteria for ASME Class 1 piping with appropriate loads for the upset loading. Since this is consistent with equations 10 and 11 of the ASME Code, the staff finds this acceptable. **Therefore, RAI EPR-25C is resolved.**

AREVA also added explanations of notes for both TR Tables 3-1 and 3-2, and confirmed that there are no other dynamic loads on the building structure that would impact piping analysis and support design, when using Equation 11a of Subparagraph NC/ND 3653.2 for reversing loads. The seismic (reversing) inertia loads are included in Equation 9 and the secondary effects of these loads are included in Equation 10 as in the 1993 Code Addenda. The staff finds this acceptable. Therefore, **RAI EPR-25D & E are acceptable and therefore, are resolved.**

From its review, the staff concludes that appropriate combinations of normal, operating transients and accident loadings are specified to provide a conservative design envelope for the design of piping systems. The load combinations are consistent with the guidelines provided in SRP Section 3.9.3 and the staff position associated with the SECY 93-087 for elimination of an OBE. Therefore, the staff finds the load combination for the U.S. EPR piping design acceptable.

3.4.4 Damping Values

In TR Section 4.2.5, AREVA identified RG 1.61, "Damping Values for Seismic Design of Nuclear Power Plants," Revision 0, for recommended values of damping (i.e., 2 percent for piping with 12-inch NPS or less, and 3 percent for piping larger than 12-inch NPS) to be used in the seismic analysis of SSCs using ISM RS analysis or TH analysis. However, for piping systems analyzed using USM RS analysis, five percent damping may be used provided that the system is not susceptible to stress corrosion cracking (SSC). Five percent damping will not be used for analyzing the dynamic response of piping systems using supports designed to dissipate energy by yielding.

The staff notes that Rev. 1 of the RG 1.61, issued in March 2007, recommends damping values for piping (i.e., four percent independent of pipe size and frequency) which are different from its Rev. 0 values. Therefore, in RAI EPR-26 the staff requested AREVA to clarify whether they will use the Rev. 0 or the Rev. 1 damping values. The use of five percent damping in USM analysis has been previously reviewed and accepted by the staff for ALWR plants on the basis that ALWR plants must be designed to a minimum 0.3g ZPA for the SSE. This high seismic acceleration provides assurance that piping systems will experience higher damping values. Its acceptance, however, was also subject to the limitations specified in RG 1.84 for ASME Code Case N-411-1 as well as several additional ALWR design-specific conditions. In RAI-EPR-26 the staff requested AREVA to clarify its position on various damping values that apply to U.S. EPR piping.

In its revised response (dated November 20, 2007), AREVA stated that the U.S. EPR will use four percent damping for systems susceptible to SCC and when supports that dissipate energy are used. AREVA also stated that this is consistent with RG 1.61, Rev. 1 damping values and will be used for ISM response spectra and TH methods of analysis. RG 1.61, Rev. 1 will also be used for piping systems analyzed using USM response spectra which do not meet all of the limitations specified in RG 1.84 for ASME Code Case N-411-1. Since this is consistent with RG 1.61, Rev.1, **the staff finds this acceptable.**

The staff notes that AREVA, however, suggests five percent damping for piping systems analyzed using USM response spectra which meets all of the limitations specified in RG 1.84 for ASME Code Case N-411-1. RG 1.61, Rev. 1 recommends frequency-dependent five percent damping for 0-10 Hz, two percent damping for greater than 20 Hz, and a linear transition from five percent to two percent for 10-20 Hz. The RG does not allow five percent damping, independent of frequency.

AREVA, in its response, justified that the seismic design criteria for U.S. EPR piping is at least as stringent as for CE System 80+, AP600, and AP1000, where the staff accepts the use of five percent damping only for USM RS analyses, subject to the same restrictions the staff previously imposed on former Code Case N-411-1. However, the staff notes that in addition to the restrictions outlined in Regulatory Position C.2 of RG 1.61, Rev.1 for frequency-dependent damping for USM method of analysis, the SERs for these design certifications also include the following additional restrictions (as stated in the FSERs for System 80+, AP600, and AP1000):

- For the primary coolant loop, a damping value of four percent must be used. For coupled piping-structure systems, an equivalent modal damping matrix or composite damping matrix is acceptable when using five percent damping for structures and four percent damping for the RCS components.
- Applicable to piping systems with rigid valves analyzed by the USM method.
- Not applicable to ISM and TH methods of analysis.
- Piping design must limit the building filtered responses to 33 Hz and below.
- Plants must be designed to a minimum 0.3g ZPA for the SSE.
- Limited to current seismic spectra applications only.

Even if one satisfies all these additional conditions, the current staff position does not allow five percent damping for all frequency range. Prior to this issuance of RG 1.61, Rev. 1, in March 2007, all other ALWR design certifications (System 80+, AP600, and AP1000) have been committed to RG 1.61, Rev.0 damping values of two and three percent, depending on the pipe size, which are much less than four percent allowed in RG 1.61, Rev.1. Based on this, the staff finds it unacceptable for using five percent damping for USM RS analysis, regardless of whether the Code Case N-411-1 limitations are satisfied, until AREVA provides additional technical justifications.

However, on April 18, 2008, AREVA provided its second revised response, in which AREVA is now committed to use damping values given in RG 1.61, Rev. 1 for both uniform support motion and independent support motion response spectrum analysis, and time history analysis. In Attachment B to this response, AREVA provided revised pages of the TR Section 4.2.5 on damping values. This is consistent with the current staff position on damping values to be used in piping systems for the EPR standard plant and therefore, the staff finds this acceptable. **RAI EPR-26 is resolved.**

3.4.5 Combination of Modal Responses

The inertial response of a piping system in a seismic response spectrum analysis is considered in two parts. First, the modal analysis calculates the peak response of the piping system for all low frequency (or non-rigid) modes with seismic excitation frequencies up to the frequency (known as the cutoff frequency) at which spectral accelerations return to the ZPA. Modal combinations associated with this part are evaluated in this section. Second, at modal frequencies above the cutoff frequency, pipe members are considered rigid. The acceleration associated with these rigid modes is usually small. However, in certain situations the response to high frequency modes can significantly affect support loads, particularly axial restraints on long piping runs. To account for these effects, AREVA presented a method of calculating the missing mass correction in TR Section 4.2.2.3.2.

In TR Section 4.2.2.3, specifically in Section 4.2.2.3.1 for low frequency modes, AREVA states that for the RS method of analysis, the modal contributions to the inertial responses (i.e., low frequency modes) are normally combined by the SRSS method. If some or all of the modes are closely spaced, any one of the methods (grouping method, 10 percent method, and double sum method, as well as the less conservative methods in Revision 2 of RG 1.92) is applicable for the combination of modal responses. The staff notes that the modal combination methods presented in RG 1.92 are applicable only to the USM response spectrum method of analysis. Specific guidance on the combination methods for groups, modes and directions to be used for the ISM method of analysis is given in NUREG-1061, V.4, and is discussed in Section 3.2.3 of this report. However, AREVA has not indicated any such differences in modal combinations between the ISM and USM methods of analysis (see RAI EPR-8). In RAI EPR-27, the staff requested AREVA to justify the use of modal combination methods in accordance with RG 1.92, Rev. 1, rather than RG 1.92, Rev. 2.

In its revised response (dated November 20, 2007), AREVA stated that in the background discussion of Section B as well as in the Regulatory Position in Section C of RG 1.92, Rev. 2, the methods of Rev. 1 are included by reference as acceptable for use. In this regard, the staff's concern is that the definition of closely spaced modes has been shown to be damping dependent. See the discussion provided in Section 2.1.4 and Appendix D of NUREG/CR-6645, as this is also noted in Regulatory Position C.1.1.1 of RG 1.92, Rev. 2. The 10 percent (i.e., five times the critical damping ratio) definition of closely spaced modes is only appropriate up to around two percent damping.

The staff previously accepted Code Case N-411-1 damping for use with the RG 1.92, Rev. 1, modal combination methods. Since the strong dependency on damping is now better understood, the staff's position is that the modal combination methods recommended in RG 1.92, Rev. 2, are more compatible with damping of four percent to five percent. The staff acknowledges that there is no explicit referencing between RG 1.92, Rev. 2 and RG 1.61, Rev. 1. However, Recommendation (3) in Section 5.2 of NUREG/CR-6645 provides a concise summary of this issue, and the appropriate use of the grouping method.

For the specific piping problem used as the basis for the comparisons in NUREG/CR-6645, the numerical results using RG 1.92, Rev. 1, modal combination methods show a comparable level of conservatism for both one percent damping and five percent damping. However, a generic conclusion cannot be drawn from this single outcome. Based on the numerical values presented in Appendix D of NUREG/CR-6645, it is feasible that the level of conservatism could diminish with increasing damping. Of real concern is the trend toward significantly greater data scattering, as evidenced by the large increase in the standard deviation between one percent and five percent damping. Comparing the results on pages 42 and 44 of the NUREG report, the standard deviation for the recommended methods in RG 1.92, Rev. 2, increased from 0.35 and 0.37, to 0.45 and 0.47, respectively, between one percent and five percent damping. For the RG 1.92, Rev. 1 methods, the standard deviation increased from 0.48, 0.67, and 0.49, to 1.21, 1.65, and 1.67, respectively, between one percent and five percent damping. This is indicative of the fact that at higher damping, these methods give increasingly unrealistic results.

As noted in NUREG/CR-6645, Section 2.1, there is no logical technical basis for any of the RG 1.92, Rev. 1, methods to account for closely spaced modes. They were intended to be conservative corrections for cases where the interaction of closely spaced modes might compromise the conservatism of the SRSS rule. The 10 percent definition for closely spaced modes is consistent with low damping (less than or equal to two percent). In the interest of obtaining more accurate results using the RS analysis method, for damping of four percent to five percent, the applicant is strongly advised to completely adopt the methods recommended in RG 1.92, Rev. 2, for obtaining the complete RS solution. This also includes the methods for separation of out-of-phase (periodic) and in-phase (rigid) response components. Based on this, the staff finds the AREVA response not acceptable until AREVA provides additional technical justification for using RG 1.92, Rev. 1 modal combination methods for higher damping values (in accordance with RG 1.61, Rev. 1) for the U.S. EPR piping design.

On April 18, 2008, AREVA provided its second revised response, in which AREVA is now committed to use the modal combination methods given in RG 1.92, Rev. 2 for uniform support motion response spectrum analysis. In Attachment B to this response, AREVA provided revised pages of the TR Section 4.2.2.3 on modal combinations. This is consistent with the current staff position on modal combination methods to be used in piping systems for the EPR standard plant and therefore, the staff finds this acceptable. **RAI EPR-27 is resolved.**

3.4.6 High-Frequency Modes

In TR Section 4.2.2.3.2, AREVA presents a procedure to account for high-frequency modes in the RS methods of analysis to be used for seismic or other dynamic loads. This procedure requires the computation of individual modal responses only for lower-frequency modes (below the ZPA). For flexible piping systems, the high frequency response may not be significant since a significant portion of the system mass is excited at frequencies below the ZPA. However, for piping systems, or portions of piping systems, which are more rigidly restrained or have lumped masses near rigid restraints, a significant portion of the system mass may not be accounted for in the low frequency modal analysis. This mass which is not excited at the lower frequencies is termed the "missing mass" of the system. While high frequency modes usually involve small displacement amplitudes and small pipe stresses, they can have a significant impact on determining the support loads.

AREVA states that the response from high frequency modes will be included in the response of the piping system if it results in an increase in the dynamic results of more than 10 percent. The peak modal responses of the system at frequencies above the ZPA are considered to be in phase. Thus, the responses of all high frequency modes are combined by absolute summation.

AREVA also states that the missing inertia forces are calculated independently for all input components of earthquake motion (i.e., in each direction for each support group). The mode displacements, member end action, and support force corresponding to each missing mass mode is determined. These results are treated as an additional modal result in the response spectrum analysis. This missing mass mode is considered to have a modal frequency and acceleration equal to the cutoff frequency used in the modal analysis. These modal results are combined with the low frequency modal results using the methods described in TR Section 4.2.2.3.1 for the low frequency modes (per RG 1.92, Rev. 1).

AREVA further states that the modal combination for the high frequency modes above the cutoff frequency for vibratory loads is performed in accordance with the Appendix A of SRP 3.7.2, Rev 2, as well as Rev. 2 of the RG 1.92 (since the Rev. 1 of the RG does not address the missing mass contribution). However, the staff notes that there are some differences between the methods of calculating the effects of missing mass presented in the SRP and the RG. In RG 1.92, Rev. 2, Regulatory Position C.1.4.1 states that for calculating the residual rigid response of the missing mass modes the criteria presented in the Appendix A of SRP 3.7.2, Rev. 2, would yield non-conservative results and Appendix A of RG 1.92, Rev. 2 now provides the updated criteria for the missing mass contribution to the total response. Since AREVA is committed to RG 1.92, Rev. 2, piping methodology for missing mass contribution presented in TR Section 4.2.2.3.2 is not consistent with the RG. Also, the staff needs clarification on the mathematical derivations presented in the TR and how the missing mass contribution is combined with the modal responses. In RAI EPR-28, the staff requested AREVA to describe the technical differences between the method presented in the TR and the method acceptable to the staff as given in the RG, and also clarify the combination method to be used for the missing mass results with the modal responses.

In its revised response (dated November 20, 2007), AREVA stated that the method detailed in the TR is based on the left-out-force method. This method is performed by the SUPERPIPE piping analysis code which has been accepted for use at many operating plants. Although this method is different than that shown in RG 1.92, Rev. 2, it produces the same result. The basic difference in the presentations of the missing mass calculation as shown in RG and as shown in the TR is that the RG equations are written for each modal degree-of-freedom while the TR equations are written in vector form. Re-writing the RG equations in vector form shows that the formulations are equivalent. BWSPAN uses the missing mass method given in Appendix A of RG 1.92, Rev. 2. TR Section 4.2.2.3.2 will be revised to state that the left-out-force method is used by SUPERPIPE, and BWSPAN uses the missing mass method outlined in Appendix A of RG 1.92 Revision 2. The staff finds this acceptable.

AREVA also stated that the residual rigid response of the missing mass modes will be included in all seismic analyses of safety related piping systems. For cases where responses at frequencies above the ZPA are in phase, the responses of all high frequency modes will be combined by algebraic summation. Also for USM, the rigid range (missing mass) results will be combined with the low frequency modal results in accordance with Regulatory Position C.1.5.1 of RG 1.92, Rev. 2. For systems analyzed using ISM, the missing mass results will be combined with the low frequency modal results by SRSS, per NUREG-1061, Vol. 4. The staff finds this acceptable.

AREVA further stated that when using the modal combination methods of Rev. 1 of RG 1.92, Combination Method A provided in Rev. 2 of RG 1.92 Section C.1.5.1 is actually applied. In these cases, the rigid modal response component of the low frequency modes is equal to zero, and the method reduces to the SRSS combination of the low frequency modal results and the high frequency missing mass results. With regards to combination of the missing mass results in the rigid range with low frequency modal results, the staff finds the Combination Method A given in Section C.1.5.1 of Rev. 2 of RG 1.92 acceptable. Therefore, **RAI EPR-28 is resolved.**

The staff also notes that another consideration involves high frequency responses of the piping system when the nonlinear analyses are used to account for gaps between the pipe and its supports and subjected to vibratory loads (other than seismic) with significant high-frequency. The description of and justification for such analyses (which may require a nonlinear analysis) must be submitted to the staff for review and approval before use. Therefore, in RAI EPR-29 the staff requested AREVA to provide the piping analysis method to be used when subjected to vibratory loads with significant high-frequency content caused by gaps between the pipe and its supports.

In its revised response (dated November 20, 2007), AREVA stated that the U.S. EPR design does not intend to utilize gapped supports. For the U.S. EPR, the normal design practice for frame structure guide supports is to utilize a nominal one-sixteenth inch gap between the surface of the pipe and the edge of the support member for both sides of the pipe in the restrained direction. Although the use of gapped supports is not anticipated for the U.S. EPR, should the need for such supports arise, the nonlinear piping analysis problem will be solved using direct integration time history methods. This is acceptable to the staff, provided the nonlinear modeling and method of analysis are accepted by the staff prior to its use. Therefore, **RAI EPR-29 is resolved subject to a condition that any nonlinear analysis used in the U.S. EPR piping design must be reviewed and approved by the staff prior to its use.**

3.4.7 Fatigue Evaluation for ASME Code Class 1 Piping

ASME Code, Section III requires that the cumulative damage from fatigue be evaluated for all ASME Code Class 1 piping. The fatigue cumulative usage factor (CUF) should take into consideration all cyclic effects caused by the plant operating transients for a 60-year design life. However, recent test data indicates that the effects of the reactor environment could reduce the fatigue resistance of certain materials. A comparison of the test data with the Code requirements indicates that the margins in the ASME Code fatigue design curves might be less than originally intended.

In TR Section 3.4.1 AREVA states that Class 1 piping will be evaluated for the effects of fatigue as a result of pressure and thermal transients and other cyclic events including earthquakes. The environmental effects of the reactor coolant on fatigue will be accounted for in the Class 1 piping fatigue analyses using methods acceptable to the NRC at the time of performance. The staff notes that AREVA must include in the FSAR regarding how the environmental effects will be accounted for in the Class 1 piping fatigue analysis for the design certification. The staff finds this acceptable.

In TR Section 3.4.1, AREVA also states that since the OBE is not considered for the U.S. EPR, the fatigue analysis of Class 1 piping greater than 1 inch NPS is performed using the ASME Code requirements with 2 SSE events with 10 maximum stress-cycles each for a total of 20 full cycles of SSE stress range (which is considered equivalent to one SSE and five OBE events with 10 maximum stress cycles per event as defined in SRP Section 3.7.3). Alternatively, per NRC memo SECY-93-087, AREVA may use the methods of Appendix D of IEEE Standard 344-1987 to determine a number of fractional vibratory cycles equivalent to 20 full SSE cycles. Thus, for a case with one-third of the SSE amplitude, 300 fractional SSE cycles will be considered. This is consistent with the requirements of SRP Section 3.7.3 and therefore, is acceptable.

3.4.8 Fatigue Evaluation of ASME Code Class 2 and 3 Piping

In TR Section 3.4.2, AREVA states that Class 2 and 3 piping is evaluated for fatigue due to thermal cycles by following the requirements of the ASME Code, which involve the reduction of Code allowables for the thermal expansion stresses calculated as determined in Table NC/ND-3611.2(e)-1, "Stress Range Reduction Factors." The environmental effects on fatigue of Class 2 and 3 piping will follow guidelines established by the NRC at the time of analysis. The staff notes that AREVA must include in the FSAR regarding how the environmental effects will be accounted for in the Class 2 and 3 piping for the design certification. Therefore, the staff finds this acceptable.

3.4.9 Thermal Oscillations in Piping Connected to the Reactor Coolant System

In accordance with NRC Bulletin 88-08, the staff requires that licensees and applicants review systems connected to the RCS (including the RPV) to determine whether any sections of this piping, that cannot be isolated, can be subjected to temperature oscillations that could be induced by leaking valves. In TR Section 3.7.3, AREVA states that unisolable sections of piping connected to the RCL will be evaluated to determine if thermal stratification and striping (i.e., temperature oscillations) caused by a leaking valve are plausible, as discussed in NRC Bulletin 88-08. In addition, contributions to fatigue from thermal stratification and striping will be considered where it is determined that these phenomena are occurring. The staff notes that AREVA must identify all sections of piping that will be subject to thermal oscillation and connected to the RCS and include it in the FSAR for the design certification review. Therefore, the staff finds this acceptable.

3.4.10 Thermal Stratification

Thermal stratification is a phenomenon that can occur in long runs of horizontal piping when two streams of fluid at different temperatures flow in separate layers without appreciable mixing. Under these stratified flow conditions, the top of the pipe may be at a much higher temperature than the bottom. This thermal gradient produces pipe deflections, support loads, pipe bending stresses, and local stresses that may not have been accounted for in the original piping design. The effects of thermal stratification have been observed in PWR piping as discussed in NRC Bulletins 79-13 (on feedwater lines) and 88-11 (on pressurizer surge lines).

NRC Bulletin 79-13 was issued as a result of a feedwater line cracking incident at D.C. Cook Nuclear Plant Unit 2 which led to the discovery of cracks in numerous other plants. The primary cause of the cracking was determined to be thermal fatigue loading due to thermal stratification and high-cycle thermal striping during low flow emergency feedwater injection. In TR Section 3.7.1, AREVA states that the steam generators and main feedwater lines in the U.S. EPR are designed to minimize thermal stratification. Separate nozzles are designed on the steam generator for the main feedwater and emergency feedwater connections and pipe runs are relatively short. The main feedwater nozzle is located in the conical section of the steam generator which aids in reducing thermal stratification. In addition, the effects of thermal stratification and striping will be evaluated during the evaluation of the main feedwater system and the evaluation will confirm that all load cases meet the ASME Code allowables.

NRC Bulletin 88-11 requires consideration of the effects of thermal stratification on the pressurizer surge line. In TR Section 3.7.2, AREVA states that the surge line on the U.S. EPR will be analyzed with the RCL piping and supports. The effects of thermal stratification and striping will be considered as part of this analysis or it will be demonstrated that the surge line is not subjected to significant stratification/striping effects due to design features that mitigate these effects.

AREVA also states that the COL applicant will confirm that thermal deflections do not create adverse conditions during hot functional testing. This is identified as the COL-Action Item 4 in TR Table 1-1.

In RAI EPR-30, the staff requested AREVA to clarify some of the suggested design features that will minimize the effects of thermal stratification in the feedwater line and the surge line. In its revised response (dated November 20, 2007), AREVA stated that since the main feedwater nozzle is attached to the sloped conical section of the steam generator, it too is inclined approximately 18 degrees from the horizontal. This incline promotes mixing of the colder and hotter fluid layers in the line which, in turn, retards stratification. The inclined design also prevents permanent thermal stratification at low flow rates and ensures run-full conditions in the nozzle. Additional information on thermal stratification will be provided in Section 3.12 of the FSAR. With regard to the pressurizer surge line, there are three major features which minimize the amount of stratification in this line: 1) The take-off from the hot leg is vertical upward and of sufficient length that turbulent penetration from hot leg flow will not spill over into the surge line beyond the take-off and cause stratification; 2) the surge line is sloped approximately five degrees between the vertical take-off at the hot leg and the vertical leg at the pressurizer, which will promote mixing of the colder and hotter fluid layers in the line; and 3) during normal operation, a continuous bypass spray flow of sufficient magnitude is maintained to further suppress turbulent penetration from the hot leg flow. Additional information on the evaluation of unisolable piping for thermal stratification due to a leaking valve (NRC Bulletin 88-08) is provided in TR Section 3.7.3 and will also be provided in Section 3.12 of the FSAR. The staff finds this acceptable at this certification stage and the thermal stratification issue will be further assessed when additional information is available during the design certification. Therefore, **RAI EPR-30 is resolved.**

3.4.11 Safety Relief Valve Design, Installation, and Testing

In TR Section 3.8.1, AREVA states that the design and installation of safety and relief valves for overpressure protection are performed to the criteria specified in Appendix O of the ASME Code, "Rules for the Design of Safety Valve Installations," 2001 Edition, 2003 Addenda. In addition, the design and installation requirements will include the additional criteria in SRP Section 3.9.3, Paragraph II.2. In TR Section 3.8.2, AREVA describes analysis requirements for pressure relieving devices when the discharge is directly to the atmosphere (open discharge) and to headers or tanks (closed discharge).

In accordance with TMI Action Item II.D.1 of NUREG-0737, both PWR and BWR licensees and applicants are required to conduct testing to qualify the RCS relief and safety valves and associated piping and supports under expected operating conditions for design-basis transients and accidents. AREVA did not discuss the testing and qualification aspects of the safety and relief valves and also did not define the design parameters or criteria that need to be specified for the piping and support design. Therefore, in RAI EPR-31 the staff requested AREVA to describe the relevant design parameters in designing pressure relief devices and automatic depressurization valves connected to the pressurizer, the safety valves, power operated relief valves on the steam lines, and the relief valve on the containment isolation lines. In response (dated July 13, 2007), AREVA stated that discussion of SRV design parameters and criteria will be addressed in the FSAR at the time of design certification. This is acceptable to the staff and therefore, **RAI EPR-31 is resolved.**

3.4.12 Functional Capability

All ASME Code Class 1, 2, and 3 piping systems that are essential for safe shutdown must retain their functional capability for all Service Level D loading conditions as required by GDC 2. Designs meeting the recommendations in NUREG-1367, "Functional Capability of Piping Systems," are accepted by the staff as satisfying the functional capability requirements.

In TR Section 3.5, AREVA states that all ASME Code Class 1, 2, and 3 piping systems that are essential for safe shutdown under the postulated events listed in the TR Table 3-3 are designed to meet the recommendations in NUREG-1367. In no case shall the piping stress exceed the limits designated for Service Level D in the ASME Code, Section III. The Service Level D limits are 3.0 S_m (not to exceed 2.0 S_y) for ASME Code Class 1 piping and 3.0 S_h (not to exceed 2.0 S_y) for Class 2 and 3 piping. In addition, the criteria also include: 1) the ratio of pipe NPS and the wall thickness (D_o/t) not to exceed 50; 2) dynamic responses for reversing dynamic loads (e.g., earthquake, building hydrodynamic loads) based on an elastic response spectrum with 15 percent peak broadening with not more than 5 percent damping; 3) the external pressure not to exceed the internal pressure; and finally, 4) steady state stresses from dead weight loads not to exceed 0.25 S_y. For piping analyzed by TH methods, uncertainties in the applied THs must be accounted for. Since AREVA is committed to satisfy all requirements of NUREG-1367, the staff finds this acceptable.

3.4.13 Combination of Inertial and Seismic Anchor Motion Effects

Piping analyses must include the effects caused by the relative building movements at supports and anchors (seismic anchor motion) as well as the seismic inertial loads. This is necessary when piping is supported at multiple locations within a single structure or is attached to two separate structures or buildings.

The effects of relative displacements at support points must be evaluated by imposing the maximum support displacements in the most unfavorable combination. This can be performed, using a static analysis procedure. Relative displacements of equipment supports (e.g., pumps or tanks) must be included in the analysis along with the building support movements.

When required for certain evaluations, such as support design, the responses that are due to the inertia effect and relative displacement effect should be combined by the absolute sum method per SRP Section 3.9.2 for the USM method of analysis, and the SRSS method per NUREG-1061 for the ISM method of analysis (assuming that the group, modal, and directional combinations follow the recommended methods in NUREG-1061, V.4). In lieu of this method, THs of support excitations may be used, in which case both inertial and relative displacement effects are already included.

In TR Section 4.2.2.5, AREVA states that the results of the SAM analysis will be combined with the results of the seismic inertia analysis using the absolute sum method. AREVA did not distinguish any differences between the USM and ISM methods of RS analysis for the inertial responses. In RAI EPR-8, the staff requested that AREVA clarify its position for the ISM method of RS analysis. AREVA is committed to use the absolute sum method for the USM method of analysis consistent with SRP 3.9.2, and the SRSS method for the ISM method of analysis consistent with NUREG-1061, Volume 4. The staff finds this acceptable.

3.4.14 OBE as a Design Load

In SECY-93-087, the staff recommended eliminating the OBE from the design for ALWRs. The Commission approved the staff recommendations in its Staff Requirements Memorandum (SRM) dated July 21, 1993. The SECY document includes specific supplemental criteria for fatigue, seismic anchor motion, and piping stress limits that should be applied when the OBE is eliminated. The staff position on the use of a single-earthquake design for SSCs is discussed in Section 3.4.3 for load combinations and Section 3.4.7 for fatigue evaluation. The effects of SAM due to the SSE should be considered in combination with the effects of other normal operational loadings that might occur concurrently. For fatigue evaluation, two SSE events with 10 maximum stress cycles per event (or an equivalent number of fractional cycles) should be considered.

For Class 1 primary stress evaluation, seismic loads need not be evaluated for consideration of Level B Service Limits for Eq. (9). However, for satisfaction of primary plus secondary stress range limits in Eq. (10), the full SSE stress range or a reduced range corresponding to an equivalent number of fractional cycles must be included for Level B Service limits. These load sets should also be used for evaluating fatigue effects. In addition, the stress that is due to the larger of the full range of SSE anchor motion or the resultant range of thermal expansion plus half the SSE anchor motion range, must not exceed 6.0 S_m. For Class 2 and 3 piping, seismic loads are not required for consideration of occasional loads in satisfying the Level B Service Limits for Eq. (9). Seismic anchor motion stresses are not required for consideration of secondary stresses in Eq. (10). However, stresses that are due to the combination of range of moments caused by thermal expansion and SSE anchor motions must not exceed 3.0 S_h. TR Table 3-2 appropriately addresses the load combinations and stress criteria for Class 2 and 3 piping design. In RAI EPR-25C, the staff requested AREVA to clarify similar criteria for Class 1 piping and AREVA has added this consideration in TR Table 3-1. This is discussed in Section 3.4.3 of this report.

In TR Section 3.4.1, AREVA states that the fatigue evaluation of ASME components will take into consideration 2 SSE events with 10 peak stress cycles per event. Alternately, an equivalent number of fractional vibratory cycles (i.e., 300 cycles) may be used (but with an amplitude not less than one-third of the maximum SSE amplitude) when derived in accordance with Appendix D of IEEE Standard 344-1987. The staff finds this acceptable, since the commitment is consistent with the NRC guidance document previously discussed above and the Commission-approved staff recommendations on the issue of OBE elimination.

3.4.15 Welded Attachments

For the analysis of local stresses at welded attachments to piping (e.g., lugs, trunnions, or stanchions), in TR Section 3.6 AREVA states that the support and restraint designs that require welded attachments to the pipe for transfer of the pipe loads to the supporting structure will adhere to industry practices and ASME Code Cases identified in TR Section 2.2. Since this will ensure the quality of these welded attachments, the staff finds this acceptable.

3.4.16 Composite Modal Damping

For subsystems that are composed of different material types (e.g., welded steel pipe and pipe supports), either a mass or stiffness weighted method can be used to determine the composite modal damping value. Composite modal damping for coupled building and piping systems can be used for piping systems that are coupled to the primary coolant loop system and the interior concrete building.

The composite modal damping ratio can be used when the modal superposition method of analysis (either TH or RS) is used, as required by SRP Section 3.7.2, II.13. AREVA has not described any methods of calculating the composite damping that may be used in the dynamic analysis of piping and supports. In RAI EPR-32, the staff requested AREVA to provide the method(s) for determining the composite modal damping to be used in the U.S. EPR piping design.

In response (dated July 13, 2007), AREVA stated that composite modal damping may be applied when the modal superposition method of analysis is used. The methods used will meet the requirements of SRP 3.7.2. The staff finds this acceptable and therefore, **RAI EPR-32 is resolved.**

3.4.17 Minimum Temperature for Thermal Analyses

In TR Section 3.3, AREVA states that the zero thermal load temperature is 70°F and for piping systems with an operating temperature equal to or less than 150°F, a thermal analysis is not required. Since these criteria are typically used by the industry, the staff finds this acceptable.

3.4.18 Intersystem LOCA

In SECY 90-016, dated January 12, 1990, the staff discussed the resolution of the Intersystem LOCA (ISLOCA) issue for advanced light water reactor plants by requiring that low pressure piping systems that interface with the RCPB be designed to withstand full RCS pressure to the extent practicable. In its June 26, 1990, SRM, the Commission approved these staff recommendations provided that all elements of the low-pressure systems are considered.

In TR Section 3.9, AREVA states that low pressure piping systems that interface with the RCL and, are thus, subjected to the full RCL pressure will be designed for the full operating pressure of the RCL. The appropriate minimum wall thickness of the piping will then be calculated for each system using Equation 1 of Subsubarticle NB-3640 of the ASME Code for Class 1 piping or Equation 3 of Subsubarticle NC/ND-3640 for Class 2 and 3 piping. The piping will be analyzed to the requirements in Subsubarticle NB/NC/ND-3650. Since this satisfies the ASME Code and ensures the low pressure piping to withstand a full RCL pressure, the staff finds this acceptable.

3.4.19 Conclusions

On the basis of the discussion in the above subsections and evaluation of TR Sections 3.0 and 4.0, the staff concludes that the stress analysis methods for the U. S. EPR piping design are acceptable for ensuring its structural integrity when subject to ASME Code-defined service loads. The staff's conclusion is based on the following:

- AREVA meets GDC 1 and 10 CFR Part 50, Appendix B with regard to piping systems being designed, fabricated, constructed, tested, and inspected to quality standards commensurate with the importance of the safety function to be performed, and with appropriate quality control.

- AREVA meets GDC 2 and 10 CFR Part 50, Appendix S with regard to design transients and resulting load combinations for piping and pipe supports to withstand the effects of earthquakes combined with the effects of normal or accident conditions.

- AREVA meets GDC 4 with regard to piping systems important to safety being designed to accommodate the effects of and to be compatible with the environmental conditions of normal and accident conditions.

- AREVA meets GDC 14 with regard to the reactor coolant pressure boundary of the primary piping systems being designed, fabricated, constructed, and tested to have an extremely low probability of abnormal leakage, of rapid propagating failure, and of gross rupture.

- AREVA meets GDC 15 with regard to the reactor coolant piping systems being designed with specific design and service limits to assure sufficient margin that the design conditions are not exceeded.

3.5 Pipe Support Design Criteria

GDC 1 requires that the piping and pipe supports should be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. 10 CFR Part 50, Appendix B requires that design quality should be controlled for ensuring structural and functional integrity of seismic Category I components. GDC 2 requires that the piping and pipe supports should withstand the effects of earthquake loads. The supporting elements should be capable of carrying the sum of all concurrently acting loads and designed to provide the required support to the piping system and allow pipe movement with thermal changes without causing overstress. All parts of the supporting equipment or structure should be fabricated and assembled so that they would not be disengaged by movement of the supported piping.

In TR Section 6.0, AREVA states that the pipe support elements will be designed to meet the requirements of the appropriate design codes and be consistent with the code requirements of the overall piping system. Pipe supports typically include structural elements, which sometimes are coupled with standard manufactured catalog items developed specifically for pipe supports. The piping analysis usually makes assumptions for the support mass and stiffness as required by the specific analysis conditions. Typically, supports are designed separately from the piping analysis, with design methods to match the assumed analysis constraints. As such, the supports should be designed to minimize their effects on the piping analysis and not invalidate the piping analysis assumptions. There are situations where AREVA did not provide criteria to address cases where assumptions made in the piping analysis deviate from those of the support design. In such cases, either the support should be redesigned in accordance with the assumptions made in the piping analysis, or the piping system should be reanalyzed using the actual parameters used in the design of the pipe supports. The staff requested AREVA to address the verification criteria of the as-built support parameters with the assumptions made during piping analysis. AREVA's responses to these RAIs are discussed here.

3.5.1 Applicable Codes

Pipe supports include hangers, snubbers, struts, spring hangers, frames, energy absorbers and limit stops and can be plate and shell type supports, linear type supports or commercially available standard piping supports. In TR Section 6.1, AREVA states that for Service Levels A, B and C, the seismic Category I pipe supports will be designed, manufactured, installed and tested in accordance with Subsection NF of the ASME Code and for Service Level D, Appendix F of Section III of the ASME Code will be utilized. In addition, the welding requirements for A500, Grade B tube steel from AWS D1.1 will be utilized.

AREVA also states that plate and shell type supports such as skirts or saddles are fabricated from plate elements and loaded to create a biaxial stress field. Linear type supports (i.e., beams, columns, frames and rings) are essentially subjected to a single component of direct stress, but may also be subjected to shear stresses. Standard supports are made from typical support catalog items such as springs, rigid struts and snubbers and are typically load rated items, but may be also qualified by plate and shell or linear analysis methods.

Further, AREVA states that seismic Category II pipe supports are designed to ANSI/AISC N690, "Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities." Non-seismic category pipe supports are designed using guidance from the AISC Manual of Steel Construction. In addition to the pipe support design codes mentioned above, expansion anchors and other steel embedments in concrete shall be designed for concrete strength in accordance with ACI-349, "Code Requirements for Nuclear Safety Related Concrete Structures."

AREVA further states that, typically, the stress limits for pipe supports are in accordance with ASME III, Subsection NF and Appendix F. The design of all supports for the non-nuclear piping satisfies the requirements of ASME/ANSI B31.1 Power Piping Code, Paragraph 120 for loads on pipe supporting elements and Paragraph 121 for design of pipe supporting elements. The staff reviewed the applicable codes in TR Section 6.1 and in RAI EPR-33 requested AREVA to clarify the applicability of some codes and standards suggested in the TR.

In response (dated July 13, 2007), AREVA stated that seismic Category I pipe supports will be designed to ASME Subsection NF loadings for Service Levels A, B, C and D, while using the acceptance limits of Subsection NF for Levels A, B and C, and the acceptance limits of Appendix F for Level D. Subsection NF of the ASME Code will be used for the manufacturing, installation and testing of all seismic Category I pipe supports.

AREVA also stated that for all seismic Category II pipe supports other than standard component supports, the design, manufacturing, installation and testing will meet the requirements of ANSI/AISC N690. Standard component supports will be designed, manufactured, installed and tested to Subsection NF of the ASME Code. Any structural members used as part of a pipe support also containing standard components will be designed, manufactured, installed and tested to ANSI/AISC N690. In its revised response (dated November 20, 2007), AREVA stated that the reference to ANSI/AISC N690 in the TR will be revised to include Supplement 2 (2004), in accordance with SRP Sections 3.8.3 and 3.8.4.

AREVA further stated that for non-seismic pipe supports supporting piping analyzed to B31.1, the requirements of B31.1 for supports (Paragraphs 120 and 121) will be met, where applicable. In addition, the structural elements will meet the requirements of the AISC Manual. For standard components used in such supports, vendors catalog requirements will be utilized, which also meet B31.1 requirements. For non-seismic pipe supports supporting unanalyzed piping, the structural elements will meet the requirements of the AISC Manual, and standard components will meet vendors catalog requirements.

The staff finds that the ASME Code Section III, Subsection NF and Appendix F, along with the other associated design documents for seismic Category II and non-seismic pipe supports are quality industry standards and are acceptable. Therefore, RAI **EPR-33 is resolved.**

3.5.2 Jurisdictional Boundaries

In TR Section 6.2, AREVA states that all piping supports are designed in accordance with the rules of Subsection NF of the ASME Code up to the building structure interface as defined by the jurisdictional boundaries in Subsubarticles NF-1130 of the ASME Code. 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 ASME Code, Subsection 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 ASME Code, Subsection NF.

The jurisdictional boundary between the pipe and its support structure will follow the guidance of Paragraph NB-1132, NC-1132, or ND-1132, as appropriate for the ASME Class of piping involved. For piping analyzed to B31.1, the jurisdictional boundary guidance of Paragraph ND-1132 will be utilized.

The staff's review of the jurisdictional boundaries in the Code finds that they are sufficiently defined to ensure a clear division among the piping, pipe support and the building structure. Therefore, the staff finds this acceptable.

3.5.3 Loads and Load Combinations

TR Section 6.3 defines the support loads and their combination methods for the design of piping supports correspond to those used for design of the supported pipe. The loadings for the pipe support design include:

- deadweight (includes pipe and fittings, contents and support itself)
- thermal (for all four service levels: normal, upset, emergency and faulted)
- friction (due to thermal expansion movement)
- system operating transients (safety/relief valve thrust, fast valve closure, water/steam hammer)
- wind and tornado
- design basis pipe break (includes jet impingement or pipe whip)
- main steam/feedwater pipe break
- LOCA
- seismic (safe shutdown earthquake and seismic anchor movement)

In TR Section 6.3.11, AREVA provided a minimum design load criteria that will be used for all supports so that uniformity is obtained in the load carrying capability of the supports. All supports will be designed for the largest of the following three loads: One hundred percent of the Level A condition load; the weight of a standard ASME B31.1 span of water filled, Schedule 80 pipe; and minimum value of 150 pounds. TR Table 6-1 provides the specific load combinations that will be used in the design of pipe supports. The acceptance criteria associated with the Service Levels will be per ASME Code, Subsection NF, ANSI/AISC N690 or the AISC Manual of Steel Construction, as appropriate.

AREVA states that, since signed thermal loadings may cancel other signed loadings, the cold condition must also always be considered for support loads. In TR Section 6.3.2, AREVA states consideration for local, radial thermal expansion of the pipe cross section must be made. This effect is often addressed by having small gaps around the pipe for such thermal growth, while still maintaining relatively tight constraints for seismic loadings.

AREVA discusses wind/tornado loads in TR Sections 6.3.5 and 6.3.6 for pipe supports. However, for the piping in TR Section 3.3.1.6 AREVA identified these loads to be the COL- Action Item 3.

Based on the above, in RAI EPR-34 the staff requested AREVA to clarify several statements made in the TR Section 6.3. In its revised response (dated November 20, 2007), AREVA clarified that the minimum design load criteria of 100 percent of the Level A condition load given in this section is based on criteria given in Welding Research Council (WRC) Bulletin 353, Section 2.4.7. The bulletin recommends 125 percent of the Level A condition load and the TR will be revised to this in order to be consistent with WRC Bulletin 353. The staff finds this acceptable.

To clarify the load combinations for different types of supports, AREVA also clarified that Table 6-1 includes three faulted load combinations which contain SSE loads. In addition, Note 3 of the table states that SSE includes inertia and SAM loads combined by the absolute sum method. These would all apply to Class 1, 2 and 3 pipe supports. In addition, struts and anchors/guides will be analyzed to all load combinations shown in the table. Snubbers will be designed to all but the normal level load combinations shown in the table. Note that Class 1 was inadvertently not included in Note 1 of Table 6-1. This will be corrected in the next revision of the TR.

With regards to wind/tornado loads, AREVA clarified the TR Section 3.3.1.6 that for design certification, no Class 1, 2 and 3 piping is exposed to wind and tornado loads, and further stated that, if a COL Applicant creates such an exposed piping condition, it will be addressed at that time. Sections 6.3.5 and 6.3.6 discuss the inclusion of such wind related loads for pipe supports. AREVA's position on wind loadings for both piping and supports is as stated in Section 3.3.1.6. Clarification will be added to Sections 6.3.5 and 6.3.6 to cross reference this section, and state that these sections show how such loads would be treated if the need arises.

AREVA also stated in its response that per WRC Bulletin 353, forces due to friction of the piping on the support shall be considered under combined deadweight and thermal loading only. Therefore, friction will not be considered with even the static analysis cases of wind and tornado. Table 6-1 of the TR will be revised to include the effects of system operating transients (RSOT) with pipe break, LOCA, and SSE loads, both in the Level C and the Level D cases.

AREVA further stated that loads due to dynamic events 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 SRSS method, provided it is demonstrated that the non-exceedance criteria given in NUREG-0484 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 summation. SSE and high energy line break (i.e., LOCA and secondary side pipe rupture) loads are always combined using the SRSS method. Note that any steady state effects from the system operating transients will be added to the combinations.

Since the load combinations presented in TR Table 6-1 are consistent with the industry practice using ASME Code, Subsection NF, ANSI/AISC N690 or AISC Manual for Steel Construction for Service Level A, B, C and D loads, and consistent with NUREG-0484 for dynamic load combinations, the staff finds this acceptable. Therefore, **RAI EPR-34 is resolved.**

3.5.4 Pipe Support Baseplate and Anchor Bolt Design

In TR Section 6.4, AREVA states that the use of baseplates with expansion anchors will be minimized in the U.S. EPR design. The concrete will be evaluated using ACI-349, Appendix B subject to the conditions and limitations of RG 1.199. 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 utilized in the development of anchor bolt loads, as addressed in IE Bulletin 79-02, Revision 2. The staff finds that baseplate and anchor bolts will be adequately designed based on the above requirements and hence, are acceptable.

3.5.5 Use of Energy Absorbers and Limit Stops

In TR Section 6.5, AREVA states that energy absorbers and limit stops for pipe supports utilizing normal design loadings will not be used for the U.S. EPR piping design. However, AREVA may use energy absorbing material in the design of pipe whip restraints, which are out of scope for this assessment. The staff finds this acceptable.

3.5.6 Use of Snubbers

The operating loads on snubbers are the loads caused by dynamic events during various operating conditions. Snubbers restrain piping against response to dynamic excitation and to the associated differential movement of the piping system support anchor points. The loads calculated in the piping dynamic analysis cannot exceed the snubber load capacity for design, normal, upset, emergency and faulted conditions. Snubbers are generally used in situations where dynamic support is required because thermal growth of the piping prohibits the use of rigid supports. The snubber locations and support directions are first decided by estimation so that the stresses in the piping system have acceptable values.

In TR Section 6.6, AREVA states that typical snubber components are manufactured standard hardware, and may be either hydraulic or mechanical in operation. Other design/analysis considerations for snubbers are related to the ability of the snubbers to properly activate for their design loadings. For snubbers which might experience high thermal growth rates, the analysis should ensure that such growth rates do not exceed the snubber lock-up velocity. Also, for parallel snubbers utilized in the same support, care must be taken to ensure that total fitting clearances are not mismatched between the tandem snubbers such that one will activate before the other.

AREVA also states that design specifications provided to the snubber suppliers will include the codes and standards, functional requirements, operating environment (both normal and post accident), materials (construction and maintenance), functional testing and certification, and requirements for construction to meet ASME Code, Subsection NF. The proper installation and operation of snubbers will be verified by the COL applicant, utilizing visual inspections, hot and cold position measurements, and observance of thermal movements during plant startup. This is identified as the COL-Action Item 7 in TR Table 1-1.

In accordance with SRP Section 3.9.3, II.3B, AREVA should provide the criteria for acceptance for snubber operability assurance for safety-related systems. The criteria should include structural analysis and systems evaluation, characterization of mechanical properties, design specifications, installation and operability verification, and inspection and testing. In RAI EPR-35, the staff requested AREVA to provide this information. In response (dated July 13, 2007), AREVA stated that the design specifications will be the responsibility of the COL applicant (See item 2 of TR Table 1-1). The specification will be generated using the snubber specification requirements given in Chapter 3 of the FSAR. Therefore, the staff finds this acceptable, and **RAI EPR-35 is resolved.**

3.5.7 Pipe Support Stiffnesses

TR Section 6.7 provides limited information about modeling the stiffness of pipe supports by using representative stiffness values either as the actual stiffness or an arbitrary rigid stiffness. Also, AREVA discusses two deflection checks that will be performed for each support modeled as rigid in the piping analysis. The first check will compare the deflection in the restrained direction(s) to a maximum of one-sixteenth inch for SSE loadings or the minimum support design loadings of TR Section 6.3.11. The second check will compare the deflection in the restrained direction(s) to a maximum of one-eighth inch for the worst case deflection for any load case combination. Note that in the development of the support deflections, dynamically flexible building elements beyond the support jurisdictional boundaries will also be considered.

AREVA does not adequately describe how the representative stiffness values are developed for all supports other than snubbers. Therefore, in RAI EPR-36, the staff requested AREVA to describe 1) the approach used to develop the representative stiffness values, 2) the procedure that will be imposed to ensure that the final designed supports match the stiffness values assumed in the piping analysis, 3) the procedure used to consider the mass (along with the support stiffness) if the pipe support is not dynamically rigid, and 4) the same information [1), 2), and 3) above] for the building steel/structure (i.e., beyond the ASME Subsection NF jurisdictional boundary) and for equipment to which the piping may be connected.

In its revised response (dated November 20, 2007), AREVA stated that the initial piping analyses will assume all supports rigid (except for the few cases where the actual support structures are included in the piping model), and therefore, utilize the default rigid support stiffness values contained in the analysis program. In addition, the initial pipe support designs will be developed to create a rigid support, based on the deflection check criteria given in Section 6.7 of the TR. If for some reason, a rigid support cannot be achieved, actual support stiffness will need to be developed for the support noted, as well as for the other supports in the model. WRC Bulletin 353 discusses the use of deflection checks to determine stiffness of supports. It discusses the use of a one-sixteenth inch deflection for Level B checks, with no more than a maximum of one-quarter inch for typical piping systems in the range of 3 to 9 Hz. frequency. The deflection check criteria used in the TR has been used in other plants and falls within the bounds of the criteria of this document.

AREVA also stated that typically, unless the support is a very simple structure, a frame support will be modeled using an analysis program such as GT STRUDL. This model will include the self-weight of the support, and will also be used to establish the deflections needed for the stiffness checks. Note that this model will include any flexible building steel, as applicable. If the deflection checks do not show rigidity, the model can be used to determine the actual stiffness of the support structure using the self-weight load case. In addition, the support mass can be determined from the model. This would be created for the supports in the model and provided to the piping analyst. At this point, the supports would need to be rechecked for the loads from the revised piping analysis. If any support changes were required, an iteration of the process would be required to assure that the stiffnesses and masses are consistent for both the support qualifications and the piping analysis. Information on GT STRUDL will be added to TR Section 5.1. Since the process described is consistent with the industry practices, the staff finds this acceptable. Therefore, **RAI EPR-36 is resolved.**

3.5.8 Seismic and Other Dynamic Load Self-Weight Excitation

In TR Section 6.8, AREVA states that the response of the support structure itself to SSE loadings is to be included in the pipe support analysis. In general, the inertial response of the support mass will be evaluated using a RS analysis similar to that performed for the piping. Damping values for welded and bolted structures are given in RG 1.61. This support self-weight SSE response, the piping inertial load SSE response and the SSE loads from SAM are to be combined by the absolute sum method. However, this criterion does not include other dynamic loads, specifically the system operating transients, and AREVA did not specifically discuss how the RG 1.61 damping will be used in the analysis since the support structure and piping damping may be different. Therefore, in RAI EPR-37 the staff requested AREVA to provide this information.

In its revised response (dated November 20, 2007), AREVA stated that in most cases, Revision 1 of RG 1.61 calls for four percent damping for the piping analysis. Similarly, the RG allows for four percent damping for welded steel or bolted steel with friction connections and seven percent for bolted steel with bearing connections, which would be applicable for the supports. If frequency-dependent damping values are used in the piping analysis, the support structure will still utilize the four percent or seven percent damping values. In those analyses where the support\restraint stiffnesses are explicitly represented in the analysis model and where the support damping is judged to be different than the piping damping, one of two approaches may be taken: 1) the lower of the support\restraint and piping damping may be applied to both support\restraints and piping, or 2) composite modal damping (as described in AREVA response to RAI EPR-32) may be used. AREVA will revise TR Section 6.8 to reference Rev. 1 of RG 1.61. Since this is consistent with the industry practices, **the staff finds this part of RAI EPR-37 acceptable.**

AREVA also stated that the support structure itself will be excited by SSE dynamic inputs, as the SSE event is applicable to the whole site in the form of ground motion. As such, the excitation for the support's attachment to the building will be applied to the self-weight of the structure in the form of response spectra g values. For other fluid dynamic transient events within the piping system, forces from the fluid moving along the pipe are included in the pipe support loads for that event, but any subsequent excitation of the support structure itself for the fluid dynamic event will not be evaluated, as the forcing function at each support beyond applied piping loads will be minimal, and not usually defined. This is standard practice in pipe support design. The supports are typically not modeled with the piping.

However, in the original RAI the staff requested AREVA to explain the criterion applicable to other dynamic loads due to system operating transients. It is not clear what AREVA meant by stating that any subsequent excitation of the support structure itself for the fluid dynamic event will not be evaluated since its effect is minimal. The staff assumes that the loads from these subsequent self excitation caused by the fluid dynamics are bounded by the piping loads. If this is not true for any dynamic condition, then AREVA must provide technical justification for not including them in the pipe support design. AREVA should clarify how other dynamic loads, such as thermal and pressure transients, water hammer, etc., are included in the design of pipe supports, including the load combinations given in TR Table 6-1. On April 18, 2008, AREVA provided in Attachment B of its second revised response a discussion to be added to TR Section 6.8.2 addressing the effect of support self-weight excitation for other dynamic loads. The staff finds this acceptable, since the criteria presented in this subsection include the dynamic characteristics of supports that are not rigid while performing the piping analysis. **Therefore, RAI EPT-37 is resolved.**

3.5.9 Design of Supplementary Steel

Supplementary steel includes structural steel within the jurisdictional boundary of ASME Subsection NF (e.g., structural steel members connecting a snubber to the building structure). TR Section 6.9 provides design criteria for the design of pipe supports using supplementary steel. Supplementary steel for pipe supports are designed in accordance with ASME Code, Section III, Subsection NF (for seismic Category I supports), to ANSI/AISC N690 (for seismic Category II supports), or AISC Manual (for non-seismic supports). The use of Subsection NF or other standards is an industry practice acceptable to the staff since it was developed by a professional society and voluntary consensus standards organization and has proven to provide adequate design guidelines for the design of structural steel for use as pipe supports. The staff finds the use of these criteria for the design of U.S. EPR supplementary steel provides reasonable assurance of the structural integrity of the supports and is therefore, acceptable.

3.5.10 Consideration of Friction Forces

In TR Section 6.10, AREVA describes the criteria for considering the effect of friction forces due to thermal movements. The friction forces are calculated using the deadweight and thermal loads normal to the applicable support member. Specifically, to calculate the friction forces, a force will only need to be calculated if the thermal movement in the applicable unrestrained direction(s) is greater than one-sixteenth inch. If this threshold is met, the force will be calculated using C x N, where C is the appropriate coefficient of friction and N is the total force normal to the movement. The coefficient of friction will be taken as 0.3 for steel-to-steel conditions and 0.1 for low friction slide/bearing plates. If support stiffness information is readily available, this calculated force can be reduced by using the force of K x D (if less than C x N), where K is the support stiffness in the movement direction and D is the movement. This is acceptable to the staff.

3.5.11 Pipe Support Gaps and Clearances

In TR Section 6.11, AREVA states that for rigid guide pipe supports 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 U.S. EPR will be to use a nominal cold condition gap of one-sixteenth inch on each side of the pipe in the restrained direction. This will lead to a maximum total cold condition gap around the pipe for a particular direction of one-eighth inch. For gaps around the pipe in an unrestrained direction, the gap magnitudes should be specified large enough to accommodate the maximum movement of the pipe. The staff finds this acceptable.

3.5.12 Instrumentation Line Support Criteria

In TR Section 6.12, AREVA states that the design and analysis loadings, load combinations and acceptance criteria to be used for instrumentation line supports will be similar to those used for pipe supports. The applicable design loads will include deadweight, thermal expansion and seismic loadings (where appropriate). The applicable loading combinations will similarly follow those used for normal and faulted levels in TR Table 6-1, utilizing the design loadings mentioned above. The acceptance criteria will be from ASME Code, Subsection NF for seismic Category I instrumentation lines, ANSI/AISC N690 for Seismic Category II instrumentation lines and the AISC Manual of Steel Construction for non-seismic instrumentation lines. The staff notes that TR Table 6-1 covers all four service level (i.e., normal, upset, emergency and faulted) load combinations for pipe supports. In RAI EPR-38, the staff requested AREVA to clarify why only the load combinations for the normal and faulted conditions are used in the pipe support design.

In response (dated July 13, 2007), AREVA stated that based on the inclusion of only deadweight, thermal and SSE seismic loadings for analysis of the tubing, the vast majority of the support loads would fall into normal or faulted conditions. Since there may be thermal loads for other levels, this section of the topical will be modified to delete the reference to only normal and faulted loading conditions. Since this change in TR Table 6-1 will be consistent with the current industry practices, the staff finds this acceptable. Therefore, **RAI EPR-38 is resolved.**

3.5.13 Pipe Deflection Limits

In TR Section 6.13, AREVA states that for pipe supports utilizing standard manufactured hardware components, the manufacturer's recommendations for limitations in its hardware will be followed. Examples of these 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 will be made in the initial designs for tolerances on such limits. This is especially important for snubber and spring design where the function of the support can be changed by an exceeded limit. AREVA did not specify any quantitative allowances for the pipe deflection limit. In RAI EPR-39, the staff requested AREVA to provide the deflection limits that will be used for different support types.

In response (dated July 13, 2007), AREVA stated that the first check mentioned is the travel range limitation for spring hangers. This check will utilize the "working range" given in the standard Load Table for Selection of Hanger Size typically given in the vendor catalogs. This working range already provides a deflection tolerance beyond each end limit of the range (with the magnitude dependent on the spring type), provided the hot and cold loads fall within the working range. The second check mentioned is the stroke limit checks for snubbers. The current project guidance is to allow at least one-half inch of stroke at each end for the initial design checks. The third check mentioned is the swing angle check for rods, struts and snubbers. For current analyses, ANVIL International[4] hardware is being used. ANVIL's limit

[4] ANVIL International is a manufacturer of pipe fittings and pipe hangers and supports.

for these checks is four degrees. AREVA will apply a tolerance of one degree to this, thus checking to three degrees for initial design. The fourth check mentioned is for alignment angles of strut and snubber paddles and their associated clamps or end brackets. ANVIL's limit is five degrees. AREVA will apply a tolerance of one degree to this, thus checking to four degrees for initial design. The fifth check mentioned is for the spring variability check. The recommended limit on this check by ANVIL is 25 percent. AREVA will apply a tolerance of five percent to this, thus checking to 20 percent for initial design. Since this is consistent with the industry practices, the staff finds these specifications and allowances acceptable. Therefore, **RAI EPR-39 is resolved.**

3.5.14 Conclusions

On the basis of these discussions and the evaluation of TR Section 6.0, the staff concludes that supports of piping systems important to safety are designed to quality standards commensurate with their importance to safety. The staff's conclusion is based on the following:

- AREVA satisfies the requirements of GDC 1 and 10 CFR 50.55a by specifying methods and procedures for the design and construction of safety related pipe supports in conformance with general engineering practice, and

- AREVA satisfies the requirements of GDC 2 and GDC 4 by designing and constructing safety-related pipe supports to withstand the effects of normal operation as well as postulated events such as LOCAs and dynamic effects resulting from the SSE.

4.0 Conclusions

The staff concludes that piping systems important to safety are designed to quality standards commensurate with their importance to safety. As committed, AREVA shall incorporate all the pertinent additional information in the next revision of the topical report. The staff also concludes the following:

- AREVA meets the requirements of GDC 1 and 10 CFR 50.55a by specifying methods and procedures for the design and construction of safety-related piping systems in conformance with general engineering practice.

- AREVA meets the requirements of GDC 2 and GDC 4 by designing and constructing the safety-related piping systems to withstand the effects of normal operation as well as postulated events such as LOCAs and dynamic effects resulting from the SSE.

- AREVA meets 10 CFR Part 50 requirements by identifying applicable codes and standards, design and analysis methods, design transients and load combinations, and design limits and service conditions to ensure adequate design of all safety-related piping and pipe supports in the U.S. EPR for their safety functions.

- AREVA meets 10 CFR Part 52 requirements by providing reasonable assurance that the piping systems will be designed and built in accordance with the certified design. The implementation of these pre-approved methods and satisfaction of the acceptance criteria will be verified through the performance of the ITAAC by the

COL holder to ensure that the as-constructed piping systems are in conformance with the certified design for their safety functions.

- AREVA meets 10 CFR Part 50, Appendix S, requirements by designing the safety-related piping systems, with a reasonable assurance to withstand the dynamic effects of earthquakes with an appropriate combination of other loads of normal operation and postulated events with an adequate margin for ensuring their safety functions.

- AREVA meets the requirements of GDC 14 by following the Code requirements with regard to the RCPB of the primary piping systems being designed, fabricated, constructed, and tested to have an extremely low probability of abnormal leakage, of rapid propagating failure, and of gross rupture.

- AREVA meets the requirements of GDC 15 by following the Code requirements with regard to the reactor coolant piping systems being designed with specific design and service limits to assure sufficient margin that the design conditions are not exceeded.

5.0 References

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

2. Response to Request for Additional Information Regarding ANP-10264NP, "U.S. EPR Piping Analysis and Pipe Support Design" (TAC No. MD3128), NRC:07:028, ANP-10264Q1, July 13, 2007.

3. Revised Response to Request for Additional Information Regarding ANP-10264NP "U.S. EPR Piping Analysis and Pipe Support Design" (TAC No. MD3128), NRC:07:064, ANP-10264Q1a, November 20, 2007.

4. Revised Response to Request for Additional Information Regarding ANP-10264NP "U.S. EPR Piping Analysis and Pipe Support Design," (TAC No. MD3128), NRC:08:024, ANP-10264Q1b, April 18, 2008.

5. Code of Federal Regulations, 10 CFR Part 50, Domestic Licensing of Production and Utilization Facilities: Appendix A - General Design Criteria for Nuclear Power Plants and Appendix B - Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants.

6. Code of Federal Regulations, 10 CFR Part 52, Early Site Permits; Standard Design Criteria and Combined Licenses for Nuclear Power Plants: Subpart B - Standard Design Certifications.

7. ASME Boiler and Pressure Vessel Code, Section III, Rules for Construction of Nuclear Power Plant Components, 2001 edition with 2003 addenda.

8. ASME Boiler and Pressure Vessel Code, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, 2001 edition with 2003 addenda.

9. ANSI/ASME B31.1, ASME Code for Pressure Piping and Power Piping, 2004.

10. ASCE Standard, ASCE 4-98, "Seismic Analysis of Safety-Related Nuclear Structures and Commentary," 1998.

11. ACI 349, "Code Requirements for Nuclear Safety Related Concrete Structures," American Concrete Institute, 2005.

12. ANSI/AISC N690-1994, "Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities," American National Standard.

13. Welding Research Council, WRC Bulletin 300, "Technical Position on Criteria Establishment; Technical Position on Damping Values for Piping - Interim Summary Report; Technical Position on Response Spectra Broadening; Technical Position on Industry Practice," December 1984.

14. Welding Research Council, WRC Bulletin 353, "Position Paper on Nuclear Plant Pipe Supports," May 1990.

15. Guidelines for the Design of Buried Steel Pipe; Report by American Lifelines Alliance, 2001.

16. Seismic Response of Buried Pipes and Structural Components; ASCE Committee on Seismic Analysis of Nuclear Structures and Materials, New York, 1983.

17. IEEE 344-1987, "Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations."

18. AWS D1.1/D1.1M:2004, "Structural Welding Code - Steel."

19. NRC Standard Review Plan, NUREG-0800, Section 3.7.3, "Seismic Subsystem Analysis," Rev. 3; Section 3.9.1, "Special Topics for Mechanical Components," Rev. 3; Section 3.9.2, "Dynamic Testing and Analysis of Systems, Components, and Equipment," Rev. 3; Section 3.9.3, "ASME Code Class 1, 2, and 3 Components, Component Supports, and Core Support Structures," Rev. 2; and Section 3.12, "ASME Code Class 1, 2, and 3 Piping Systems, Piping Components and Their Associated Supports," Initial Issuance, March 2007.

20. U.S. NRC Regulatory Guide 1.26, "Quality Group Classifications and Standards for Water-, Steam-, and Radioactive-Waste-Containing Components of Nuclear Power Plants," Revision 4, March 2007.

21. U.S. NRC Regulatory Guide 1.29, "Seismic Design Classification," Revision 3, September 1978.

22. U.S. NRC Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants," Revision 1, March 2007.

23. U.S. NRC Regulatory Guide 1.84, Design, Fabrication, and Materials Code Case Acceptability, ASME Section III, Revision 33, August 2005.

24. U.S. NRC Regulatory Guide 1.92, "Combining Modal Responses and Spatial Components in Seismic Response Analysis." Rev. 1. February 1976.

25. U.S. NRC Regulatory Guide 1.92, "Combining Modal Responses and Spatial Components in Seismic Response Analysis," Rev. 2, July 2006.

26. U.S. NRC Regulatory Guide 1.122, "Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components," Revision 1, February 1978.

27. U.S. NRC Regulatory Guide 1.142, Safety-Related Concrete Structures for Nuclear Power Plants (Other than Reactor Vessels and Containments), Revision 2, November 2001.

28. U.S. NRC Regulatory Guide 1.147, Inservice Inspection Code Case Acceptability, ASME Section XI, Division 1, Revision 14, August 2005.

29. U.S. NRC Regulatory Guide 1.199, Anchoring Components and Structural Supports in Concrete, November 2003.

30. U.S. NRC Regulatory Guide 1.206, Combined License Applications for Nuclear Power Plants, June 2007.

31. NUREG-0484, "Methodology for Combining Dynamic Responses," Revision 1, May 1980.

32. NUREG-1061, "Report of the U.S. Nuclear Regulatory Commission Piping Review Committee - Evaluation of Other Loads and Load Combinations," Volume 4, December 1984.

33. NUREG-1367, "Functional Capability of Piping Systems," November 1992.

34. NUREG-1503, "Final Safety Evaluation Report Related to the Certification of the Advanced. Boiling-Water Reactor."

35. NUREG/CR-1677, Bezler, P., Hartzman, M. and Reich, M., "Piping Benchmark Problems - Dynamic Analysis Uniform Support Motion Response Spectrum Method," BNL-NUREG-51267, Vol. 1, August 1980.

36. NUREG/CR-1677, Bezler, P., Subudhi, M. and Hartzman, M., "Piping Benchmark Problems - Dynamic Analysis Independent Support Motion Response Spectrum Method," BNL-NUREG-51267, Vol. II, August 1985.

37. NUREG/CR-1980, Curreri, J., Bezler, P., and Hartzman, M., "Dynamic Analysis of Piping Using the Structural Overlap Method," BNL-NUREG-51357, March 1981.

38. NUREG/CR-6645, Morante, R. and Wang, Y., "Reevaluation of Regulatory Guidance on Modal Response Combination Methods for Seismic Response Spectrum Analysis," BNL-NUREG-52576, December 1999.

39. NUREG/CR-6876, Braverman, J., DeGrassi, G., Martinez-Guridi, G., Morante, R., and Hofmayer, C., "Risk-Informed Assessment of Degraded Buried Piping Systems in Nuclear Power Plants," BNL-NUREG-74000-2005, June 2005.

40. NUREG/CR-6919, Morante, R. J., "Recommendations for Revision of Seismic Damping Values in Regulatory Guide 1.61," BNL-NUREG-77174-2006, November 2006.

41. SECY-90-016, "Evolutionary Light Water Reactor (LWR) Certification Issues and their Relationship to Current Regulatory Requirements," January 12, 1990.

42. SECY-93-087, "Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs," April 2, 1993.

43. IE Bulletin No. 79-2, Revision 2, "Pipe Support Base Plate Designs Using Concrete Expansion Anchor Bolts," November 8, 1979.

44. NRC Bulletin 79-13, "Cracking in Feedwater System Piping," Revision 2.

45. NRC Bulletin 88-08, with Supplement 3, "Thermal Stresses in Piping Connected to Reactor Coolant System."

46. NRC Bulletin 88-11, "Pressurizer Surge Line Thermal Stratification.

Attachment
Staff's Resolution of AREVA's Comment

Comment No.	Page	Sect.	Comment	Proposed Resolution	Disposition
1.	6	3.1.2	First paragraph, second sentence, refers to "pre-certification." This terminology does not apply to the U.S. EPR design certification application. Note: this also appears in the following locations of the DSER: • Page 20, Section 3.3.1, second paragraph, last sentence • Page 21, Section 3.3.1, first paragraph, second and last sentence • Page 21, Section 3.3.1, last paragraph on this page, third sentence • Page 29, Section 3.4.1, first paragraph on the page, first sentence • Page 30, Section 3.4.2, second paragraph, second sentence • Page 39, Section 3.4.10, last paragraph, next to last sentence	Change "pre-certification" to "certification."	Incorporated

Comment No.	Page	Sect.	Comment	Proposed Resolution	Disposition
2.	6	3.1.2	The COL action item referenced in the first paragraph in Section 3.1.2 of the DSER was removed from the TR in Attachment D to the revised RAI responses for the TR (reference AREVA NP letter NRC:07:064 dated November 20, 2007). As noted in Attachment D, the reason for deleting this COL action item was "The COL applicant is permitted to use other code cases as long as they are listed in RG 1.84 as a conditionally or unconditionally accepted code case."	Revise this paragraph as follows: "The only acceptable ASME Code Cases that may be used for the design of ASME Code Class 1, 2, and 3 piping systems in the U.S. EPR standard plant are those either conditionally or unconditionally approved in RG 1.84 and RG 1.147 in effect at the time of design certification. This review is based on Revision 33 of RG 1.84, dated August 2005, since AREVA did not identify any code cases associated with Section XI of the ASME Code for RG 1.147 at this pre-certification stage. Both RGs include Code Cases listed up to Supplement 6 (or 2003 Addenda) to the 2001 Edition of the ASME B&PV Code. ~~AREVA states in TR Table 1-1 that COL applicant will identify any additional Code Cases used that are not listed in this TR for piping and are, therefore, not included in the scope of the U.S. EPR Design Certification. This is identified as COL Action Item 1.~~ The staff finds ***this*** ~~statement of the COL Action Item~~ to be acceptable as long as the additional Code Cases are listed in RG 1.84 and RG 1.147 as a conditionally or unconditionally accepted Code Cases at the time of their use."	Incorporated
3.	7	3.1.3	First paragraph, last sentence of this section should only address piping consistent with Section 2.3 of the TR.	Revise this sentence as follows: "In the TR, AREVA committed to construct all safety-related ***piping*** components~~, such as vessels, pumps, valves and piping systems,~~ to applicable requirements of the ASME Code, Section III."	Incorporated with "piping components" changed to "piping systems"

Comment No.	Page	Sect.	Comment	Proposed Resolution	Disposition
4.	12	3.2.3	Last paragraph, fourth sentence should also reflect that changes to TR Section 4.2.2 were also addressed in the revised RAI responses contained in AREVA NP letter dated April 18, 2008. Also "model" should be "modal"	Revise this sentence as follows: "AREVA will revise various subsections of TR Section 4.2.2 in order to include all provisions of NUREG-1061, including the combination of the missing mass effects with the low frequency ~~model~~ ***modal*** responses, as committed in its revised responses of November 20, 2007***, and April 18, 2008***."	Incorporated
5.	13	3.2.4	First paragraph on this page, next to last sentence is not accurate in that it implies that RG 1.92 refers to the SRP. Rather, quote RG 1.92 Rev. 2.	Revise this sentence as follows: "In addition, RG 1.92 Section 1.4.1 states "The guideline provided in References 10 and 19, ~~it is shown~~ that the missing mass contribution needs to be considered only if the fraction of the missing mass at any degrees of freedom exceeds 0.1~~, as stated in the SRP may produce~~ ***is*** non-conservative ~~response~~ and should not be used."	Incorporated
6.	17	3.2.5	Second full paragraph on this page, first sentence, the factor of 1.5 for the highest spectral acceleration should be changed to 1.0 consistent with the last paragraph of this section	Revise this sentence as follows: "In general, if the system behaves essentially as a single degree of freedom system and the fundamental frequency of this system is known, a factor of ~~1.5~~ ***1.0*** of the spectral acceleration at the highest spectral acceleration value at or beyond the fundamental frequency may be used."	Incorporated

Comment No.	Page	Sect.	Comment	Proposed Resolution	Disposition
7.	18	3.2.8	Third paragraph, second sentence is not clearly comprehensible as currently written.	Revise this sentence as follows: "***AREVA clarified in its response to RAI EPR-14 for isolation criteria (dated July 13, 2007)*, *that, in*** cases where it is not possible, or practical, to isolate the seismic piping, ~~In response to RAI EPR-14 for isolation criteria (dated July 13, 2007), AREVA clarified that~~ isolation of a non-seismic piping is achieved when two piping systems in the same room (one seismic and one non-seismic) ~~by~~ ***are*** physically locat***ed***~~ing~~ away from each other as much as possible, such that there will be little chance of the non-seismic piping adversely interacting with the seismic piping, potentially causing damage to the seismic piping during a seismic event."	Incorporated

Comment No.	Page	Sect.	Comment	Proposed Resolution	Disposition
8.	18	3.2.8	Third paragraph, third sentence from the end of this paragraph does not clearly depict the changes to TR section 4.2.2 that AREVA committed to in the revised RAI EPR-14 response of November 20, 2007.	Revise this sentence as follows: "Furthermore, in its revised response (dated November 2007), AREVA agreed to remove ~~some of~~ the ***following*** interaction criteria given in TR Section 4.4.2***:*** • ***If the non-seismic piping is supported by seismic restraints within the ASME B31.1 Code suggested pipe support spacing shown in Table 4-1, it is considered to lose its pressure boundary integrity, but not fall.*** • ***All moderate energy piping should be assumed to fall vertically downward from its original position. Side motion should be assumed to be ±6 inches (centerline to centerline) from the original pipe position. Pipe whip should be considered for high energy piping.*** • ***Safety-related piping with NPS and thickness equal to or greater than that of the non-seismic piping may be assumed to stop the downward motion of the non-seismic piping without failure of the safety-related piping."***	Incorporated

Comment No.	Page	Sect.	Comment	Proposed Resolution	Disposition
9.	21	3.3.1	Fourth paragraph on this page implies that computer code GT STRUDL will only be used to calculate pipe support stiffnesses. As discussed in Section 3.5.7 of the SER, GT STRUDL is being used to analyze the support structure, to include beam stresses, deflection checks for stiffness purposes, and loads applied to embedded plates. It is not just being used to generate support stiffnesses.	Revise this sentence as follows: "As discussed in Section 3.5.7 of this report, in response to RAI EPR-36 AREVA is also committed to add the computer code GT STRUDL at this phase of the design certification~~,~~ ~~since AREVA intends to use this program to calculate the pipe support stiffnesses in the pipe support design~~."	Incorporated
10.	29	3.4.1	First paragraph top of the page, second sentence states: "However, AREVA should develop these input spectra using the guidelines given in RG 1.60 and SRP Section 3.7.1 and include them in the FSAR." This information has been provided in the FSAR and the last paragraph in this section, next to last sentence states that NRC will asses this information.	Delete the second sentence in the first paragraph at the top of Page 29. Revise the next to last sentence in Section 3.4.1 as follows: "The staff will assess the development of seismic input and floor response spectra ~~when it is described~~ in the FSAR.	Incorporated

Comment No.	Page	Sect.	Comment	Proposed Resolution	Disposition
11.	36	3.4.6	Fourth paragraph implies that only BWSPAN will be used to calculate missing mass for piping whereas SUPERPIPE also performs this function. This sentence should be revised consistent with the revised response to RAI EPR-28.	Revise this paragraph as follows: "In its revised response (dated November 20, 2007), AREVA stated that the method detailed in the TR is based on the left-out-force method. This method is performed by the SUPERPIPE piping analysis code which has been accepted for use at many operating plants. Although this method is different than that shown in RG 1.92, Rev. 2, it produces the same result. The basic difference in the presentations of the missing mass calculation as shown in RG and as shown in the TR is that the RG equations are written for each modal degree-of-freedom while the TR equations are written in vector form. Re-writing the RG equations in vector form shows that the formulations are equivalent. ~~However,~~ BWSPAN uses the missing mass method given in Appendix A of RG 1.92, Rev. 2~~, and U. S. EPR piping design will use BWSPAN for calculating the missing mass~~. ***TR Section 4.2.2.3.2 will be revised to state that the left-out-force method is used by SUPERPIPE BWSPAN uses the missing mass method outlined in Appendix A of RG 1.92 Revision 2."***	Incorporated with ***"SUPERPIPE BWSPAN" changed to "SUPERPIPE, and BWSPAN"***
12.	37	3.4.6	First paragraph, third sentence states: "It should be noted that the staff has not accepted the AREVA-suggested modal combination methods of RG 1.92, Rev. 1 (per RAI EPR-27)." NRC resolution of RAI EPR-27 is addressed in Section 3.4.5 of the DSER	Delete this sentence.	Incorporated

Comment No.	Page	Sect.	Comment	Proposed Resolution	Disposition
13.	45	3.5.1	First paragraph at the top of the page, last sentence should be clarified to note that the commitment to revise the reference to ANSI/AISC N690 in the TR was made in the revised RAI responses provided in the AREVA NP letter dated November 20, 2007.	Revise this sentence as follows: "***In its revised response (dated November 20, 2007), AREVA stated that t***he reference to ANSI/AISC N690 in the TR will be revised to include Supplement 2 (2004), in accordance with SRP Sections 3.8.3 and 3.8.4."	Incorporated

AREVA

September 29, 2006
NRC:06:040

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Request for Review and Approval of ANP-10264(NP) Revision 0, "U.S. EPR Piping Analysis and Pipe Support Design"

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

AREVA NP Inc. (AREVA NP) requests the NRC's review and approval of the topical report ANP-10264(NP) Revision 0, "U.S. EPR Piping Analysis and Pipe Support Design," (Reference 1). This report addresses NRC regulatory requirements for design and analysis of piping and pipe supports utilizing the additional guidance provided by the NRC's Standard Review Plan (SRP) (NUREG-0800) and the requirements established in the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code), Section III, Division 1 for Code Class 1, 2 and 3 pressure retaining components and their supports. The report provides a description of the code requirements, analysis methods, modeling techniques and acceptance criteria for Class 1, 2 and 3 piping systems and their supports.

AREVA NP requests that the NRC issue a Safety Evaluation Report (SER) that approves the methodology described in the topical report as meeting NRC regulatory requirements for the design and analysis of piping and pipe supports and finds that it is acceptable for application to the U.S. EPR design. AREVA NP plans to reference the approved version of Reference 1 in its Design Control Document (DCD) for the U.S. EPR and will use these methods to support detailed design activities.

AREVA NP requests that the NRC complete its review of Reference 1 and issue the SER by March 2007. This schedule is necessary to support the initiation of detailed design activities for the U.S. EPR in early calendar-year 2007.

The topical report as provided on the enclosed CD does not contain any information that AREVA NP considers to be proprietary.

Ms. Sandra M. Sloan, Regulatory Affairs Manager for New Plants Deployment, remains the point of contact with the NRC for U.S. EPR licensing activities. She may be reached by telephone at 434-832-2369, or by e-mail at sandra.sloan@areva.com.

Sincerely,

Ronnie L. Gardner

Ronnie L. Gardner, Manager
Site Operations and Regulatory Affairs
AREVA NP Inc.

cc: L. J. Burkhart
J. F. Williams
Project 733

NRC 1C 06 031

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

December 14, 2006

Ronnie L. Gardner, Manager
Site Operations and Regulatory Affairs
AREVA NP
3315 Old Forrest Road
P.O. Box 10935
Lynchburg, VA 24506-0935

SUBJECT: ACCEPTANCE FOR REVIEW OF "U.S. EPR PIPING ANALYSIS AND SUPPORT DESIGN" TOPICAL REPORT (TAC NO. MD3128)

Dear Mr. Gardner:

By letter dated September 29, 2006 (ML062770021), AREVA NP (AREVA) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review Topical Report (TR) ANP-10264NP, Revision 0, "U.S. EPR Piping Analysis and Support Design" (ML062770023). The NRC staff has performed an acceptance review of the subject TR and has found that the material presented is sufficient to begin our comprehensive review. The staff expects to issue any requests for additional information (RAI) by April 6, 2007, and issue its draft safety evaluation by September 28, 2007, and estimates that the review will require approximately 320 staff hours including project management efforts, and 560 contractor hours. The review schedule milestones and estimated review costs were discussed and agreed upon in a telephone conference between Ronda Daflucas of your staff and the NRC staff on December 1, 2006. The schedule and cost estimates are based on a timely resolution of one round of RAI. Should there be a need for more than one round of RAI, the estimates will be adjusted accordingly.

Per AREVA's request, a postsubmittal meeting will be scheduled at a mutually agreed upon time and mostly likely prior to issuing the requests for additional information letter.

Section 170.21 of Title 10 of the *Code of Federal Regulations* requires that TRs are subject to fees based on the full cost of the review. You did not request a fee exemption; therefore, staff hours will be billed accordingly.

Sincerely,

Getachew Tesfaye

Getachew Tesfaye, Project Manager
AP1000 Projects Branch 1
Division of New Reactor Licensing
Office of New Reactors

Project 733

cc: See next page

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Letter to Ronnie L. Gardner from Getachew Tesfaye, dated December 14, 2006

SUBJECT: ACCEPTANCE FOR REVIEW OF "U.S. EPR PIPING ANALYSIS AND SUPPORT DESIGN" TOPICAL REPORT (TAC NO. MD3128)

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April 5, 2007

Ronnie L. Gardner, Manager
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SUBJECT: SUPPLEMENT TO THE ACCEPTANCE REVIEW OF "U.S. EPR PIPING ANALYSIS AND SUPPORT DESIGN" TOPICAL REPORT (TAC NO. MD3128)

Dear Mr. Gardner:

By letter dated September 29, 2006 (ML062770021), AREVA NP (AREVA) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review Topical Report (TR) ANP-10264NP, Revision 0, "U.S. EPR Piping Analysis and Support Design" (ML062770023). This letter supplements our December 14, 2006, letter (ML0634000080) that forwarded the acceptance review of the subject TR. The staff's review of the TR did not start on time to support the schedule we provided you in the December 14 letter due to the delayed approval of NRC's 2007 budget. As a result, the staff now expects to issue any requests for additional information (RAI) by June 16, 2007, and issue its draft safety evaluation (SE) by November 30, 2007. The revised review schedule was discussed and agreed upon in a telephone conference between Ronda Daflucas of your staff and the NRC staff on March 27, 2007. The RAI and SE schedules are based on a timely resolution of one round of RAI. Should there be a need for more than one round of RAI, the estimates will be adjusted accordingly.

Sincerely,

Getachew Tesfaye

Getachew Tesfaye, Project Manager
AP1000 Projects Branch 1
Division of New Reactor Licensing
Office of New Reactors

Project 733

cc: See next page

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nrc-1c-07-030

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May 29, 2007

Mr. Ronnie L. Gardner
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SUBJECT: REQUEST FOR ADDITIONAL INFORMATION REGARDING ANP-10264NP, "U.S. EPR PIPING ANALYSIS AND PIPE SUPPORT DESIGN TOPICAL REPORT" (TAC NO. MD3128)

Dear Mr. Ronnie L. Gardner:

By letter dated September 29, 2006 (ML062770021), AREVA NP submitted for U.S. Nuclear Regulatory Commission (NRC) staff review Topical Report ANP-10264NP, Revision 0, "U.S. EPR Piping Analysis and Pipe Support Design Topical Report" (ML062770023). The NRC staff has reviewed the application and has determined that additional information is required. Our questions are provided in the Enclosure.

A draft of the additional information requested was provided to you on May 15, 2007 (ML071430124), and discussed with your staff on May 22, 2007. Your staff has agreed that your response would be provided within 30 days of the date of this letter.

If you have any questions regarding this matter, I may be reached at 301-415-3361.

Sincerely,

Getachew Tesfaye, Senior Project Manager
EPR Projects Branch 1
Division of New Reactor Licensing
Office of New Reactors

Project 733

Enclosure:
Request for Additional Information

cc Arnold Lee, Jennifer Dixon-Herrity, Larry Burkhart, Joe Colaccino, Tarun Roy

cc w/encl: See next page

<u>REQUEST FOR ADDITIONAL INFORMATION (RAI)</u>

<u>ANP-10264NP, "U.S. EPR PIPING ANALYSIS</u>

<u>AND PIPE SUPPORT DESIGN</u>

<u>TOPICAL REPORT" (TAC NO. MD3128)</u>

<u>PROJECT NUMBER 733</u>

<u>RAI EPR-1:</u> Piping and Pipe Support Design - General

Section 1.0 of the Topical Report (TR) states that the reactor coolant loop (RCL) and pressurizer surge line piping requirements, modeling techniques, analysis approaches and acceptance criteria are not specifically addressed in this document and will be included in the design control document (DCD). The TR presents nearly all of the design certification requirements, acceptance criteria, analysis methods and modeling techniques for the American Society for Engineers (ASME) Class 1, 2 and 3 piping and pipe supports, as required in the Standard Review Plan (SRP) Section 3.12 for new reactors. Describe any significant differences between the requirements, techniques, approaches and design criteria for the RCL and pressurizer surge line piping, and those included in the TR.

<u>RAI EPR-2:</u> ASME B31.1 and Section XI Codes

A. In accordance with RG 1.26, Quality Group (QG) D piping that may contain radioactive material is considered to be outside the ASME Code Class 1, 2, and 3 piping systems. The Regulatory Guide (RG) recommends that these piping and pipe supports are to be designed in accordance with the requirements of the ASME B31.1, "Power Piping" Code. Please clarify if the Evolutionary Power Reactor (EPR) piping and pipe supports will have QG D systems; and confirm that whether EPR piping design will use the ASME B31.1 Code for these systems, otherwise provide technical justification for using other than the B31.1 Code requirements for the QG D piping systems.

B. Confirm that ASME Code Section XI requirements will be used in the piping and pipe support design for EPR.

<u>RAI EPR-3:</u> 10CFR50.55a(b) Limitations and Modifications

Section 2.1 of the TR states that for the dynamic loads, including seismic loads, the pipe stress analyses will be performed in accordance with the Sub-articles NB/NC/ND-3650 of the 1993 Addenda of the ASME Code as required by 10CFR50.55a(b)(1)(iii). However, AREVA did not address other limitations and modifications (related to Section III materials, weld leg dimensions, etc.) applicable to piping system design as included in 10CFR50.55a(b)(1). Explain how all limitations and modifications specified in 10CFR50.55a(b) will be satisfied.

ENCLOSURE

RAI EPR-4: Mathematical Modeling

TR Section 4.2 states that the seismic analysis methods for seismic Category I systems to withstand the effects of a safe shutdown earthquate (SSE) and to maintain the capability of performing their safety function will use the methods in accordance with SRP 3.7.3.

A. Describe the mathematical representation of a piping system, including the development of the mass, stiffness, and damping matrices in the analytical model, that will be used in the three methods of analysis (i.e., response spectrum, time history, and equivalent static load methods). Also, discuss the types of loading functions that will be used in each of these methods of analysis.

B. Confirm if these methods of analysis will be limited to an elastic basis. If not, discuss the application limits for these three methods.

C. Identify conditions or limits when each of these three methods of analysis will be used in obtaining the piping system responses.

D. Discuss the analysis methods that will be used in the design of non-seismic Category I (or seismic Category II) piping systems.

RAI EPR-5: Piping Analysis Methods

After constructing a mathematical model to reflect the static or dynamic characteristics of the piping system, describe the step by step computations (e.g., static analysis, modal analysis, modal participation factors) that may be performed to obtain the piping system response for each of the three methods of analysis (i.e., response spectrum, time history, and equivalent static load methods).

RAI EPR-6: Piping Analysis Criteria

A. SRP Section 3.9.2, Item II.2.A(i)(3) requires an investigation for a sufficient number of modes to be included in the piping modeling to ensure that all significant modes have participated in the analysis. Provide the criterion that would ensure this requirement.

B. The cutoff frequency for modal responses is defined as the frequency at which the spectral acceleration approximately returns to the zero period acceleration (ZPA) of the input response spectrum. Define this cutoff frequency qualitatively or quantitatively for seismic and other building dynamic loads (if any) applicable to the piping analysis for the EPR.

RAI EPR-7: Branch Pipe Inputs

When a small seismic Category I or non-seismic Category I piping is directly attached to seismic Category I piping, it can be decoupled from seismic Category I piping if it satisfies the decoupling criteria. However, the TR did not describe how the inputs for the small branch piping will be determined for both inertial and seismic anchor motion (SAM) response analyses when the piping system is decoupled from a large pipe run or connected to flexible equipment connections. The staff notes that computer code RESPECT (TR Section 5.1.8) generates seismic amplified response spectra at the branch nozzle locations in a model of a piping system. Describe the seismic analysis methods and procedures, including the input response spectra and input SAM displacements, that apply to the small branch piping design when decoupled from a large run pipe or connected to flexible equipment. The description should also discuss how any amplification effects and SAM effects, from the main run pipe at the attachment to the small branch pipe, are considered.

RAI EPR-8: Independent Support Motion Method

The current staff position for the Independent Support Motion (ISM) method of analysis is presented in Volume 4, Section 2 of NUREG-1061, "Report of the US NRC Piping Review Committee. "Some differences (e.g., modal combinations per RG 1.92 for uniform support motion (USM) only) were noted between the ISM method of response combinations (both methods and their sequence) presented in the TR Section 4.2.2.2.2, and the method given in NUREG-1061. Indicate whether all of the provisions (for groups, modes, spatial and inertial and SAM combination methods) contained in NUREG-1061 for the ISM method of analysis will be followed or provide the technical justification for any alternatives or methods described in the TR.

RAI EPR-9: Time History Analysis Using Modal Superposition Method

Since many of the dynamic loads specified in the TR, using the time history method of analysis, may have a short duration and contain very high frequency content, the use of the modal superposition method must consider all modes up to the appropriate cutoff frequency as well as the missing mass contribution. Discuss how the proposed modal superposition method will address these considerations in accordance with RG 1.92, Rev.2.

RAI EPR-10: Time Step for Time History Analysis

In a time history analysis, the numerical integration time step, Δt, must be sufficiently small to accurately define the dynamic excitation and to ensure stability and convergence of the solution up to the highest frequency of significance. In TR Section 4.2.3, AREVA indicates that for the most commonly used numerical integration methods, the maximum time step is limited to one-tenth of the shortest period of significance. However, this is typically selected for choosing an initial time step which is later checked against analysis results and their stability and convergence. An acceptable approach for selecting the time step, Δt, is that the Δt used shall be small enough such that the use of ½ of Δt does not change the response by more than 10%. Indicate whether this is part of the analysis requirements for time history method of analysis or provide a technical justification for not considering this criterion along with the criterion for initially choosing the time step described for seismic and other dynamic loading analyses.

RAI EPR-11: Time History Analysis Uncertainties

TR Section 4.2.3 states that to account for uncertainties in the structural analysis using the time history method, similar to peak shifting in the response spectrum method of analysis, three separate input time histories with modified time steps will be analyzed. Alternatively, the time histories at the attachment points may be derived considering variations in the concrete stiffness.

A. Describe the detailed procedure for using the peak shifting method that will be used in the time history method of analysis with modified time steps for seismic and other dynamic loadings.

B. Describe all of the dynamic loads for which the time history will be adjusted to account for material and/or modeling uncertainties and provide the basis for the amount of the adjustment.

C. Explain how the time histories at the attachment point derived considering variations in the concrete stiffness are alternate to the peak shifting method to be used in the time history method of analysis. Also, provide the percentage variations in the concrete stiffness to be used in the EPR piping design.

RAI EPR-12: Equivalent Static Load Analysis

Confirm that the equivalent static load is always determined by multiplying 1.5 to the peak acceleration for all cases including a single degree of freedom system with known fundamental frequency or a rigid system with the fundamental frequency beyond the cutoff frequency. If not, then provide the criterion that will be used for these special cases.

RAI EPR-13: Small Bore Piping

The TR did neither define nor address the design of small bore piping to be used in the EPR piping design. Define the small bore piping to be used in the EPR piping design and discuss, with technical bases, the methods of analysis (handbook or a system flexibility analysis) that will be used in the small bore piping design for ASME Class 1, 2, 3 and QG D piping.

RAI EPR-14: Non-Seismic/Seismic Interaction

A. TR Section 4.4.1 states that non-seismic piping which cannot be completely separated from seismic systems is routed as far away as possible. With examples, please discuss under what conditions this type of isolation is used in the EPR piping design and also, quantify the meaning of "as far away as possible."

B. TR Section 4.4.2 states that following the failure of the non-seismic pipe, (i) if the non-seismic piping is supported by seismic restraints within the ASME B31.1 Code-suggested pipe support spacing shown in TR Table 4-1, it is considered to lose its pressure boundary integrity, but not fall onto a safety-related piping or equipment. Provide the technical basis for this assumption. (ii) the side motion of a failed moderate energy piping is assumed to be ±6 inches (centerline to centerline) from the original position. Provide the technical basis for this assumption of ±6 inches side motion for all pipe sizes. (iii) safety-related piping with NPS and thickness equal to or greater than that of the non-seismic piping may be assumed to stop the downward motion of the non-seismic piping without failure of the safety-related piping. Provide the technical basis for this assumption.

RAI EPR-15: Buried Piping

TR Section 3.10 did not give details on the analysis method and how the criteria are to be applied in the design of buried piping.

A. Based on the criteria presented in the TR, describe the analysis method and design requirements that will be used for buried piping design (including buried pipe tunnel if used in the design). Explain how these methods compare to the analytical methods referenced in the recently published NRC Standard Review Plan 3.7.3, Rev. 3, (i.e., ASCE Standard 4-98, ASCE Report - Seismic Response of Buried Pipes and Structural Components, and NUREG/CR-1161).

B. Why doesn't TR Section 3.10 include consideration of ground-water effects and soil arching effects which could increase or decrease the stresses in the pipe due to the overlying soil plus the ground surface loads?

C. How is the assumption related to soil liquefaction and fault displacement, which is noted in TR Section 3.10, assured?

D. TR Table 3-4 provides the design conditions, load combinations and acceptance criteria for Class 2/3 buried piping. Explain clearly the term non-repeated anchor movement, Equation 9U (vs 9), and Equation 9E (vs 9). While the intent may be interpreted, it is important that these terms be clearly defined in the TR. For Equations 10M and 11M, which are identified as "modified to include axial friction forces," provide the equations to show how they are modified.

E. For the Faulted loading condition in TR Table 3-4, why isn't the load thermal anchor movement (TAM) included in the load combination, as it is in Table 3-2 for Class 2 & 3 Piping? Also, why is the stress criteria of $3S_h$ used rather than the minimum of 3.0 S_h and 2.0 S_y, as presented in Table 3-2?

F. Confirm that Note 5 in the TR Table is applicable to all cases cited in TR Table 3-4 since it is not referenced in the Table like the other notes are. Also, explain how the criteria of NC/ND-3133 of the ASME Code (Note 5 in the Table) will be implemented in conjunction with meeting the loads and loading conditions specified in Table 3-4.

RAI EPR-16: Computer Codes

TR Section 5.1 provides short descriptions of the major computer programs to be used in the analysis and design of safety-related piping systems. Piping related computer programs include SUPERPIPE, BWSPAN, BWHIST, BWSPEC, COMPAR2, CRAFT2, P91232, and RESPECT. AREVA states that SUPERPIPE has been thoroughly verified and validated to U.S. NRC standards. For all other computer codes, AREVA did not indicate if these programs are verified for their application by appropriate methods, such as hand calculations, or comparison with results from similar programs, experimental tests, or published literature, including analytical results or numerical results to the benchmark problems and validated as the piping program. Moreover, AREVA did not mention how the quality of these programs and computer results is controlled. To facilitate the staff review of the computer programs used in the EPR design, provide the following additional information:

A. Identify which computer programs will be used during the design certification phase.

B. Identify which programs have previously been reviewed by the NRC on prior plant license applications. Include the program name, version, and prior plant license application. As stated in SRP 3.9.1, this will eliminate the need for the licensee to resubmit, in a subsequent license application, the computer solutions to the test problems used for verification.

C. Confirm that the following information is available for staff review for each program: the author, source, dated version, and facility; a description, and the extent and limitation of the program application; and the computer solutions to the test problems described above.

RAI EPR-17: Inclusion of Support Mass

TR Section 5.2 describes a criterion for inclusion of support masses to the piping model mass at the support attachment location and states that a portion of the weight of the support is considered in the piping analysis and also, because the mass of a given support will not contribute to the piping response in the direction of the support, only the unsupported directions need to be considered.

A. Clarify under what conditions only a portion of the support weight would be considered.

B. Provide justification as to why the support mass would not contribute to the piping response in the direction of the support if the support is flexible (e.g., spring hangers).

RAI EPR-18: Piping Model Structural Boundaries

TR Sections 5.4.1.2 and 5.4.1.3 describe two alternate approaches of separating a piping analysis model using an elbow or a tee within the piping model. While these approaches may be technically sound, no references or technical justifications are provided for each of these methods. Provide technical justifications and limitations (if any) for these two methods of establishing piping model terminations. Also, discuss the basis for selecting the dimensions of L_1 and L_2 in TR Figure 5-1 for a restrained elbow and Figure 5-2 for a restrained tee.

RAI EPR-19: Piping Model Boundaries Using Model Isolations

TR Sections 5.4.3.1 and 5.4.3.2 describe two approaches of dividing a large piping analysis model using the overlap region or the influence zone method. While these approaches may be technically sound, no references or technical justifications are provided for each of these methods. Provide technical justifications and limitations (if any) for these two methods of isolating piping models. Also, discuss the basis for selecting the overlap region and the influence zone in TR Figure 5-3.

RAI EPR-20: Piping Benchmark Program

Final piping and pipe support stress analyses cannot be completed before design certification because their completion is dependent on as-built or as-procured information. Under a piping benchmark program, the combined operating license (COL) applicant applies his computer program to construct a series of selected piping system mathematical models that are representative of the standard plant piping designs. Please confirm if AREVA has established such a piping benchmark program to be used by the COL applicants and whether its own piping analysis computer code described in Section 5.1 was verified using models representative of the U.S. EPR.

RAI EPR-21: Model Decoupling Criteria

TR Section 5.4.2 states that adequate flexibility in the branch line is provided by maintaining a minimum length from the run pipe to the first restraint of ½ of the pipe span in TR Table 4-1 for the branch line. The mass to be considered at the branch connection of the run pipe is the mass of ½ of the first span of the branch pipe, including concentrated weights, in each direction. However, AREVA did not discuss other effects (e.g., moment or torsional load at the branch connection) of the eccentric concentrated masses, such as valves, in the first one-half span length from the main run pipe. Provide technical justification on how to account for the effect of a large concentrated mass near the branch connection in the decoupling criteria discussed in the TR.

RAI EPR-22: Dynamic Analysis of Branch Lines

TR Section 5.4.2 states that for the SSE inertia load case, each individual run pipe movement shall be analyzed as a separate anchor movement load case on the branch line and combined with its respective load case by absolute summation. Provide additional clarification to explain this procedure.

RAI EPR-23: Model Isolation and Analysis

A. TR Section 5.5 states that when the isolation methods discussed in TR Section 5.4.3 are used, isolation of dynamic effects is provided by three (3) seismic restraints in each of the three orthogonal directions beyond the seismic Category I design boundary. However, TR Section 5.4.3.1 states that as a minimum, four (4) such restraints in each orthogonal direction in the overlap region are required for the same isolation method. Explain this discrepancy.

B. TR Section 5.5 states that for loads resulting from the potential failure of the non-seismic piping and pipe supports, three separate analyses are performed by applying a plastic moment in each of three orthogonal directions at the termination of the model and then the results of these three analyses are enveloped. Please clarify how these loads are calculated and how the results from the three analyses are combined with the results of the dynamic analysis of the seismic Category I piping.

RAI EPR-24: Transient Loads

Provide the list of transients and the number of events associated with each of these transients during a life span of 60 years that will be part of the design requirements of ASME Code Class piping and pipe supports. If such a list is not developed at this stage of the design certification, then include this in the DCD or include as one of the COL-Action Items listed in TR Table 1-1.

RAI EPR-25: Piping Load Combinations

The staff needs clarification of several items associated with TR Section 3.3 and Tables 3-1 and 3-2.

A. In TR Section 3.3.1.7, it is stated that pipe breaks in the RCL, main steam and pressurizer surge lines which meet the leak-before-break (LBB) size criteria are eliminated from the consideration based on LBB analysis. However, the impact of smaller attached lines and other lines outside the LBB analyzed zone will be considered. Per SECY 93-087, the staff has approved the LBB approach on a case-by-case basis for austenitic stainless steel and carbon steel with stainless steel clad piping inside the primary containment and pipe size of at least 6-inch NPS. Based on this document, appropriate bounding limits are to be established using preliminary analysis results during the design certification phase and verified during the COL phase by performing the appropriate ITAAC discussed in it. Discuss the technical basis for exclusion of pipe break analysis for the above three lines, with the LBB criteria to be used for the EPR piping design.

B. Note 3 to TR Table 3-1 states that dynamic loads are to be combined considering timing and causal relationships. SSE and Design Basis Pipe Break (including loss-of-coolant accident (LOCA)) shall be combined using the square root of the sum of the squares (SRSS) method. This is acceptable in accordance to NUREG-0484, Rev. 1. However, for dynamic responses resulting from the same initiating events (other than SSE), when time-phase relationship between the responses cannot be established, the absolute summation of these dynamic responses should be used. Confirm if this is true for the EPR piping design. If not, discuss with technical justification the combination method to be used when multiple LOCA or other dynamic load events are required to be combined. This combination criterion is also applicable to note 5 of the TR Table 3-2, which states that dynamic loads are combined by the SRSS.

C. Note 8 to TR Table 3-1 states that the earthquake inertial load used in the Level D Primary Stress (Equation 9F) calculations shall be taken as the peak SSE inertial load. The earthquake anchor motion load used in the Level D Primary Stress (Equation 9F) calculations shall be taken as the peak SSE anchor motion load. The staff position on the use of a single-earthquake design in SECY-93-087 states that the effects of anchor displacements in the piping caused by an SSE be considered with the Service Level D limits. For simplified elastic-plastic discontinuity analysis, if Eq. 10 cannot be satisfied for all pairs of load sets, then the alternative analysis per NB-3653.6 for Service Level D should be followed. In addition, the combined moment range for either the resultant thermal expansion and thermal anchor movements plus ½ the SSE seismic anchor motion or the resultant moment due to the full SSE anchor motion alone, whichever is greater must satisfy the equation (known as Eq. 12a) given in NB-3656(b)(4). Clarify if this is applicable to EPR piping design. Also, justify why this anchor motion stress is categorized as a primary stress in the TR Table 3-1 for the faulted condition.

D. Identify the applicability of notes 3 and 5 in the TR Table 3-2.

E. Explain why equation 11a under NC/ND-3653.2 is not included in the TR Table. Are there any dynamic loads other than the SSE (e.g., building response due to hydrodynamic loads such as SRV actuation) that can occur?

<u>RAI EPR-26:</u> Piping Damping Values

In TR Section 4.2.5, it is identified that Rev. 0 of the RG 1.61 values of damping will be used in the seismic analysis of structures, systems, and components (SSCs) using ISM response spectrum analysis or time history analysis. However, for piping systems analyzed using USM response spectrum analysis, 5% damping will be used provided that the system is not susceptible to stress corrosion cracking. Five percent damping will not be used for analyzing the dynamic response of piping systems using supports designed to dissipate energy by yielding.

A. Since staff has issued the Rev.1 of RG 1.61 in March 2007, indicate if the design of EPR piping systems will use Rev. 1 of the RG-recommended damping values.

B. For piping systems analyzed using uniform support motion response spectrum analysis and 5% damping, verify that all of the limitations specified in RG 1.84 for ASME Code Case N-411 (or RG 1.61, Rev.1) will be met.

C. Also, discuss what damping values will be used for cases when the system is susceptible to SCC and when using supports designed to dissipate energy by yielding.

<u>RAI EPR-27:</u> Modal Combinations

In TR Section 4.2.2.3.1, it is stated that for the response spectrum method of analysis, the modal contributions to the inertial responses are normally combined by the SRSS method. If some or all of the modes are closely spaced, any one of the methods (Grouping method, 10% method, and Double Sum method, as well as the less conservative methods in revision 2 of the RG 1.92) is applicable for the combination of modal responses. This combination method is applicable to both USM and ISM methods of analysis.

A. If guidance given in Revision 2 of the RG 1.92 is used for the EPR piping design, then Revision 2 of the RG no longer recognizes the Grouping method, 10% method and Double Sum method for closely spaced modes. These methods are renamed and AREVA should identify them as noted in the RG.

B. TR states that for closely spaced modes AREVA may use less conservative methods discussed in the RG. Please identify which methods are less conservative methods and explain why they are less conservative with respect to the other method(s).

RAI EPR-28: Missing Mass

TR Section 4.2.2.3.2 presents a procedure to account for high-frequency modes in the response spectrum methods for calculating seismic and other dynamic load responses.

A. Discuss the differences in the mathematical derivations of the high frequency modes presented in the TR versus the methods acceptable to the staff as given in RG 1.92, Rev. 2.

B. The TR states that the response from high frequency modes will be included in the response of the piping system if it results in an increase in the dynamic results of more than 10%. However, in accordance with RG 1.92, Rev.2, C.1.4.1, this criterion may yield non-conservative results and should not be used. Since this guideline does not consider the total mass that is missing, which, in the limit, could be 10%, provide technical justification for using this criteria as a screening requirement for including the effects of any missing mass.

C. The TR also states that peak modal responses of the system at frequencies above the ZPA are considered to be in phase. Thus, the responses of all high frequency modes are combined by absolute summation. Explain if the peak modal responses are in phase, then why the absolute sum method is recommended for the EPR piping design.

D. Finally, the TR states that this missing mass mode is considered to have a modal frequency and acceleration equal to the cut-off frequency used in the modal analysis. These modal results are combined with the low frequency modal results using the methods described in TR Section 4.2.2.3.1 for the low frequency modes (per RG 1.92). Please explain the combination method for the results to be used from both low and high frequency modes.

RAI EPR-29: Nonlinear Vibrations Due to Support Gaps

The TR does not provide an analytical method to account for nonlinear effects of excessively large gaps (for frame type supports) between the pipe and supports subject to high frequency vibration loads. Should such large gaps exist, provide the piping analysis method to be used to address the nonlinearity when subjected to vibratory loads with significant high-frequency caused by the gaps between the pipe and its supports.

RAI EPR-30: Thermal Stratification

A. TR Section 3.7.1 states that the main feedwater nozzle is located in the conical section of the steam generator which aids in reducing thermal stratification. Please explain how this reduces thermal stratification.

B. TR Section 3.7.2 states that the surge line may not be subjected to significant stratification/striping effects due to design features that mitigate these effects. Describe these design features and explain how they mitigate the effects of thermal stratification in the surge line.

RAI EPR-31: Safety Relief Valve

Describe the SRV design parameters and criteria that will need to be specified to the COL applicant to ensure that the specific piping configuration and safety relief valves (SRVs) purchased and installed at the COL applicant stage will match the test and design parameters used at the design certification stage. An example is the minimum rise time for the SRV valve operation; this can greatly affect the transient loads imposed on the piping system analysis. Also, any change in the discharge piping system configuration may affect the SRV loadings.

RAI EPR-32: Composite Damping

The composite modal damping ratio can be used when the modal superposition method of analysis (either time history or response spectrum) is used, as described in SRP Section 3.7.2, II.13. If AREVA plans to use composite modal damping for U.S. EPR piping design, provide a description of the methods for determining the composite modal damping value.

RAI EPR-33: Codes for Support Design

A. TR Section 6.1 states that for Service Levels A, B and C, the seismic Category I pipe supports will be designed in accordance with Subsection NF of the ASME Code and for Service Level D, Appendix F of Section III of the ASME Code will be utilized. However, TR Section 6.2 states that all piping supports designed in accordance with the rules of Subsection NF of the Code up to the building structure interface are defined by the jurisdictional boundaries in Subsection NF-1130 of the ASME Codes. (i) Since Appendix F of the Section III provides only the Service Level D limits for evaluation of loading [per Code Table NF-3523(b)-1 for stress limit factors] for Class 1, 2, 3 and MC type supports, clarify if the seismic Category I pipe supports will be designed to ASME Subsection NF for all four Service Level A, B, C and D loads, while using the acceptance stress limits by the Appendix F for Service Level D supports. (ii) Also, clarify if the Subsection NF will be used to manufacture, install and test all seismic Category I pipe supports. If not, which other standard will be used.

B. AREVA also states that seismic Category II pipe supports are designed to ANSI/AISC N690, "Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities." These standards are used to design the structures or structural elements of a support for nuclear facilities, not the standard component supports (e.g., clamps, snubbers). ASME Code Subsection NF is typically used for seismic Category II pipe supports. Identify the standard that will be used to design, manufacture, install and test seismic Category II pipe supports.

C. AREVA states that non-seismic category pipe supports are designed using guidance from the AISC Manual of Steel Construction. This manual is used to design steel constructions in frame type or other structural element of component supports. Based on TR Section 6.2, ASME Code B31.1 is being used for a certain class of piping (also see request for additional information (RAI) EPR-2). The design of all supports for the non-nuclear piping (that typically uses B31.1 for piping analysis) should satisfy the requirements of ASME/ANSI B31.1 Power Piping Code, Paragraph 120 for loads on pipe supporting elements and Paragraph 121 for design of pipe supporting elements. Clarify if this is applicable to U.S. EPR pipe support design, otherwise explain how the AISC manual will be used to design component supports (e.g., clamps, springs).

RAI EPR-34: Load Combination for Supports

While reviewing TR Section 6.3, the staff needs clarification of the following items.

A. TR Section 6.3.11 provided a minimum design load criteria that will be used for all supports so that uniformity is obtained in the load carrying capability of the supports. All supports will be designed for the largest of the following three loads: 100% of the Level A condition load, the weight of a standard ASME B31.1 span of water filled, schedule 80 pipe, and minimum value of 150 pounds. Provide the technical basis for this criteria.

B. TR Table 6-1 provides the specific load combinations that will be used in the design of pipe supports. The acceptance criteria associated with the Service Levels will be per ASME Code, Subsection NF, ANSI/AISC N690 or the AISC Manual of Steel Construction, as appropriate. Note 1 to the Table states that operating basis earthquake (OBE) inertia and SAM loads are not included in the design of Class 2/3 piping. Explain how the seismic inertia and SAM loads are accounted for in the design of Class 2/3 pipe supports. Also, clarify how the same table is applicable to snubbers, struts, and anchors/guides.

C. AREVA discusses wind/tornado loads in TR Sections 6.3.5 and 6.3.6 for pipe supports. However, for the piping in TR Section 3.3.1.6, AREVA identified these loads to be COL-Action Item 3. Clarify AREVA's position on this.

RAI EPR-35: Snubber Design

AREVA, in TR Section 6.6, states that design specifications are to be provided to the snubber suppliers and the installation and operation of snubbers will be verified by the COL applicant. For design certification, SRP Section 3.9.3 requires that design, installation, operation and testing of the snubbers should be included in the design document. Clarify, whether AREVA intends to include all design-related specifications associated with snubbers in the TR or in the DCD.

RAI EPR-36: Support Stiffness

AREVA does not adequately describe in TR Section 6.7 how the representative stiffness values are developed for all supports other than snubbers. Describe:

1. the approach used to develop the representative stiffness values,

2. the procedure that will be imposed to ensure that the final designed supports match the stiffness values assumed in the piping analysis,

3. the procedure used to consider the mass (along with the support stiffness) if the pipe support is not dynamically rigid, and

4. the same information [(1), (2), and (3) above] for the building steel/structure (i.e., beyond the NF jurisdictional boundary) and for equipment to which the piping may be connected to.

RAI EPR-37: Inclusion of Support Self-Weight Excitation

In TR Section 6.8, AREVA did not indicate if the criteria presented is also applicable to other dynamic loads and did not discuss how the damping value will be used in the response spectrum analysis.

A. Clarify whether the criterion presented in the TR is also applicable to other dynamic loads. If not, provide technical justification.

B. Since the piping and support structure damping value may be different per RG 1.61, discuss what damping value will be used in the response spectrum analysis when the support structure is also modeled as part of the piping analysis. See also RAI EPR-32.

RAI EPR-38: Instrument Line Support Design

TR Section 6.12 states that the applicable loading combinations for instrumentation lines will follow those used for normal and faulted levels in TR Table 6-1. Please explain why the load combinations for upset and emergency levels in TR Table 6-1 are not applicable to instrumentation line supports.

RAI EPR-39: Pipe Deflection Limits

In TR Section 6.13, AREVA provided examples of the limitations which include 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 will be made in the initial designs for tolerances on such limits. Please specify the actual allowable limits that are applicable to EPR support design for pipe deflection limits.

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AREVA

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U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Response to a Request for Additional Information Regarding ANP-10264NP "U.S. EPR Piping Analysis and Pipe Support Design" (TAC No. MD3128)

Ref. 1: Letter, Ronnie L. Gardner (AREVA NP Inc.) to Document Control Desk (NRC), "Request for Review and Approval of ANP-10264(NP) Revision 0, 'U.S. EPR Piping Analysis and Pipe Support Design'," NRC:06:040, September 29, 2006.

Ref. 2: Letter, Getachew Tesfaye (NRC) to Ronnie L. Gardner (AREVA NP Inc.), "Request for Additional Information Regarding ANP-10264NP, 'U.S. EPR Piping Analysis and Pipe Support Design' Topical Report (TAC No. MD3128)," June 13, 2007.

Ref. 3: Letter, Getachew Tesfaye (NRC) to Ronnie L. Gardner (AREVA NP Inc.), "Acceptance for Review of 'U.S. EPR Piping Analysis and Pipe Support Design' Topical Report (TAC No. MD3128)," December 14, 2006.

Ref. 4: Letter, Getachew Tesfaye (NRC) to Ronnie L. Gardner (AREVA NP Inc.), "Supplement to the Acceptance Review of 'U.S. EPR Piping Analysis and Pipe Support Design' Topical Report (TAC No. MD3128)," April 5, 2007.

AREVA NP Inc. (AREVA NP) requested the NRC's review and approval of the topical report ANP-10264(NP) Revision 0 in Reference 1. The NRC provided a Request for Additional Information (RAI) regarding this topical report in Reference 2. The response to this RAI is enclosed with this letter, ANP-10264Q1, "Response to Request for Additional Information ANP-10264(NP), U.S. EPR Piping Analysis and Pipe Support Design."

The RAI response as provided on the enclosed CD does not contain any information that AREVA NP considers to be proprietary.

AREVA NP plans to reference the topical report ANP-10264(NP) in its Design Control Document (DCD) for the U.S. EPR. Reference 4 states that the NRC plans to complete its review of the topical report and issue the draft safety evaluation by November 30, 2007.

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AREVA NP understands that this timely response to the RAI supports the scheduled deliverable of the draft safety evaluation.

If you have any questions related to this submittal, please contact Ms. Sandra M. Sloan, Regulatory Affairs Manager for New Plants Deployment. She may be reached by telephone at 434-832-2369 or by e-mail at sandra.sloan@areva.com.

Sincerely,

Ronnie L. Gardner, Manager
Site Operations and Regulatory Affairs
AREVA NP Inc.

Enclosures

cc: L. Burkhart
G. Tesfaye
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Response to Request for Additional Information – ANP-10264NP
"U.S. EPR Piping Analysis and Pipe Support Design Topical Report"
(TAC No. MD3128)

RAI EPR-1: *Piping and Pipe Support Design - General*

Section 1.0 of the Topical Report (TR) states that the reactor coolant loop (RCL) and pressurizer surge line piping requirements, modeling techniques, analysis approaches and acceptance criteria are not specifically addressed in this document and will be included in the design control document (DCD). The TR presents nearly all of the design certification requirements, acceptance criteria, analysis methods and modeling techniques for the American Society for Engineers (ASME) Class 1, 2 and 3 piping and pipe supports, as required in the Standard Review Plan (SRP) Section 3.12 for new reactors. Describe any significant differences between the requirements, techniques, approaches and design criteria for the RCL and pressurizer surge line piping, and those included in the TR.

Response 1:

Reactor Coolant System large bore piping requirements, modeling techniques, analysis approaches and acceptance criteria are not specifically addressed in the TR because of the major differences in mathematical modeling and model loading approaches and techniques that exist between the RCL structural analysis and Class 1 piping analysis. The RCL loop structural model includes representation of the nuclear island basemat and the Interior Concrete Structure (ICS), to which the RCL supports are attached, as well as very detailed representations of the primary components and their internals. In addition, in most cases, the RCL supports are explicitly represented in the model. Class 1 piping models do not include representations of the supporting concrete structures or detailed representations of components, and the supports are not typically explicitly modeled. The method of seismic loading is also quite different, with the RCL loop structural model being loaded through application of basemat excitation to the base of the ICS, whereas Class 1 piping models are loaded through the application of attachment point response spectra (or time histories), floor response spectra (or time histories) and seismic anchor motions at the various support locations in the model. Other aspects of RCL structural analysis are the same as those described for Class 1 piping in this TR, aspects such as damping requirements, load combinations, mass distribution requirements, cut-off frequency requirements, and applicable ASME stress and fatigue allowables. A thorough description of the approaches and methods employed in the structural, stress and fatigue analysis of the RCL piping will be included in Chapter 3 of the U.S. EPR Design Control Document.

RAI EPR-2: *ASME B31.1 and Section XI Codes*

A. *In accordance with RG 1.26, Quality Group (QG) D piping that may contain radioactive material is considered to be outside the ASME Code Class 1, 2, and 3 piping systems. The Regulatory Guide (RG) recommends that these piping and pipe supports are to be designed in accordance with the requirements of the ASME B31.1, "Power Piping" Code. Please clarify if the Evolutionary Power Reactor (EPR) piping and pipe supports will have QG D systems; and confirm that whether EPR piping design will use the ASME*

B31.1 Code for these systems, otherwise provide technical justification for using other than the B31.1 Code requirements for the QG D piping systems.

B. Confirm that ASME Code Section XI requirements will be used in the piping and pipe support design for EPR.

Response 2:

A. The U.S. EPR piping systems containing radioactive material (outside the Reactor Coolant Pressure Boundary) are classified as Quality Group D and are designed to ASME B31.1, 2004.

Section 1.0 and 2.1 of the TR will be revised to include the following text:

> "Quality Group D piping will be analyzed to ASME B31.1, 2004 Edition, no addenda."

B. The U.S. EPR adheres to the requirements of the ASME XI, 2004 Edition, no addenda. No Section XI code cases are used for the U.S. EPR.

RAI EPR-3: *10CFR50.55a(b) Limitations and Modifications*

Section 2.1 of the TR states that for the dynamic loads, including seismic loads, the pipe stress analyses will be performed in accordance with the Sub-articles NB/NC/ND-3650 of the 1993 Addenda of the ASME Code as required by 10CFR50.55a(b)(1)(iii). However, AREVA did not address other limitations and modifications (related to Section III materials, weld leg dimensions, etc.) applicable to piping system design as included in 10CFR50.55a(b)(1). Explain how all limitations and modifications specified in 10CFR50.55a(b) will be satisfied.

Response 3:

The limitations of 10CFR50.55a(b)(1) are considered in the U.S. EPR design as follows:

- (b)(1)(i) Section III "Materials" – This is not considered for the U.S. EPR because it addresses the application of 1992 Edition of ASME. The U.S. EPR uses a later version of the code.
- (b)(1)(ii), "Weld leg dimensions" is incorporated into the U.S. EPR design.
- (b)(1)(iv) "Quality Assurance" – U.S. EPR Quality Assurance program is developed for a later edition of the code. This restriction does not apply to the U.S. EPR.
- (b)(1)(v) – Independence of Inspection – The inspection program for the U.S. EPR will not apply NCA-4134.10(a).

- (b)(1)(vi) Subsection NH – The U.S. EPR will not use Type 316 stainless pressurizer heater sleeves above a service temperature of 900°F.

For clarity, Section 2.1 of the TR will be revised to include the following text:

> "Piping analysis and pipe support design for the U.S. EPR addressed in this Topical Report use the 2001 ASME Code, Section III, Division 1, 2003 addenda as the base code with limitations identified in the Code of Federal Regulations, 10 CFR 50.55a(b)(1)(ii) "*Weld leg" and (iii)" Seismic" and* "All other limitations of 10CFR50.55a(b)(1) do not apply to the U.S. EPR."

<u>RAI EPR-4:</u> *Mathematical Modeling*

TR Section 4.2 states that the seismic analysis methods for seismic Category I systems to withstand the effects of a safe shutdown earthquake (SSE) and to maintain the capability of performing their safety function will use the methods in accordance with SRP 3.7.3.

A. Describe the mathematical representation of a piping system, including the development of the mass, stiffness, and damping matrices in the analytical model, that will be used in the three methods of analysis (i.e., response spectrum, time history, and equivalent static load methods). Also, discuss the types of loading functions that will be used in each of these methods of analysis.

B. Confirm if these methods of analysis will be limited to an elastic basis. If not, discuss the application limits for these three methods.

C. Identify conditions or limits when each of these three methods of analysis will be used in obtaining the piping system responses.

D. Discuss the analysis methods that will be used in the design of non-seismic Category I (or seismic Category II) piping systems.

Response 4:

A. A description of the mathematical modeling techniques is presented in TR Section 5.2. A section cross reference will be added to Section 4.2.

Section 4.2 will be revised to incorporate the following text:

> "The seismic response of a piping system is determined by developing a mathematical model of the system suitable for calculating the response of the system to the seismic input. Dynamic equilibrium equations are formulated for the system using the direct stiffness method. In this method, the element stiffness matrices are formed according to virtual work principles and assembled to form a global stiffness matrix for the system relating external forces and moments to nodal displacements and rotations. Details on the dynamic piping model can be found in Section 5.2.

Once the mathematical model has been established, dynamic equilibrium equations are solved to determine the seismic response of the system by performing either a modal analysis by either the Response Spectrum Method or Time History Method. Alternatively, the Direct Integration Time History Method and, where applicable, the Equivalent Static Load Method may be used."

B. The modeling techniques in TR Section 5.2 are used for elastic analysis.

C. Factors considered when choosing the analysis method to be used for a given piping configuration include complexity of the system, type of loads to be included in the analysis, class of piping (ASME 1,2, 3 or non-seismic) and analysis tools available. In general, for seismic load cases, response spectra (RS) and time history (TH) will produce similar results with TH producing acceptable results that are not as conservative as RS. Class 1 piping analysis which requires considerably more detail may be analyzed by TH methods although RS will yield acceptable results. Time history is also used when transient loads due to pipe break, water hammer or other dynamic events are anticipated and static analysis produces a high level of conservatism. Class 2/3 and non seismic piping analysis is generally analyzed using RS methods. Equivalent static analysis can only be used on Class 2/3 and non seismic piping 2 NPS and smaller where the piping configuration can be reduced to simple models.

D. Non-seismic piping that interacts with seismic systems will be analyzed by RS or equivalent static methods.

RAI EPR-5: *Piping Analysis Methods*

After constructing a mathematical model to reflect the static or dynamic characteristics of the piping system, describe the step by step computations (e.g., static analysis, modal analysis, modal participation factors) that may be performed to obtain the piping system response for each of the three methods of analysis (i.e., response spectrum, time history, and equivalent static load methods).

Response 5:

Section 4.2.2 will be revised to include the step by step computations for response spectra analysis. Section 4.2.2 will be revised as provided in Attachment A to this document.

Section 4.2.3 will be revised as follows to address the computations when Time History Analysis is employed:

"The modal superposition method of time history analysis is used for seismic piping analyses with acceleration time history seismic input. This method is based on decoupling of the differential equations of motion, considering a linear elastic system, using the same method as that described in Section 4.2.2."

"The Direct Integration Time History Analysis method may be used as an alternative to the modal superposition time history analysis. In this method the differential equation of motion, as provided in Section 4.2.2, is solved directly on the uncoupled equations without transformation. Rayleigh damping, or mass and stiffness damping, is used when direct integration time history analysis is performed."

Section 4.2.4 will be revised to include the following:

"For cases where piping configurations are calculated as single degree of freedom systems with known fundamental frequencies or rigid systems with fundamental frequencies beyond the cutoff frequency, a factor of 1.0 may be used with the spectral accelerations at that frequency. Mathematically the seismic force F_1 on a mass point in one (1) direction is represented as:

$$F_1 = kmS_a$$

Where:

k	=	1.0 for single degree of freedom or rigid system
		1.5 for multiple degree of freedom system
m	=	mass in direction 1
S_a	=	value of acceleration from response spectrum

The forces from each of the three orthogonal directions of earthquake are applied to calculate seismic stresses and then combined by SRSS to calculate overall seismic stresses."

<u>RAI EPR-6:</u> *Piping Analysis Criteria*

A. SRP Section 3.9.2, Item II.2.A(i)(3) requires an investigation for a sufficient number of modes to be included in the piping modeling to ensure that all significant modes have participated in the analysis. Provide the criterion that would ensure this requirement.

B. The cutoff frequency for modal responses is defined as the frequency at which the spectral acceleration approximately returns to the zero period acceleration (ZPA) of the input response spectrum. Define this cutoff frequency qualitatively or quantitatively for seismic and other building dynamic loads (if any) applicable to the piping analysis for the EPR.

Response 6:

A. The criterion for the inclusion of sufficient number of modes stated in SRP 3.9.2 II A(i)(3) is that the "inclusion of additional modes does not result in more than a 10-percent increase in responses." All modes with frequencies below the ZPA frequency are included in the piping analysis. Above this frequency, in the rigid range, the effects of all additional modes are included by the application of the missing mass correction as discussed in TR Sections 4.2.2.3.2 and 4.2.3.

B. The cutoff frequency for a given spectra is the frequency at which the response curves for all damping values converge to the same acceleration value (ZPA) and remain at this value for all frequencies above this cutoff frequency. Section 4.2.2.3 will be revised to add, "For the U.S. EPR the cutoff frequency is 50 hertz or as defined by figure 2 and 3 in RG 1.92, Rev 2."

RAI EPR-7: *Branch Pipe Inputs*

When a small seismic Category I or non-seismic Category I piping is directly attached to seismic Category I piping, it can be decoupled from seismic Category I piping if it satisfies the decoupling criteria. However, the TR did not describe how the inputs for the small branch piping will be determined for both inertial and seismic anchor motion (SAM) response analyses when the piping system is decoupled from a large pipe run or connected to flexible equipment connections. The staff notes that computer code RESPECT (TR Section 5.1.8) generates seismic amplified response spectra at the branch nozzle locations in a model of a piping system. Describe the seismic analysis methods and procedures, including the input response spectra and input SAM displacements, that apply to the small branch piping design when decoupled from a large run pipe or connected to flexible equipment. The description should also discuss how any amplification effects and SAM effects, from the main run pipe at the attachment to the small branch pipe, are considered.

Response 7:

The model of a decoupled Class 1 branch line includes an anchor where the branch line connects to the RCL. The seismic inertial analysis of the RCL yields time histories at branch connections and equipment nozzles. The inertial seismic analysis results then become input into the Class 1 branch line seismic analysis in the form of time histories or response spectra which are generated from the time histories using classical response spectra generation techniques. If response spectra are used, they are peak broadened by ±15% in accordance with RG 1.60 R1 before application to the Class 1 branch line model. The analysis of the Class 1 branch line also considers seismic movements generated from the RCL (seismic anchor motions), which are applied as static displacements at the branch-to-RCL anchor. This analysis captures the effects of run pipe amplification on the branch pipe.

For the remaining decoupled branch lines (not connected to the RCL), the model of a decoupled branch line includes an anchor at the run to branch intersection. The analysis of the branch line includes all anchor movements greater than 1/16" from the run pipe applied at the run to branch anchor for all load cases. The inertial seismic input for the branch line comes from the appropriately applied building and/or flexible equipment spectra based on support configurations and the inertial movements from the run pipe. The decoupling criterion stated in the TR assures that the run pipe is rigid compared to the branch pipe and no amplification effects are considered.

The last paragraph of Section 5.4.2 will be changed to the following:

> "The branch pipe analysis must include more consideration for the effects of the run piping. The branch point is considered as an anchor in the analysis of the branch pipe with the same SIF and/or stress indices as the run pipe at this point. The movements (displacements and rotations) of the run pipe at the branch intersection due to statically applied loads in the run pipe analysis (such as thermal and seismic anchor movement (SAM)) shall be applied as anchor movements with their respective load cases in the

branch line analysis. The inertial effects of the run pipe on the branch line are considered in one of the following methods:

- For branch lines decoupled from the RCL, the inertial input to the branch line is generated from the analysis of the RCL. The analysis of the RCL yields time history responses at the branch connections and equipment nozzles. This time history response of the RCL, or a response spectrum generated from the time history response, is then applied as the input inertial excitation at the branch-to-RCL intersection. This method may also be used for decoupling pipe from flexible equipment if the response of the equipment is known.
- For other decoupled lines, the effects of inertial loads from the run pipe on the branch line are captured through the proper application of the building excitation and the inertial movements from the run pipe analysis. At the branch-to-run pipe anchor, the applied inertial excitation to be included in the branch line analysis shall include the envelope of building excitations for the nearest supports on both the branch and run pipes. The inertial movements of the run pipe at the branch intersection are obtained from the run pipe analysis. These movements are statically applied, in individual load cases for each direction, at the branch-to-run pipe anchor. The results of these statically applied load cases are combined by the square root sum of squares (SRSS) to capture the effects of the inertial movement of the run pipe on the branch line. These results are then combined with the inertial analysis of the branch line by absolute summation to obtain the total inertial response."

RAI EPR-8: *Independent Support Motion Method*

The current staff position for the Independent Support Motion (ISM) method of analysis is presented in Volume 4, Section 2 of NUREG-1061, "Report of the US NRC Piping Review Committee. "Some differences (e.g., modal combinations per RG 1.92 for uniform support motion (USM) only) were noted between the ISM method of response combinations (both methods and their sequence) presented in the TR Section 4.2.2.2.2, and the method given in NUREG-1061. Indicate whether all of the provisions (for groups, modes, spatial and inertial and SAM combination methods) contained in NUREG-1061 for the ISM method of analysis will be followed or provide the technical justification for any alternatives or methods described in the TR.

Response 8:

The provisions of NUREG-1061 for the ISM method of analysis will be followed. Specifically, level (group) results will first be combined using the absolute summation method. This will be followed by modal combinations by SRSS (without consideration of closely spaced modes) and directional (spatial) result combinations by SRSS. If Inertia and SAM results are combined for stresses, they will be combined using the SRSS method when using ISM.

The following revisions to the TR will be made for clarification:

Section 4.2.2.2.2 will be revised to include a reference to NUREG-1061, Volume 4 as follows:

> "When using independent support motion, the seismic response of each mode is calculated by combining the responses of all support groups into one by using absolute summation method per the recommendations of NUREG-1061, Volume 4."

Section 4.2.2.3.1 will be revised to add the text "performed using USM" as follows:

> "RG 1.92 provides guidance on combining the individual modal results due to each response spectrum in a dynamic analysis *performed using USM"* (emphasis added).
>
> and add the following text:
>
> "For piping systems analyzed using ISM methods, modal results are combined without the consideration of closely spaced modes, per NUREG-1061. Therefore, for these systems, modal results are combined by the SRSS method presented above."

Section 4.2.2.5 will be revised to read as follows:

> "The analysis of these seismic anchor motions (SAM) will be performed as a static analysis with all dynamic supports active. The results of this analysis shall be combined with the piping system seismic inertia analysis results by absolute summation when an enveloped uniform support motion is used for the dynamic analysis, per SRP 3.7.3. When independent support motion is used in the inertial analysis, the responses due to the relative displacements and those due to inertia are combined by the SRSS method, per NUREG-1061."

RAI EPR-9: *Time History Analysis Using Modal Superposition Method*

Since many of the dynamic loads specified in the TR, using the time history method of analysis, may have a short duration and contain very high frequency content, the use of the modal superposition method must consider all modes up to the appropriate cutoff frequency as well as the missing mass contribution. Discuss how the proposed modal superposition method will address these considerations in accordance with RG 1.92, Rev.2.

Response 9:

Missing mass will be accounted for in time history modal superposition analyses in accordance with Appendix A of RG 1.92, Rev. 2.

The TR Section 4.2.3 will be revised to address this RAI as follows:

> "The mode shapes and frequencies are determined as they are in response spectrum analysis. The cutoff frequency for the determination of modal properties is 50 Hz, as this is expected to encompass all of the important response frequencies of the system. Missing mass effects of the high frequency modes beyond the cutoff frequency are included via the Missing Mass Method described in Regulatory Position C.1.4.1 and Appendix A of RG 1.92, Rev. 2."

RAI EPR-10: *Time Step for Time History Analysis*

In a time history analysis, the numerical integration time step, Δt, must be sufficiently small to accurately define the dynamic excitation and to ensure stability and convergence of the solution up to the highest frequency of significance. In TR Section 4.2.3, AREVA indicates that for the most commonly used numerical integration methods, the maximum time step is limited to one-tenth of the shortest period of significance. However, this is typically selected for choosing an initial time step which is later checked against analysis results and their stability and convergence. An acceptable approach for selecting the time step, Δt, is that the Δt used shall be small enough such that the use of ½ of Δt does not change the response by more than 10%. Indicate whether this is part of the analysis requirements for time history method of analysis or provide a technical justification for not considering this criterion along with the criterion for initially choosing the time step described for seismic and other dynamic loading analyses.

Response 10:

The integration time step used in time history analyses will be taken as 1/50 (or smaller) of the shortest period of importance or a time step study will be performed.

The TR Section 4.2.3 will be revised to incorporate the responses to this RAI as follows:

> "The integration time step used in time history analyses will be 1/50 (or smaller) of the shortest period of importance for the system in question. Alternatively, the initial integration time step will be set to no larger than one-tenth (1/10) of the cut-off frequency and a time step study will be performed: the integration time step will be halved until it can be shown that halving it further will not increase the response of the system by more than 10%."

RAI EPR-11: *Time History Analysis Uncertainties*

TR Section 4.2.3 states that to account for uncertainties in the structural analysis using the time history method, similar to peak shifting in the response spectrum method of analysis, three separate input time histories with modified time steps will be analyzed. Alternatively, the time histories at the attachment points may be derived considering variations in the concrete stiffness.

A. Describe the detailed procedure for using the peak shifting method that will be used in the time history method of analysis with modified time steps for seismic and other dynamic loadings.

B. Describe all of the dynamic loads for which the time history will be adjusted to account for material and/or modeling uncertainties and provide the basis for the amount of the adjustment.

C. Explain how the time histories at the attachment point derived considering variations in the concrete stiffness are alternate to the peak shifting method to be used in the time *history method of analysis. Also, provide the percentage variations in the concrete stiffness to be used in the EPR piping design.*

Response 11:

A. The method of accounting for uncertainties in time history analysis will be further described in the TR, as indicated below.

B. Topical Report will be revised to clarify that methods used to account for uncertainties will only be used in seismic analysis as the intent is to approximate the effect of the application of peak broadened spectra in a response spectrum analysis. The time step compression/expansion approach to account for uncertainties will be clarified and equated to the peak shifting method used in response spectrum analysis as described in TR Section 4.2.2.1.2.

C. The approach of considering variations in concrete stiffness to account for uncertainties in seismic time history analysis will be removed from the TR.

The fifth paragraph of TR Section 4.2.3 will be revised to incorporate the responses to this RAI as follows:

> "To account for uncertainties in the structural analysis for seismic loading, a peak shifting approach, similar to that described in Section 4.2.2.1.2 for response spectrum analysis, is used. This is accomplished by first converting the seismic time history excitations into response spectra, and then proceeding through the methodology outlined in Section 4.2.2.1.2. Note that shifting of the input excitation peaks is accomplished by adjusting the time step of the time histories which represent the excitations."

RAI EPR-12: *Equivalent Static Load Analysis*

Confirm that the equivalent static load is always determined by multiplying 1.5 to the peak acceleration for all cases including a single degree of freedom system with known fundamental frequency or a rigid system with the fundamental frequency beyond the cutoff frequency. If not, then provide the criterion that will be used for these special cases.

Response 12:

For clarity, Section 4.2.4 will be revised to include the following text:

> "For multiple degree of freedom systems, the peak acceleration of the appropriate floor response spectra will be multiplied by 1.5. For cases where piping configurations are calculated as single degree of freedom systems with known fundamental frequencies or rigid systems with fundamental frequencies beyond the cutoff frequency (ZPA), a factor of 1.0 may be used with the spectral accelerations at that frequency."

<u>RAI EPR-13:</u> *Small Bore Piping*

The TR did neither define nor address the design of small bore piping to be used in the EPR piping design. Define the small bore piping to be used in the EPR piping design and discuss, with technical bases, the methods of analysis (handbook or a system flexibility analysis) that will be used in the small bore piping design for ASME Class 1, 2, 3 and QG D piping.

Response 13:

Section 4.5 of the TR will be added to include the following text:

> "Small bore piping for the U.S. EPR is defined as ASME Class 1 piping that is 1" NPS and smaller and Class 2, 3 and QG D that is 2" NPS and smaller. This piping may be analyzed using response spectrum methods described in 4.2.2 of the Topical Report, the equivalent static method described in 4.2.3 or by handbook method."

If the COL applicant elects to use the handbook method, the COL applicant will develop the handbook.

<u>RAI EPR-14:</u> *Non-Seismic/Seismic Interaction*

A. TR Section 4.4.1 states that non-seismic piping which cannot be completely separated from seismic systems is routed as far away as possible. With examples, please discuss under what conditions this type of isolation is used in the EPR piping design and also, quantify the meaning of "as far away as possible."

B. TR Section 4.4.2 states that following the failure of the non-seismic pipe, (i) if the non-seismic piping is supported by seismic restraints within the ASME B31.1 Code-suggested pipe support spacing shown in TR Table 4-1, it is considered to lose its pressure boundary integrity, but not fall onto a safety-related piping or equipment. Provide the technical basis for this assumption. (ii) the side motion of a failed moderate energy piping is assumed to be ±6 inches (centerline to centerline) from the original position. Provide the technical basis for this assumption of ±6 inches side motion for all pipe sizes. (iii) safety-related piping with NPS and thickness equal to or greater than that of the non-seismic piping may be assumed to stop the downward motion of the non-seismic piping without failure of the safety-related piping. Provide the technical basis for this assumption.

Response 14:

A. Section 4.4.1 states "Non-seismic piping which cannot be completely separated from seismic systems is routed as far away as possible." The sentence in the TR stems from standard seismic "II over I" layout guidance, which would, for example, have two piping systems in the same room (one seismic and one non-seismic) be physically located away from each other as much as possible, such that there will be little chance of the non-seismic piping adversely interacting with the seismic piping, potentially causing damage to the seismic piping during a seismic event.

In addition to the physical separation distance used in common areas, the layouts utilize physical barriers within the area, such as large equipment items which can provide obvious protection for the seismic system from the potential effects of the damaged non-seismic system. The present guidance is that any non-seismic piping in a common area with seismic piping has been upgraded to a Seismic Class II status to preclude any potential adverse interactions between the two.

For clarity, the sentence in the TR will be revised as follows:

> "Non-seismic piping which cannot be completely separated from seismic systems must be shown to have no interaction with the seismic systems based on separation distance or an intermediate barrier, or be classified as Seismic Category II piping."

B. (i) Table 4-1 provides the maximum deadweight support spacings, as provided in the B31.1 Code for proper deadweight supporting of B31.1 piping. It is possible that supports may exist for a piping line which will provide restraint to the piping during a seismic event (such as rigid guide supports), but are not seismically analyzed. If these supports are placed within the B31.1 deadweight spacings, such a supporting scheme will provide a level of seismic restraint to the piping. There is still the potential in this case for plasticity of the piping and the supports, however it can be expected that the piping will not fall, but likewise may be expected to not necessarily remain functional. The support scheme from B31.1, which will limit deadweight deflections to less than 1/8 inch, and deadweight stresses to approximately 1,500 psi, should in turn also provide reasonable seismic supporting to accomplish prevention of the pipe falling.

(ii) The six inches of side motion assumed for a falling non-seismic pipe is based on Section D.2.1 of Appendix D of the SQUG Generic Implementation Procedure. The Appendix is entitled "Seismic Interaction" and contains the following phrase for consideration of seismic interaction of distribution systems due to lateral movements: "…and 6 inches for relatively flexible systems would normally be adequate to prevent impacts…."

(iii) Per Section III.2 of SRP 3.6.2, an unrestrained whipping pipe is not postulated to cause breaks or cracks in target pipes of equal or larger diameter and thickness. This justification also applies to a falling non-seismic pipe, where failure of its supports has occurred.

<u>RAI EPR-15:</u> *Buried Piping*

TR Section 3.10 did not give details on the analysis method and how the criteria are to be applied in the design of buried piping.

A. Based on the criteria presented in the TR, describe the analysis method and design requirements that will be used for buried piping design (including buried pipe tunnel if used in the design). Explain how these methods compare to the analytical methods referenced in the recently published NRC Standard Review Plan 3.7.3, Rev. 3, (i.e., *ASCE Standard 4-98, ASCE Report - Seismic Response of Buried Pipes and Structural Components, and NUREG/CR-1161).*

B. *Why doesn't TR Section 3.10 include consideration of ground-water effects and soil arching effects which could increase or decrease the stresses in the pipe due to the overlying soil plus the ground surface loads?*

C. *How is the assumption related to soil liquefaction and fault displacement, which is noted in TR Section 3.10, assured?*

D. *TR Table 3-4 provides the design conditions, load combinations and acceptance criteria for Class 2/3 buried piping. Explain clearly the term non-repeated anchor movement, Equation 9U (vs 9), and Equation 9E (vs 9). While the intent may be interpreted, it is important that these terms be clearly defined in the TR. For Equations 10M and 11M, which are identified as "modified to include axial friction forces," provide the equations to show how they are modified.*

E. *For the Faulted loading condition in TR Table 3-4, why isn't the load thermal anchor movement (TAM) included in the load combination, as it is in Table 3-2 for Class 2 & 3 Piping? Also, why is the stress criteria of $3S_h$ used rather than the minimum of 3.0 S_h and 2.0 S_y, as presented in Table 3-2?*

F. *Confirm that Note 5 in the TR Table is applicable to all cases cited in TR Table 3-4 since it is not referenced in the Table like the other notes are. Also, explain how the criteria of NC/ND-3133 of the ASME Code (Note 5 in the Table) will be implemented in conjunction with meeting the loads and loading conditions specified in Table 3-4.*

Response 15:

A. Section 3.10 of the TR will be revised to include analysis methods and design requirements for buried piping, as shown in Attachment B to this response.

The methods developed for the U.S. EPR buried piping meet requirements in SRP 3.7.3, Rev. 3, NUREG/CR-1161, ASCE Standard 4-98 and ASCE Report-Seismic Response of Buried Pipes and Structural Components.

B. Section 3.10 will be revised to include buoyancy forces from ground-water, overburden and surface traffic from trucks, rail and construction equipment, as shown in Attachment B to this response.

C. The path of any buried piping should be surveyed to determine soil conditions with emphasis on avoiding soil conditions such as liquefaction and faults. Section 3.10 of the TR will be revised to include options that can be used to avoid these soil conditions or repair them, as shown in Attachment B to this response.

D. Non-repeated anchor movements, in the case of buried pipe, refers to building settlement at the point where the buried pipe enters the building. Equations 9U and 9F refer to upset and faulted respectively. These designations are used to distinguish the differences in plant events that occur during the upset or faulted plant conditions and must be combined per equation 9 and meet the allowable stresses as noted in the various section of NC/ND 3650.

$$S_E = \frac{iM_C}{Z} + E\alpha(T_2 - T_1) - \upsilon(\frac{PD}{2t}) \qquad \text{Equation 10M}$$

$$S_{TE} = \frac{PD_O}{4t_n} + 0.75i\frac{M_A}{Z} + i\frac{M_C}{Z} + E\alpha(T_2 - T_1) - \upsilon\frac{PD}{2t} \leq (S_h + S_a) \qquad \text{Equation 11M}$$

Where: M_C is moments from arching or thermal anchor movements
M_A is moments from weight of pipe
and the remaining part of the equation is the stress from friction due to thermal differences due to soil/pipe interaction.

E. Thermal Anchor Movements (TAM) will be added to the faulted load condition in Table 3-4. The allowable stress for the faulted condition is less than or equal to $3.0S_h$ but not greater than $2.0S_Y$.

F. Note 5 will be added to Table 3-4 as appropriate. As shown in Attachment B, the external pressure of the soil overburden defined in NC/ND-3133 will be added to the discussion in 3.10.

RAI EPR-16: *Computer Codes*

TR Section 5.1 provides short descriptions of the major computer programs to be used in the analysis and design of safety-related piping systems. Piping related computer programs include SUPERPIPE, BWSPAN, BWHIST, BWSPEC, COMPAR2, CRAFT2, P91232, and RESPECT. AREVA states that SUPERPIPE has been thoroughly verified and validated to U.S. NRC standards. For all other computer codes, AREVA did not indicate if these programs are verified for their application by appropriate methods, such as hand calculations, or comparison with results from similar programs, experimental tests, or published literature, including analytical results or numerical results to the benchmark problems and validated as the piping program. Moreover, AREVA did not mention how the quality of these programs and computer results is controlled. To facilitate the staff review of the computer programs used in the EPR design, provide the following additional information:

A. Identify which computer programs will be used during the design certification phase.

B. Identify which programs have previously been reviewed by the NRC on prior plant license applications. Include the program name, version, and prior plant license application. As stated in SRP 3.9.1, this will eliminate the need for the licensee to resubmit, in a subsequent license application, the computer solutions to the test problems used for verification.

C. Confirm that the following information is available for staff review for each program: the author, source, dated version, and facility; a description, and the extent and limitation of the program application; and the computer solutions to the test problems described above.

Response 16:

A. BWSPAN is being used for analysis of the RCL piping during the design certification phase. While the other codes given in the initial version of the TR are also being used for RCL analysis in the design certification phase, they are not strictly piping analysis codes (they are general purpose hydraulic and post processing codes) and so their description will be removed from the TR.

SUPERPIPE is being used during design certification for the analysis of ASME Class 2 and 3 piping. It may be used for Class 1 piping.

B. The use of BWSPAN for Class 1 RCL analysis has previously been approved by the NRC, see letter David E. LaBarge (NRC) to W.R. McCollum, Jr. (Duke Energy Corporation), "Oconee Nuclear Station, Units 1, 2 and 3 Re: Reactor Coolant Loop Analysis Methodology for Steam Generator Replacement (TAC Nos. MA9886, MA9887, and MA9888)," dated September 6, 2001.

Earlier versions of BWSPAN have been successfully benchmarked to the piping problems given in NUREG/CR-1677. Later versions have been benchmarked to a prior version of BWSPAN by running selected sample problems which demonstrate that the changes made in moving from one version to the next have been correctly implemented. BWSPAN is controlled and maintained per AREVA NP, Inc. administrative procedures. The files which document the verification, validation, maintenance and control of BWSPAN are available. These files will provide the author, source, dated version, program description, the extent and limitation of the program application; and the computer solutions to the test problems described above.

SUPERPIPE - The use of SUPERPIPE, in previous versions, has been approved by the NRC for a number of previous license applications including the Catawba Nuclear Station (CNS UFSAR, Rev. 12, Table 3-68) and the System 80+ Design Certification (NUREG-1462, Section 3.12.3). Current versions of SUPERPIPE have been subsequently verified under the AREVA software QA program by comparison of results to the results of previously accepted versions.

SUPERPIPE is controlled and maintained per AREVA NP Inc. administrative procedures. The files which document the verification, validation, maintenance and control of SUPERPIPE are available. These files will provide the author, source, dated version, program description, the extent and limitation of the program application; and the computer solutions to the test problems described above.

C. The information on computer codes is available for NRC inspection. These files will provide the author, source, dated version, program description, the extent and limitation of the program application; and the computer solutions to the test problems described above.

RAI EPR-17: *Inclusion of Support Mass*

TR Section 5.2 describes a criterion for inclusion of support masses to the piping model mass at the support attachment location and states that a portion of the weight of the support is considered in the piping analysis and also, because the mass of a given support will not contribute to the piping response in the direction of the support, only the unsupported directions need to be considered.

A. Clarify under what conditions only a portion of the support weight would be considered.

B. Provide justification as to why the support mass would not contribute to the piping response in the direction of the support if the support is flexible (e.g., spring hangers).

Response 17:

A. The TR states "The mass contributed by the support is included in the analysis when it is greater than 10% of the total mass of the adjacent pipe span (including pipe contents, insulation and concentrated masses)."

B. It is agreed that if the support is determined to be flexible in the direction of the restraint, the support mass should also be included in this direction, as well as for the unrestrained directions.

TR Section 5.2 will be revised as follows:

"Because the mass of a given support will not typically contribute to the piping response in the direction of the support, only the support mass in the unsupported directions needs to be considered, unless the support is flexible in the supported direction."

RAI EPR-18: *Piping Model Structural Boundaries*

TR Sections 5.4.1.2 and 5.4.1.3 describe two alternate approaches of separating a piping analysis model using an elbow or a tee within the piping model. While these approaches may be technically sound, no references or technical justifications are provided for each of these methods. Provide technical justifications and limitations (if any) for these two methods of establishing piping model terminations. Also, discuss the basis for selecting the dimensions of L_1 and L_2 in TR Figure 5-1 for a restrained elbow and Figure 5-2 for a restrained tee.

Response 18:

The configurations shown in Figures 5-1 and 5-2 produce boundaries which, over a relatively short distance, provide effective restraint for the six degrees of freedom. The configuration creates a rigid zone of pipe with natural frequencies well above the ZPA and provides four restraints in the out-of-plane direction. The location of the two in-plane restraints on each side of the elbow or each segment of the tee provides a very short, stiff segment of piping from the intersect point and therefore create an effective axial restraint for the piping in the in plane direction. This configuration meets the recommendations for an overlap zone presented in NUREG/CR-1980.

RAI EPR-19: *Piping Model Boundaries Using Model Isolations*

TR Sections 5.4.3.1 and 5.4.3.2 describe two approaches of dividing a large piping analysis model using the overlap region or the influence zone method. While these approaches may be technically sound, no references or technical justifications are provided for each of these methods. Provide technical justifications and limitations (if any) for these two methods of isolating piping models. Also, discuss the basis for selecting the overlap region and the influence zone in TR Figure 5-3.

Response 19:

The overlap methodology provided in TR Section 5.4.3.1 is consistent with the recommendations of NUREG/CR 1980. The following phrase will be added to the text in 5.4.3.1:

> "...and must meet the following criteria which are consistent with the recommendations of NUREG/CR-1980."

The Zone of Influence (ZOI) method is provided as an option when the requirement for a rigid section of piping can not be met in order to use the overlap methodology. In this method, all piping must be modeled to a point where boundary conditions and loadings no longer impact the piping being qualified. This will typically be more piping than is required by the overlap method and the validity of the boundary is required to be demonstrated during the analysis. TR Section 5.4.3.2 will be revised to include these statements.

As stated in TR Section 5.4.3, TR Figure 5-3 is included to show the differences in the boundaries of qualification for piping and supports when using the Overlap Method versus the Influence Zone Method. It is not used as a guide for selecting the overlap or influence zone regions. The title of the figure will be revised to *"Model Isolation Methods of Division - Comparison of Qualification Boundaries."*

RAI EPR-20: *Piping Benchmark Program*

Final piping and pipe support stress analyses cannot be completed before design certification because their completion is dependent on as-built or as-procured information. Under a piping benchmark program, the combined operating license (COL) applicant applies his computer program to construct a series of selected piping system mathematical models that are representative of the standard plant piping designs. Please confirm if AREVA has established such a piping benchmark program to be used by the COL applicants and whether its own piping analysis computer code described in Section 5.1 was verified using models representative of the U.S. EPR.

Response 20:

AREVA will identify three (3) representative calculations from the analyses currently being completed for the U.S. EPR Design Certification to be used in the benchmark program. These calculations will be completed prior to the submittal of the DCD and will utilize the piping analysis codes identified in 5.1 of the TR.

The COL applicant will implement this benchmarking program if he chooses to use programs other than those stated in TR 5.1. This requirement is Item 6 of Table 1-1.

RAI EPR-21: *Model Decoupling Criteria*

TR Section 5.4.2 states that adequate flexibility in the branch line is provided by maintaining a minimum length from the run pipe to the first restraint of ½ of the pipe span in TR Table 4-1 for the branch line. The mass to be considered at the branch connection of the run pipe is the mass of ½ of the first span of the branch pipe, including concentrated weights, in each direction. However, AREVA did not discuss other effects (e.g., moment or torsional load at the branch connection) of the eccentric concentrated masses, such as valves, in the first one-half span length from the main run pipe. Provide technical justification on how to account for the effect of a large concentrated mass near the branch connection in the decoupling criteria discussed in the TR.

Response 21:

In the third paragraph of TR 5.2 it is stated "Torsional effects of eccentric masses are included in the analysis." This applies to all eccentric masses including valves in the first half span of a branch line.

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 must be considered. In these cases, the branch piping will be modeled and analyzed with the run pipe, or a portion of the branch line shall be included in the run pipe analysis to adequately include the torsional effects of the eccentric weight.

<u>RAI EPR-22:</u> *Dynamic Analysis of Branch Lines*

TR Section 5.4.2 states that for the SSE inertia load case, each individual run pipe movement shall be analyzed as a separate anchor movement load case on the branch line and combined with its respective load case by absolute summation. Provide additional clarification to explain this procedure.

Response 22:

For branch lines decoupled from the RCL, the inertial seismic input at the branch-to run anchor is a time history or response spectrum generated by seismic analysis of the RCL as discussed in RAI EPR-7. The analysis of the branch line also includes the thermal and seismic movements of the RCL which are applied as static displacements at the branch-to-RCL anchor.

For decoupled branches analyzed using run pipe displacements to capture the inertial effect of the run pipe, Section 5.4.2 of the TR will be revised as follows to clarify the following method of combination:

> "The inertial movements of the run pipe at the branch intersection are obtained from the run pipe analysis. These movements are statically applied, in individual load cases for each direction, at the branch-to-run pipe anchor. The results of these statically applied load cases are combined by the SRSS to capture the effects of the inertial movement of the run pipe on the branch line. These results are then combined with the inertial analysis of the branch line by absolute summation to obtain the total inertial response."

<u>RAI EPR-23:</u> *Model Isolation and Analysis*

A. *TR Section 5.5 states that when the isolation methods discussed in TR Section 5.4.3 are used, isolation of dynamic effects is provided by three (3) seismic restraints in each of the three orthogonal directions beyond the seismic Category I design boundary. However, TR Section 5.4.3.1 states that as a minimum, four (4) such restraints in each orthogonal direction in the overlap region are required for the same isolation method. Explain this discrepancy.*

B. *TR Section 5.5 states that for loads resulting from the potential failure of the non-seismic piping and pipe supports, three separate analyses are performed by applying a plastic moment in each of three orthogonal directions at the termination of the model and then the results of these three analyses are enveloped. Please clarify how these loads are calculated and how the results from the three analyses are combined with the results of the dynamic analysis of the seismic Category I piping.*

Response 23:

A. The statement in 5.5 will be changed to "four seismic restraints in each of the three orthogonal directions beyond the Seismic Category I system boundary."

B. The following text will be added to 5.5:

"The plastic moment is calculated as:

$$M_P = S_Y Z_P \quad \text{and} \quad Z_P = \left(D^3 - d^3\right)/6$$

Where, M_P = Plastic moment to be applied

S_Y = Material Yield Strength at 70°F
Z_P = Plastic section modulus of the pipe
D = Outside diameter of the pipe
d = Inside diameter of the pipe

Each moment is applied and evaluated in a separate analysis and the results of each analysis are individually combined with the seismic inertia results by absolute summation methods. The results of these three analyses are then enveloped to obtain the design loads for the piping and supports."

RAI EPR-24: *Transient Loads*

Provide the list of transients and the number of events associated with each of these transients during a life span of 60 years that will be part of the design requirements of ASME Code Class piping and pipe supports. If such a list is not developed at this stage of the design certification, then include this in the DCD or include as one of the COL-Action Items listed in TR Table 1-1.

Response 24:

The list of transients will be included in Chapter 3 of the DCD.

RAI EPR-25: *Piping Load Combinations*

The staff needs clarification of several items associated with TR Section 3.3 and Tables 3-1 and 3-2.

A. In TR Section 3.3.1.7, it is stated that pipe breaks in the RCL, main steam and pressurizer surge lines which meet the leak-before-break (LBB) size criteria are eliminated from the consideration based on LBB analysis. However, the impact of smaller attached lines and other lines outside the LBB analyzed zone will be considered. Per SECY 93-087, the staff has approved the LBB approach on a case-by-case basis for austenitic stainless steel and carbon steel with stainless steel clad piping inside the primary containment and pipe size of at least 6-inch NPS. Based on this document, appropriate bounding limits are to be established using preliminary analysis results *during the design certification phase and verified during the COL phase by performing the appropriate ITAAC discussed in it. Discuss the technical basis for exclusion of pipe break analysis for the above three lines, with the LBB criteria to be used for the EPR piping design.*

B. *Note 3 to TR Table 3-1 states that dynamic loads are to be combined considering timing and causal relationships. SSE and Design Basis Pipe Break (including loss-of-coolant accident (LOCA)) shall be combined using the square root of the sum of the squares (SRSS) method. This is acceptable in accordance to NUREG-0484, Rev. 1. However, for dynamic responses resulting from the same initiating events (other than SSE), when time-phase relationship between the responses cannot be established, the absolute summation of these dynamic responses should be used. Confirm if this is true for the EPR piping design. If not, discuss with technical justification the combination method to be used when multiple LOCA or other dynamic load events are required to be combined. This combination criterion is also applicable to note 5 of the TR Table 3-2, which states that dynamic loads are combined by the SRSS.*

C. *Note 8 to TR Table 3-1 states that the earthquake inertial load used in the Level D Primary Stress (Equation 9F) calculations shall be taken as the peak SSE inertial load. The earthquake anchor motion load used in the Level D Primary Stress (Equation 9F) calculations shall be taken as the peak SSE anchor motion load. The staff position on the use of a single-earthquake design in SECY-93-087 states that the effects of anchor displacements in the piping caused by an SSE be considered with the Service Level D limits. For simplified elastic-plastic discontinuity analysis, if Eq. 10 cannot be satisfied for all pairs of load sets, then the alternative analysis per NB-3653.6 for Service Level D should be followed. In addition, the combined moment range for either the resultant thermal expansion and thermal anchor movements plus ½ the SSE seismic anchor motion or the resultant moment due to the full SSE anchor motion alone, whichever is greater must satisfy the equation (known as Eq. 12a) given in NB-3656(b)(4). Clarify if this is applicable to EPR piping design. Also, justify why this anchor motion stress is categorized as a primary stress in the TR Table 3-1 for the faulted condition.*

D. *Identify the applicability of notes 3 and 5 in the TR Table 3-2.*

E. *Explain why equation 11a under NC/ND-3653.2 is not included in the TR Table. Are there any dynamic loads other than the SSE (e.g., building response due to hydrodynamic loads such as SRV actuation) that can occur?*

Response 25:

A. Leak-Before-Break will be addressed in Chapter 3 of the DCD. It was not included in the TR because it was not addressed in SRP 3.12.

B. AREVA expects to be able to establish the timing and causal relationships between dynamic events such as pipe rupture and valve actuation. However, if this relationship cannot be established between two dynamic events, the responses from these events will be combined by absolute sum. Table 3-1 will be revised to clarify this point as shown in Attachment C to this response.

Note 5 of Table 3-2 will be revised to include:

> "When causal relationships can be established, dynamic loads will be combined by the square root of the sum of the squares (SRSS). When this relationship cannot be established, dynamic loads will be combined by absolute sum. SSE and High Energy Line Break loads are always combined using the SRSS method."

C. At the time that the Topical Report was written, portions of Section III NB-3600 in the 2004 Edition of the ASME Boiler and Pressure Code were not endorsed by the NRC, per the version of 10CFR50.55a in effect at that time. The proposed draft of 10CFR50.55a which was published in spring of 2007 indicates that restrictions on the use of the rules involving seismic loading have been removed. AREVA will therefore reference the equations from NB-3656(b)(4) for the treatment of SSE anchor motions. Table 3-1 has been revised for this reason and to provide further clarification of the Class 1 load combinations.

D. Note 3 applies to the "Design" loading condition and Equation 8. Note 5 applies to Equations 9E and 9F.

E. Equation 11a of NC/ND 3653.2 is for reversing loads such as seismic but it did not appear until after the 1993 addenda. Therefore, it was not included in the TR. The seismic (reversing) inertia loads are included in Equation 9 and the secondary effects of these loads are included in Equation 10 as in the 1993 Code Addenda. See also response to RAI EPR-3. There are no other dynamic loads on the building structure that would impact piping analysis and support design.

<u>RAI EPR-26:</u> *Piping Damping Values*

In TR Section 4.2.5, it is identified that Rev. 0 of the RG 1.61 values of damping will be used in the seismic analysis of structures, systems, and components (SSCs) using ISM response spectrum analysis or time history analysis. However, for piping systems analyzed using USM response spectrum analysis, 5% damping will be used provided that the system is not susceptible to stress corrosion cracking. Five percent damping will not be used for analyzing the dynamic response of piping systems using supports designed to dissipate energy by yielding.

A. Since staff has issued the Rev.1 of RG 1.61 in March 2007, indicate if the design of EPR piping systems will use Rev. 1 of the RG-recommended damping values.

B. For piping systems analyzed using uniform support motion response spectrum analysis and 5% damping, verify that all of the limitations specified in RG 1.84 for ASME Code Case N-411 (or RG 1.61, Rev.1) will be met.

C. Also, discuss what damping values will be used for cases when the system is susceptible to SCC and when using supports designed to dissipate energy by yielding.

Response 26:

A. TR Section 4.2.5 will be revised to allow the use of Reg. Guide 1.61 Rev. 1 damping values.

B. TR Section 4.2.5 will be revised to state that piping analyzed using the uniform support motion response spectrum method and meeting all limitations specified in Regulatory Guide 1.61, Rev. 1 will use 5 percent damping.

C. TR Section 4.2.5 will be revised to state that the U.S. EPR will use 4 percent damping for systems susceptible to SCC and when supports that dissipate energy are used.

RAI EPR-27: *Modal Combinations*

In TR Section 4.2.2.3.1, it is stated that for the response spectrum method of analysis, the modal contributions to the inertial responses are normally combined by the SRSS method. If some or all of the modes are closely spaced, any one of the methods (Grouping method, 10% method, and Double Sum method, as well as the less conservative methods in revision 2 of the RG 1.92) is applicable for the combination of modal responses. This combination method is applicable to both USM and ISM methods of analysis.

A. If guidance given in Revision 2 of the RG 1.92 is used for the EPR piping design, then Revision 2 of the RG no longer recognizes the Grouping method, 10% method and Double Sum method for closely spaced modes. These methods are renamed and AREVA should identify them as noted in the RG.

B. TR states that for closely spaced modes AREVA may use less conservative methods discussed in the RG. Please identify which methods are less conservative methods and explain why they are less conservative with respect to the other method(s).

Response 27:

A. In the Background discussion of Section B of RG 1.92 Revision 2, the methods of Revision 1 are included by reference as remaining acceptable for use. AREVA will add Revision 1 of RG 1.92 to the references since the detail for these methods are not provided in Revision 2.

B. This statement is only intended to point out that the methods of modal combination provided in Revision 2 of RG 1.92 are less conservative than the methods presented in Revision 1 as stated in the Background discussion of the RG.

RAI EPR-28: *Missing Mass*

TR Section 4.2.2.3.2 presents a procedure to account for high-frequency modes in the response spectrum methods for calculating seismic and other dynamic load responses.

A. Discuss the differences in the mathematical derivations of the high frequency modes presented in the TR versus the methods acceptable to the staff as given in RG 1.92, Rev. 2.

B. The TR states that the response from high frequency modes will be included in the response of the piping system if it results in an increase in the dynamic results of more than 10%. However, in accordance with RG 1.92, Rev.2, C.1.4.1, this criterion may yield non-conservative results and should not be used. Since this guideline does not consider the total mass that is missing, which, in the limit, could be 10%, provide technical justification for using this criteria as a screening requirement for including the effects of any missing mass.

C. The TR also states that peak modal responses of the system at frequencies above the ZPA are considered to be in phase. Thus, the responses of all high frequency modes are combined by absolute summation. Explain if the peak modal responses are in phase, then why the absolute sum method is recommended for the EPR piping design.

D. Finally, the TR states that this missing mass mode is considered to have a modal frequency and acceleration equal to the cut-off frequency used in the modal analysis. These modal results are combined with the low frequency modal results using the methods described in TR Section 4.2.2.3.1 for the low frequency modes (per RG 1.92). Please explain the combination method for the results to be used from both low and high frequency modes.

Response 28:

A. The method detailed in the TR is based on the Left-Out-Force method. This method is performed by the SUPERPIPE piping analysis code which has been accepted for use at many operating plants. Although this method is different than that shown in RG 1.92, it produces the same result. BWSPAN uses the missing mass method given in Appendix A of RG 1.92, R2. TR Section 2.2.3.2 will be revised to state that BWSPAN uses the missing mass method outlined in Appendix A of RG 1.92 Revision 2.

B. The residual rigid response of the missing mass modes will be included in all seismic analyses of SSCs. Section 4.2.2.3.2 will be revised to remove the option of using the 10% criteria.

C. The TR Section 4.2.2.3.2 will be revised as follows:

> "Thus, the responses of all high frequency modes are combined by algebraic summation."

D. The TR will be revised to state that the rigid range (missing mass) results will be combined with the low frequency modal results by SRSS.

RAI EPR-29: *Nonlinear Vibrations Due to Support Gaps*

The TR does not provide an analytical method to account for nonlinear effects of excessively large gaps (for frame type supports) between the pipe and supports subject to high frequency vibration loads. Should such large gaps exist, provide the piping analysis method to be used to address the nonlinearity when subjected to vibratory loads with significant high-frequency caused by the gaps between the pipe and its supports.

Response 29:

As stated in TR Section 6.5, and further discussed in Section 6.11, the U.S. EPR design does not intend to utilize gapped supports. For the U.S. EPR, the normal design practice for frame structure guide supports is to utilize a nominal 1/16" gap between the surface of the pipe and the edge of the support member for both sides of the pipe in the restrained direction.

Section 6.5 will be revised to add the following text:

> "Although the use of gapped supports is not anticipated for the U.S. EPR, should the need for such supports arise, one of the following two methodologies would be employed. Either the non-linear piping analysis problem is solved using direct integration time history methods, or the piping is analyzed as a linear problem, where the supports are assumed effective and the results are summed with the results of a static load case which deflects the pipe enough to close the support gap(s). These linear analyses will use either response spectra or time history modal superposition techniques."

RAI EPR-30: *Thermal Stratification*

A. TR Section 3.7.1 states that the main feedwater nozzle is located in the conical section of the steam generator which aids in reducing thermal stratification. Please explain how this reduces thermal stratification.

B. TR Section 3.7.2 states that the surge line may not be subjected to significant stratification/striping effects due to design features that mitigate these effects. Describe these design features and explain how they mitigate the effects of thermal stratification in the surge line.

Response 30:

A. Since the main feedwater nozzle is attached to the sloped conical section of the steam generator, it too is inclined: ~18 degrees from the horizontal. This incline promotes mixing of the colder and hotter fluid layers in the line which in turn retards stratification. The inclined design also prevents permanent thermal stratification at low flow rates and ensures run-full conditions in the nozzle.

B. There are three major features of the surge line which minimize the amount of stratification in the line: 1) The take-off from the hot leg is vertical upward and of sufficient length that turbulent penetration from hot leg flow does not spill over into the surge line beyond the take-off, and thus causing stratification; 2) the surge line is sloped ~5 degrees between the vertical take-off at the hot leg and the vertical leg at the pressurizer, which promotes contributes to mixing of the colder and hotter fluid layers in the line; and 3) during normal operation, a continuous bypass spray flow of sufficient magnitude is maintained to further suppress turbulent penetration from the hot leg flow.

RAI EPR-31: *Safety Relief Valve*

Describe the SRV design parameters and criteria that will need to be specified to the COL applicant to ensure that the specific piping configuration and safety relief valves (SRVs) purchased and installed at the COL applicant stage will match the test and design parameters used at the design certification stage. An example is the minimum rise time for the SRV valve operation; this can greatly affect the transient loads imposed on the piping system analysis. Also, any change in the discharge piping system configuration may affect the SRV loadings.

Response 31:

Discussion of SRV design parameters and criteria is beyond the scope of this TR. Relevant parameters and criteria will be addressed in the DCD.

RAI EPR-32: *Composite Damping*

The composite modal damping ratio can be used when the modal superposition method of analysis (either time history or response spectrum) is used, as described in SRP Section 3.7.2, II.13. If AREVA plans to use composite modal damping for U.S. EPR piping design, provide a description of the methods for determining the composite modal damping value.

Response 32:

Composite modal damping may be applied when the modal superposition method of analysis is used. The methods used will meet the requirements of SRP 3.7.2. Section 4.2.5 of the TR will be revised as follows:

"When composite modal damping is applied in a dynamic analysis, each model subgroup (piping, supports, equipment, etc) is assigned an appropriate damping value per RG 1.61 R1. The equivalent modal damping matrix, or composite modal damping matrix, is calculated for each mode by one of the two methods shown below:

$$\bar{\beta}_j = \{\phi\}^T [\bar{M}] \{\phi\} \qquad (1)$$

$$\beta_j = \frac{\{\phi\}^T [\bar{K}] \{\phi\}}{K^*} \qquad (2)$$

Where:

K*	=	$\{\varphi\}^T[K]\{\varphi\}$
[K]	=	assembled stiffness matrix
$\bar{\beta}_j$	=	equivalent modal damping ratio of the jth mode
$[\bar{K}],[\bar{M}]$	=	the modified stiffness or mass matrix constructed from element matrices formed by the product of the damping ratio for the element and its stiffness or mass matrix
{φ}	=	jth normalized modal vector

Note: Damping beyond 20 percent will not be used."

RAI EPR-33: *Codes for Support Design*

A. *TR Section 6.1 states that for Service Levels A, B and C, the seismic Category I pipe supports will be designed in accordance with Subsection NF of the ASME Code and for Service Level D, Appendix F of Section III of the ASME Code will be utilized. However, TR Section 6.2 states that all piping supports designed in accordance with the rules of Subsection NF of the Code up to the building structure interface are defined by the jurisdictional boundaries in Subsection NF-1130 of the ASME Codes. (i) Since Appendix F of the Section III provides only the Service Level D limits for evaluation of loading [per Code Table NF-3523(b)-1 for stress limit factors] for Class 1, 2, 3 and MC type supports, clarify if the seismic Category I pipe supports will be designed to ASME Subsection NF for all four Service Level A, B, C and D loads, while using the acceptance stress limits by the Appendix F for Service Level D supports. (ii) Also, clarify if the Subsection NF will be used to manufacture, install and test all seismic Category I pipe supports. If not, which other standard will be used.*

B. *AREVA also states that seismic Category II pipe supports are designed to ANSI/AISC N690, "Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities." These standards are used to design the structures or structural elements of a support for nuclear facilities, not the standard component supports (e.g., clamps, snubbers). ASME Code Subsection NF is typically used for seismic Category II pipe supports. Identify the standard that will be used to design, manufacture, install and test seismic Category II pipe supports.*

C. *AREVA states that non-seismic category pipe supports are designed using guidance from the AISC Manual of Steel Construction. This manual is used to design steel constructions in frame type or other structural element of component supports. Based on TR Section 6.2, ASME Code B31.1 is being used for a certain class of piping (also see request for additional information (RAI) EPR-2). The design of all supports for the non-nuclear piping (that typically uses B31.1 for piping analysis) should satisfy the requirements of ASME/ANSI B31.1 Power Piping Code, Paragraph 120 for loads on pipe supporting elements and Paragraph 121 for design of pipe supporting elements. Clarify if this is applicable to U.S. EPR pipe support design, otherwise explain how the AISC manual will be used to design component supports (e.g., clamps, springs).*

Response 33:

A. (i) TR Section 6.1 will be corrected to indicate that Seismic Category I pipe supports will be designed to ASME Subsection NF loadings for Service Levels A, B, C and D, while using the acceptance limits of Subsection NF for Levels A, B and C, and the acceptance limits of Appendix F for Level D.

(ii) Subsection NF of the ASME Code will be used for the manufacturing, installation and testing of all Seismic Category I pipe supports.

B. For all Seismic Category II pipe supports other than standard component supports, the design, manufacturing, installation and testing will meet the requirements of ANSI/AISC N690. Standard component supports will be designed, manufactured, installed and tested to Subsection NF of the ASME Code. Any structural members used as part of a pipe support also containing standard components will be designed, manufactured, installed and tested to ANSI/AISC N690.

C. For non-seismic pipe supports supporting piping analyzed to B31.1, the requirements of B31.1 for supports (Sections 120 and 121) will be met, where applicable. In addition, the structural elements will meet the requirements of the AISC Manual. For standard components used in such supports, vendor’s catalog requirements will be utilized, which also meet B31.1 requirements.

For non-seismic pipe supports supporting unanalyzed piping, the structural elements will meet the requirements of the AISC Manual and standard components will meet vendor’s catalog requirements.

RAI EPR-34: *Load Combination for Supports*

While reviewing TR Section 6.3, the staff needs clarification of the following items.

A. TR Section 6.3.11 provided a minimum design load criteria that will be used for all supports so that uniformity is obtained in the load carrying capability of the supports. All supports will be designed for the largest of the following three loads: 100% of the Level A condition load, the weight of a standard ASME B31.1 span of water filled, schedule 80 pipe, and minimum value of 150 pounds. Provide the technical basis for this criteria.

B. TR Table 6-1 provides the specific load combinations that will be used in the design of pipe supports. The acceptance criteria associated with the Service Levels will be per ASME Code, Subsection NF, ANSI/AISC N690 or the AISC Manual of Steel Construction, as appropriate. Note 1 to the Table states that operating basis earthquake (OBE) inertia and SAM loads are not included in the design of Class 2/3 piping. Explain how the seismic inertia and SAM loads are accounted for in the design of Class 2/3 pipe supports. Also, clarify how the same table is applicable to snubbers, struts, and anchors/guides.

C. AREVA discusses wind/tornado loads in TR Sections 6.3.5 and 6.3.6 for pipe supports. However, for the piping in TR Section 3.3.1.6, AREVA identified these loads to be COL-Action Item 3. Clarify AREVA's position on this.

Response 34:

A. The Minimum Design Load criteria given in this section is based on criteria given in Welding Research Council (WRC) Bulletin 353, Section 2.4.7. The bulletin recommends 125% of the Level A condition load, as the only difference from the topical's criteria. Presently, for the analyses being performed as part of the Design Certification process, the guidance is to apply a 25 percent increase to all pipe support loads to allow for possible future increases in support loads beyond the initial design.

B. Table 6-1 includes three Faulted load combinations which contain SSE loads. In addition, Note 3 of the table states that SSE includes inertia and SAM loads combined by absolute sum. These would all apply to Class 1, 2 &3 pipe supports. In addition, struts and anchors/guides will be analyzed to all load combinations shown in the table. Snubbers will be designed to all but the Normal Level load combinations shown in the table.

Note that Class 1 was inadvertently not included in Note 1 of Table 6-1. This will be corrected in the next revision of the TR. Note 1 will be revised to state, "OBE inertia and SAM loads are not included in the design of Class 1, 2 & 3 piping."

C. Section 3.3.1.6 states that for Design Certification, no Class 1, 2 and 3 piping is exposed to wind and tornado loads, and further states that if a COL Applicant creates such an exposed piping condition, it will be addressed at that time. Sections 6.3.5 and 6.3.6 discuss the inclusion of such wind related loads for pipe supports.

AREVA's position on wind loadings for both piping and supports is as stated in Section 3.3.1.6. Clarification will be added to Sections 6.3.5 and 6.3.6 to cross reference this section, and state that these sections show how such loads would be treated if the need arises.

RAI EPR-35: *Snubber Design*

AREVA, in TR Section 6.6, states that design specifications are to be provided to the snubber suppliers and the installation and operation of snubbers will be verified by the COL applicant. For design certification, SRP Section 3.9.3 requires that design, installation, operation and testing of the snubbers should be included in the design document. Clarify, whether AREVA intends to include all design-related specifications associated with snubbers in the TR or in the DCD.

Response 35:

As stated in item 2 of Table 1-1 of the TR, design specifications will be the responsibility of the COL applicant. The specification will be generated using the snubber specification requirements given in Chapter 3 of the DCD.

RAI EPR-36: *Support Stiffness*

AREVA does not adequately describe in TR Section 6.7 how the representative stiffness values are developed for all supports other than snubbers. Describe:

1. *the approach used to develop the representative stiffness values,*
2. *the procedure that will be imposed to ensure that the final designed supports match the stiffness values assumed in the piping analysis,*
3. *the procedure used to consider the mass (along with the support stiffness) if the pipe support is not dynamically rigid, and*
4. *the same information [(1), (2), and (3) above] for the building steel/structure (i.e., beyond the NF jurisdictional boundary) and for equipment to which the piping may be connected to.*

Response 36:

The initial piping analyses will assume all supports rigid (except for the few cases where the actual support structures are included in the piping model), and therefore utilize the default rigid support stiffness values contained in the analysis program. In addition, the initial pipe support designs will be developed to create a rigid support, based on the deflection check criteria given in Section 6.7 of the topical. If for some reason, a rigid support cannot be achieved, an actual support stiffness will need to be developed for the support noted, as well as for the other supports in the model.

Typically, unless the support is a very simple structure, a frame support will be modeled using an analysis program such as GT STRUDL. This model will include the self-weight of the support, and will also be used to establish the deflections needed for the stiffness checks. Note that this model will include any flexible building steel, as applicable. If the deflection checks do not show rigidity, the model can be used to determine the actual stiffness of the support structure using the self-weight load case. In addition, the support mass can be determined from the model. This would be created for the supports in the model and provided to the piping analyst. At this point, the supports would need to be rechecked for the loads from the revised piping analysis. If any support changes were required, an iteration of the process would be required to assure that the stiffnesses and masses are consistent for both the support qualifications and the piping analysis.

RAI EPR-37: *Inclusion of Support Self-Weight Excitation*

In TR Section 6.8, AREVA did not indicate if the criteria presented is also applicable to other dynamic loads and did not discuss how the damping value will be used in the response spectrum analysis.

A. *Clarify whether the criterion presented in the TR is also applicable to other dynamic loads. If not, provide technical justification.*

B. Since the piping and support structure damping value may be different per RG 1.61, discuss what damping value will be used in the response spectrum analysis when the support structure is also modeled as part of the piping analysis. See also RAI EPR-32.

Response 37:

A. The support structure itself will be excited by SSE dynamic inputs, as the SSE event is applicable to the whole site in the form of ground motion. As such, the excitation for the support's attachment to the building will be applied to the self-weight of the structure in the form of response spectra g values. For other fluid dynamic transient events within the piping system, forces from the fluid moving along the pipe are included in the pipe support loads for that event, but any subsequent excitation of the support structure itself for the fluid dynamic event will not be evaluated, as the forcing function at each support beyond applied piping loads will be minimal, and not usually defined. This is standard practice in pipe support design. The supports are typically not modeled with the piping.

B. In most cases, Revision 1 of RG 1.61 calls for 4 percent damping for the piping analysis. Similarly, the RG allows for 4 percent damping for welded steel or bolted steel with friction connections and 7 percent for bolted steel with bearing connections, which would be applicable for the supports. If frequency dependent damping values are used in the piping analysis, the support structure will still utilize the 4 percent or 7 percent damping values.

RAI EPR-38: *Instrument Line Support Design*

TR Section 6.12 states that the applicable loading combinations for instrumentation lines will follow those used for normal and faulted levels in TR Table 6-1. Please explain why the load combinations for upset and emergency levels in TR Table 6-1 are not applicable to instrumentation line supports.

Response 38:

Based on the inclusion of only deadweight, thermal and SSE seismic loadings for analysis of the tubing, the vast majority of the support loads would fall into Normal or Faulted conditions. Since there may be thermal loads for other levels, this section of the topical will be modified to delete the reference to only Normal and Faulted loading conditions.

Section 6.12 will be revised to state:

> "The applicable loading combinations will similarly follow those used for the ASME Levels in Table 6-1utilizing the design loadings mentioned above."

RAI EPR-39: *Pipe Deflection Limits*

In TR Section 6.13, AREVA provided examples of the limitations which include 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 will be made in the initial designs for tolerances on such limits. Please specify the actual allowable limits that are applicable to EPR support design for pipe deflection limits.

Response 39:

The first check mentioned is the travel range limitation for spring hangers. This check will utilize the "working range" given in the standard Load Table for Selection of Hanger Size typically given in the vendor catalogs. This working range already provides a deflection tolerance beyond each end limit of the range (with the magnitude dependent on the spring type), provided the hot and cold loads fall within the working range.

The second check mentioned is the stroke limit checks for snubbers. The current project guidance is to allow at least ½ inch of stroke at each end for the initial design checks.

The third check mentioned is the swing angle check for rods, struts and snubbers. For current analyses, ANVIL, International hardware is being used. ANVIL's limit for these checks is 4 degrees. AREVA will apply a tolerance of 1 degree to this, thus checking to 3 degrees for initial design.

The fourth check mentioned is for alignment angles of strut and snubber paddles and their associated clamps or end brackets. ANVIL's limit is 5 degrees. AREVA will apply a tolerance of 1 degree to this, thus checking to 4 degrees for initial design.

The fifth check mentioned is for the spring variability check. The recommended limit on this check by ANVIL is 25 percent. AREVA will apply a tolerance of 5 percent to this, thus checking to 20 percent for initial design.

4.2.2 *Response Spectrum Method*

The effects of the ground motion during an SSE event are transmitted through structures to the piping systems at support and equipment anchorage locations. In the response spectrum method of analysis, peak values of response are determined for each mode of the piping system by application of floor response spectra, which represent the maximum acceleration response of an idealized single-degree-of-freedom damped oscillator as a function of natural frequency to the vibratory input motion of the structure.

The floor response spectra are applied to the piping system at locations of structural attachment, such as support or equipment locations. The response spectra analysis is performed using either enveloped uniform response spectra or independent support motion using multiple spectra.

Response spectrum analysis of piping systems subjected to dynamic seismic loads is performed using a linear method of analysis based on normal mode – modal superposition techniques. In this approach, seismic analysis of linear systems is based on the solution of simultaneous differential equations subject to a set of initial conditions and forces.

The response of a multi degree-of-freedom linear system subjected to seismic excitation is represented by the following differential equation of motion:

$$[M]\{\ddot{X}\}+[C]\{\dot{X}\}+[K]\{X\}=-[M]\{\ddot{u}\}$$

Where: $[M]$ = mass matrix (n x n);

$[C]$ = damping matrix (n x n);

$[K]$ = stiffness matrix (n x n);

$\{X\}$ = column vector of relative displacements (n x 1);

$\{\dot{X}\}$ = column vector of relative velocities (n x 1);

$\{\ddot{X}\}$ = column vector of relative accelerations (n x 1);

$\{\ddot{u}\}$ = input acceleration vector

n = number of degrees of freedom

The response spectrum method of analysis uses modal-superposition methods where the mode shapes are used to transform X in the equations of motion into a generalized coordinate system by substitution of the following:

$$\{X\} = [\phi]\{Y\}$$

Where: $[\phi]$ = mass normalized mode shape matrix; $[\phi]^T[M][\phi] = [1]$

$\{Y\}$ = vector of normal, or generalized, coordinates

This transformation decouples the equation of motion above when each term is multiplied by the transposition of the mode shape matrix. This solution assumes that the mode shapes are normal (orthogonal) and also assumes orthogonality of the damping matrix.

The decoupled equation of motion for a system subjected to input acceleration due to seismic motion, $\ddot{u}$, for the nth mode is:

$$\ddot{Y}_n + 2\lambda_n\omega_n\dot{Y}_n + \omega_n{}^2 Y_n = -\Gamma_n\ddot{u}$$

Where: Y_n = generalized coordinate of nth mode;

λ_n = damping ratio for the nth mode expressed as fraction of critical damping;

ω_n = circular frequency of nth mode of the system (radians/second);

Γ_n = modal participation factor of the nth mode

$= \{\phi_n\}^T [M]\{r\}/(\{\phi_n\}^T [M]\{\phi_n\})$

where $\{r\}$ = influence coefficient vector due to a unit input displacement

If all support points in a piping system move in phase (i.e., uniform excitation), then $\{r\}$ consists of ones and zeros to reflect the direction of input excitation. If all support points do not move in phase (i.e., multiple excitation), $\{r\}$ is calculated to reflect the attenuation of the effect of motion of one support group through the other support groups and a unique influence coefficient matrix is developed for each support group. The magnitude of the influence coefficient at a given point in the system is equivalent to the motion at the point of interest due to a statically applied unit displacement of the support group subjected to the excitation.

For the response spectrum method, the generalized response of each mode is determined from the expression below.

$$Y_n(\max) = \Gamma_n \left(\frac{S_{an}}{\omega_n{}^2} \right)$$

Where: S_{an} = Spectral acceleration corresponding to frequency ω_n

The maximum displacement of node *j* relative to the base due to mode *n* is then:

$$X_{jn}(\max) = \phi_{jn} Y_n(\max)$$

This expression gives the maximum displacement from which other modal response quantities, such as forces, can be calculated. In performing these calculations for response quantities of interest, the signs of the participation factor, Γ, the maximum generalized coordinate, $Y_{jn}(\max)$, the maximum displacement of node *j* relative to the base due to mode j, $X_{jn}(\max)$, and other response quantities are retained.

The acceleration of a mass point and the associated inertia force are calculated in a similar manner as follows:

$$\ddot{Y}_n = \omega_n^2 Y_n = \Gamma_n S_{an}$$

and the acceleration of node j due to mode n, a_{jn}, equals:

$$a_{jn} = \ddot{Y}_n \phi_{jn}$$

and the inertia force at node j due to mode n, F_{jn}, equals:

$$F_{jn} = M_j a_{jn} = M_j \ddot{Y}_n \phi_{jn}$$

The floor response spectra are applied to the piping system in each of 3 orthogonal directions. Each of the directional components of earthquake motion input will in turn produce responses in the piping system in all three directions at each natural frequency of the piping system. The total seismic response of the system is determined by combining the modal and spatial results using the methods below.

3.10 *Seismic Category I Buried Pipe*

Class 2 and 3 Seismic Category I buried piping systems in the U.S. EPR will be analyzed for pressure, weight, thermal expansion and seismic loads using dynamic or equivalent static load methods. The acceptance criteria are the same as that used for non-buried piping systems described in Table 3-2.

3.10.1 *Static Loads and Load Combinations for Buried Pipe*

Loads and Loading Conditions are similar to those outlined in 3.3 but are modified for additional considerations of strains and stresses induced by the motion of the pipe in the surrounding soil mass. Thermal loads are impacted by the friction between the pipe and soil due to expansion and contraction of the pipe.

3.10.1.1 *Pressure*

Internal design pressure, P, is calculated as described in 3.3.1.1. However, there is an external pressure, P_x, for buried pipe associated with the overburden of soil. The allowable external pressure is calculated using the methods and formula in NC/ND-3133. The external pressure counteracts the internal pressure but for many applications, this external pressure is significantly less than the internal pressure and its impact on design is not significant.

3.10.1.2 *Deadweight*

For buried pipe, deadweight loads must include the weight of the soil overburden. It must also include live loads from surface traffic such as trucks, rail and construction equipment.

3.10.1.3 *Soil Overburden*

Soil overburden pressure is dependent on the diameter of buried pipe as well as the burial depth relative to the ground water table. Buried pipes are designed for soil load corresponding to weight of the overlying soil prism.

$P_v = \gamma H$. This equation applies to pipes buried above the groundwater table.

Where P_v = overburden pressure on pipe due to soil

γ = unit weight of backfill material

H = burial depth

In the case where the pipe is located below ground water table or where seasonal change in ground water table is significant, the effect of buoyancy and increased weight of water should be considered. For such condition, soil pressure should be computed as follows:

$$P_v = \gamma H - 0.33 \frac{h}{H} + \gamma_w h$$

Where h = depth of groundwater above pipe

γ_w = unit weight of water

3.10.1.4 *Surface Loads*

Live loads such as those imposed by trucks, rail, and construction equipment or other construction conditions should be considered in the analysis and design. The pressure transmitted to the buried pipe under these loads may be computed as follows:

$$P_p = 0.48 \frac{P_s}{H^2 \left[1 + \left(\frac{d}{H} \right)^2 \right]^{2.5}}$$

Where P_p = surface load transmitted to the buried pipe

d = offset distance from the surface load to buried pipe

H = thickness of soil cover above the pipe

P_s = concentrated surface load

The magnitude of P_p above is multiplied by an impact factor which is dependent on the soil cover and type of surface load. Table 3-5 [13] shows some recommended values of impact factors.

The magnitude of P_p may be taken from Table 3-6 which is based on AASHTO HS-20 Truck and Copper E-80 railroad loads [13]. The values reported in Table 3-6 include an impact factor of 1.50.

COL applicants should perform detailed geotechnical engineering analysis to determine if the surface load will cause lateral and/or vertical displacement of bearing soil for the piping. Consideration should also be given to the effect of wide and extra heavy loads when evaluating the buried utility.

3.10.1.5 *Bouyancy Force*

For utilities buried below groundwater table, vertical force due to buoyancy should be considered and may be evaluated as follows:

$$F_b = W_w - W_p - P_v D + \gamma_w h_w D$$

The above equation conservatively assumes that the pipe is empty.

Where F_b = buoyancy force per unit length of pipe

D = external diameter of the pipe

P_v = γH = overburden pressure due to soil

W_w = weight of water displaced by pipe per unit length

W_p = self weight of pipe per unit length

The corresponding buoyancy stress on the utility may be computed as follows:

$$\sigma_b = \frac{F_b L^2}{10Z}$$

Where L = length of the utility in the buoyancy zone

Z = section modulus of the utility

The effects of pressure (P, P_x, P_s, P_v), dead and live loads must meet the requirements of Table 3-4 as follows for Equation 8:

$$S_{SL} = \frac{B_1 P D_O}{2t_n} + \frac{B_2 M_A}{Z} + \frac{F_b L^2}{10Z} \le 1.5 S_h$$

P = Internal pressure + P_X +P_S +P_V

3.10.2 *Thermal Expansion and Contraction*

Depending on the relative temperature of the soil in which the pipe is buried and the temperature of the fluid contained in the pipe, a pipe that is fully restrained by the surrounding soil may experience contraction or expansion. This thermal-induced stress (due to friction between the pipe and soil) should be considered and may be evaluated as follows:

$$\sigma_A = E\alpha(T_2 - T_1) - \upsilon \frac{PD}{2t}$$

Where σ_A = axial compressive stress in fully restrained pipe due to difference in temperature between soil and pipe content.

E = modulus of elasticity of the pipe material

α = coefficient of thermal expansion of the pipe

T_2 = maximum operating temperature of fluid in the pipe

T_1 = burial installation temperature

υ = Poisson ratio of the pipe material

D = diameter of the pipe

t = pipe thickness

The effects of restrained thermal expansion/contraction forces in buried pipe are evaluated against the requirements of NC/ND-3653.2(a) by using a modified Equation 10 or NC/ND-3653.2(c) by using a modified Equation 11. From Reference 2, the equations are as follows:

$$S_E = \frac{iM_C}{Z} + E\alpha(T_2 - T_1) - \upsilon\frac{PD}{2t}$$ Equation 10M

or

$$S_{TE} = \frac{PD_O}{4t_n} + 0.75i\frac{M_A}{Z} + i\frac{M_C}{Z} + E\alpha(T_2 - T_1) - \upsilon\frac{PD}{2t} \leq (S_h + S_a)$$ Equation 11M

3.10.3 *Seismic Loads*

Seismic-induced damage to buried piping is largely due to wave propagation or permanent ground deformation resulting from fault movement, landslide, and liquefaction-induced lateral spread. Where buried piping enters a structure, the seismic anchor movements of the structure must be accounted for in the design of the piping. Other forms of damage related to ground movement such as elastic and consolidation settlement (total and differential), freeze-thaw induced settlement, and seismic-induced settlement due to soil compaction and rearrangement should be considered on a case-by-case basis. For the case of piping anchored to an adjacent building, strain development in the utility due to settlement of the building should be evaluated. The seismic effects on buried piping are self limiting in that strains are limited by the surrounding soil. Therefore the stresses due to these strains are secondary in nature.

COL applicants shall carry out site investigation to assess the best route for the underground piping. During this field investigation, sites that are vulnerable to fault movement and liquefaction-induced landslide and lateral spread should be avoided. If a pipe must be buried in loose saturated cohesionless soil susceptible to liquefaction, rigorous linear and non-linear pipe-soil interaction analysis should be carried out to evaluate the integrity of the pipe under settlement and lateral spread conditions that may be caused by the liquefiable soil. If the result of the soil-pipe interaction is not acceptable, any of the following options recommended in Reference [14] may be adopted:

(1) Re-route the pipe to avoid areas of liquefiable loose saturated cohesionless soils;

(2) Modify the strength of the soil by using appropriate stabilizing agent;

(3) Excavate liquefiable soil and replace with competent structural fill materials; or

(4) Support the pipe in soil that is not susceptible to failure.

3.10.3.1 *Axial and Bending Strains Due to Propagation of Seismic Waves*

Typically, the magnitude of axial and bending strains on buried piping due to propagation of seismic wave is dependent on several factors such as the buried material and soil properties and pipe-soil interfacial properties. Conservatively, axial and bending strains on the buried piping are taken to be the same as those of the seismic wave if there is no site specific field instrumentation to measure the strain level experienced by the buried piping. Based on the axial and bending strains developed in the buried piping assuming long, linear runs remote from anchors or bends, the corresponding axial load and bending stress can be computed as follows:

$$F_a = \varepsilon_a A E$$

$$M_b = \sigma_b Z$$

Where $\sigma_b = \varepsilon_b E$.

In above equations,

E = Young Modulus of the buried piping

ε_a = Axial strain in the buried piping due to wave propagation

ε_b = Bending strain in the buried piping due to wave propagation

Z = Section modulus of the buried piping.

For the computation of loads developed at elbows, the simplified procedures outlined in reference [14] are recommended for flexible and rigid conditions. At site locations where the differential settlement is significant, flexible anchors may be used in lieu of rigid anchors. All support structures (anchors) should be designed to resist the resulting axial loads and bending stresses.

The general axial and bending strains due to seismic wave propagation may be found as follows:

$$\varepsilon_a = \pm \frac{v}{c}$$

$$\varepsilon_b = \pm \frac{Ra}{c^2}$$

Where v = velocity of the soil layer (particle) in which the piping is embedded

a = acceleration of the soil layer (particle) in which the piping is embedded

c = apparent velocity relative to ground surface

R = radius of the pipe

ε_b = bending strain

ε_a = axial strain

In reference [14], it is noted that axial and bending strains are a result of three types of seismic waves, (1) compression, (2) shear and (3) surface or Rayleigh. The strain for each wave is calculated using the general form for axial and bending noted above.

The effects of seismic loads on above ground piping must meet the requirements of NC/ND-3655 as noted in Table 3-2. However, since seismic loads on buried piping are treated as secondary loads, the following equation must be met:

$$S_{OL} = \frac{iM_C}{Z} + \frac{iM_{SAM}}{Z} + \varepsilon_b + \varepsilon_a + E\alpha(T_2 - T_1) \leq 3.0S_h \text{ but not greater than } 2.0S_y$$

Where M_c = bending moment due to restrained thermal/contraction

M_{SAM} = bending moment from seismic anchor movements

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13. Guideline for the Design of Buried Steel Pipe; Report by American Lifelines Alliance, 2001.

14. Seismic Response of Buried Pipes and Structural Components; ASCE Committee on Seismic Analysis of Nuclear Structures and Materials, New York, 1983.

Table 3-4: Design Conditions, Load Combination and Stress Criteria for ASME Class 2&3 Buried Piping

Loading Condition	Service Levels	Loads	Stress Criteria
Design	-	Primary Stress Loads: Pressure, Weight Loads(1), Other Sustained Mechanical Loads	Equation 8 NC/ND-3652
Normal/ Upset	A/B	Occasional: Pressure, Weight Loads(1), Other Sustained Mechanical Loads, DFL	Equation 9U NC/ND-3653.1 (Level B Only)
		Secondary Stress: Thermal Expansion, TAM, Thermal Friction Forces	Equation 10M(2) (4) NC/ND-3653.2(a)
		Non-Repeated Anchor Movement	Equation 10a NC/ND-3653.2(b)
		Sustained Plus Secondary Stress: Pressure, Weight Loads(1), Other Sustained Mechanical Loads, Thermal Expansion, TAM, Thermal Friction Forces	Equation 11M(3) (4) NC/ND- 3653.2(c)
Emergency	C	Occasional Stress: Pressure, Weight Loads(1), DFL	Equation 9E NC/ND-3654.2(a)
Faulted	D	Secondary Stress: SSE Inertia & SAM(M_{SSE}), Thermal Expansion and TAM (M_C), Friction Axial Forces from Thermal Expansion ($F_{a(T)}$), Friction Axial Forces from Seismic Loads ($F_{a(SSE)}$)	$\frac{i(M_{SSE} + M_c)}{Z} + \varepsilon_a + \varepsilon_b + E\alpha(T_2 - T_1) \leq 3.0S_h$ but not greater than $2.0S_y$

Notes:

1. Weight loads for buried pipe include the pipe weight (including contents and insulation, as well as soil overburden loads and loads due to motor vehicles and train cars.
2. Equation 10 modified to include stress due to axial friction forces caused by thermal expansion and soil interaction.
3. Equation 11 modified to include stress due to axial friction forces caused by thermal expansion and soil interaction.
4. Stresses must meet Equation 10M or 11M, not both.
5. Buried piping systems must be designed to meet the external pressure load criteria of NC/ND-3133 of the ASME Code.

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping

Service Condition	Service Level	Category	Loading or Stress Component	Acceptance Criteria(1)
Design	-	Primary Stress	Design Pressure, Deadweight, Steady State Flow Load and Dynamic Fluid Load[2] specified as Level A	Eq 9 NB-3652
Normal	A	Primary plus Secondary Stress Intensity Range (S.I.R.)	Range of Level A: Service Pressure, Steady State Flow Load, Dynamic Fluid Load, Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3], Cyclic Thermal Load[4], Material Discontinuity Stress	Eq 10 NB-3653.1
		Peak S.I.R.	Same as for Level A Primary plus Secondary S.I.R. plus Range of Level A Thermal Radial Gradient Stress (linear and non-linear)	Eq 11 NB-3653.2
		Thermal Bending S.I.R.[5]	Range of Level A: Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3], Cyclic Thermal Load	Eq 12 NB-3653.6(a)
		Primary plus Secondary Membrane plus Bending S.I.R.[5]	Same as for Level A Primary plus Secondary S.I.R. except Range of Level A Thermal Expansion Load, Thermal Expansion Anchor Motion Load and Cyclic Thermal Load is not Considered	Eq 13 NB-3653.6(b)
		Alternating Stress Intensity (S.I.) (Fatigue Usage)[6]	Same as for Level A Peak S.I.R.	Eq 14 NB-3653.6(c)
		Thermal Stress Ratchet	Range of Level A Linear Thermal Radial Gradient	NB-3653.7

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping (Continued)

Service Condition	Service Level	Category	Loading or Stress Component	Acceptance Criteria
Upset	B	Permissible Pressure	Maximum Level B Service Pressure	NB-3654.1
		Primary Stress	Coincident Level B Service Pressure, Deadweight, Steady State Flow Load, Dynamic Fluid Load	Eq 9U NB-3654.2(a)
		Primary plus Secondary S.I.R.	Same as for Level A Primary plus Secondary S.I.R. (except Level B Load and Stress Ranges are used)	Eq 10 NB-3654.2(b)
		Peak S.I.R.[7]	Same as for Level B Primary plus Secondary S.I.R. plus Earthquake Inertial Load[8] plus Range of Level B Thermal Radial Gradient Stress (linear and non-linear)	Eq 11 NB-3654.2(b)
		Thermal S.I.R.[5]	Range of Level B: Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3], and Cyclic Thermal Load	Eq 12 NB-3654.2(b)
		Primary plus Secondary Membrane plus Bending S.I.R.[5]	Same as for Level B Primary plus Secondary S.I.R. except Range of Level B Thermal Expansion Load, Thermal Expansion Anchor Motion Load and Cyclic Thermal Load is not Considered	Eq 13 NB-3654.2(b)
		Alternating S.I. (Fatigue Usage)[6]	Same as for Level B Peak S.I.R.	Eq 14 NB-3654.2(b)
		Thermal Stress Ratchet	Range of Level B Linear Thermal Radial Gradient	NB-3654.2(b)
		Deformation Limits	As Set Forth in the Design Specification	NB-3654.2(b)

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping (Continued)

Service Condition	Service Level	Category	Loading or Stress Component	Acceptance Criteria
Emergency[9]	C	Permissible Pressure	Maximum Level C Service Pressure	NB-3655.1
		Primary Stress	Coincident Level C Service Pressure, Deadweight, Steady State Flow Load, Dynamic Fluid Load	Eq 9E NB-3655.2(a)
		Deformation Limits	As Set Forth in the Design Specification	NB-3655.3
Faulted	D	Permissible Pressure	Maximum Level D Service Pressure	NB-3656(a)(1)
		Primary Stress[10]	Coincident Level D Service Pressure, Deadweight, Steady State Flow Load, Dynamic Fluid Load[11], Earthquake Inertial Load[11], High Energy Line Break Load[11] (Loss-of-Coolant Accident or Secondary Side Pipe Rupture)	Eq 9F NB-3656(a)(2)
		Secondary Stress	Range of Axial Force and Range of Bending Moments due to Earthquake Anchor Motion Load	NB-3656(b)(4)
Pressure Testing[12]	-	Primary Membrane S.I.	Test Pressure, Deadweight	NB-3657 NB-3226(b)
		Primary Membrane plus Bending S.I.	Test Pressure, Deadweight	NB-3657 NB-3226(c)

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping (Continued)

Notes:

1. Acceptance Criteria are taken from the referenced section in Section III of the ASME Boiler and Pressure Vessel Code.
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 150F.
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 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 12).
7. 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.
8. The Earthquake Inertial Load considered in the Level B Peak Stress Intensity Range and Alternating Stress Intensity calculations (Equations 11 and 14) is taken as 1/3 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 shall be considered. If the earthquake inertial load is taken as 1/3 of the peak SSE inertial load then the number of cycles to be considered for earthquake loading shall be 300 (the equivalent number of 20 full SSE cycles as derived in accordance with Appendix D of IEEE Standard 344-1987[8]). If the earthquake inertial load is taken as the peak SSE inertial load then 20 cycles of earthquake loading shall be considered.
9. If a piping system is subjected to more than 25 Emergency Condition transient cycles which result in an alternating stress intensity (S_a) value greater than that for 10^6 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 are combined considering the time phasing of the events (i.e. whether the loads are coincident in time). When the time phasing relationship cannot be established, dynamic loads are combined by absolute sum. SSE and High Energy Line Break (i.e. Loss-of-Coolant Accident and Secondary Side Pipe Rupture) loads are always combined using the Square-Root-of-the-Sum-of-the-Squares method.
12. If a piping system is subjected to more than 10 Pressure Test cycles which result in an alternating stress intensity (S_a) value greater than that for 10^6 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.

From: Getachew Tesfaye
To: DAFLUCAS Ronda M.
Date: Thu, Aug 23, 2007 6:12 AM
Subject: Fwd: Review of EPR Topical Report - BNL's Comments

Ronda,
Attached please find BNL's comments on your responses to the Piping TR RAIs. Please let's know when we can have a conference call to discuss these comments. Next week will not be good for BNL.
Thanks,
Getachew Tesfaye
NRO/DNRL/NARP

CC: Arnold Lee; Larry Burkhart; Tarun Roy

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Subject: Fwd: Review of EPR Topical Report - BNL's Comments
Creation Date Thu, Aug 23, 2007 6:12 AM
From: Getachew Tesfaye

Created By: GXT2@nrc.gov

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REQUESTS FOR ADDITIONAL INFORMATION (RAI) RESPONSE EVALUATION

AREVA Topical Report ANP-10264NP (Rev. 0) for U.S. EPR Piping Analysis and Pipe Support Design

RAI Topic	RAI Description	AREVA Response	BNL Disposition
Piping and Pipe Support Design - General	**RAI EPR-1:** Section 1.0 of the Topical Report (TR) states that the reactor coolant loop (RCL) and pressurizer surge line piping requirements, modeling techniques, analysis approaches and acceptance criteria are not specifically addressed in this document and will be included in the design control document (DCD). The TR presents nearly all of the design certification requirements, acceptance criteria, analysis methods and modeling techniques for the American Society for Engineers (ASME) Class 1, 2 and 3 piping and pipe supports, as required in the Standard Review Plan (SRP) Section 3.12 for new reactors. Describe any significant differences between the requirements, techniques, approaches and design criteria for the RCL and pressurizer surge line piping, and those included in the TR.	Reactor Coolant System large bore piping requirements, modeling techniques, analysis approaches and acceptance criteria are not specifically addressed in the TR because of the major differences in mathematical modeling and model loading approaches and techniques that exist between the RCL structural analysis and Class 1 piping analysis. The RCL loop structural model includes representation of the nuclear island basemat and the Interior Concrete Structure (ICS), to which the RCL supports are attached, as well as very detailed representations of the primary components and their internals. In addition, in most cases, the RCL supports are explicitly represented in the model. Class 1 piping models do not include representations of the supporting concrete structures or detailed representations of components, and the supports are not typically explicitly modeled. The method of seismic loading is also quite different, with the RCL loop structural model being loaded through application of	**Acceptable.**

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		basemat excitation to the base of the ICS, whereas Class 1 piping models are loaded through the application of attachment point response spectra (or time histories), floor response spectra (or time histories) and seismic anchor motions at the various support locations in the model. Other aspects of RCL structural analysis are the same as those described for Class 1 piping in this TR, aspects such as damping requirements, load combinations, mass distribution requirements, cut-off frequency requirements, and applicable ASME stress and fatigue allowables. A thorough description of the approaches and methods employed in the structural, stress and fatigue analysis of the RCL piping will be included in Chapter 3 of the U.S. EPR Design Control Document.	
ASME B31.1 and Section XI Codes	**RAI EPR-2:** A. In accordance with RG 1.26, Quality Group (QG) D piping that may contain radioactive material is considered to be outside the ASME Code Class 1, 2, and 3	A. The U.S. EPR piping systems containing radioactive material (outside the Reactor Coolant Pressure Boundary) are classified as Quality Group D and are designed to ASME B31.1, 2004.	**A. Acceptable.** AREVA needs to change the TR Section with the proposed text.

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	piping systems. The Regulatory Guide (RG) recommends that these piping and pipe supports are to be designed in accordance with the requirements of the ASME B31.1, "Power Piping" Code. Please clarify if the Evolutionary Power Reactor (EPR) piping and pipe supports will have QG D systems; and confirm that whether EPR piping design will use the ASME B31.1 Code for these systems, otherwise provide technical justification for using other than the B31.1 Code requirements for the QG D piping systems. B. Confirm that ASME Code Section XI requirements will be used in the piping and pipe support design for EPR.	Section 1.0 and 2.1 of the TR will be revised to include the following text: "Quality Group D piping will be analyzed to ASME B31.1, 2004 Edition, no addenda." B. The U.S. EPR adheres to the requirements of the ASME XI, 2004 Edition, no addenda. No Section XI code cases are used for the U.S. EPR.	**B. Not Acceptable** 10 CFR 50.55a has not yet endorsed 2004 Edition. Justify using this edition of the ASME Code.
10CFR50.55a(b) Limitations and	<u>**RAI EPR-3:**</u> Section 2.1 of the TR states that for the dynamic loads, including seismic loads,	The limitations of 10CFR50.55a(b)(1) are considered in the U.S. EPR design as follows:	**Not Acceptable.** Explain why the limitations in items (v) and (vi) are not

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Modifications	the pipe stress analyses will be performed in accordance with the Sub-articles NB/NC/ND-3650 of the 1993 Addenda of the ASME Code as required by 10CFR50.55a(b)(1)(iii). However, AREVA did not address other limitations and modifications (related to Section III materials, weld leg dimensions, etc.) applicable to piping system design as included in 10CFR50.55a(b)(1). Explain how all limitations and modifications specified in 10CFR50.55a(b) will be satisfied.	• (b)(1)(i) Section III "Materials" – This is not considered for the U.S. EPR because it addresses the application of 1992 Edition of ASME. The U.S. EPR uses a later version of the code. • (b)(1)(ii), "Weld leg dimensions" is incorporated into the U.S. EPR design. • (b)(1)(iv) "Quality Assurance" – U.S. EPR Quality Assurance program is developed for a later edition of the code. This restriction does not apply to the U.S. EPR. • (b)(1)(v) – Independence of Inspection – The inspection program for the U.S. EPR will not apply NCA-4134.10(a). • (b)(1)(vi) Subsection NH – The U.S. EPR will not use Type 316 stainless pressurizer heater sleeves above a service temperature of 900°F. For clarity, Section 2.1 of the TR will be revised to include the following text: "Piping analysis and pipe support design for the U.S. EPR addressed in this Topical Report use the 2001 ASME Code, Section III, Division 1, 2003 addenda as the base code with limitations identified in the Code of	applicable to EPR. If the US EPR meets these limitations, then why aren't these 2 items simply included in the proposed text that states the design meets the 2001 ASME Code, Section III, Division 1 through the 2003 addenda with limitations in 10CFR50.55a(b)(1) (ii) Weld Leg, (iii) Seismic, (v) Independence of Inspection, and (vi) Inspection NH, and other limitations (i) Section III-Materials and (iv) Quality Assurance do not apply?

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		Federal Regulations, 10 CFR 50.55a(b)(1)(ii) "Weld leg" and (iii)" Seismic" and "All other limitations of 10CFR50.55a(b)(1) do not apply to the U.S. EPR."	
Mathematical Modeling	<u>**RAI EPR-4:**</u> Mathematical Modeling TR Section 4.2 states that the seismic analysis methods for seismic Category I systems to withstand the effects of a safe shutdown earthquake (SSE) and to maintain the capability of performing their safety function will use the methods in accordance with SRP 3.7.3. A. Describe the mathematical representation of a piping system, including the development of the mass, stiffness, and damping matrices in the analytical model, that will be used in the three methods of analysis (i.e., response spectrum, time history, and equivalent static load methods).	 A. A description of the mathematical modeling techniques is presented in TR Section 5.2. A section cross reference will be added to Section 4.2. Section 4.2 will be revised to incorporate the following text: "The seismic response of a piping system is determined by developing a mathematical model of the system suitable for calculating the response of	 **A. Acceptable.** AREVA needs to change the TR Section with the proposed text.

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	Also, discuss the types of loading functions that will be used in each of these methods of analysis.	the system to the seismic input. Dynamic equilibrium equations are formulated for the system using the direct stiffness method. In this method, the element stiffness matrices are formed according to virtual work principles and assembled to form a global stiffness matrix for the system relating external forces and moments to nodal displacements and rotations. Details on the dynamic piping model can be found in Section 5.2. Once the mathematical model has been established, dynamic equilibrium equations are solved to determine the seismic response of the system by performing either a modal analysis by either the Response Spectrum Method or Time History Method. Alternatively, the Direct Integration Time History Method and, where applicable, the Equivalent Static Load Method may be used."	
	B. Confirm if these methods of analysis will be limited to an	B. The modeling techniques in TR Section 5.2 are used for elastic analysis.	**B. Acceptable.**

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	elastic basis. If not, discuss the application limits for these three methods. C. Identify conditions or limits when each of these three methods of analysis will be used in obtaining the piping system responses.	C. Factors considered when choosing the analysis method to be used for a given piping configuration include complexity of the system, type of loads to be included in the analysis, class of piping (ASME 1,2, 3 or non-seismic) and analysis tools available. In general, for seismic load cases, response spectra (RS) and time history (TH) will produce similar results with TH producing acceptable results that are not as conservative as RS. Class 1 piping analysis which requires considerably more detail may be analyzed by TH methods although RS will yield acceptable results. Time history is also used when transient loads due to pipe break, water hammer or other dynamic events are anticipated and static analysis produces a high level of conservatism. Class 2/3 and non seismic piping analysis is generally analyzed using RS methods. Equivalent static analysis can only be used on Class 2/3 and non seismic piping 2 NPS and smaller where the piping	**C. Acceptable.**

REQUESTS FOR ADDITIONAL INFORMATION (RAI) RESPONSE EVALUATION

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	D. Discuss the analysis methods that will be used in the design of non-seismic Category I (or seismic Category II) piping systems.	configuration can be reduced to simple models. D. Non-seismic piping that interacts with seismic systems will be analyzed by RS or equivalent static methods.	**D. Not Acceptable.** Describe the analysis methods to be used in those seismic Category II piping which do not interact with seismic Category I piping.
Piping Analysis Methods	**<u>RAI EPR-5:</u>** After constructing a mathematical model to reflect the static or dynamic characteristics of the piping system, describe the step by step computations (e.g., static analysis, modal analysis, modal participation factors) that may be performed to obtain the piping system response for each of the three methods of analysis (i.e., response spectrum, time history, and equivalent static load methods).	Section 4.2.2 will be revised to include the step by step computations for response spectra analysis. Section 4.2.2 will be revised as provided in Attachment A to this document. Section 4.2.3 will be revised as follows to address the computations when Time History Analysis is employed: "The modal superposition method of time history analysis is used for seismic piping analyses with acceleration time history seismic input. This method is based on decoupling of the differential equations of motion, considering a linear elastic system, using the same	**Not Acceptable.** Regarding the proposed changes in Section 4.2.4, the staff position on the case of a factor of 1.0 is as follows: For cases where a piping configuration can be demonstrated to respond as a single degree of freedom system with a known fundamental frequency or rigid system with a fundamental frequency beyond the cutoff frequency, a factor of 1.0 may be used with the highest spectral acceleration at that frequency or any higher frequency (as may be the case for multiple peak input spectra). The

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		method as that described in Section 4.2.2." "The Direct Integration Time History Analysis method may be used as an alternative to the modal superposition time history analysis. In this method the differential equation of motion, as provided in Section 4.2.2, is solved directly on the uncoupled equations without transformation. Rayleigh damping, or mass and stiffness damping, is used when direct integration time history analysis is performed." Section 4.2.4 will be revised to include the following: "For cases where piping configurations are calculated as single degree of freedom systems with known fundamental frequencies or rigid systems with fundamental frequencies beyond the cutoff frequency, a factor of 1.0 may be used with the spectral accelerations at that frequency. Mathematically the seismic force F1 on a mass point in one (1) direction is	proposed text for the Section 4.2.4 are not consistent with the staff position. Therefore, address this inconsistency.

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		represented as: $F_1 = kmS_a$ Where: k = 1.0 for single degree of freedom or rigid system k=1.5 for multiple degree of freedom system m = mass in direction 1 Sa = value of acceleration from response spectrum The forces from each of the three orthogonal directions of earthquake are applied to calculate seismic stresses and then combined by SRSS to calculate overall seismic stresses."	
Piping Analysis Criteria	<u>**RAI EPR-6:**</u> A. SRP Section 3.9.2, Item II.2.A(i)(3) requires an investigation for a sufficient number of modes to be included in the piping modeling to ensure that all significant modes have participated in the analysis. Provide the criterion that would ensure this requirement.	A. The criterion for the inclusion of sufficient number of modes stated in SRP 3.9.2 II A(i)(3) is that the "inclusion of additional modes does not result in more than a 10-percent increase in responses." All modes with frequencies below the ZPA frequency are included in the piping analysis. Above this frequency, in the rigid range, the effects of all additional modes are included by the application of the missing mass	**A. Acceptable.**

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	B. The cutoff frequency for modal responses is defined as the frequency at which the spectral acceleration approximately returns to the zero period acceleration (ZPA) of the input response spectrum. Define this cutoff frequency qualitatively or quantitatively for seismic and other building dynamic loads (if any) applicable to the piping analysis for the EPR.	correction as discussed in TR Sections 4.2.2.3.2 and 4.2.3. B. The cutoff frequency for a given spectra is the frequency at which the response curves for all damping values converge to the same acceleration value (ZPA) and remain at this value for all frequencies above this cutoff frequency. Section 4.2.2.3 will be revised to add, "For the U.S. EPR the cutoff frequency is 50 hertz or as defined by figure 2 and 3 in RG 1.92, Rev 2."	**B. Not Acceptable.** Either provide technical justification for the selection of 50 Hz as the cutoff frequency or commit to the criteria as defined in Figure 2 and 3 in RG 1.92, Rev 2. Also, note that the resolution of this also applies to the text proposed for RAI EPR-9.
Branch Pipe Inputs	<u>RAI EPR-7:</u> When a small seismic Category I or non-seismic Category I piping is directly attached to seismic Category I piping, it can be decoupled from seismic Category I piping if it satisfies the decoupling criteria. However, the TR did not describe how the inputs for the small branch piping will be determined for both inertial and seismic anchor motion (SAM) response analyses	The model of a decoupled Class 1 branch line includes an anchor where the branch line connects to the RCL. The seismic inertial analysis of the RCL yields time histories at branch connections and equipment nozzles. The inertial seismic analysis results then become input into the Class 1 branch line seismic analysis in the form of time histories or response spectra which are generated from the time histories using classical response spectra generation techniques. If	**Not Acceptable.** Note the following: (a) The reference to RG 1.60 R1 for the ±15% spectra broadening should be RG 1.122 R1. (b) For the remaining decoupled branch lines not connected to the RCL, the amplification of the RS and SAM at the small pipe connection locations should be used in the analysis, as in the case of the RCL. The method presented in the responseis not in

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	when the piping system is decoupled from a large pipe run or connected to flexible equipment connections. The staff notes that computer code RESPECT (TR Section 5.1.8) generates seismic amplified response spectra at the branch nozzle locations in a model of a piping system. Describe the seismic analysis methods and procedures, including the input response spectra and input SAM displacements, that apply to the small branch piping design when decoupled from a large run pipe or connected to flexible equipment. The description should also discuss how any amplification effects and SAM effects, from the main run pipe at the attachment to the small branch pipe, are considered.	response spectra are used, they are peak broadened by ±15% in accordance with RG 1.60 R1 before application to the Class 1 branch line model. The analysis of the Class 1 branch line also considers seismic movements generated from the RCL (seismic anchor motions), which are applied as static displacements at the branch-to-RCL anchor. This analysis captures the effects of run pipe amplification on the branch pipe. For the remaining decoupled branch lines (not connected to the RCL), the model of a decoupled branch line includes an anchor at the run to branch intersection. The analysis of the branch line includes all anchor movements greater than 1/16" from the run pipe applied at the run to branch anchor for all load cases. The inertial seismic input for the branch line comes from the appropriately applied building and/or flexible equipment spectra based on support configurations and the inertial movements from the run pipe. The decoupling criterion stated in the TR	agreement with this approach, and therefore, the technical basis for the treatment of the inertial effects of the main run (large diameter piping) needs to be provided. The technical basis shall also explain what input spectra will be used at the branch-to-run pipe anchor in the method when performing the dynamic analysis of the branch line. Note that the envelope of building excitations for the nearest supports on the branch pipes alone may be acceptable only on case-by-case basis, when it can be demonstrated that there is no significant amplification caused by the main run piping at the branch pipe anchor connection.

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		assures that the run pipe is rigid compared to the branch pipe and no amplification effects are considered. The last paragraph of Section 5.4.2 will be changed to the following: "The branch pipe analysis must include more consideration for the effects of the run piping. The branch point is considered as an anchor in the analysis of the branch pipe with the same SIF and/or stress indices as the run pipe at this point. The movements (displacements and rotations) of the run pipe at the branch intersection due to statically applied loads in the run pipe analysis (such as thermal and seismic anchor movement (SAM)) shall be applied as anchor movements with their respective load cases in the branch line analysis. The inertial effects of the run pipe on the branch line are considered in one of the following methods: • For branch lines decoupled from the RCL, the inertial input to the branch line is generated from the analysis of the RCL. The analysis of the RCL yields	

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		time history responses at the branch connections and equipment nozzles. This time history response of the RCL, or a response spectrum generated from the time history response, is then applied as the input inertial excitation at the branch-to-RCL intersection. This method may also be used for decoupling pipe from flexible equipment if the response of the equipment is known. • For other decoupled lines, the effects of inertial loads from the run pipe on the branch line are captured through the proper application of the building excitation and the inertial movements from the run pipe analysis. At the branch-to-run pipe anchor, the applied inertial excitation to be included in the branch line analysis shall include the envelope of building excitations for the nearest supports on both the branch and run pipes. The inertial movements of the run pipe at the branch intersection are obtained from the run pipe analysis. These movements are statically applied, in individual load cases for each direction, at the branch-	

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		to-run pipe anchor. The results of these statically applied load cases are combined by the square root sum of squares (SRSS) to capture the effects of the inertial movement of the run pipe on the branch line. These results are then combined with the inertial analysis of the branch line by absolute summation to obtain the total inertial response."	
Independent Support Motion Method	**RAI EPR-8:** The current staff position for the Independent Support Motion (ISM) method of analysis is presented in Volume 4, Section 2 of NUREG-1061, "Report of the US NRC Piping Review Committee. "Some differences (e.g., modal combinations per RG 1.92 for uniform support motion (USM) only) were noted between the ISM method of response combinations (both methods and their sequence) presented in the TR Section 4.2.2.2.2, and the method given in NUREG-1061. Indicate whether all of the	The provisions of NUREG-1061 for the ISM method of analysis will be followed. Specifically, level (group) results will first be combined using the absolute summation method. This will be followed by modal combinations by SRSS (without consideration of closely spaced modes) and directional (spatial) result combinations by SRSS. If Inertia and SAM results are combined for stresses, they will be combined using the SRSS method when using ISM. The following revisions to the TR will be made for clarification: Section 4.2.2.2.2 will be revised to	**Not Acceptable.** NUREG-1061 also provides guidance for the high frequency mode combinations as well as combination of high frequency modes with low frequency modes. Clarify if these methods are also included in the EPR piping design and revise the TR to include these criteria as well.

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	provisions (for groups, modes, spatial and inertial and SAM combination methods) contained in NUREG-1061 for the ISM method of analysis will be followed or provide the technical justification for any alternatives or methods described in the TR.	include a reference to NUREG-1061, Volume 4 as follows: "When using independent support motion, the seismic response of each mode is calculated by combining the responses of all support groups into one by using absolute summation method per the recommendations of NUREG-1061, Volume 4." Section 4.2.2.3.1 will be revised to add the text "performed using USM" as follows: "RG 1.92 provides guidance on combining the individual modal results due to each response spectrum in a dynamic analysis *performed using USM"* (emphasis added). and add the following text: "For piping systems analyzed using ISM methods, modal results are combined without the consideration of closely spaced modes, per NUREG-1061. Therefore, for these systems, modal results are combined by the SRSS method presented above."	

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		Section 4.2.2.5 will be revised to read as follows: "The analysis of these seismic anchor motions (SAM) will be performed as a static analysis with all dynamic supports active. The results of this analysis shall be combined with the piping system seismic inertia analysis results by absolute summation when an enveloped uniform support motion is used for the dynamic analysis, per SRP 3.7.3. When independent support motion is used in the inertial analysis, the responses due to the relative displacements and those due to inertia are combined by the SRSS method, per NUREG-1061."	
Time History Analysis Using Modal Superposition Method	<u>RAI EPR-9:</u> Since many of the dynamic loads specified in the TR, using the time history method of analysis, may have a short duration and contain very high frequency content, the use of the modal superposition method must consider all modes up to the appropriate cutoff	Missing mass will be accounted for in time history modal superposition analyses in accordance with Appendix A of RG 1.92, Rev. 2. The TR Section 4.2.3 will be revised to address this RAI as follows: "The mode shapes and frequencies are	**Not Acceptable.** The staff assessment for using 50 Hz as the cutoff frequency is presented in RAI EPR-6.

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	frequency as well as the missing mass contribution. Discuss how the proposed modal superposition method will address these considerations in accordance with RG 1.92, Rev.2.	determined as they are in response spectrum analysis. The cutoff frequency for the determination of modal properties is 50 Hz, as this is expected to encompass all of the important response frequencies of the system. Missing mass effects of the high frequency modes beyond the cutoff frequency are included via the Missing Mass Method described in Regulatory Position C.1.4.1 and Appendix A of RG 1.92, Rev. 2."	
Time Step for Time History Analysis	**RAI EPR-10:** In a time history analysis, the numerical integration time step, Ät, must be sufficiently small to accurately define the dynamic excitation and to ensure stability and convergence of the solution up to the highest frequency of significance. In TR Section 4.2.3, AREVA indicates that for the most commonly used numerical integration methods, the maximum time step is limited to one-tenth of the shortest period of significance. However, this is	The integration time step used in time history analyses will be taken as 1/50 (or smaller) of the shortest period of importance or a time step study will be performed. The TR Section 4.2.3 will be revised to incorporate the responses to this RAI as follows: "The integration time step used in time history analyses will be 1/50 (or smaller) of the shortest period of importance for the system in question. Alternatively, the initial integration time	**Not Acceptable.** The first criterion states that the integration time step used in time history analyses will be 1/50 (or smaller) of the shortest period of importance for the system in question. Explain how the shortest period of importance is defined and how this would ensure the convergence of the time history analysis?

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	typically selected for choosing an initial time step which is later checked against analysis results and their stability and convergence. An acceptable approach for selecting the time step, Δt, is that the Δt used shall be small enough such that the use of ½ of Δt does not change the response by more than 10%. Indicate whether this is part of the analysis requirements for time history method of analysis or provide a technical justification for not considering this criterion along with the criterion for initially choosing the time step described for seismic and other dynamic loading analyses.	step will be set to no larger than one-tenth (1/10) of the cut-off frequency and a time step study will be performed: the integration time step will be halved until it can be shown that halving it further will not increase the response of the system by more than 10%."	
Time History Analysis Uncertainties	**RAI EPR-11:** TR Section 4.2.3 states that to account for uncertainties in the structural analysis using the time history method, similar to peak shifting in the response spectrum method of analysis, three separate input time histories with		

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	modified time steps will be analyzed. Alternatively, the time histories at the attachment points may be derived considering variations in the concrete stiffness.		
	A. Describe the detailed procedure for using the peak shifting method that will be used in the time history method of analysis with modified time steps for seismic and other dynamic loadings.	A. The method of accounting for uncertainties in time history analysis will be further described in the TR, as indicated below. The fifth paragraph of TR Section 4.2.3 will be revised to incorporate the responses to this RAI as follows: "To account for uncertainties in the structural analysis for seismic loading, a peak shifting approach, similar to that described in Section 4.2.2.1.2 for response spectrum analysis, is used. This is accomplished by first converting the seismic time history excitations into response spectra, and then proceeding through the methodology outlined in Section 4.2.2.1.2. Note that shifting of the input excitation peaks is	**A. Not Acceptable.** More detailed explanation should be provided about this approach, which should also include: (1) The response indicates that the starting point is "seismic time history excitations." Does this mean that there are multiple sets of time histories in each of the orthogonal directions for each support or a single set. If multiple sets, then are the results from all of these time history analyses enveloped? (2) Do these different sets of time histories correspond to different supports or one set of time histories for all supports which bound the excitation at all supports?

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		accomplished by adjusting the time step of the time histories which represent the excitations."	(3) Clarify the steps following the development of the shifting factor presented in TR Section 4.2.2.1.2.
	B. Describe all of the dynamic loads for which the time history will be adjusted to account for material and/or modeling uncertainties and provide the basis for the amount of the adjustment.	B. Topical Report will be revised to clarify that methods used to account for uncertainties will only be used in seismic analysis as the intent is to approximate the effect of the application of peak broadened spectra in a response spectrum analysis. The time step compression/expansion approach to account for uncertainties will be clarified and equated to the peak shifting method used in response spectrum analysis as described in TR Section 4.2.2.1.2.	**B. Acceptable.** AREVA needs to revise the TR Section.
	C. Explain how the time histories at the attachment point derived considering variations in the concrete stiffness are alternate to the peak shifting method to be used in the time history method of analysis. Also, provide the percentage variations in the concrete stiffness to be used in the EPR piping design.	C. The approach of considering variations in concrete stiffness to account for uncertainties in seismic time history analysis will be removed from the TR.	**C. Acceptable.** AREVA needs to revise the TR Section.

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Equivalent Static Load Analysis	RAI EPR-12: Confirm that the equivalent static load is always determined by multiplying 1.5 to the peak acceleration for all cases including a single degree of freedom system with known fundamental frequency or a rigid system with the fundamental frequency beyond the cutoff frequency. If not, then provide the criterion that will be used for these special cases.	For clarity, Section 4.2.4 will be revised to include the following text: "For multiple degree of freedom systems, the peak acceleration of the appropriate floor response spectra will be multiplied by 1.5. For cases where piping configurations are calculated as single degree of freedom systems with known fundamental frequencies or rigid systems with fundamental frequencies beyond the cutoff frequency (ZPA), a factor of 1.0 may be used with the spectral accelerations at that frequency."	**Not Acceptable.** The staff assessment for the equivalent static load method is presented under RAI EPR-5.
Small Bore Piping	RAI EPR-13: The TR did neither define nor address the design of small bore piping to be used in the EPR piping design. Define the small bore piping to be used in the EPR piping design and discuss, with technical bases, the methods of analysis (handbook or a system flexibility analysis) that will be used in the small bore piping design for ASME Class 1, 2, 3 and QG D piping.	Section 4.5 of the TR will be added to include the following text: "Small bore piping for the U.S. EPR is defined as ASME Class 1 piping that is 1" NPS and smaller and Class 2, 3 and QG D that is 2" NPS and smaller. This piping may be analyzed using response spectrum methods described in 4.2.2 of the Topical Report, the equivalent static method described in 4.2.3 or by handbook method."	**Not Acceptable.** For the case of the handbook method to be developed by the COL applicant, either include the criteria for the approach in the TR or this should be noted in the TR as a COL action item in TR Table 1-1. In addition, confirm that the criteria provided for the small bore piping also is intended to cover instrumentation lines. Include this in the TR.

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		If the COL applicant elects to use the handbook method, the COL applicant will develop the handbook.	
Non-Seismic/ Seismic Interaction	<u>**RAI EPR-14:**</u> A. TR Section 4.4.1 states that non-seismic piping which cannot be completely separated from seismic systems is routed as far away as possible. With examples, please discuss under what conditions this type of isolation is used in the EPR piping design and also, quantify the meaning of "as far away as possible."	A. Section 4.4.1 states "Non-seismic piping which cannot be completely separated from seismic systems is routed as far away as possible." The sentence in the TR stems from standard seismic "II over I" layout guidance, which would, for example, have two piping systems in the same room (one seismic and one non-seismic) be physically located away from each other as much as possible, such that there will be little chance of the non-seismic piping adversely interacting with the seismic piping, potentially causing damage to the seismic piping during a seismic event. In addition to the physical separation distance used in common areas, the layouts utilize physical barriers within the area, such as large equipment items which can provide obvious protection for the seismic system from the potential effects of the damaged	**A. Acceptable.** AREVA needs to change the TR Section with the proposed text.

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		nonseismic system. The present guidance is that any non-seismic piping in a common area with seismic piping has been upgraded to a Seismic Class II status to preclude any potential adverse interactions between the two. For clarity, the sentence in the TR will be revised as follows: "Non-seismic piping which cannot be completely separated from seismic systems must be shown to have no interaction with the seismic systems based on separation distance or an intermediate barrier, or be classified as Seismic Category II piping."	
	B. TR Section 4.4.2 states that following the failure of the non-seismic pipe, (i) if the nonseismic piping is supported by seismic restraints within the ASME B31.1 Code suggested pipe support spacing shown in TR Table 4-1, it is considered to lose its pressure boundary integrity, but not fall onto a safety-related piping or	B. (i) Table 4-1 provides the maximum deadweight support spacings, as provided in the B31.1 Code for proper deadweight supporting of B31.1 piping. It is possible that supports may exist for a piping line which will provide restraint to the piping during a seismic event (such as rigid guide supports), but are not seismically analyzed. If these supports are placed within the B31.1 deadweight spacings, such a supporting	**B(i). Not Acceptable.** The response does not provide technical justification which demonstrates that supports (not seismically analyzed) would provide adequate restraint for the piping to prevent their collapse, such that the margin of safety is equivalent to that of the Category I piping as required by SRP Section 3.7.2.II.8. This needs to

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	equipment. Provide the technical basis for this assumption.	scheme will provide a level of seismic restraint to the piping. There is still the potential in this case for plasticity of the piping and the supports, however it can be expected that the piping will not fall, but likewise may be expected to not necessarily remain functional. The support scheme from B31.1, which will limit deadweight deflections to less than 1/8 inch, and deadweight stresses to approximately 1,500 psi, should in turn also provide reasonable seismic supporting to accomplish prevention of the pipe falling.	also be demonstrated for the piping as well. This needs to be addressed and the TR revised accordingly.
	(ii) the side motion of a failed moderate energy piping is assumed to be ±6 inches (centerline to centerline) from the original position. Provide the technical basis for this assumption of ±6 inches side motion for all pipe sizes.	(ii) The six inches of side motion assumed for a falling non-seismic pipe is based on Section D.2.1 of Appendix D of the SQUG Generic Implementation Procedure. The Appendix is entitled "Seismic Interaction" and contains the following phrase for consideration of seismic interaction of distribution systems due to lateral movements: "...and 6 inches for relatively flexible systems would normally be adequate to prevent impacts...."	**B(ii). Not Acceptable.** The guidance provided in the SQUG Generic Implementation Procedure is applicable to verification of the seismic adequacy of equipment in existing plants, not for the design of new plants. In addition, if a non-seismic pipe fails at one location, it can rotate and deform much more than 6 inches at the other end that is still attached.

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	(iii) safety-related piping with NPS and thickness equal to or greater than that of the non-seismic piping may be assumed to stop the downward motion of the nonseismic piping without failure of the safety-related piping. Provide the technical basis for this assumption.	(iii) Per Section III.2 of SRP 3.6.2, an unrestrained whipping pipe is not postulated to cause breaks or cracks in target pipes of equal or larger diameter and thickness. This justification also applies to a falling non-seismic pipe, where failure of its supports has occurred.	Therefore, provide justification requested in the RAI or revise the criteria. **B(iii). Not Acceptable.** Pipe break criterion is not applicable for evaluating the seismic adequacy of seismic Category I piping subjected to the collapse of non-seismic Category I components. Also, there are conditions where the criterion given in the response would not be applicable. One such case as if the end of a section of pipe falls first, it could pierce the Category I pipe even if the Category I pipe has a larger diameter and thickness. Therefore, provide justification for the approach in the TR or revise the criteria.
Buried Piping	<u>RAI EPR-15:</u> TR Section 3.10 did not give details on the analysis method and how the criteria are to be applied in the design of buried piping. A. Based on the criteria	A. Section 3.10 of the TR will be revised to include analysis methods and design requirements for buried piping, as shown in Attachment B to this response. The methods developed for the U.S. EPR buried piping meet	**A & B. Not Acceptable.** Note the following: (i) The last equation given in Section 3.10.1.3 does not appear to be correct. (ii) In Section 3.10.1.1, the use of

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	presented in the TR, describe the analysis method and design requirements that will be used for buried piping design (including buried pipe tunnel if used in the design). Explain how these methods compare to the analytical methods referenced in the recently published NRC Standard Review Plan 3.7.3, Rev. 3, (i.e., ASCE Standard 4-98, ASCE Report - Seismic Response of Buried Pipes and Structural Components, and NUREG/CR-1161). B. Why doesn't TR Section 3.10 include consideration of ground-water effects and soil arching effects which could increase or decrease the stresses in the pipe due to the overlying soil plus the ground surface loads?	requirements in SRP 3.7.3, Rev. 3, NUREG/CR-1161, ASCE Standard 4-98 and ASCE Report-Seismic Response of Buried Pipes and Structural Components. B. Section 3.10 will be revised to include buoyancy forces from ground-water, overburden and surface traffic from trucks, rail and construction equipment, as shown in Attachment B to this response.	the external pressure Px due to the overburden soil can be used to determine the required pipe wall thickness in accordance with NC/ND-3133. However, the statement that the external pressure counteracts the internal pressure is not always true since there would be conditions when the internal pressure would be zero. The design should also consider this condition. (iii) For stress analysis of buried pipe the external pressures Px, Ps, and Pv are not normally treated as external radial pressure loads which would reduce the internal pressures. These soil pressures are generally represented as vertical loads acting on the top upper half of the pipe cross section (see NUREG/CR-6876, Section 5). In view of this, what is the technical basis for defining P=internal pressure +Px+Ps+Pv in Section 3.10.1 and are all of the values always treated as positive? If not,

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			then see item (ii) above. (iv) Where are Tables 3-5 and 3-6, which referred to in Section 3.10.1.4? (v) The equation for thermal-induced stress and equations 10M and 11M given in Section 3.10.2 include the expression for pressure-induced stress with an opposite sign. Explain why P in this expression is used in light of item (iii) above, why it acts to reduce all of the other stresses, and why in P need twice in equation 10M and 11M? Also, what is the allowable stress for equation 10M? (vi) Section 3.10.3.1 should be updated to reflect some of the changes made in the more recent ASCE 4-98 standard (e.g., E should be the secant modulus, equations given in axial and bending strains should include the wave velocity coefficients, etc.). (vii) The equation given for S_{OL} at the end of Section 3.10.3.1 has two terms for strains which should

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			be stresses. Also, why wasn't the stress contribution from pressure also included? These items also affect Table 3-4.
	C. How is the assumption related to soil liquefaction and fault displacement, which is noted in TR Section 3.10, assured?	C. The path of any buried piping should be surveyed to determine soil conditions with emphasis on avoiding soil conditions such as liquefaction and faults. Section 3.10 of the TR will be revised to include options that can be used to avoid these soil conditions or repair them, as shown in Attachment B to this response.	**C. Acceptable.** AREVA needs to revise the TR Section.
	D. TR Table 3-4 provides the design conditions, load combinations and acceptance criteria for Class 2/3 buried piping. Explain clearly the term non-repeated anchor movement, Equation 9U (vs 9), and Equation 9E (vs 9). While the intent may be interpreted, it is important that these terms be clearly defined in the TR. For Equations 10M and 11M, which are identified as "modified to include axial friction	D. Non-repeated anchor movements, in the case of buried pipe, refers to building settlement at the point where the buried pipe enters the building. Equations 9U and 9F refer to upset and faulted respectively. These designations are used to distinguish the differences in plant events that occur during the upset or faulted plant conditions and must be combined per equation 9 and meet the allowable stresses as noted in the various section of NC/ND 3650.	**D. Not Acceptable.** As requested in the RAI define all terms used in the TR equations.

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	forces," provide the equations to show how they are modified.	SEE EQ 10M AND 11M FROM RESPONSE. Where: M_C is moments from arching or thermal anchor movements M_A is moments from weight of pipe and the remaining part of the equation is the stress from friction due to thermal differences due to soil/pipe interaction.	
	E. For the Faulted loading condition in TR Table 3-4, why isn't the load thermal anchor movement (TAM) included in the load combination, as it is in Table 3-2 for Class 2 & 3 Piping? Also, why is the stress criteria of 3Sh used rather than the minimum of 3.0 Sh and 2.0 Sy, as presented in Table 3-2?	E. Thermal Anchor Movements (TAM) will be added to the faulted load condition in Table 3-4. The allowable stress for the faulted condition is less than or equal to $3.0S_h$ but not greater than $2.0S_Y$.	**E. Acceptable.** AREVA needs to revise the TR Section.
	F. Confirm that Note 5 in the TR Table is applicable to all cases cited in TR Table 3-4 since it is not referenced in the Table like the other notes are. Also, explain how the criteria of NC/ND-3133 of the ASME Code (Note 5 in the	F. Note 5 will be added to Table 3-4 as appropriate. As shown in Attachment B, the external pressure of the soil overburden defined in NC/ND-3133 will be added to the discussion in 3.10.	**F. Not Acceptable.** Attachment B still does not indicate where note 5 is applicable. Explain why.

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	Table) will be implemented in conjunction with meeting the loads and loading conditions specified in Table 3-4.		
Computer Codes	**RAI EPR-16:** TR Section 5.1 provides short descriptions of the major computer programs to be used in the analysis and design of safety-related piping systems. Piping related computer programs include SUPERPIPE, BWSPAN, BWHIST, BWSPEC, COMPAR2, CRAFT2, P91232, and RESPECT. AREVA states that SUPERPIPE has been thoroughly verified and validated to U.S. NRC standards. For all other computer codes, AREVA did not indicate if these programs are verified for their application by appropriate methods, such as hand calculations, or comparison with results from similar programs, experimental tests, or published literature, including analytical results or numerical results to the benchmark		

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	problems and validated as the piping program. Moreover, AREVA did not mention how the quality of these programs and computer results is controlled. To facilitate the staff review of the computer programs used in the EPR design, provide the following additional information:		
	A. Identify which computer programs will be used during the design certification phase.	A. BWSPAN is being used for analysis of the RCL piping during the design certification phase. While the other codes given in the initial version of the TR are also being used for RCL analysis in the design certification phase, they are not strictly piping analysis codes (they are general purpose hydraulic and post processing codes) and so their description will be removed from the TR. SUPERPIPE is being used during design certification for the analysis of ASME Class 2 and 3 piping. It may be used for Class 1 piping.	**A. Acceptable.** AREVA needs to revise the TR Section.
	B. Identify which programs have	B. The use of BWSPAN for Class 1 RCL analysis has previously been	**B. Acceptable.**

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	previously been reviewed by the NRC on prior plant license applications. Include the program name, version, and prior plant license application. As stated in SRP 3.9.1, this will eliminate the need for the licensee to resubmit, in a subsequent license application, the computer solutions to the test problems used for verification.	approved by the NRC, see letter David E. LaBarge (NRC) to W.R. McCollum, Jr. (Duke Energy Corporation), "Oconee Nuclear Station, Units 1, 2 and 3 Re: Reactor Coolant Loop Analysis Methodology for Steam Generator Replacement (TAC Nos. MA9886, MA9887, and MA9888)," dated September 6, 2001. Earlier versions of BWSPAN have been successfully benchmarked to the piping problems given in NUREG/CR-1677. Later versions have been benchmarked to a prior version of BWSPAN by running selected sample problems which demonstrate that the changes made in moving from one version to the next have been correctly implemented. BWSPAN is controlled and maintained per AREVA NP, Inc. administrative procedures. The files which document the verification, validation, maintenance and control of BWSPAN are available. These files will provide the author, source, dated version, program description, the extent and limitation of the program application; and the computer solutions to the test problems	

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	C. Confirm that the following	described above. SUPERPIPE - The use of SUPERPIPE, in previous versions, has been approved by the NRC for a number of previous license applications including the Catawba Nuclear Station (CNS UFSAR, Rev. 12, Table 3-68) and the System 80+ Design Certification (NUREG-1462, Section 3.12.3). Current versions of SUPERPIPE have been subsequently verified under the AREVA software QA program by comparison of results to the results of previously accepted versions. SUPERPIPE is controlled and maintained per AREVA NP Inc. administrative procedures. The files which document the verification, validation, maintenance and control of SUPERPIPE are available. These files will provide the author, source, dated version, program description, the extent and limitation of the program application; and the computer solutions to the test problems described above. C. The information on computer codes is available for NRC inspection. These files will provide the author, source,	**C. Acceptable.**

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	information is available for staff review for each program: the author, source, dated version, and facility; a description, and the extent and limitation of the program application; and the computer solutions to the test problems described above.	dated version, program description, the extent and limitation of the program application; and the computer solutions to the test problems described above.	
Inclusion of Support Mass	<u>**RAI EPR-17:**</u> TR Section 5.2 describes a criterion for inclusion of support masses to the piping model mass at the support attachment location and states that a portion of the weight of the support is considered in the piping analysis and also, because the mass of a given support will not contribute to the piping response in the direction of the support, only the unsupported directions need to be considered. A. Clarify under what conditions only a portion of the support weight would be considered.	A. The TR states "The mass contributed by the support is included in the analysis when it is greater than 10% of	**A. Acceptable.**

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	B. Provide justification as to why the support mass would not contribute to the piping response in the direction of the support if the support is flexible (e.g., spring hangers).	the total mass of the adjacent pipe span (including pipe contents, insulation and concentrated masses)." B. It is agreed that if the support is determined to be flexible in the direction of the restraint, the support mass should also be included in this direction, as well as for the unrestrained directions. TR Section 5.2 will be revised as follows: "Because the mass of a given support will not typically contribute to the piping response in the direction of the support, only the support mass in the unsupported directions needs to be considered, unless the support is flexible in the supported direction."	**B. Acceptable.** AREVA needs to change the TR Section with the proposed text.
Piping Model Structural Boundaries	<u>**RAI EPR-18:**</u> TR Sections 5.4.1.2 and 5.4.1.3 describe two alternate approaches of separating a piping analysis model using an elbow or a tee within the piping model. While	The configurations shown in Figures 5-1 and 5-2 produce boundaries which, over a relatively short distance, provide effective restraint for the six degrees of freedom. The configuration creates a rigid zone of pipe with natural	**Acceptable.**

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	these approaches may be technically sound, no references or technical justifications are provided for each of these methods. Provide technical justifications and limitations (if any) for these two methods of establishing piping model terminations. Also, discuss the basis for selecting the dimensions of L1 and L2 in TR Figure 5-1 for a restrained elbow and Figure 5-2 for a restrained tee.	frequencies well above the ZPA and provides four restraints in the out-of-plane direction. The location of the two in-plane restraints on each side of the elbow or each segment of the tee provides a very short, stiff segment of piping from the intersect point and therefore create an effective axial restraint for the piping in the in plane direction. This configuration meets the recommendations for an overlap zone presented in NUREG/CR-1980.	
Piping Model Boundaries Using Model Isolations	<u>**RAI EPR-19:**</u> TR Sections 5.4.3.1 and 5.4.3.2 describe two approaches of dividing a large piping analysis model using the overlap region or the influence zone method. While these approaches may be technically sound, no references or technical justifications are provided for each of these methods. Provide technical justifications and limitations (if any) for these two methods of	The overlap methodology provided in TR Section 5.4.3.1 is consistent with the recommendations of NUREG/CR 1980. The following phrase will be added to the text in 5.4.3.1: "...and must meet the following criteria which are consistent with the recommendations of NUREG/CR-1980." The Zone of Influence (ZOI) method is provided as an option when the requirement for a rigid section of piping can not be met in order to use the	**Acceptable.** AREVA needs to change the TR Section with the proposed text.

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	isolating piping models. Also, discuss the basis for selecting the overlap region and the influence zone in TR Figure 5-3.	overlap methodology. In this method, all piping must be modeled to a point where boundary conditions and loadings no longer impact the piping being qualified. This will typically be more piping than is required by the overlap method and the validity of the boundary is required to be demonstrated during the analysis. TR Section 5.4.3.2 will be revised to include these statements. As stated in TR Section 5.4.3, TR Figure 5-3 is included to show the differences in the boundaries of qualification for piping and supports when using the Overlap Method versus the Influence Zone Method. It is not used as a guide for selecting the overlap or influence zone regions. The title of the figure will be revised to "*Model Isolation Methods of Division - Comparison of Qualification Boundaries.*"	
Piping Benchmark Program	**<u>RAI EPR-20:</u>** Final piping and pipe support stress analyses cannot be completed before	AREVA will identify three (3) representative calculations from the analyses currently being completed for	**Not Acceptable.** TR Section 5.3 and item 6 of TR Table 1-1 refer to the "NRC

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	design certification because their completion is dependent on as-built or as-procured information. Under a piping benchmark program, the combined operating license (COL) applicant applies his computer program to construct a series of selected piping system mathematical models that are representative of the standard plant piping designs. Please confirm if AREVA has established such a piping benchmark program to be used by the COL applicants and whether its own piping analysis computer code described in Section 5.1 was verified using models representative of the U.S. EPR.	the U.S. EPR Design Certification to be used in the benchmark program. These calculations will be completed prior to the submittal of the DCD and will utilize the piping analysis codes identified in 5.1 of the TR. The COL applicant will implement this benchmarking program if he chooses to use programs other than those stated in TR 5.1. This requirement is Item 6 of Table 1-1.	benchmark program," not the AREVA benchmark program for the 3 representative calculations. This is somewhat confusing. Therefore, clarify the text in TR Section 5.3 and item 6 of TR Table 1-1 to match the description provided in the RAI response.
Model Decoupling Criteria	**RAI EPR-21:** TR Section 5.4.2 states that adequate flexibility in the branch line is provided by maintaining a minimum length from the run pipe to the first restraint of ½ of the pipe span in	In the third paragraph of TR 5.2 it is stated "Torsional effects of eccentric masses are included in the analysis." This applies to all eccentric masses including valves in the first half span of a branch line.	**Not Acceptable.** The first para refers to the general application of the analyzed piping system, not to the decoupled system. Therefore, as requested in the RAI, provide technical

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	TR Table 4-1 for the branch line. The mass to be considered at the branch connection of the run pipe is the mass of ½ of the first span of the branch pipe, including concentrated weights, in each direction. However, AREVA did not discuss other effects (e.g., moment or torsional load at the branch connection) of the eccentric concentrated masses, such as valves, in the first one-half span length from the main run pipe. Provide technical justification on how to account for the effect of a large concentrated mass near the branch connection in the decoupling criteria discussed in the TR.	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 must be considered. In these cases, the branch piping will be modeled and analyzed with the run pipe, or a portion of the branch line shall be included in the run pipe analysis to adequately include the torsional effects of the eccentric weight.	justification on how to account for the effect of a large concentrated mass near the branch connection in the decoupling criteria discussed in the TR. The second paragraph is acceptable but requires a change to the TR.
Dynamic Analysis of Branch Lines	<u>**RAI EPR-22:**</u> TR Section 5.4.2 states that for the SSE inertia load case, each individual run pipe movement shall be analyzed as a separate anchor movement load case on the branch line and combined	For branch lines decoupled from the RCL, the inertial seismic input at the branch-to run anchor is a time history or response spectrum generated by seismic analysis of the RCL as discussed in RAI EPR-7. The analysis of the branch line also includes the	**Not Acceptable.** It is still not clear how the inertial movements of the run pipe is included as part of the inertial analysis of the branch pipe. How can the SAM analysis of the branch pipe take care of the

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	with its respective load case by absolute summation. Provide additional clarification to explain this procedure.	thermal and seismic movements of the RCL which are applied as static displacements at the branch-to-RCL anchor. For decoupled branches analyzed using run pipe displacements to capture the inertial effect of the run pipe, Section 5.4.2 of the TR will be revised as follows to clarify the following method of combination: "The inertial movements of the run pipe at the branch intersection are obtained from the run pipe analysis. These movements are statically applied, in individual load cases for each direction, at the branch-to-run pipe anchor. The results of these statically applied load cases are combined by the SRSS to capture the effects of the inertial movement of the run pipe on the branch line. These results are then combined with the inertial analysis of the branch line by absolute summation to obtain the total inertial response."	inertial effects of the run pipe? What spectra are used at the run-to-branch connection when performing the dynamic analysis of the branch pipe; do they include the amplified spectra at the main run pipe to branch line connection? This is also addressed in RAI EPR-7.
Model Isolation and	<u>**RAI EPR-23:**</u> A. TR Section 5.5 states that when the isolation	A. The statement in 5.5 will be changed to “four seismic restraints in each of the	**A. Acceptable.** AREVA needs to change the TR

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Analysis	methods discussed in TR Section 5.4.3 are used, isolation of dynamic effects is provided by three (3) seismic restraints in each of the three orthogonal directions beyond the seismic Category I design boundary. However, TR Section 5.4.3.1 states that as a minimum, four (4) such restraints in each orthogonal direction in the overlap region are required for the same isolation method. Explain this discrepancy.	three orthogonal directions beyond the Seismic Category I system boundary."	Section with the proposed text.
	B. TR Section 5.5 states that for loads resulting from the potential failure of the non-seismic piping and pipe supports, three separate analyses are performed by applying a plastic moment in each of three orthogonal directions at the termination of the model and then the results of these three analyses are enveloped. Please clarify how	B. The following text will be added to 5.5: "The plastic moment is calculated as: TWO EQs. SEE RESPONSE Each moment is applied and evaluated in a separate analysis and the results of each analysis are individually combined with the seismic inertia results by absolute summation methods. The	**B. Acceptable.** AREVA needs to change the TR Section with the proposed text.

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	these loads are calculated and how the results from the three analyses are combined with the results of the dynamic analysis of the seismic Category I piping.	results of these three analyses are then enveloped to obtain the design loads for the piping and supports."	
Transient Loads	**RAI EPR-24:** Provide the list of transients and the number of events associated with each of these transients during a life span of 60 years that will be part of the design requirements of ASME Code Class piping and pipe supports. If such a list is not developed at this stage of the design certification, then include this in the DCD or include as one of the COL-Action Items listed in TR Table 1-1.	The list of transients will be included in Chapter 3 of the DCD.	**Acceptable.**
Piping Load Combinations	**RAI EPR-25:** The staff needs clarification of several items associated with TR Section 3.3 and Tables 3-1 and 3-2. A. In TR Section 3.3.1.7, it is stated that pipe breaks in the RCL, main steam and	 A. Leak-Before-Break will be addressed in Chapter 3 of the DCD. It was not included in the TR because it was not	 **A. Acceptable.**

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	pressurizer surge lines which meet the leak-before-break (LBB) size criteria are eliminated from the consideration based on LBB analysis. However, the impact of smaller attached lines and other lines outside the LBB analyzed zone will be considered. Per SECY 93-087, the staff has approved the LBB approach on a case-by-case basis for austenitic stainless steel and carbon steel with stainless steel clad piping inside the primary containment and pipe size of at least 6-inch NPS. Based on this document, appropriate bounding limits are to be established using preliminary analysis results during the design certification phase and verified during the COL phase by performing the appropriate ITAAC discussed in it. Discuss the technical basis for exclusion of pipe break analysis for the above three lines, with the LBB criteria to be used for	addressed in SRP 3.12.	

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	the EPR piping design. B. Note 3 to TR Table 3-1 states that dynamic loads are to be combined considering timing and causal relationships. SSE and Design Basis Pipe Break (including loss-of-coolant accident (LOCA)) shall be combined using the square root of the sum of the squares (SRSS) method. This is acceptable in accordance to NUREG-0484, Rev. 1. However, for dynamic responses resulting from the same initiating events (other than SSE), when time-phase relationship between the responses cannot be established, the summation of these dynamic responses should be used. Confirm if this is true for the EPR piping design. If not, discuss with technical justification the combination method to be used when multiple LOCA or other dynamic load events are required to be	B. AREVA expects to be able to establish the timing and causal relationships between dynamic events such as pipe rupture and valve actuation. However, if this relationship cannot be established between two dynamic events, the responses from these events will be combined by absolute sum. Table 3-1 will be revised to clarify this point as shown in Attachment C to this response. Note 5 of Table 3-2 will be revised to include: "When causal relationships can be established, dynamic loads will be combined by the square root of the sum of the squares (SRSS). When this relationship cannot be established, dynamic loads will be combined by absolute sum. SSE and High Energy Line Break loads are always combined using the SRSS method."	**B. Not Acceptable.** The criteria for SSE plus LOCA as well as the combination method between dynamic events when the causal relationship cannot be established are acceptable. However, when causal relationships can be established between dynamic events, will the criteria in NUREG-0484, rev.1 regarding the non-exceedance probability be used to determine whether absolute sum or SRSS is used? This also needs to be reflected in TR Tables 3-1 and 3-2.

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	combined. This combination criterion is also applicable to note 5 of the TR Table 3-2, which states that dynamic loads are combined by the SRSS. C. Note 8 to TR Table 3-1 states that the earthquake inertial load used in the Level D Primary Stress (Equation 9F) calculations shall be taken as the peak SSE inertial load. The earthquake anchor motion load used in the Level D Primary Stress (Equation 9F) calculations shall be taken as the peak SSE anchor motion load. The staff position on the use of a single-earthquake design in SECY-93-087 states that the effects of anchor displacements in the piping caused by an SSE be considered with the Service Level D limits. For simplified elastic-plastic discontinuity analysis, if Eq. 10 cannot be satisfied for all pairs of load sets, then the alternative analysis per	C. At the time that the Topical Report was written, portions of Section III NB-3600 in the 2004 Edition of the ASME Boiler and Pressure Code were not endorsed by the NRC, per the version of 10CFR50.55a in effect at that time. The proposed draft of 10CFR50.55a which was published in spring of 2007 indicates that restrictions on the use of the rules involving seismic loading have been removed. AREVA will therefore reference the equations from NB-3656(b)(4) for the treatment of SSE anchor motions. Table 3-1 has been revised for this reason and to provide further clarification of the Class 1 load combinations.	**C. Not Acceptable.** Since the OBE is eliminated for design, the staff position for ASME Code Class 1, 2 and 3 piping is that the following items in TR Tables 3-1 and 3-2 be addressed: For Class 1 (TR Table 3-1) (1) In the upset loading condition for primary plus secondary stress intensity range (EQ 10), the loads should include the SSE. The SSE was originally included in the TR. However, it was deleted in the Table submitted with the RAI response and added to the Peak SIR (EQ 11). The SSE loading needs to be included in both EQ 10 and 11 calculations. (2) The current staff position (as delineated in NUREG-1503, Section 3) for simplified elastic-plastic discontinuity analysis (NB-3653.6) is that if Eq. 10 cannot be

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	NB-3653.6 for Service Level D should be followed. In addition, the combined moment range for either the resultant thermal expansion and thermal anchor movements plus ½ the SSE seismic anchor motion or the resultant moment due to the full SSE anchor motion alone, whichever is greater must satisfy the equation (known as Eq. 12a) given in NB-3656(b)(4). Clarify if this is applicable to EPR piping design. Also, justify why this anchor motion stress is categorized as a primary stress in the TR Table 3-1 for the faulted condition.		satisfied for all pairs of load sets, then the alternative analysis as described in NB-3653.6 should be followed. In addition, the following condition shall be satisfied: $S_{sam} = (C_2D_o/2I)(M_i^*+M_i^{**}) \leq 6S_m$ Where M_i^* is same as M_i^* in Eq. 12 and M_i^{**} is the same as M_i in Eq. 10 except that it includes only moments due to SAM caused by an SSE. The combined moment range for either the resultant thermal expansion and thermal anchor movements plus ½ the SSE seismic anchor motion or the resultant moment due to the full SSE anchor motion alone, whichever is greater.
	D. Identify the applicability of notes 3 and 5 in the TR Table 3-2.	D. Note 3 applies to the "Design" loading condition and Equation 8. Note 5 applies to Equations 9E and 9F.	**D. Not Acceptable.** For the combination of dynamic loads, see staff assessment under Item B above. Why doesn't

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	E. Explain why equation 11a under NC/ND-3653.2 is not included in the TR Table. Are there any dynamic loads other than the SSE (e.g., building response due to hydrodynamic loads such as SRV actuation) that can occur?	E. Equation 11a of NC/ND 3653.2 is for reversing loads such as seismic but it did not appear until after the 1993 addenda. Therefore, it was not included in the TR. The seismic (reversing) inertia loads are included in Equation 9 and the secondary effects of these loads are included in Equation 10 as in the 1993 Code Addenda. See also response to RAI EPR-3. There are no other dynamic loads on the building structure that would impact piping analysis and support design.	the Table shows these notes at the applicable locations? Confirm this is done for all the notes in both Tables 3-1 and 3-2. **E. Acceptable.**
Piping Damping Values	<u>**RAI EPR-26:**</u> In TR Section 4.2.5, it is identified that Rev. 0 of the RG 1.61 values of damping will be used in the seismic analysis of structures, systems, and components (SSCs) using ISM response spectrum analysis or time history analysis. However, for piping systems analyzed using USM		

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	response spectrum analysis, 5% damping will be used provided that the system is not susceptible to stress corrosion cracking. Five percent damping will not be used for analyzing the dynamic response of piping systems using supports designed to dissipate energy by yielding.		
	A. Since staff has issued the Rev.1 of RG 1.61 in March 2007, indicate if the design of EPR piping systems will use Rev. 1 of the RG-recommended damping values.	A. TR Section 4.2.5 will be revised to allow the use of Reg. Guide 1.61 Rev. 1 damping values.	**A. Not Acceptable.** The TR should be revised to specify that Rev.1 of RG 1.61 "will be used" (not "allow the use") for the EPR piping design.
	B. For piping systems analyzed using uniform support motion response spectrum analysis and 5% damping, verify that all of the limitations specified in RG 1.84 for ASME Code Case N-411 (or RG 1.61, Rev.1) will be met.	B. TR Section 4.2.5 will be revised to state that piping analyzed using the uniform support motion response spectrum method and meeting all limitations specified in Regulatory Guide 1.61, Rev. 1 will use 5 percent damping.	**B. Not Acceptable.** Based on the response and the current text in TR Section 4.2.5, it is not clear that the use of 5% constant damping is in agreement with RG 1.61, Rev.1. The current staff position for damping of piping regardless of pipe size is 4% for the SSE and 3% for the OBE for time history, response spectra, and equivalent static

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			analysis procedures. As an alternative for the response spectrum analysis using an envelope of the spectra at all support points, frequency-dependent damping may be used subject to five restrictions. All of these criteria are presented in RG 1.61, Rev. 1 (March 2007). Therefore, indicate whether the criteria in the RG will be followed as stated here or provide technical justification for the 5% damping value independent of frequency described in TR Section 4.2.5.
	C. Also, discuss what damping values will be used for cases when the system is susceptible to SCC and when using supports designed to dissipate energy by yielding.	C. TR Section 4.2.5 will be revised to state that the U.S. EPR will use 4 percent damping for systems susceptible to SCC and when supports that dissipate energy are used.	**C. Acceptable.**
Modal Combinations	**RAI EPR-27:** In TR Section 4.2.2.3.1, it is stated that for the response spectrum method of analysis, the modal contributions		

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	to the inertial responses are normally combined by the SRSS method. If some or all of the modes are closely spaced, any one of the methods (Grouping method, 10% method, and Double Sum method, as well as the less conservative methods in revision 2 of the RG 1.92) is applicable for the combination of modal responses. This combination method is applicable to both USM and ISM methods of analysis.		
	A. If guidance given in Revision 2 of the RG 1.92 is used for the EPR piping design, then Revision 2 of the RG no longer recognizes the Grouping method, 10% method and Double Sum method for closely spaced modes. These methods are renamed and AREVA should identify them as noted in the RG.	A. In the Background discussion of Section B of RG 1.92 Revision 2, the methods of Revision 1 are included by reference as remaining acceptable for use. AREVA will add Revision 1 of RG 1.92 to the references since the detail for these methods are not provided in Revision 2.	**A. Not Acceptable.** The current practice for advanced reactors is to follow the current NRC regulatory guidance. Therefore, RG 1.92, Rev. 2 should be the followed. The phrase in the "Background" discussion referred to in RG 1.92, Rev. 2, was primarily included because the use of the Rev. 1 version for existing plants is still considered acceptable. The new RG 1.92, Rev. 2 is the currently

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			the preferred method for new plants because it incorporates improved and more accurate methods, and in many cases reduces unnecessary conservatisms. Also, RG 1.92, Rev.2 has additional requirements that were not captured in the Rev. 1 version (e.g., residual rigid response of missing mass, definition of cutoff frequency, etc.). Clarify if RG 1.92 Rev.2 is still the guidance document for modal combinations to be used in the EPR piping design.
	B. TR states that for closely spaced modes AREVA may use less conservative methods discussed in the RG. Please identify which methods are less conservative methods and explain why they are less conservative with respect to the other method(s).	B. This statement is only intended to point out that the methods of modal combination provided in Revision 2 of RG 1.92 are less conservative than the methods presented in Revision 1 as stated in the Background discussion of the RG.	**B. Not Acceptable.** See staff assessment presented under item A above for resolution of this item.
Missing Mass	<u>**RAI EPR-28:**</u> TR Section 4.2.2.3.2 presents a procedure		

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	to account for high-frequency modes in the response spectrum methods for calculating seismic and other dynamic load responses.		
	A. Discuss the differences in the mathematical derivations of the high frequency modes presented in the TR versus the methods acceptable to the staff as given in RG 1.92, Rev. 2.	A. The method detailed in the TR is based on the Left-Out-Force method. This method is performed by the SUPERPIPE piping analysis code which has been accepted for use at many operating plants. Although this method is different than that shown in RG 1.92, it produces the same result. BWSPAN uses the missing mass method given in Appendix A of RG 1.92, R2. TR Section 2.2.3.2 will be revised to state that BWSPAN uses the missing mass method outlined in Appendix A of RG 1.92 Revision 2.	**A. Not Acceptable.** Provide the technical basis that demonstrate both methods produce the same result.
	B. The TR states that the response from high frequency modes will be included in the response of the piping system if it results in an increase in the dynamic results of more than 10%. However, in accordance with RG 1.92, Rev.2, C.1.4.1,	B. The residual rigid response of the missing mass modes will be included in all seismic analyses of SSCs. Section 4.2.2.3.2 will be revised to remove the option of using the 10% criteria.	**B. Not Acceptable.** Guidance for including the missing mass effects should only refer to RG 1.92, Rev. 2, and not Appendix A of SRP 3.7.2. Note that in the current SRP 3.7.2, this criteria was removed. Therefore, section 4.2.2.3.2 should be revised to reflect the above.

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	this criterion may yield non-conservative results and should not be used. Since this guideline does not consider the total mass that is missing, which, in the limit, could be 10%, provide technical justification for using this criteria as a screening requirement for including the effects of any missing mass. C. The TR also states that peak modal responses of the system at frequencies above the ZPA are considered to be in phase. Thus, the responses of all high frequency modes are combined by absolute summation. Explain if the peak modal responses are in phase, then why the absolute sum method is recommended for the EPR piping design. D. Finally, the TR states that this missing mass mode is considered to have a modal frequency and acceleration equal to the cut-off frequency used in	C. The TR Section 4.2.2.3.2 will be revised as follows: "Thus, the responses of all high frequency modes are combined by algebraic summation." D. The TR will be revised to state that the rigid range (missing mass) results will be combined with the low frequency modal results by SRSS.	**C. Acceptable.** AREVA needs to change the TR Section with the proposed text. **D. Not Acceptable.** The acceptable combination methods for the missing mass and low frequency modal results are described in Section 1.5 of RG 1.92, Rev. 2. Explain whether

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	the modal analysis. These modal results are combined with the low frequency modal results using the methods described in TR Section 4.2.2.3.1 for the low frequency modes (per RG 1.92). Please explain the combination method for the results to be used from both low and high frequency modes.		these combination methods (A or B) are used. These would require a change to the TR. For ISM, see RAI EPR-8.
Nonlinear Vibrations Due to Support Gaps	**RAI EPR-29:** The TR does not provide an analytical method to account for nonlinear effects of excessively large gaps (for frame type supports) between the pipe and supports subject to high frequency vibration loads. Should such large gaps exist, provide the piping analysis method to be used to address the nonlinearity when subjected to vibratory loads with significant high-frequency caused by the gaps between the pipe and its supports.	As stated in TR Section 6.5, and further discussed in Section 6.11, the U.S. EPR design does not intend to utilize gapped supports. For the U.S. EPR, the normal design practice for frame structure guide supports is to utilize a nominal 1/16" gap between the surface of the pipe and the edge of the support member for both sides of the pipe in the restrained direction. Section 6.5 will be revised to add the following text: "Although the use of gapped supports is not anticipated for the U.S. EPR, should the need for such supports arise, one of the following two methodologies would	**Not Acceptable.** AREVA needs to change the TR Section with the proposed text. If the second methodology for analyzing piping systems with gapped supports is utilized, the technical basis for the approach needs to be submitted for staff review.

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		be employed. Either the non-linear piping analysis problem is solved using direct integration time history methods, or the piping is analyzed as a linear problem, where the supports are assumed effective and the results are summed with the results of a static load case which deflects the pipe enough to close the support gap(s). These linear analyses will use either response spectra or time history modal superposition techniques."	
Thermal Stratification	<u>**RAI EPR-30:**</u> A. TR Section 3.7.1 states that the main feedwater nozzle is located in the conical section of the steam generator which aids in reducing thermal stratification. Please explain how this reduces thermal stratification. B. TR Section 3.7.2 states that the surge line may not be subjected to significant	A. Since the main feedwater nozzle is attached to the sloped conical section of the steam generator, it too is inclined: ~18 degrees from the horizontal. This incline promotes mixing of the colder and hotter fluid layers in the line which in turn retards stratification. The inclined design also prevents permanent thermal stratification at low flow rates and ensures run-full conditions in the nozzle. B. There are three major features of the surge line which minimize the amount of stratification in the line: 1) The take-	**A. Not Acceptable.** Per TR Section 3.7.1, the effects of thermal stratification and striping will be evaluated during the evaluation of the main feedwater system and the evaluation will confirm that all load cases meet the ASME Code allowables. Confirm that this evaluation will be fully described in the DCD. **B. Not Acceptable.** Per TR Section 3.7.2, the effects of thermal stratification and

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	stratification/striping effects due to design features that mitigate these effects. Describe these design features and explain how they mitigate the effects of thermal stratification in the surge line.	off from the hot leg is vertical upward and of sufficient length that turbulent penetration from hot leg flow does not spill over into the surge line beyond the take-off, and thus causing stratification; 2) the surge line is sloped ~5 degrees between the vertical take-off at the hot leg and the vertical leg at the pressurizer, which promotes contributes to mixing of the colder and hotter fluid layers in the line; and 3) during normal operation, a continuous bypass spray flow of sufficient magnitude is maintained to further suppress turbulent penetration from the hot leg flow.	striping on the pressurizer surge line will be analyzed with the RCL piping and supports or it will be demonstrated that the surge line is not subjected to significant stratification/striping effects. Confirm that this evaluation will be fully described in the DCD. For TR Section 3.7.3, covering unisolable piping due to leaking valve, also confirm that this evaluation will be fully described in the DCD.
Safety Relief Valve	<u>**RAI EPR-31:**</u> Describe the SRV design parameters and criteria that will need to be specified to the COL applicant to ensure that the specific piping configuration and safety relief valves (SRVs) purchased and installed at the COL applicant stage will match the test and design parameters used at the design certification stage. An example is the minimum rise time for the SRV	Discussion of SRV design parameters and criteria is beyond the scope of this TR. Relevant parameters and criteria will be addressed in the DCD.	**Acceptable.**

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	valve operation; this can greatly affect the transient loads imposed on the piping system analysis. Also, any change in the discharge piping system configuration may affect the SRV loadings.		
Composite Damping	**RAI EPR-32:** The composite modal damping ratio can be used when the modal superposition method of analysis (either time history or response spectrum) is used, as described in SRP Section 3.7.2, II.13. If AREVA plans to use composite modal damping for U.S. EPR piping design, provide a description of the methods for determining the composite modal damping value.	Composite modal damping may be applied when the modal superposition method of analysis is used. The methods used will meet the requirements of SRP 3.7.2. Section 4.2.5 of the TR will be revised as follows: "When composite modal damping is applied in a dynamic analysis, each model subgroup (piping, supports, equipment, etc) is assigned an appropriate damping value per RG 1.61 R1. The equivalent modal damping matrix, or composite modal damping matrix, is calculated for each mode by one of the two methods shown below: EQUATIONS, SEE RESPONSE. Note: Damping beyond 20 percent will	**Acceptable.** AREVA needs to change the TR Section with the proposed text.

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		not be used."	
Codes for Support Design	**RAI EPR-33:** A. TR Section 6.1 states that for Service Levels A, B and C, the seismic Category I pipe supports will be designed in accordance with Subsection NF of the ASME Code and for Service Level D, Appendix F of Section III of the ASME Code will be utilized. However, TR Section 6.2 states that all piping supports designed in accordance with the rules of Subsection NF of the Code up to the building structure interface are defined by the jurisdictional boundaries in Subsection NF-1130 of the ASME Codes. (i) Since Appendix F of the Section III provides only the Service Level D limits for evaluation of loading [per Code Table NF-3523(b)-1 for stress limit factors] for Class 1, 2, 3 and MC type supports, clarify if the seismic Category I pipe supports will be designed to ASME Subsection NF for all four	A. (i) TR Section 6.1 will be corrected to indicate that Seismic Category I pipe supports will be designed to ASME Subsection NF loadings for Service Levels A, B, C and D, while using the acceptance limits of Subsection NF for Levels A, B and C, and the acceptance limits of Appendix F for Level D. (ii) Subsection NF of the ASME Code will be used for the manufacturing, installation and testing of all Seismic Category I pipe supports.	**A. Acceptable.** AREVA needs to revise the TR Section.

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	Service Level A, B, C and D loads, while using the acceptance stress limits by the Appendix F for Service Level D supports. (ii) Also, clarify if the Subsection NF will be used to manufacture, install and test all seismic Category I pipe supports. If not, which other standard will be used.		
	B. AREVA also states that seismic Category II pipe supports are designed to ANSI/AISC N690, "Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities." These standards are used to design the structures or structural elements of a support for nuclear facilities, not the standard component supports (e.g., clamps, snubbers). ASME Code Subsection NF is typically used for seismic Category II pipe supports. Identify the standard that will be used to design,	B. For all Seismic Category II pipe supports other than standard component supports, the design, manufacturing, installation and testing will meet the requirements of ANSI/AISC N690. Standard component supports will be designed, manufactured, installed and tested to Subsection NF of the ASME Code. Any structural members used as part of a pipe support also containing standard components will be designed, manufactured, installed and tested to ANSI/AISC N690.	**B. Not Acceptable.** AREVA needs to revise the TR Section. The use of ANSI/AISC N690 should include Supplement 2 (2004) of the specification N690, in accordance with SRP Sections 3.8.3 and 3.8.4, March 2007.

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	manufacture, install and test seismic Category II pipe supports.		
	C. AREVA states that non-seismic category pipe supports are designed using guidance from the AISC Manual of Steel Construction. This manual is used to design steel constructions in frame type or other structural element of component supports. Based on TR Section 6.2, ASME Code B31.1 is being used for a certain class of piping (also see request for additional information (RAI) EPR-2). The design of all supports for the non-nuclear piping (that typically uses B31.1 for piping analysis) should satisfy the requirements of ASME/ANSI B31.1 Power Piping Code, Paragraph 120 for loads on pipe supporting elements and Paragraph 121 for design of pipe supporting elements. Clarify if this is applicable to U.S. EPR	C. For non-seismic pipe supports supporting piping analyzed to B31.1, the requirements of B31.1 for supports (Sections 120 and 121) will be met, where applicable. In addition, the structural elements will meet the requirements of the AISC Manual. For standard components used in such supports, vendor's catalog requirements will be utilized, which also meet B31.1 requirements. For non-seismic pipe supports supporting unanalyzed piping, the structural elements will meet the requirements of the AISC Manual and standard components will meet vendor's catalog requirements.	**C. Acceptable.** AREVA needs to revise the TR Section.

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	pipe support design, otherwise explain how the AISC manual will be used to design component supports (e.g., clamps, springs).		
Load Combination for Supports	<u>RAI EPR-34:</u> While reviewing TR Section 6.3, the staff needs clarification of the following items. A. TR Section 6.3.11 provided a minimum design load criteria that will be used for all supports so that uniformity is obtained in the load carrying capability of the supports. All supports will be designed for the largest of the following three loads: 100% of the Level A condition load, the weight of a standard ASME B31.1 span of water filled, schedule 80 pipe, and minimum value of 150 pounds. Provide the technical basis for this criteria. B. TR Table 6-1 provides the specific load combinations that	 A. The Minimum Design Load criteria given in this section is based on criteria given in Welding Research Council (WRC) Bulletin 353, Section 2.4.7. The bulletin recommends 125% of the Level A condition load, as the only difference from the topical's criteria. Presently, for the analyses being performed as part of the Design Certification process, the guidance is to apply a 25 percent increase to all pipe support loads to allow for possible future increases in support loads beyond the initial design. B. Table 6-1 includes three Faulted load	 **A. Not Acceptable.** If the current approach stated in the response is to apply a 25% increase to all pipe support loads for possible future increases, and this approach is also recommended in the WRC Bulletin 353, then the TR should state this. **B. Not Acceptable.**

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	will be used in the design of pipe supports. The acceptance criteria associated with the Service Levels will be per ASME Code, Subsection NF, ANSI/AISC N690 or the AISC Manual of Steel Construction, as appropriate. Note 1 to the Table states that operating basis earthquake (OBE) inertia and SAM loads are not included in the design of Class 2/3 piping. Explain how the seismic inertia and SAM loads are accounted for in the design of Class 2/3 pipe supports. Also, clarify how the same table is applicable to snubbers, struts, and anchors/guides.	combinations which contain SSE loads. In addition, Note 3 of the table states that SSE includes inertia and SAM loads combined by absolute sum. These would all apply to Class 1, 2 &3 pipe supports. In addition, struts and anchors/guides will be analyzed to all load combinations shown in the table. Snubbers will be designed to all but the Normal Level load combinations shown in the table. Note that Class 1 was inadvertently not included in Note 1 of Table 6-1. This will be corrected in the next revision of the TR. Note 1 will be revised to state, "OBE inertia and SAM loads are not included in the design of Class 1, 2 & 3 piping."	AREVA needs to revise the TR Section. Define all terms used in the Table 6-1 and include the definitions in Table 6-1 or cross reference where they are already defined. It is acceptable to design snubbers to all load combinations except normal level load combinations. However, for the load combinations where wind and tornado occur, will the piping and all supports be designed for the following two conditions: snubbers included and snubbers excluded? If not, explain why not.
	C. AREVA discusses wind/tornado loads in TR Sections 6.3.5 and 6.3.6 for pipe supports. However, for the piping in TR Section 3.3.1.6, AREVA identified these loads to be COL Action Item 3. Clarify AREVA's position on this.	C. Section 3.3.1.6 states that for Design Certification, no Class 1, 2 and 3 piping is exposed to wind and tornado loads, and further states that if a COL Applicant creates such an exposed piping condition, it will be addressed at that time. Sections 6.3.5 and 6.3.6	**C. Not Acceptable.** (1) Explain why the friction load F is not included in the load combinations that contain wind or tornado since these two loads may not always act as dynamic type loadings. (2) For piping

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		discuss the inclusion of such wind related loads for pipe supports. AREVA's position on wind loadings for both piping and supports is as stated in Section 3.3.1.6. Clarification will be added to Sections 6.3.5 and 6.3.6 to cross reference this section, and state that these sections show how such loads would be treated if the need arises.	design and pipe support design why isn't R_{SOT} considered in other load combinations (i.e., in combination with R_{DBPB}, $R_{MS/FWPB}$, LOCA, R_{DBPB}+SSE, $R_{MS/FWPB}$+SSE, and LOCA+SSE)?
Snubber Design	<u>**RAI EPR-35:**</u> AREVA, in TR Section 6.6, states that design specifications are to be provided to the snubber suppliers and the installation and operation of snubbers will be verified by the COL applicant. For design certification, SRP Section 3.9.3 requires that design, installation, operation and testing of the snubbers should be included in the design document. Clarify, whether AREVA intends to include all design-related specifications associated with snubbers in the TR or in the DCD.	As stated in item 2 of Table 1-1 of the TR, design specifications will be the responsibility of the COL applicant. The specification will be generated using the snubber specification requirements given in Chapter 3 of the DCD.	**Acceptable.**

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Support Stiffness	**RAI EPR-36:** AREVA does not adequately describe in TR Section 6.7 how the representative stiffness values are developed for all supports other than snubbers. Describe: 1. the approach used to develop the representative stiffness values, 2. the procedure that will be imposed to ensure that the final designed supports match the stiffness values assumed in the piping analysis, 3. the procedure used to consider the mass (along with the support stiffness) if the pipe support is not dynamically rigid, and 4. the same information [(1), (2), and (3) above] for the building steel/structure (i.e., beyond the NF jurisdictional boundary) and for equipment to which the piping may be connected to.	The initial piping analyses will assume all supports rigid (except for the few cases where the actual support structures are included in the piping model), and therefore utilize the default rigid support stiffness values contained in the analysis program. In addition, the initial pipe support designs will be developed to create a rigid support, based on the deflection check criteria given in Section 6.7 of the topical. If for some reason, a rigid support cannot be achieved, an actual support stiffness will need to be developed for the support noted, as well as for the other supports in the model. Typically, unless the support is a very simple structure, a frame support will be modeled using an analysis program such as GT STRUDL. This model will include the self-weight of the support, and will also be used to establish the deflections needed for the stiffness checks. Note that this model will include any flexible building steel, as applicable. If the deflection checks do not show rigidity, the model can be used to	**Not Acceptable.** (1) Explain and justify the definition of rigid supports (e.g., frequency greater than some value with the mass of the support and contributing pipe spans in each direction), default rigid support stiffness, how the rigid support stiffness corresponds to the definition of rigid supports, and how do the deflection requirements in TR Section 6.7 ensure the supports are rigid. (2) Since GT STRUDL may be used for evaluation of pipe supports, provide the information and validation approach in accordance with the request made in RAI EPR-16 for piping computer codes. This should be done for GT STRUDL and any other structural computer code that may be used.

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		determine the actual stiffness of the support structure using the self-weight load case. In addition, the support mass can be determined from the model. This would be created for the supports in the model and provided to the piping analyst. At this point, the supports would need to be rechecked for the loads from the revised piping analysis. If any support changes were required, an iteration of the process would be required to assure that the stiffnesses and masses are consistent for both the support qualifications and the piping analysis.	
Inclusion of Support Self-Weight Excitation	<u>**RAI EPR-37:**</u> In TR Section 6.8, AREVA did not indicate if the criteria presented is also applicable to other dynamic loads and did not discuss how the damping value will be used in the response spectrum analysis. A. Clarify whether the criterion presented in the TR is also applicable to other dynamic loads. If not, provide technical	 A. The support structure itself will be excited by SSE dynamic inputs, as the SSE event is applicable to the whole	 **A. Not Acceptable.** Section 6.8 of the TR refers to RG 1.61, October 1973 for damping

RAI Topic	RAI Description	AREVA Response	BNL Disposition
	justification.	site in the form of ground motion. As such, the excitation for the support's attachment to the building will be applied to the self-weight of the structure in the form of response spectra g values. For other fluid dynamic transient events within the piping system, forces from the fluid moving along the pipe are included in the pipe support loads for that event, but any subsequent excitation of the support structure itself for the fluid dynamic event will not be evaluated, as the forcing function at each support beyond applied piping loads will be minimal, and not usually defined. This is standard practice in pipe support design. The supports are typically not modeled with the piping.	values to be used in the evaluation of support self weight response to the SSE event. The current staff position is to use RG 1.61, Rev. 1 March 2007. Also, using the current version of RG 1.61 for supports and piping results in a consistent set of criteria for piping systems. Explain whether this approach will be followed or why not.
	B. Since the piping and support structure damping value may be different per RG 1.61, discuss what damping value will be used in the response spectrum analysis when the support structure is also modeled as part of the piping analysis. See also RAI EPR-32.	B. In most cases, Revision 1 of RG 1.61 calls for 4 percent damping for the piping analysis. Similarly, the RG allows for 4 percent damping for welded steel or bolted steel with friction connections and 7 percent for bolted steel with bearing connections, which would be	**B. Not Acceptable.** The response did not address the requested information. When the support is modeled in the piping analysis, if the damping values are different for the supports and the piping, how is damping treated? [i.e., is the lower (more

RAI Topic	RAI Description	AREVA Response	BNL Disposition
		applicable for the supports. If frequency dependent damping values are used in the piping analysis, the support structure will still utilize the 4 percent or 7 percent damping values.	conservative) value used for both or is the composite modal damping method discussed in the response to RAI EPR-32 used?]
Instrument Line Support Design	<u>RAI EPR-38:</u> TR Section 6.12 states that the applicable loading combinations for instrumentation lines will follow those used for normal and faulted levels in TR Table 6-1. Please explain why the load combinations for upset and emergency levels in TR Table 6-1 are not applicable to instrumentation line supports.	Based on the inclusion of only deadweight, thermal and SSE seismic loadings for analysis of the tubing, the vast majority of the support loads would fall into Normal or Faulted conditions. Since there may be thermal loads for other levels, this section of the topical will be modified to delete the reference to only Normal and Faulted loading conditions. Section 6.12 will be revised to state: "The applicable loading combinations will similarly follow those used for the ASME Levels in Table 6-1utilizing the design loadings mentioned above."	**Acceptable.** AREVA needs to change the TR Section with the proposed text.
Pipe Deflection Limits	<u>RAI EPR-39:</u> In TR Section 6.13, AREVA provided examples of the limitations which include travel limits for spring hangers, stroke limits for snubbers, swing angles for rods, struts and	The first check mentioned is the travel range limitation for spring hangers. This check will utilize the "working range" given in the standard Load Table for Selection of Hanger Size typically given in the vendor catalogs. This working	**Acceptable.**

RAI Topic	RAI Description	AREVA Response	BNL Disposition
	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 will be made in the initial designs for tolerances on such limits. Please specify the actual allowable limits that are applicable to EPR support design for pipe deflection limits.	range already provides a deflection tolerance beyond each end limit of the range (with the magnitude dependent on the spring type), provided the hot and cold loads fall within the working range. The second check mentioned is the stroke limit checks for snubbers. The current project guidance is to allow at least ½ inch of stroke at each end for the initial design checks. The third check mentioned is the swing angle check for rods, struts and snubbers. For current analyses, ANVIL, International hardware is being used. ANVIL's limit for these checks is 4 degrees. AREVA will apply a tolerance of 1 degree to this, thus checking to 3 degrees for initial design. The fourth check mentioned is for alignment angles of strut and snubber paddles and their associated clamps or end brackets. ANVIL's limit is 5 degrees. AREVA will apply a tolerance of 1 degree to this, thus checking to 4 degrees for initial design. The fifth check mentioned is for the spring variability check. The recommended limit on this check by ANVIL is 25 percent. AREVA will apply	

RAI Topic	RAI Description	AREVA Response	BNL Disposition
		a tolerance of 5 percent to this, thus checking to 20 percent for initial design.	

November 20, 2007
NRC:07:064

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Revised Response to an RAI on the Topical Report ANP-10264(NP) "U.S. EPR Piping Analysis and Pipe Support Design" (TAC No. MD3128)

Ref. 1: Letter, Ronnie L. Gardner (AREVA NP Inc.) to Document Control Desk (NRC), "Request for Review and Approval of ANP-10264(NP) Revision 0, 'U.S. EPR Piping Analysis and Pipe Support Design'," NRC:06:040, September 29, 2006.

Ref. 2: Letter, Getachew Tesfaye (NRC) to Ronnie L. Gardner (AREVA NP Inc), "Request for Additional Information Regarding Topical Report ANP-10264(NP), 'U.S. EPR Piping Analysis and Pipe Support Design' (TAC No. MD3128)," June 13, 2007.

Ref. 3: Letter, Ronnie L. Gardner (AREVA NP Inc.) to Document Control Desk (NRC), "Response to a Request for Additional Information Regarding ANP-10264NP 'U.S. EPR Piping Analysis and Pipe Support Design' (TAC No. MD3128)," NRC:06:036, July 13, 2007.

Ref. 4: E-mail, Getachew Tesfaye (NRC) to Ronda M. Daflucas (AREVA NP Inc.), "Fwd: Review of EPR Topical Report - BNL's Comments," (ML073110113) dated August 23, 2007.

Ref. 5: Letter, Getachew Tesfaye (NRC) to Ronnie L. Gardner (AREVA NP Inc.), "Supplement to the Acceptance Review of 'U.S. EPR Piping Analysis and Pipe Support Design' Topical Report (TAC No. MD3128)," April 5, 2007.

AREVA NP Inc. (AREVA NP) requested the NRC's review and approval of the topical report ANP-10264(NP) Revision 0 in Reference 1. The NRC provided a Request for Additional Information (RAI) regarding this topical report in Reference 2. The AREVA NP response to this RAI was provided in Reference 3. NRC provided comments on this RAI response in Reference 4 and a conference call with the NRC to discuss these comments was conducted on October 4, 2007. A revised RAI response is enclosed with this letter, Revised Response to Request for Additional Information – ANP-10264(NP), 'U.S. EPR Piping Analysis and Pipe Support Design Topical Report'." The enclosure to this letter only contains those RAI responses that are being revised as a result of the information provided in Reference 4. Additionally, the enclosure to this letter contains revised pages to the topical report that were provided in Attachments B and C of Reference 3. No changes were required to Attachment A of Reference 3.

In addition to the revised RAI responses as a result of Reference 4, the response to RAI EPR-20 was also revised to remove the statement that the calculations in support of the benchmark program will be completed prior to submittal of the design certification application. AREVA NP

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plans to perform these calculations in a timeframe necessary to support NRC review of the design certification application. Also, Attachment D describes a change to the topical report that is unrelated to the revised RAI responses. The basis for this change is also provided in Attachment D.

The RAI response as provided on the enclosed CD does not contain any information that AREVA NP considers to be proprietary.

Reference 5 states that the NRC plans to complete its review of the topical report and issue the draft safety evaluation by November 30, 2007. AREVA NP understands that this revised response to the RAI impacts the NRC's schedule and AREVA NP requests that the NRC issue the draft safety evaluation by January 31, 2008.

If you have any questions related to this submittal, please contact Ms. Sandra M. Sloan, Regulatory Affairs Manager for New Plants Deployment. She may be reached by telephone at 434-832-2369 or by e-mail at sandra.sloan@areva.com.

Sincerely,

Ronnie L. Gardner

Ronnie L. Gardner, Manager
Site Operations and Corporate Regulatory Affairs
AREVA NP Inc.

Enclosures

cc: L. Burkhart
G. Tesfaye
Project 733

Revised Response to Request for Additional Information – ANP-10264NP
"U.S. EPR Piping Analysis and Pipe Support Design Topical Report"
(TAC No. MD3128)

RAI EPR-2: *ASME B31.1 and Section XI Codes*

B. Confirm that ASME Code Section XI requirements will be used in the piping and pipe support design for EPR.

Response 2:

B. The U.S. EPR adheres to the requirements of the ASME Code Section XI requirements.

RAI EPR-3: *10CFR50.55a(b) Limitations and Modifications*

Section 2.1 of the TR states that for the dynamic loads, including seismic loads, the pipe stress analyses will be performed in accordance with the Sub-articles NB/NC/ND-3650 of the 1993 Addenda of the ASME Code as required by 10CFR50.55a(b)(1)(iii). However, AREVA did not address other limitations and modifications (related to Section III materials, weld leg dimensions, etc.) applicable to piping system design as included in 10CFR50.55a(b)(1). Explain how all limitations and modifications specified in 10CFR50.55a(b) will be satisfied.

Response 3:

The limitations of 10CFR50.55a(b)(1) are considered in the U.S. EPR design as follows:

- (b)(1)(i) Section III "Materials" – This is not considered for the U.S. EPR because it addresses the application of 1992 Edition of ASME. The U.S. EPR uses a later version of the code.
- (b)(1)(ii), "Weld leg dimensions" is incorporated into the U.S. EPR design.
- (b)(1)(iv) "Quality Assurance" – U.S. EPR Quality Assurance program is developed for a later edition of the code. This restriction does not apply to the U.S. EPR.
- (b)(1)(v) – Independence of Inspection – The inspection program for the U.S. EPR will not apply NCA-4134.10(a).
- (b)(1)(vi) Subsection NH – The U.S. EPR will not use Type 316 stainless pressurizer heater sleeves above a service temperature of 900°F.

For clarity, Section 2.1 of the TR will be revised to include the following text:

> "Piping analysis and pipe support design for the U.S. EPR addressed in this Topical Report use the 2001 ASME Code, Section III, Division 1, 2003 addenda as the base code with limitations identified in the Code of Federal Regulations, 10 CFR 50.55a(b)(1).

<u>RAI EPR-4:</u> *Mathematical Modeling*

TR Section 4.2 states that the seismic analysis methods for seismic Category I systems to withstand the effects of a safe shutdown earthquake (SSE) and to maintain the capability of performing their safety function will use the methods in accordance with SRP 3.7.3.

D. Discuss the analysis methods that will be used in the design of non-seismic Category I (or seismic Category II) piping systems.

Response 4:

D. Non-seismic piping that interacts with seismic systems and seismic Category II piping will be analyzed by response spectra (RS) or equivalent static methods

<u>RAI EPR-5:</u> *Piping Analysis Methods*

After constructing a mathematical model to reflect the static or dynamic characteristics of the piping system, describe the step by step computations (e.g., static analysis, modal analysis, modal participation factors) that may be performed to obtain the piping system response for each of the three methods of analysis (i.e., response spectrum, time history, and equivalent static load methods).

Response 5:

Section 4.2.2 will be revised to include the step by step computations for response spectra analysis. Section 4.2.2 will be revised as provided in Attachment A to this document.

Section 4.2.3 will be revised as follows to address the computations when Time History Analysis is employed:

> "The modal superposition method of time history analysis is used for seismic piping analyses with acceleration time history seismic input. This method is based on decoupling of the differential equations of motion, considering a linear elastic system, using the same method as that described in Section 4.2.2."
>
> "The Direct Integration Time History Analysis method may be used as an alternative to the modal superposition time history analysis. In this method the differential equation of motion, as provided in Section 4.2.2, is solved directly on the uncoupled equations without transformation. Rayleigh damping, or mass and stiffness damping, is used when direct integration time history analysis is performed."

Section 4.2.4 will be revised to include the following:

"For cases where a piping configuration can be demonstrated to respond as a single degree of freedom system with a known fundamental frequency or rigid system with a fundamental frequency beyond the cutoff frequency, a factor of 1.0 may be used with the highest spectral acceleration at that frequency or any higher frequency (as may be the case for multiple peak input spectra).

Mathematically the seismic force F_1 on a mass point in one (1) direction is represented as:

$$F_1 = kmS_a$$

Where:

k	=	1.0 for single degree of freedom or rigid system
		1.5 for multiple degree of freedom system
m	=	mass in direction 1
S_a	=	value of acceleration from response spectrum

The forces from each of the three orthogonal directions of earthquake are applied to calculate seismic stresses and then combined by SRSS to calculate overall seismic stresses."

(Note: the above revision to 4.2.4 is also addressed in RAI EPR-12).

RAI EPR-6: *Piping Analysis Criteria*

B. The cutoff frequency for modal responses is defined as the frequency at which the spectral acceleration approximately returns to the zero period acceleration (ZPA) of the input response spectrum. Define this cutoff frequency qualitatively or quantitatively for seismic and other building dynamic loads (if any) applicable to the piping analysis for the EPR.

Response 6:

B. Revised analysis and evaluation by AREVA NP has determined that since the ground motion cutoff frequency is 40 Hz, this same cutoff frequency is applicable to response spectra that have been developed using this ground motion.

TR Section 4.2.2.3 will be revised as follows:

"For the U.S. EPR the cutoff frequency is 40 Hz or as defined by Figure 2 and 3 in RG 1.92, Rev 2".

RAI EPR-7: *Branch Pipe Inputs*

When a small seismic Category I or non-seismic Category I piping is directly attached to seismic Category I piping, it can be decoupled from seismic Category I piping if it satisfies the *decoupling criteria. However, the TR did not describe how the inputs for the small branch piping will be determined for both inertial and seismic anchor motion (SAM) response analyses when the piping system is decoupled from a large pipe run or connected to flexible equipment connections. The staff notes that computer code RESPECT (TR Section 5.1.8) generates seismic amplified response spectra at the branch nozzle locations in a model of a piping system. Describe the seismic analysis methods and procedures, including the input response spectra and input SAM displacements, that apply to the small branch piping design when decoupled from a large run pipe or connected to flexible equipment. The description should also discuss how any amplification effects and SAM effects, from the main run pipe at the attachment to the small branch pipe, are considered.*

Response 7:

The model of a decoupled Class 1 branch line includes an anchor where the branch line connects to the RCL. The seismic inertial analysis of the RCL yields time histories at branch connections and equipment nozzles. The inertial seismic analysis results then become input into the Class 1 branch line seismic analysis in the form of time histories or response spectra which are generated from the time histories using classical response spectra generation techniques. If response spectra are used, they are peak broadened by ±15% in accordance with RG 1.122 R1 before application to the Class 1 branch line model. The analysis of the Class 1 branch line also considers seismic movements generated from the RCL (seismic anchor motions), which are applied as static displacements at the branch-to-RCL anchor. This analysis captures the effects of run pipe amplification on the branch pipe.

For the remaining decoupled branch lines (not connected to the RCL), the model of a decoupled branch line includes an anchor at the run to branch intersection. The analysis of the branch line includes all anchor movements greater than 1/16” from the run pipe applied at the run to branch anchor for all load cases. The inertial seismic input for the branch line comes from the appropriately applied building spectra for branch lines connected to rigid run pipes or equipment and/or amplified response spectra for branch lines connected to flexible run piping or equipment (fundamental frequency below the ZPA cutoff frequency), based on support configurations. As an alternative to a decoupled analysis, the branch pipe analysis may include a portion of the run pipe meeting one of the model isolation methods described in TR Section 5.4.3 in order to capture the possible amplification of inertial input from the run pipe.

The last paragraph of Section 5.4.2 will be changed to the following:

> “The branch pipe analysis must include more consideration for the effects of the run piping. The branch point is considered as an anchor in the analysis of the branch pipe with the appropriate SIF and/or stress indices for the branch connection. The movements (displacements and rotations) of the run pipe at the branch intersection due to statically applied loads in the run pipe analysis (such as thermal and seismic anchor movement (SAM)) shall be applied as anchor movements with their respective load cases in the branch line analysis. Additionally, in the branch analysis, the applied SAMs at the decoupled location shall include the run pipe movements from both the run pipe SAM analysis and the run pipe SSE inertia analysis. The inertial effects of the run pipe on the branch line are considered in one of the following methods:
>
> - For branch lines decoupled from the RCL, the inertial input to the branch line is generated from the analysis of the RCL. The analysis of the RCL yields time

history responses at the branch connections and equipment nozzles. This time history response of the RCL, or a response spectrum generated from the time history response, is then applied as the input inertial excitation at the branch-to-RCL intersection. This method may also be used for decoupling pipe from flexible equipment if the response of the equipment is known.

- For other decoupled lines, branch piping analysis will include one of the following:
  - The fundamental frequency of the run pipe at the branch location will determined. If this frequency is at or above the ZPA cutoff frequency, the run pipe is considered as rigid and there will be no amplification of the building response spectra. Therefore, the applied inertial excitation at the branch-to-run pipe anchor shall include the envelope of building excitations for the nearest supports on both the branch and run pipes.
  - If the fundamental frequency of the run pipe at the branch location is below the ZPA cutoff frequency, the run pipe at this location is considered to be flexible and therefore may amplify the input inertial effects. Where practical, in these cases, amplified response spectra will be developed from the run pipe analysis and applied at the branch-to-run pipe anchor in the branch pipe analysis.
  - As an alternative to a decoupled analysis, for branch lines connected to flexible run piping where amplified response spectra are not generated, the branch line analysis may include a portion of the run pipe meeting one of the model isolation methods described in Section 5.4.3 in order to capture the possible amplification of inertial input from the run pipe. Therefore, the applied inertial excitation shall include the envelope of building excitations for the nearest supports on both the branch and run pipes. In these cases, the run pipe analysis remains qualified by the decoupled analysis.

RAI EPR-8: *Independent Support Motion Method*

The current staff position for the Independent Support Motion (ISM) method of analysis is presented in Volume 4, Section 2 of NUREG-1061, "Report of the US NRC Piping Review Committee. "Some differences (e.g., modal combinations per RG 1.92 for uniform support motion (USM) only) were noted between the ISM method of response combinations (both methods and their sequence) presented in the TR Section 4.2.2.2.2, and the method given in NUREG-1061. Indicate whether all of the provisions (for groups, modes, spatial and inertial and SAM combination methods) contained in NUREG-1061 for the ISM method of analysis will be followed or provide the technical justification for any alternatives or methods described in the TR.

Response 8:

All of the provisions of NUREG-1061, Volume 4, for using the ISM method of analysis will be followed. The following revisions to the TR will be made for clarification:

Section 4.2.2.2.1, the 2nd paragraph will be revised as follows:

> "The combinations of modal responses and spatial components for systems analyzed using USM are performed consistent with the guidance provided in RG 1.92. The modal and directional responses are combined as discussed in Sections ...."

Section 4.2.2.2.2 will be revised to include a reference to NUREG-1061, Volume 4 as follows:

> "The combinations of modal responses and spatial components for systems analyzed using ISM are performed consistent with the recommendations in NUREG-1061, Volume 4. Additionally, when using independent support motion, the seismic response of each mode is calculated by combining the responses of all support groups into one by using absolute summation method per the recommendations of NUREG-1061."

Section 4.2.2.3.1, first sentence, will be revised as follows:

> "RG 1.92 provides guidance on combining the individual modal results due to each response spectrum in a dynamic analysis performed using USM."
>
> and the following text will be added to the end of this section:
>
> "For piping systems analyzed using ISM methods, modal results are combined without the consideration of closely spaced modes, per NUREG-1061. Therefore, for these systems, modal results are combined by the SRSS method presented above."

Section 4.2.2.3.2, the second sentence of the second paragraph which referred to RG 1.92, will be revised to read as follows:

> "Guidance for including the missing mass effects is provided in RG 1.92[16] for USM and NUREG-1061 for ISM."
>
> and the last paragraph will be revised to read:
>
> "For systems analyzed using USM, the rigid range (missing mass) results will be combined with the low frequency modal results in accordance with Regulatory Position C.1.5.1 of RG 1.92. For systems analyzed using ISM, the missing mass results will be combined with the low frequency modal results by SRSS, per NUREG-1061."

See RAI EPR-28(D) for additional discussion on the combination of high frequency modes with low frequency modes.

Section 4.2.2.5 will be revised to read as follows:

> "The analysis of these seismic anchor motions (SAM) will be performed as a static analysis with all dynamic supports active. The results of this analysis shall be combined with the piping system seismic inertia analysis results by absolute summation when an enveloped uniform support motion is used for the dynamic analysis, per SRP 3.7.3. When independent support motion is used in the inertial analysis, the responses due to the relative displacements and those due to inertia are combined by the SRSS method, per NUREG-1061."

RAI EPR-9: *Time History Analysis Using Modal Superposition Method*

Since many of the dynamic loads specified in the TR, using the time history method of analysis, may have a short duration and contain very high frequency content, the use of the modal superposition method must consider all modes up to the appropriate cutoff frequency as well as the missing mass contribution. Discuss how the proposed modal superposition method will address these considerations in accordance with RG 1.92, Rev.2.

Response 9:

Missing mass will be accounted for in time history modal superposition analyses in accordance with Appendix A of RG 1.92, Rev. 2.

The TR Section 4.2.3 will be revised to address this RAI as follows:

> "The mode shapes and frequencies are determined as they are in response spectrum analysis. The cutoff frequency for the determination of modal properties is 40 Hz or as defined by figure 2 and 3 in RG 1.92, Rev 2 as this is expected to encompass all of the important response frequencies of the system. Missing mass effects of the high frequency modes beyond the cutoff frequency are included via the Missing Mass Method described in Regulatory Position C.1.4.1 and Appendix A of RG 1.92, Rev. 2."

Also see the revised response to RAI EPR-6.

RAI EPR-10: *Time Step for Time History Analysis*

In a time history analysis, the numerical integration time step, Δt, must be sufficiently small to accurately define the dynamic excitation and to ensure stability and convergence of the solution up to the highest frequency of significance. In TR Section 4.2.3, AREVA indicates that for the most commonly used numerical integration methods, the maximum time step is limited to one-tenth of the shortest period of significance. However, this is typically selected for choosing an initial time step which is later checked against analysis results and their stability and convergence. An <u>acceptable</u> approach for selecting the time step, Δt, is that the Δt used shall be small enough such that the use of ½ of Δt does not change the response by more than 10%. Indicate whether this is part of the analysis requirements for time history method of analysis or provide a technical justification for not considering this criterion along with the criterion for initially choosing the time step described for seismic and other dynamic loading analyses.

Response 10:

AREVA has performed a time step study for the direct integration time history analysis of the RPV isolated model considering seismic loading. This model contains a representation of the RCS piping, components and supports, including the pressurizer and surge line, as well as a representation of the reactor building internal structure. In this study, a representative seismic case was analyzed using two integration time steps: 0.0005 seconds and 0.0025 seconds. Comparison of results (accelerations, displacements and forces) at several locations within the RPV and its internals indicates that the solution has converged (the maximum difference in response was identified as 5.5%). Based on this study, AREVA is confident that a 0.0001 second integration time step would be more than sufficient to achieve convergence. However, recognizing that there are inherent differences between the dynamic characteristics of the RPV isolated model and models of pure piping systems, AREVA will perform time step studies for three of the Class 1 attached piping problems for the U.S. EPR. This represents a sample of greater than 10% of the Class 1 piping problems that AREVA will analyze. The smallest integration time step required for convergence in these sample analyses will be used for all of the Class 1 piping analyses. It is currently not anticipated that time history analysis will be used for Class 2\3 piping, but if it is, the integration time step will be established in the same manner, i.e. through time step studies on a representative sample of Class 2\3 piping problems. The intent of these time step studies is to identify a practical lower bound integration time step that provides adequate assurance of convergence. Convergence will be determined by halving the integration time step until it can be shown that halving it further will not increase the response of the system by more than 10%.

The TR Section 4.2.3 will be revised to replace, "The time step to be used is to be no larger than one tenth (1/10) of the period of the cutoff frequency" with:

> "Time step studies will be performed for three of the Class 1 attached piping problems for the U.S. EPR. The smallest integration time step required for convergence in these sample analyses will be used for all of the Class 1 piping analyses. Convergence will be determined by halving the integration time step until it can be shown that halving it further will not increase the response of the system by more than 10%. If time history analysis of Class 2\3 piping problems is performed, the integration time step will be established in a similar manner, that is, through time step studies on a representative sample of Class 2\3 piping problems."

<u>RAI EPR-11:</u> *Time History Analysis Uncertainties*

TR Section 4.2.3 states that to account for uncertainties in the structural analysis using the time history method, similar to peak shifting in the response spectrum method of analysis, three separate input time histories with modified time steps will be analyzed. Alternatively, the time histories at the attachment points may be derived considering variations in the concrete stiffness.

A. Describe the detailed procedure for using the peak shifting method that will be used in the time history method of analysis with modified time steps for seismic and other dynamic loadings.

Response 11:

A. The method of accounting for uncertainties in time history analysis will be further described in the TR, as indicated below.

The fifth paragraph of TR Section 4.2.3 will be revised to incorporate the responses to this RAI as follows:

"To account for uncertainties in the structural analysis for seismic loading, a peak shifting approach, similar to that described in Section 4.2.2.1.2 for response spectrum analysis, is used. This is accomplished by first converting the seismic time history excitations into response spectra, and then proceeding through the methodology outlined in Section 4.2.2.1.2. Note that shifting of the input excitation peaks is accomplished by adjusting the time step of the time histories which represent the excitations."

Further supporting information for the above revision to the TR is provided below:

(1) The seismic design basis of the U.S. EPR includes twelve different seismic analysis cases (twelve different combinations of soil conditions and seismic control motion); all twelve cases are anchored to a PGA of 0.3g). Therefore, there will be three translational time histories (one in each of the three orthogonal directions) at each anchor point and at each support\restraint in the piping system. AREVA NP intends to analyze each of the twelve seismic cases individually, though enveloping them is a conservative option.

(2) There will be sets of three translational time histories at each terminal point\support\restraint in the piping systems being analyzed. There are two options available regarding how to treat these different sets of time histories that are applicable to the various terminal points\supports\restraints in the piping systems:

i. The time histories at terminal points\supports\restraints can be enveloped by: a) turning them into response spectra, b) developing the enveloping terminal point\support\restraint response spectra, and then c) generating an artificial time history (and resulting response spectra) which envelopes the enveloping terminal point\support\restraint response spectra within the guidance of SRP 3.7.1.

ii. For Class 1 piping systems, the piping system in question can be coupled to the model used to perform reactor coolant loop (RCL) analysis, which has a representation of the reactor building interior structure (RBIS) in it and a representation of the containment building can be added (if necessary because one or more of the supports\restraints are attached to the containment building). The resulting model has one point of excitation (the nuclear island basemat) and therefore only one set of earthquake time histories per seismic case.

(3) Once the peak shifting factors are determined by the procedure described in Section 4.2.2.1.2 of the TR, the time steps of the translational time histories (either the enveloping time histories described in 2(i) above, or the basemat time histories described in 2(ii) above) are reduced, or increased, in order to move the peak input accelerations to the desired frequencies. Note that each orthogonal direction is treated separately. The piping model is then analyzed separately for the resulting time histories (N+3 for each orthogonal direction, see Section 4.2.2.1.2 of the TR). The maximum piping system response (accelerations, displacements and loads in the x, y and z directions) among the global X direction excitations, among the global Y direction excitations, and among the global Z direction excitations are combined at each time point.

RAI EPR-12: *Equivalent Static Load Analysis*

Confirm that the equivalent static load is always determined by multiplying 1.5 to the peak acceleration for all cases including a single degree of freedom system with known fundamental frequency or a rigid system with the fundamental frequency beyond the cutoff frequency. If not, then provide the criterion that will be used for these special cases.

Response 12:

See the revised response to RAI EPR-5.

RAI EPR-13: *Small Bore Piping*

The TR did neither define nor address the design of small bore piping to be used in the EPR piping design. Define the small bore piping to be used in the EPR piping design and discuss, with technical bases, the methods of analysis (handbook or a system flexibility analysis) that will be used in the small bore piping design for ASME Class 1, 2, 3 and QG D piping.

Response 13:

Section 4.5 of the TR will be added to include the following text:

> "Small bore piping (including instrumentation lines) for the U.S. EPR is defined as ASME Class 1 piping that is 1" NPS and smaller and Class 2, 3 and QG D that is 2" NPS and smaller. This piping may be analyzed using response spectrum methods described in 4.2.2 of the Topical Report, the equivalent static method described in 4.2.3 or by handbook method."

If the COL applicant elects to use the handbook method, the COL applicant will develop the handbook.

This COL action item will be added to Table 1-1 of the TR.

RAI EPR-14: *Non-Seismic/Seismic Interaction*

B. TR Section 4.4.2 states that following the failure of the non-seismic pipe, (i) if the non-seismic piping is supported by seismic restraints within the ASME B31.1 Code-suggested pipe support spacing shown in TR Table 4-1, it is considered to lose its pressure boundary integrity, but not fall onto a safety-related piping or equipment. Provide the technical basis for this assumption. (ii) the side motion of a failed moderate energy piping is assumed to be ±6 inches (centerline to centerline) from the original position. Provide the technical basis for this assumption of ±6 inches side motion for all pipe sizes. (iii) safety-related piping with NPS and thickness equal to or greater than that of the non-seismic piping may be assumed to stop the downward motion of the non-seismic piping without failure of the safety-related piping. Provide the technical basis for this assumption.

Response 14:

B. (i) The second sentence in the third bullet in Section 4.4.2, Item 1, of the TR will be deleted.

(ii) The first bullet in Section 4.4.2, Item 2, of the TR will be removed.

(iii) The second bullet in Section 4.4.2, Item 2, of the TR will be removed (see attached mark-up).

RAI EPR-15: *Buried Piping*

TR Section 3.10 did not give details on the analysis method and how the criteria are to be applied in the design of buried piping.

A. Based on the criteria presented in the TR, describe the analysis method and design requirements that will be used for buried piping design (including buried pipe tunnel if used in the design). Explain how these methods compare to the analytical methods referenced in the recently published NRC Standard Review Plan 3.7.3, Rev. 3, (i.e., ASCE Standard 4-98, ASCE Report - Seismic Response of Buried Pipes and Structural Components, and NUREG/CR-1161).

B. Why doesn't TR Section 3.10 include consideration of ground-water effects and soil arching effects which could increase or decrease the stresses in the pipe due to the overlying soil plus the ground surface loads?

D. TR Table 3-4 provides the design conditions, load combinations and acceptance criteria for Class 2/3 buried piping. Explain clearly the term non-repeated anchor movement, Equation 9U (vs 9), and Equation 9E (vs 9). While the intent may be interpreted, it is important that these terms be clearly defined in the TR. For Equations 10M and 11M, which are identified as "modified to include axial friction forces," provide the equations to show how they are modified.

F. Confirm that Note 5 in the TR Table is applicable to all cases cited in TR Table 3-4 since it is not referenced in the Table like the other notes are. Also, explain how the criteria of NC/ND-3133 of the ASME Code (Note 5 in the Table) will be implemented in conjunction with meeting the loads and loading conditions specified in Table 3-4.

Response 15:

A. Section 3.10 of the TR will be revised to include analysis methods and design requirements for buried piping, as shown in Attachment B to this response.

The methods developed for the U.S. EPR buried piping meet requirements in SRP 3.7.3, Rev. 3, ASCE Standard 4-98 and ASCE Report-Seismic Response of Buried Pipes and Structural Components.

The last equation given in Section 3.10.1.3 of the TR will be revised as shown in Attachment B. Additionally, Section 3.10.1.1 of the TR will be revised as shown in Attachment B to delete the following sentence:

> "The external pressure counteracts the internal pressure, this external pressure is significantly less than the internal pressure and its impact on design is not significant."

Section 3.10.1.1 of the TR will be revised as shown in Attachment B to indicate that, for conservatism, P will be defined as the sum of internal pressure and the absolute sum of P_V and P_P.

The revised Attachment B also includes Tables 3-5 and 3-6 that are referred to in Section 3.10.1.4 of the TR.

Thermal induced stresses, as defined in Reference 13 of the TR includes a term for hoop stress due to internal pressure. Hoop stress acts to reduce the stress due to restrained longitudinal expansion or contraction. Since this term is usually considered small, equations 10M and 11M for thermal expansion and contraction will be revised to remove this term. The allowable stress for 10M is S_a.

Section 3.10.3.1 of the TR was revised as shown in Attachment B to reflect some of the changes made in the more recent ASCE 4-98 standard (e.g., E is the secant modulus, equations given in axial and bending strains include the wave velocity coefficients, etc.).

Equation for S_{OL} in the TR will be revised as shown in Attachment B to include $E_{sct}\varepsilon_a$ and $E_{sct}\varepsilon_{b.}$ Seismic stresses in buried piping are considered secondary stresses. Therefore, the pressure stress (primary) is not included in this equation.

B. Section 3.10 of the TR will be revised as shown in Attachment B to include buoyancy forces from ground-water, overburden, and surface traffic from trucks, rail and construction equipment, as shown in Attachment B to this response.

D. Non-repeated anchor movements, in the case of buried pipe, refers to building settlement at the point where the buried pipe enters the building. Equations 9U and 9E refer to upset and emergency respectively. These designations are used to distinguish the differences in plant events that occur during the upset or emergency plant conditions and must be combined per Equation 9 and meet the allowable stresses as noted in the various section of NC/ND 3650.

The TR will be revised as shown in Attachment B to show equations 10M and 11M and to define the terms in all equations associated with buried pipe.

F. Note 5 will be added to Table 3-4 as appropriate. As shown in Attachment B, the external pressure of the soil overburden defined in NC/ND-3133 will be added to the discussion in 3.10. Note 5 applies to the equations that include a pressure term. The TR will be revised to include this term.

<u>RAI EPR-20:</u> *Piping Benchmark Program*

Final piping and pipe support stress analyses cannot be completed before design certification because their completion is dependent on as-built or as-procured information. Under a piping benchmark program, the combined operating license (COL) applicant applies his computer program to construct a series of selected piping system mathematical models that are representative of the standard plant piping designs. Please confirm if AREVA has established such a piping benchmark program to be used by the COL applicants and whether its own piping analysis computer code described in Section 5.1 was verified using models representative of the U.S. EPR.

Response 20:

AREVA will identify three (3) representative calculations from the analyses currently being completed for the U.S. EPR design certification to be used in the benchmark program. These calculations will utilize the piping analysis codes identified in 5.1 of the TR.

The COL applicant will implement this benchmarking program if he chooses to use programs other than those stated in TR 5.1. This requirement is Item 6 of Table 1-1.

Additionally, TR Section 5.3 and item 6 of TR Table 1-1 will be revised to change the term “NRC benchmark program” to “U.S. EPR benchmark program.”

<u>RAI EPR-21:</u> *Model Decoupling Criteria*

TR Section 5.4.2 states that adequate flexibility in the branch line is provided by maintaining a minimum length from the run pipe to the first restraint of ½ of the pipe span in TR Table 4-1 for the branch line. The mass to be considered at the branch connection of the run pipe is the mass of ½ of the first span of the branch pipe, including concentrated weights, in each direction. However, AREVA did not discuss other effects (e.g., moment or torsional load at the branch connection) of the eccentric concentrated masses, such as valves, in the first one-half span length from the main run pipe. Provide technical justification on how to account for the effect of a large concentrated mass near the branch connection in the decoupling criteria discussed in the TR.

Response 21:

TR Section 5.4.2 will be revised to include the following information:

> "Large concentrated masses should not be located within the first span of the branch pipe. 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 must be considered. In these cases, the branch piping will be modeled and analyzed with the run pipe, or a portion of the branch line shall be included in the run pipe analysis to adequately include the torsional effects of the eccentric mass."

RAI EPR-22: *Dynamic Analysis of Branch Lines*

TR Section 5.4.2 states that for the SSE inertia load case, each individual run pipe movement shall be analyzed as a separate anchor movement load case on the branch line and combined with its respective load case by absolute summation. Provide additional clarification to explain this procedure.

Response 22:

See the revised response to RAI EPR-7 for changes to TR section 5.4.2.

RAI EPR-25: *Piping Load Combinations*

The staff needs clarification of several items associated with TR Section 3.3 and Tables 3-1 and 3-2.

B. Note 3 to TR Table 3-1 states that dynamic loads are to be combined considering timing and causal relationships. SSE and Design Basis Pipe Break (including loss-of-coolant accident (LOCA)) shall be combined using the square root of the sum of the squares (SRSS) method. This is acceptable in accordance to NUREG-0484, Rev. 1. However, for dynamic responses resulting from the same initiating events (other than SSE), when time-phase relationship between the responses cannot be established, the absolute summation of these dynamic responses should be used. Confirm if this is true for the EPR piping design. If not, discuss with technical justification the combination method to be used when multiple LOCA or other dynamic load events are required to be combined. This combination criterion is also applicable to note 5 of the TR Table 3-2, which states that dynamic loads are combined by the SRSS.

C. Note 8 to TR Table 3-1 states that the earthquake inertial load used in the Level D Primary Stress (Equation 9F) calculations shall be taken as the peak SSE inertial load. The earthquake anchor motion load used in the Level D Primary Stress (Equation 9F) calculations shall be taken as the peak SSE anchor motion load. The staff position on the use of a single-earthquake design in SECY-93-087 states that the effects of anchor displacements in the piping caused by an SSE be considered with the Service Level D limits. For simplified elastic-plastic discontinuity analysis, if Eq. 10 cannot be satisfied for all pairs of load sets, then the alternative analysis per NB-3653.6 for Service Level D should be followed. In addition, the combined moment range for either the resultant thermal expansion and thermal anchor movements plus ½ the SSE seismic anchor motion or the resultant moment due to the full SSE anchor motion alone, whichever is greater must satisfy the equation (known as Eq. 12a) given in NB-3656(b)(4). Clarify if this is applicable to EPR piping design. Also, justify why this anchor motion stress is categorized as a primary stress in the TR Table 3-1 for the faulted condition.

D. Identify the applicability of notes 3 and 5 in the TR Table 3-2.

Response 25:

B. AREVA expects to be able to establish the timing and causal relationships between dynamic events such as pipe rupture and valve actuation. When the causal relationship between two dynamic events can be established, the results from the two events will be combined by SRSS, provided it is demonstrated that the non-exceedance criteria provided in NUREG-0484 is met, or by absolute summation. However, if this relationship cannot be established between two dynamic events, the responses from these events will be combined by absolute sum. Table 3-1 will be revised to clarify this point as shown in Attachment C to this response.

Note 11 of Table 3-1 will be revised as follows:

> "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 is met. When the time phasing relationship cannot be established, or when the non-exceedance criteria given in NUREG-0484 are not met, dynamic loads must be combined by absolute sum. SSE and High Energy Line Break loads are always combined using the SRSS method."

Note 5 of Table 3-2 will be revised to include:

> "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 is met. When the causal relationship cannot be established , or when the non-exceedance criteria given in NUREG-0484 are not met, dynamic loads must be combined by absolute sum. SSE and High Energy Line Break loads are always combined using the SRSS method."

C. At the time that the Topical Report was written, portions of Section III NB-3600 in the 2004 Edition of the ASME Boiler and Pressure Code were not endorsed by the NRC, per the version of 10CFR50.55a in effect at that time. The proposed draft of 10CFR50.55a which was published in spring of 2007 indicates that restrictions on the use of the rules involving seismic loading have been removed. AREVA will therefore reference the equations from NB-3656(b)(4) for the treatment of SSE anchor motions. Table 3-1 has been revised for this reason and to provide further clarification of the Class 1 load combinations.

Table 3-1 will also be revised to include the following:

- In the upset loading condition for primary plus secondary stress intensity range (equations 10 and 11), the loads will include the SSE.
- If equation 10 cannot be satisfied for all pairs of load sets, then the alternative analysis as described in NB-3653.6 will be followed. In addition, the following condition shall be satisfied:

$S_{sam} = (C_2 D_o/2I)(M_{AM}) \leq 6S_m$

Where M_{AM} is the combined moment range for either the resultant thermal expansion and thermal anchor movements plus ½ the SSE seismic anchor motion or the resultant moment due to the full SSE anchor motion alone, whichever is greater.

D. Note 3 applies to the "Design" loading condition and Equation 8. Note 5 applies to Equations 9E and 9F. The TR will be revised to clearly identify the applicability of these notes.

RAI EPR-26: *Piping Damping Values*

In TR Section 4.2.5, it is identified that Rev. 0 of the RG 1.61 values of damping will be used in the seismic analysis of structures, systems, and components (SSCs) using ISM response spectrum analysis or time history analysis. However, for piping systems analyzed using USM response spectrum analysis, 5% damping will be used provided that the system is not susceptible to stress corrosion cracking. Five percent damping will not be used for analyzing the dynamic response of piping systems using supports designed to dissipate energy by yielding.

A. Since staff has issued the Rev.1 of RG 1.61 in March 2007, indicate if the design of EPR piping systems will use Rev. 1 of the RG-recommended damping values.

B. For piping systems analyzed using uniform support motion response spectrum analysis and 5% damping, verify that all of the limitations specified in RG 1.84 for ASME Code Case N-411 (or RG 1.61, Rev.1) will be met.

Response 26:

A. TR Section 4.2.5 will be revised to state:

> "RG 1.61, Rev. 1 damping values will be used for Independent Support Motion response spectra and Time-History analysis. RG 1.61, Rev. 1 will also be used for piping systems analyzed using uniform support motion response spectra which do not meet all of the limitations specified in RG 1.84 for ASME Code Case N-411."

B. TR Section 4.2.5 will be revised to state:

> "5 percent damping is used for piping that is analyzed using the uniform support motion response spectrum method. Piping that is analyzed using this method meets the limitations specified in RG 1.84 for ASME Code Case N-411."

AREVA NP recognizes that the damping value for piping in RG 1.61, Rev. 1 is limited to 4 percent. Accordingly, in the U.S. EPR design certification application, AREVA NP will identify the use of 5 percent damping for piping analyzed using the uniform support motion response spectrum method as an exception to RG 1.61, Rev. 1. The basis for this exception is provided below.

Regulatory precedent exists for using 5 percent damping for piping for advanced light-water reactors (ALWRs). Specifically, NRC has approved the use of 5 percent damping for System 80+, AP600, and AP1000. Further justification for the use of 5 percent damping for piping analyzed using the uniform support motion response spectrum method is provided below.

In AP1000 RAI No. 210.040 dated September 30, 2002, NRC requested the following information:

> "Section 3.7.3.15: Westinghouse should verify that all limitations specified in RG 1.84 for Code Case N-411 apply to the use of 5 percent damping."

The above RAI is almost identical to RAI EPR-26, item B above. In response to AP1000 RAI No.210.040[1], Westinghouse agreed to apply the limitations specified in RG 1.84 for Code Case N-411 for piping where the use of 5 percent damping is utilized. Subsequently, in the AP1000 Final Safety Evaluation Report (FSER)[2], NRC states:

> "The staff had reviewed and accepted for the AP600 the use of 5-percent damping for piping systems for ALWR plants on the basis that ALWR plants must be designed to a minimum 0.3 ZPA for the SSE. This high seismic acceleration provides assurance that piping systems will experience higher damping valves. Its acceptance was also subject to certain limitations specified in RG 1.84 for ASME Code Case N-411-1. The limitations applicable to design include (1) limiting the building filtered responses to 33 Hz and below, (2) using damping values only in those analyses in which current seismic spectra are used, (3) not allowing the use of damping values when using supports to dissipate energy by yielding, and (4) not allowing their use where stress-corrosion cracking is a concern. In RAI 210.040, the staff requested the applicant to verify that these limitations will apply to AP1000 piping. The applicant's response confirmed the staff's assumptions. The applicant stated that the 5-percent damping value will be used consistently for all piping system seismic analyses utilizing enveloped response spectrum methods. The enveloped response spectra are developed in accordance with RG 1.122, as described in the DCD. The design of the AP1000 piping systems does not include supports designed to dissipate energy by yielding, and the piping systems analyzed are not susceptible to stress-corrosion cracking. The staff concurs that these limitations conform to the RG 1.84 limitations."

Similarly, in the System 80+ FSER[3], NRC states:

> "ABB-CE proposed revisions to DCD Section 3.7.1.3, Figure 3.7-32, Table 3.7-1,

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1 See Westinghouse letter AW-021557 dated October 2, 2002 (accession numbers ML022810020 and ML022810434).

2 See NUREG-1793 dated September 2004.

3 See NUREG-1462 Supplement 1, Section 3.12.5.4, dated May 1997.

and Appendix 3.9A. These revisions changed the maximum allowable damping value for piping analyzed using the uniform envelope response spectrum method from the ASME Code Case N-411-1 values to a 5% value for all modes of vibration. The revised Table 3.7-I contains a footnote stating that when the 5% value is used for such piping, the conditions in RG 1.84 for using CC N-411-1 will apply even though Code Case N-411-1 is not being used. Piping analyzed using either the time history or independent support method will use the appropriate values in Table 3.7-1."

"In section 3.12.5.4 of the FSER, the NRC staff reported that as an alternative to the RG 1.61 damping values, which are in Table 3.7-1, variable damping values in accordance with the requirements and limitations of the ASME Code Case N-411-1 may be used, subject to the conditions given in RG 1.84 relative to the use of Code Case N-411-1. In its evaluation of the above changes, the NRC staff considered the following inherent conservatisms implicit in the overall DCD criteria:

1. Implementation of the conditions specified in RG 1.84 will generally result in a conservative design.
2. The use of the uniform 5% value could result in a small under-prediction of support loads and piping deflection at higher frequencies. However, because the DCD (and other ALWR) seismic criteria are (1) based on ground response spectra as defined in RG 1.60 that are enhanced in the high frequency range (approximately 8-40 Hz), and (2) anchored at a relatively high peak ground acceleration value of 0.3g, the NRC staff finds that the use of the uniform 5% damping is acceptable only for use on ALWRs."

"On the basis of the above evaluation, the staff has concluded that use of the uniform 5% damping value when implemented with the seismic and piping design Criteria in the DCD will provide piping designs with margins which are consistent with those of designs using Code Case N-411-1, as limited by RG 1.84, and is therefore acceptable."

Reg. 1.84, Table 4, "Annulled Conditionally Acceptable Section III Code Cases," contains the Code Cases "that the NRC determined to be acceptable provided that they were used with the identified limitations or modifications, but that the ASME subsequently annulled." Table 4 indicates that Code Case N-411 was annulled on May 5, 2000. However, as noted in the quoted RAI and FSER for AP1000 (both of which were issued after Code Case N-411 was annulled), NRC has determined that the limitations specified in RG 1.84 for Code Case N-411 are still acceptable for the use of 5 percent damping.

During a conference call between AREVA NP and the NRC on October 4, 2007, representatives from Brookhaven National Laboratory (BNL) stated that: 1) the approval for 5 percent damping for AP1000 was case specific; and 2) AREVA NP needed to provide technical justification to utilize the 5 percent damping value. AREVA NP's response to these statements is provided below:

1) BNL's statement that the 5 percent damping was a case specific approval is based on a similar statement in NUREG/CR-6919 (BNL-NUREG-77174-2006), "Recommendations for Revision of Seismic Damping Values in Regulatory Guide 1.61," dated November 2006, prepared by BNL. Specifically, Section 4.2 of NUREG/CR-6919 states:

> "The NRC previously accepted ASME Code Case N411-1 damping (Ref. 9), with qualifications in accordance with Regulatory Guide 1.84 (Ref. 10). At the time the qualifications were initially specified, the NRC had intended to conduct studies aimed at evaluating the validity of these qualifications, and as appropriate, remove some of the restrictions on N411 damping. However, the required studies were not conducted.
>
> ASME has annulled Code Case N411-1, because Non-Mandatory Appendix N to Section III currently recommends 5% damping at all frequencies, for both OBE and SSE (Ref. 4). The staff had previously accepted 5% SSE damping for AP1000, for uniform support motion, response spectrum analysis of piping systems (Ref. 16). The staff invoked restrictions on its use, consistent with the qualifications formerly in Regulatory Guide 1.84 for Code Case N411-1.
>
> The staff continues to accept former Code Case N411-1 damping subject to the restrictions identified in Regulatory Guide 1.84. The staff considers acceptance of 5% damping for AP1000 to be a case-specific determination."

AREVA NP contends that the NRC acceptance for damping is not a "case-specific determination." As previously noted, NRC has approved the use of 5 percent damping for other ALWRs besides AP1000 (i.e., System 80+ and AP600). The stated basis for these determinations was the high seismic demand level required for ALWRs. As quoted in the NRC FSER for AP1000, NRC approved the "use of 5-percent damping for piping systems for ALWR plants on the basis that ALWR plants must be designed to a minimum 0.3 ZPA for the SSE." Similarly, as quoted in the System 80+ FSER, "because the DCD (and other ALWR) seismic criteria are (1) based on ground response spectra as defined in RG 1.60 . . . the NRC staff finds that the use of the uniform 5% damping is acceptable only for use on ALWRs." The seismic demand for the U.S. EPR piping meets or exceeds the seismic demand that NRC considered for AP600 and AP1000 in making this determination. If NRC still believes that use of 5 percent damping is a case specific determination, then AREVA NP requests that a similar determination be made for the U.S. EPR based on the same justification that NRC approved for the other ALWRs.

2) AREVA NP contends that no further technical justification is needed to support the 5 percent damping for piping analyzed using the uniform support motion response spectrum method. As previously noted, RAI EPR-26 is almost identical to AP1000 RAI No. 210.040. Similar to the AP1000 RAI response, which NRC accepted, AREVA NP has agreed to revise the TR to meet the limitations specified in RG 1.84 for ASME Code Case N-411. This justification was also

accepted by the NRC for the System 80+ and AP600. Also, Regulatory Position 2 in Section C of RG 1.61, Rev.1 provides the piping damping values that resulted from the NRC experience with ASME Code Case N–411 and application reviews of new reactor designs. Therefore, no further justification is required for the utilization of the 5 percent damping for piping analyzed using the uniform support motion response spectrum method.

RAI EPR-27: *Modal Combinations*

In TR Section 4.2.2.3.1, it is stated that for the response spectrum method of analysis, the modal contributions to the inertial responses are normally combined by the SRSS method. If some or all of the modes are closely spaced, any one of the methods (Grouping method, 10% method, and Double Sum method, as well as the less conservative methods in revision 2 of the RG 1.92) is applicable for the combination of modal responses. This combination method is applicable to both USM and ISM methods of analysis.

A. If guidance given in Revision 2 of the RG 1.92 is used for the EPR piping design, then Revision 2 of the RG no longer recognizes the Grouping method, 10% method and Double Sum method for closely spaced modes. These methods are renamed and AREVA should identify them as noted in the RG.

B. TR states that for closely spaced modes AREVA may use less conservative methods discussed in the RG. Please identify which methods are less conservative methods and explain why they are less conservative with respect to the other method(s).

Response 27:

A. In the Background discussion of Section B as well as in the Regulatory Position in Section C of RG 1.92 Revision 2, the methods of Revision 1 are included by reference as remaining acceptable for use. AREVA will add Revision 1 of RG 1.92 to the references since the detail for these methods are not provided in Revision 2.

During a conference call between AREVA NP and the NRC on October 4, 2007, NRC stated that the use of the RG 1.92 Rev. 1 methods for modal combination require that the lower damping values from RG 1.61 Rev. 0 also be used. This would limit the damping to 2 percent or 3 percent, depending on pipe size. NRC further stated that the methods described in these RGs are complementary (i.e., they are to be considered as a set in that one cannot choose to use previously approved methods in one and newer methods in another).

AREVA NP is not aware of any documented basis or indication that the increased damping values presented in Regulatory Guide 1.61 Revision 1 may only be used with the modal combination methods presented in Revision 2 of Regulatory Guide 1.92, or that revisions to these Regulatory Guides must be used as a set. In presenting the damping values to be used in the seismic design of nuclear power plant SSCs, RG 1.61 Revision 1 does not state any limitation of use based on the combination of modal responses. Furthermore, neither of the revised RGs makes reference to the other to indicate any relationship in the use of the methods in one being based on the use of the other.

Revised RGs 1.92 and 1.61 provide more accurate and realistic response in the dynamic analysis of nuclear power plant structures, systems, and components (SSCs) while reducing unnecessary conservatism included in the previous revisions.

RG 1.92, Rev. 2, was issued July 2006 and provides new methods for the combination of modal results when performing response spectrum analyses. These new methods introduce refined methods for the combination of out-of-phase responses of closely spaced modes. In the Rev. 2 methods, the combination of these responses includes a definition for closely spaced modes and a phase correlation coefficient which are dependent on the damping ratio. While this revision specifically states the allowance of the Revision 1 methods, it does not impose any damping value limits.

Revision 1 of RG 1.61 was issued in March 2007 and provides increased damping values for piping analysis. Additionally, Rev. 1 incorporates the acceptance of frequency-dependent damping which had previously been accepted as ASME Code Case N-411, along with the conditional restrictions on its use from RG 1.84. At the time of issuance of this revision to the Regulatory Guide, all methods of modal combination from Revisions 1 and 2 of RG 1.92 were considered acceptable and there is no mention of the use of the damping values being restricted to the Revision 2 modal combination methods.

NRC also referred to NUREG/CR-6645 to support their position that when the more conservative modal combination methods approved in Revision 1 of RG 1.92 are used in the pipe stress analysis, the more conservative damping values presented in Revision 0 of RG 1.61 must also be used. This NUREG/CR was prepared by BNL to re-evaluate the regulatory guidance for combining modal responses in response spectrum analysis and recommend revisions to RG 1.92.

NUREG/CR-6645 presents a comparison of results of numerous response spectra analysis (RSA) techniques versus a time history analysis which is considered to represent the most accurate analytical response. Review of the results presented show that the methods included in Revision 2 of RG 1.92 (Rosenblueth Double Sum Combination (DSC) and Der Kiureghian Complete Quadratic Combination (CQC)) produce overall more accurate results (a smaller standard deviation) than the methods in Revision 1 of RG 1.92 (the NRC Grouping, NRC Ten Percent and NRC Double-Sum methods). However, NUREG/CR-6645 shows that the methods from Revision 1 of RG 1.92 are more conservative even when considering 5% damping (Tables 3-16 and 3-17). Additionally, when looking only at the Revision 1 methods, more conservatism is noticed in the 5% damping solutions compared to the applicable time history results than in the same analyses considering 1% damping (Tables 3-14 and 3-15). On page 27 of NUREG/CR-6645, BNL makes the following statement: "The overall level of conservatism for RSA methods is higher at 5% damping than at 1%; however, the scatter is also significantly larger. The NRC methods and SRSS exhibit the largest increases in conservatism and scatter."

In conclusion, AREVA NP contends that there is no documented or technical basis or precedence to treat the revisions to RG 1.61 and RG 1.92 as a set. A review of NUREG/CR-6645 affirms that the use of the increased damping values discussed within this document with the modal combination methods of RG 1.92 Revision 1 will produce an acceptable, conservative, result as compared to the use of the Revision 2 methods. Therefore, based on this review, the use of the methods of RG 1.92 Revision 1 remain acceptable for use, as stated in the regulatory position in Revision 2, without additional damping restrictions.

B. See the response to item A above.

<u>RAI EPR-28:</u> *Missing Mass*

TR Section 4.2.2.3.2 presents a procedure to account for high-frequency modes in the response spectrum methods for calculating seismic and other dynamic load responses.

A. Discuss the differences in the mathematical derivations of the high frequency modes presented in the TR versus the methods acceptable to the staff as given in RG 1.92, Rev. 2.

B. The TR states that the response from high frequency modes will be included in the response of the piping system if it results in an increase in the dynamic results of more than 10%. However, in accordance with RG 1.92, Rev.2, C.1.4.1, this criterion may yield non-conservative results and should not be used. Since this guideline does not consider the total mass that is missing, which, in the limit, could be 10%, provide technical justification for using this criteria as a screening requirement for including the effects of any missing mass.

D. Finally, the TR states that this missing mass mode is considered to have a modal frequency and acceleration equal to the cut-off frequency used in the modal analysis. These modal results are combined with the low frequency modal results using the methods described in TR Section 4.2.2.3.1 for the low frequency modes (per RG 1.92). Please explain the combination method for the results to be used from both low and high frequency modes.

Response 28:

A. The method detailed in the TR is based on the Left-Out-Force method. This method is performed by the SUPERPIPE piping analysis code which has been accepted for use at many operating plants. Although this method is different than that shown in RG 1.92, it produces the same result. The basic difference in the presentations of the missing mass calculation as shown in RG 1.92 and as shown in the TR is that the RG equations are written for each modal degree-of-freedom while the TR equations are written in vector form. Re-writing the SRP equations in vector form shows that the formulations are equivalent.

BWSPAN uses the missing mass method given in Appendix A of RG 1.92, R2. TR Section 2.2.3.2 will be revised to state that BWSPAN uses the missing mass method outlined in Appendix A of RG 1.92 Revision 2.

B. The residual rigid response of the missing mass modes will be included in all seismic analyses of safety related piping systems. Section 4.2.2.3.2 will be revised to remove the option of using the 10% criteria. Additionally, references to Appendix A of SRP 3.7.2 with regards to the calculation of missing mass were removed when the 10% criteria mentioned above was removed.

D. The TR will be revised to state that, for USM, the rigid range (missing mass) results will be combined with the low frequency modal results in accordance with Regulatory Position C.1.5.1 of RG 1.92, Rev. 2. For systems analyzed using ISM, the missing mass results will be combined with the low frequency modal results by SRSS, per NUREG-1061. See RAI EPR-8 for revised text for TR Section 4.2.2.3.2.

When using the modal combination methods of Rev. 1 of RG 1.92, Combination Method A provided in Rev. 2 of RG 1.92 Section C.1.5.1 is applied. In these cases, the rigid modal response component of the low frequency modes is equal to zero, and the method reduces to the SRSS combination of the low frequency modal results and the high frequency missing mass results.

RAI EPR-29: *Nonlinear Vibrations Due to Support Gaps*

The TR does not provide an analytical method to account for nonlinear effects of excessively large gaps (for frame type supports) between the pipe and supports subject to high frequency vibration loads. Should such large gaps exist, provide the piping analysis method to be used to address the nonlinearity when subjected to vibratory loads with significant high-frequency caused by the gaps between the pipe and its supports.

Response 29:

As stated in TR Section 6.5, and further discussed in Section 6.11, the U.S. EPR design does not intend to utilize gapped supports. For the U.S. EPR, the normal design practice for frame structure guide supports is to utilize a nominal 1/16" gap between the surface of the pipe and the edge of the support member for both sides of the pipe in the restrained direction.

Section 6.5 will be revised to add the following text:

" Although the use of gapped supports is not anticipated for the U.S. EPR, should the need for such supports arise, the non-linear piping analysis problem will be solved using direct integration time history methods."

RAI EPR-30: *Thermal Stratification*

A. *TR Section 3.7.1 states that the main feedwater nozzle is located in the conical section of the steam generator which aids in reducing thermal stratification. Please explain how this reduces thermal stratification.*

B. *TR Section 3.7.2 states that the surge line may not be subjected to significant stratification/striping effects due to design features that mitigate these effects. Describe these design features and explain how they mitigate the effects of thermal stratification in the surge line.*

Response 30:

A. Since the main feedwater nozzle is attached to the sloped conical section of the steam generator, it too is inclined: ~18 degrees from the horizontal. This incline promotes mixing of the colder and hotter fluid layers in the line which in turn retards stratification. The inclined design also prevents permanent thermal stratification at low flow rates and ensures run-full conditions in the nozzle. Additional information on thermal stratification is provided in Section 3.12 of the design certification application.

B. There are three major features of the surge line which minimize the amount of stratification in the line: 1) The take-off from the hot leg is vertical upward and of sufficient length that turbulent penetration from hot leg flow does not spill over into the surge line beyond the take-off, and thus causing stratification; 2) the surge line is sloped ~5 degrees between the vertical take-off at the hot leg and the vertical leg at the pressurizer, which promotes contributes to mixing of the colder and hotter fluid layers in the line; and 3) during normal operation, a continuous bypass spray flow of sufficient magnitude is maintained to further suppress turbulent penetration from the hot leg flow. Additional information on the evaluation of unisolable piping for thermal stratification due to a leaking valve (NRC Bulletin 88-08) is provided in TR Section 3.7.3 and will be provided in Section 3.12 of the design certification application.

RAI EPR-33: *Codes for Support Design*

B. *AREVA also states that seismic Category II pipe supports are designed to ANSI/AISC N690, "Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities." These standards are used to design the structures or structural elements of a support for nuclear facilities, not the standard component supports (e.g., clamps, snubbers). ASME Code Subsection NF is typically used for seismic Category II pipe supports. Identify the standard that will be used to design, manufacture, install and test seismic Category II pipe supports.*

Response 33:

B. For all Seismic Category II pipe supports other than standard component supports, the design, manufacturing, installation and testing will meet the requirements of ANSI/AISC N690. Standard component supports will be designed, manufactured, installed and tested to Subsection NF of the ASME Code. Any structural members used as part of a pipe support also containing standard components will be designed, manufactured, installed and tested to ANSI/AISC N690. The reference to ANSI/AISC N690 in the TR will be revised to include Supplement 2 (2004), in accordance with SRP Sections 3.8.3 and 3.8.4.

RAI EPR-34: *Load Combination for Supports*

While reviewing TR Section 6.3, the staff needs clarification of the following items.

A. *TR Section 6.3.11 provided a minimum design load criteria that will be used for all supports so that uniformity is obtained in the load carrying capability of the supports. All supports will be designed for the largest of the following three loads: 100% of the Level A condition load, the weight of a standard ASME B31.1 span of water filled, schedule 80 pipe, and minimum value of 150 pounds. Provide the technical basis for this criteria.*

B. *TR Table 6-1 provides the specific load combinations that will be used in the design of pipe supports. The acceptance criteria associated with the Service Levels will be per ASME Code, Subsection NF, ANSI/AISC N690 or the AISC Manual of Steel Construction, as appropriate. Note 1 to the Table states that operating basis earthquake (OBE) inertia and SAM loads are not included in the design of Class 2/3 piping. Explain how the seismic inertia and SAM loads are accounted for in the design of Class 2/3 pipe supports. Also, clarify how the same table is applicable to snubbers, struts, and anchors/guides.*

C. *AREVA discusses wind/tornado loads in TR Sections 6.3.5 and 6.3.6 for pipe supports. However, for the piping in TR Section 3.3.1.6, AREVA identified these loads to be COL-Action Item 3. Clarify AREVA's position on this.*

Additionally, in Reference 4, NRC also requested the following information:

1. *Explain why the friction load F is not included in the load combinations that contain wind or tornado since these two loads may not always act as dynamic type loadings.*

2. *For piping design and pipe support design why isn't RSOT considered in other load combinations (i.e., in combination with RDBPB, RMS/FWPB, LOCA, RDBPB+SSE, RMS/FWPB+SSE, and LOCA+SSE)?*

Response 34:

A. The Minimum Design Load criteria given in this section is based on criteria given in Welding Research Council (WRC) Bulletin 353, Section 2.4.7. The bulletin recommends 125% of the Level A condition load, as the only difference from the topical's criteria. Presently, for the analyses being performed as part of the design certification process, the guidance is to apply a 25 percent increase to all pipe support loads to allow for possible future increases in support loads beyond the initial design. TR section 6.3.11 will be revised to change the criteria to use 125% of Level A loading, versus 100%. This is consistent with WRC Bulletin 353.

B. Table 6-1 includes three Faulted load combinations which contain SSE loads. In addition, Note 3 of the table states that SSE includes inertia and SAM loads combined by absolute sum. These would all apply to Class 1, 2 &3 pipe supports. In addition, struts and anchors/guides will be analyzed to all load combinations shown in the table. Snubbers will be designed to all but the Normal Level load combinations shown in the table.

Note that Class 1 was inadvertently not included in Note 1 of Table 6-1. This will be corrected in the next revision of the TR. Note 1 will be revised to state, “OBE inertia and SAM loads are not included in the design of Class 1, 2 & 3 piping.”

The terms in Table 6-1 are defined in 6.3.1 through 6.3.10, as discussed in 6.3. TR sections 6.3.5 and 6.3.6 will be revised to indicate that snubbers are active in the dynamic case noted, and inactive in the static case.

C. Section 3.3.1.6 states that for design certification, no Class 1, 2 and 3 piping is exposed to wind and tornado loads, and further states that if a COL Applicant creates such an exposed piping condition, it will be addressed at that time. Sections 6.3.5 and 6.3.6 discuss the inclusion of such wind related loads for pipe supports.

AREVA’s position on wind loadings for both piping and supports is as stated in Section 3.3.1.6. Clarification will be added to Sections 6.3.5 and 6.3.6 to cross reference this section, and state that these sections show how such loads would be treated if the need arises.

Responses to the additional information for this RAI in Reference 4 is provided below:

C.1 Per WRC Bulletin 353, “Forces due to friction of the piping on the support shall be considered under combined deadweight and thermal loading only.” Therefore, friction will not be considered with even the static analysis cases of wind and tornado.

C.2 Table 6-1 of the TR will be revised to include the effects of system operating transients (R_{SOT}) with pipe break, LOCA, and SSE loads, both in the Level C and the Level D cases. In addition, the following note will be added to the table:

"Loads due to dynamic events 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 is met. When the time phasing relationship cannot be established, or when the non-exceedance criteria in NUREG-0484 is not met, dynamic loads are combined by absolute sum. SSE and High Energy Line Break (i.e. Loss-Of-Coolant-Accident and Secondary Side Pipe Rupture) loads are always combined using the SRSS method."

Note that any steady state effects from the system operating transients will be added to the combinations. Note also that the piping load combination tables 3-1 and 3-2 already have these loadings combined.

RAI EPR-36: *Support Stiffness*

AREVA does not adequately describe in TR Section 6.7 how the representative stiffness values are developed for all supports other than snubbers. Describe:

1. *the approach used to develop the representative stiffness values,*

2. *the procedure that will be imposed to ensure that the final designed supports match the stiffness values assumed in the piping analysis,*

3. *the procedure used to consider the mass (along with the support stiffness) if the pipe support is not dynamically rigid, and*

4. *the same information [(1), (2), and (3) above] for the building steel/structure (i.e., beyond the NF jurisdictional boundary) and for equipment to which the piping may be connected to.*

Response 36:

The initial piping analyses will assume all supports rigid (except for the few cases where the actual support structures are included in the piping model), and therefore utilize the default rigid support stiffness values contained in the analysis program. In addition, the initial pipe support designs will be developed to create a rigid support, based on the deflection check criteria given in Section 6.7 of the topical. If for some reason, a rigid support cannot be achieved, an actual support stiffness will need to be developed for the support noted, as well as for the other supports in the model. WRC Bulletin 353 discusses the use of deflection checks to determine stiffness of supports. It discusses the use of a 1/16 inch deflection for Level B checks, with no more than a maximum of 1/4 inch, for typical piping systems in the range of 3 to 9 Hz frequency. The deflection check criteria used in the TR has been used in other plants and falls within the bounds of the criteria of this document.

Typically, unless the support is a very simple structure, a frame support will be modeled using an analysis program such as GT STRUDL. This model will include the self-weight of the support, and will also be used to establish the deflections needed for the stiffness checks. Note that this model will include any flexible building steel, as applicable. If the deflection checks do not show rigidity, the model can be used to determine the actual stiffness of the support structure using the self-weight load case. In addition, the support mass can be determined from the model. This would be created for the supports in the model and provided to the piping analyst. At this point, the supports would need to be rechecked for the loads from the revised piping analysis. If any support changes were required, an iteration of the process would be required to assure that the stiffnesses and masses are consistent for both the support qualifications and the piping analysis. Information on GT STRUDL will be added to TR Section 5.1.

<u>RAI EPR-37:</u> *Inclusion of Support Self-Weight Excitation*

In TR Section 6.8, AREVA did not indicate if the criteria presented is also applicable to other dynamic loads and did not discuss how the damping value will be used in the response spectrum analysis.

A. Clarify whether the criterion presented in the TR is also applicable to other dynamic loads. If not, provide technical justification.

B. Since the piping and support structure damping value may be different per RG 1.61, discuss what damping value will be used in the response spectrum analysis when the support structure is also modeled as part of the piping analysis. See also RAI EPR-32.

Response 37:

A. The support structure itself will be excited by SSE dynamic inputs, as the SSE event is applicable to the whole site in the form of ground motion. As such, the excitation for the support's attachment to the building will be applied to the self-weight of the structure in the form of response spectra g values. For other fluid dynamic transient events within the piping system, forces from the fluid moving along the pipe are included in the pipe support loads for that event, but any subsequent excitation of the support structure itself for the fluid dynamic event will not be evaluated, as the forcing function at each support beyond applied piping loads will be minimal, and not usually defined. This is standard practice in pipe support design. The supports are typically not modeled with the piping. Per the revised response to comment B below, Section 6.8 of the TR will be revised to reference Rev. 1 of RG 1.61.

B. In most cases, Revision 1 of RG 1.61 calls for 4 percent damping for the piping analysis. Similarly, the RG allows for 4 percent damping for welded steel or bolted steel with friction connections and 7 percent for bolted steel with bearing connections, which would be applicable for the supports. If frequency dependent damping values are used in the piping analysis, the support structure will still utilize the 4 percent or 7 percent damping values.

In those analyses where the support\restraint stiffnesses are explicitly represented in the analysis model and where the support damping is judged to be different than the piping damping, one of two approaches may be taken: 1) the lower of the support\restraint and piping damping may be applied to both support\restraints and piping, or 2) composite modal damping (as described in AREVA response to RAI EPR-32) may be used.

3.10 *Seismic Category I Buried Pipe*

Class 2 and 3 Seismic Category I buried piping systems in the U.S. EPR will be analyzed for pressure, weight, thermal expansion and seismic loads using dynamic or equivalent static load methods. The acceptance criteria for buried piping systems are described in Table 3-4.

3.10.1 *Static Loads and Load Combinations for Buried Pipe*

Loads and Loading Conditions are similar to those outlined in 3.3 but are modified for additional considerations of strains and stresses induced by the motion of the pipe in the surrounding soil mass. Thermal loads are impacted by the friction between the pipe and soil due to expansion and contraction of the pipe.

3.10.1.1 *Pressure*

Internal design pressure, P, is calculated as described in 3.3.1.1. However, there is an external pressure, P_V, for buried pipe associated with the overburden of soil and P_P for loads from surface loads. The allowable external pressure is calculated using the methods and formula in NC/ND-3133.

3.10.1.2 *Deadweight*

For buried pipe, deadweight loads must include the weight of the soil overburden. It must also include live loads from surface traffic such as trucks, rail and construction equipment.

3.10.1.3 *Soil Overburden*

Soil overburden pressure is dependent on the diameter of buried pipe as well as the burial depth relative to the ground water table. Buried pipes are designed for soil load corresponding to weight of the overlying soil prism.

$P_v = \gamma H$. This equation applies to pipes buried above the groundwater table.

Where P_v = overburden pressure on pipe due to soil

γ = unit weight of backfill material

H = burial depth

In the case where the pipe is located below ground water table or where seasonal change in ground water table is significant, the effect of buoyancy and increased weight of water should be considered. For such condition, soil pressure should be computed as follows:

$$P_v = \gamma H - 0.33\gamma h + \gamma_w h$$

Where h = depth of groundwater above pipe

γ_w = unit weight of water

3.10.1.4 *Surface Loads*

Live loads such as those imposed by trucks, rail, and construction equipment or other construction conditions should be considered in the analysis and design. The pressure transmitted to the buried pipe under these loads may be computed as follows:

$$P_p = 0.48 \frac{P_s}{H^2 \left[1 + \left(\frac{d}{H}\right)^2\right]^{2.5}}$$

Where P_p = surface load transmitted to the buried pipe

d = offset distance from the surface load to buried pipe

H = thickness of soil cover above the pipe

P_s = concentrated surface load

The magnitude of P_p above is multiplied by an impact factor which is dependent on the soil cover and type of surface load. Table 3-5 [13] shows some recommended values of impact factors.

The magnitude of P_p may be taken from Table 3-6 which is based on AASHTO HS-20 Truck and Copper E-80 railroad loads [13]. The values reported in Table 3-6 include an impact factor of 1.50.

COL applicants should perform detailed geotechnical engineering analysis to determine if the surface load will cause lateral and/or vertical displacement of bearing soil for the piping. Consideration should also be given to the effect of wide and extra heavy loads when evaluating the buried utility.

3.10.1.5 *Bouyancy Force*

For utilities buried below groundwater table, vertical force due to buoyancy should be considered and may be evaluated as follows:

$$F_b = W_w - W_p - P_v D + \gamma_w h_w D$$

The above equation conservatively assumes that the pipe is empty.

Where F_b = buoyancy force per unit length of pipe

D = external diameter of the pipe

P_v = γH = overburden pressure due to soil

W_w = weight of water displaced by pipe per unit length

W_p = self weight of pipe per unit length

The corresponding buoyancy stress on the utility may be computed as follows:

$$\sigma_b = \frac{F_b L^2}{10Z}$$

Where L = length of the utility in the buoyancy zone

Z = section modulus of the utility

The effects of pressure (P, P_P, P_V), dead and live loads must meet the requirements of Table 3-4 as follows for Equation 8:

$$S_{SL} = \frac{B_1 P D_O}{2t_n} + \frac{B_2 M_A}{Z} + \frac{F_b L^2}{10Z} \leq 1.5 S_h$$

Where S_{SL} = Stress from sustained loads

P = Internal pressure + ABS Sum (P_P +P_V)

B_1, B_2 = Stress indices

D_O = Pipe outside diameter

t_n = Pipe nominal wall thickness

M_A = Moment due to weight

S_h = Allowable stress (hot)

3.10.2 *Thermal Expansion and Contraction*

Depending on the relative temperature of the soil in which the pipe is buried and the temperature of the fluid contained in the pipe, a pipe that is fully restrained by the surrounding soil may experience contraction or expansion. This thermal-induced stress (due to friction between the pipe and soil) should be considered and may be evaluated as follows:

$$\sigma_A = E\alpha(T_2 - T_1)$$

Where σ_A = axial compressive stress in fully restrained pipe due to difference in temperature between soil and pipe content.

E = modulus of elasticity of the pipe material

α = coefficient of thermal expansion of the pipe

T_2 = maximum operating temperature of fluid in the pipe

T_1 = burial installation temperature

The effects of restrained thermal expansion/contraction forces in buried pipe are evaluated against the requirements of NC/ND-3653.2(a) by using a modified Equation 10 or NC/ND-3653.2(c) by using a modified Equation 11. From Reference 2, the equations are as follows:

$$S_E = \frac{iM_C}{Z} + E\alpha(T_2 - T_1) \le S_a$$ Equation 10M

Where S_a = Allowable thermal expansion stress

M_C = Bending moment due to restrained thermal expansion

or

$$S_{TE} = \frac{PD_O}{4t_n} + 0.75i\frac{M_A}{Z} + i\frac{M_C}{Z} + E\alpha(T_2 - T_1) \le (S_h + S_a)$$ Equation 11M

Where S_E = Stress from restrained thermal expansion

S_{TE} = Stress from pressure, weight and thermal expansion

3.10.3 *Seismic Loads*

Seismic-induced damage to buried piping is largely due to wave propagation or permanent ground deformation resulting from fault movement, landslide, and liquefaction-induced lateral spread. Where buried piping enters a structure, the seismic anchor movements of the structure must be accounted for in the design of the piping. Other forms of damage related to ground movement such as elastic and consolidation settlement (total and differential), freeze-thaw induced settlement, and seismic-induced settlement due to soil compaction and rearrangement should be considered on a case-by-case basis. For the case of piping anchored to an adjacent building, strain development in the utility due to settlement of the building should be evaluated. The seismic effects on buried piping are self limiting in that strains are limited by the surrounding soil. Therefore the stresses due to these strains are secondary in nature.

COL applicants shall carry out site investigation to assess the best route for the underground piping. During this field investigation, sites that are vulnerable to fault movement and liquefaction-induced landslide and lateral spread should be avoided. If a pipe must be buried in loose saturated cohesionless soil susceptible to liquefaction, rigorous linear and non-linear pipe-soil interaction analysis should be carried out to evaluate the integrity of the pipe under settlement and lateral spread conditions that may be caused by the liquefiable soil. If the result of the soil-pipe interaction is not acceptable, any of the following options recommended in Reference [14] may be adopted:

(1) Re-route the pipe to avoid areas of liquefiable loose saturated cohesionless soils;

(2) Modify the strength of the soil by using appropriate stabilizing agent;

(3) Excavate liquefiable soil and replace with competent structural fill materials; or

(4) Support the pipe in soil that is not susceptible to failure.

3.10.3.1 *Axial and Bending Strains Due to Propagation of Seismic Waves*

Typically, the magnitude of axial and bending strains on buried piping due to propagation of seismic wave is dependent on several factors such as the buried material and soil properties and pipe-soil interfacial properties. Conservatively, axial and bending strains on the buried piping are taken to be the same as those of the seismic wave if there is no site specific field instrumentation to measure the strain level experienced by the buried piping. Based on the axial and bending strains developed in the buried piping assuming long, linear runs remote from anchors or bends, the corresponding axial load and bending stress can be computed as follows:

$$F_a = \varepsilon_a AE$$

$$M_b = \sigma_b Z$$

Where $\sigma_b = \varepsilon_b E_{sct}$

In above equations,

E_{sct} = Secant modulus of the buried piping

ε_a = Axial strain in the buried piping due to wave propagation

ε_b = Bending strain in the buried piping due to wave propagation

Z = Section modulus of the buried piping.

For the computation of loads developed at elbows, the simplified procedures outlined in reference [14] are recommended for flexible and rigid conditions. At site locations where the differential settlement is significant, flexible anchors may be used in lieu of rigid anchors. All support structures (anchors) should be designed to resist the resulting axial loads and bending stresses.

The general axial and bending strains due to seismic wave propagation may be found as follows:

$$\varepsilon_a = \pm \frac{v}{\alpha c}$$

$$\varepsilon_b = \pm \frac{Ra}{\alpha c^2}$$

Where v = velocity of the soil layer (particle) in which the piping is embedded

a = acceleration of the soil layer (particle) in which the piping is embedded

c = apparent velocity relative to ground surface

R = radius of the pipe

ε_b = bending strain

ε_a = axial strain

α = wave velocity coefficient (compression=1.0, shear=2.0, Rayleigh=1.0)

In reference [14], it is noted that axial and bending strains are a result of three types of seismic waves, (1) compression, (2) shear and (3) surface or Rayleigh. The strain for each wave is calculated using the general form for axial and bending noted above.

The effects of seismic loads on above ground piping must meet the requirements of NC/ND-3655 as noted in Table 3-2. However, since seismic loads on buried piping are treated as secondary loads, the following equation must be met:

$$S_{OL} = \frac{iM_C}{Z} + \frac{iM_{SSE}}{Z} + \varepsilon_b E_{sct} + \varepsilon_a E_{sct} + E\alpha(T_2 - T_1) \leq 3.0 S_h \text{ but not greater than } 2.0 S_y$$

Where S_{OL} = stress from occasional loads

M_{SSE} = moment from seismic anchor movements

S_Y = yield stress

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13. Guideline for the Design of Buried Steel Pipe; Report by American Lifelines Alliance, 2001.

14. Seismic Response of Buried Pipes and Structural Components; ASCE Committee on Seismic Analysis of Nuclear Structures and Materials, New York, 1983.

Table 3-4: Design Conditions, Load Combination and Stress Criteria for ASME Class 2&3 Buried Piping

Loading Condition	Service Levels	Loads	Stress Criteria
Design	-	Primary Stress Loads: Pressure(1), Weight Loads, Other Sustained Mechanical Loads	Equation 8(5) NC/ND-3652
Normal/ Upset	A/B	Occasional: Pressure(1), Weight Loads, Other Sustained Mechanical Loads, DFL	Equation 9U(5) NC/ND-3653.1 (Level B Only)
		Secondary Stress: Thermal Expansion, TAM, Thermal Friction Forces	Equation 10M(2) (4) NC/ND-3653.2(a)
		Non-Repeated Anchor Movement	Equation 10a NC/ND-3653.2(b)
		Sustained Plus Secondary Stress: Pressure(1), Weight Loads, Other Sustained Mechanical Loads, Thermal Expansion, TAM, Thermal Friction Forces	Equation 11M(3) (4)(5) NC/ND- 3653.2(c)
Emergency	C	Occasional Stress: Pressure(1), Weight Loads, DFL	Equation 9E(5) NC/ND-3654.2(a)
Faulted	D	Secondary Stress: SSE Inertia & SAM(M_{SSE}), Thermal Expansion and TAM (M_C), Friction Axial Forces from Thermal Expansion	See note 6

Notes:

1. Pressure for buried pipe includes internal pressure and the soil overburden loads and loads due to motor vehicles and train cars.
2. Equation 10 modified to include stress due to axial friction forces caused by thermal expansion and soil interaction.
3. Equation 11 modified to include stress due to axial friction forces caused by thermal expansion and soil interaction.
4. Stresses must meet Equation 10M or 11M, not both.
5. Buried piping systems must be designed to meet the external pressure load criteria of NC/ND-3133 of the ASME Code.
6. Faulted D Equation is: $\frac{i(M_{SSE} + M_{C})}{Z} + \varepsilon_a E_{sct} + \varepsilon_b E_{sct} + E\alpha(T_2 - T_1) \leq 3.0 S_h$ but not greater than 2.0 S_Y

Table 3-5: Impact Factor for Surface Load Effect on Buried Pipes

Cover thickness (ft)	Surface Load Condition	
	Highways	Railways
0 - 1	1.50	1.75
1 - 2	1.35	1.50
2 - 3	1.15	1.50
> 3.0	1.00	1.35

Table 3-6: Recommended Surface Load for Buried Pipe

Cover thickness, ft	Surface load transmitted to pipe (lb/in^2)		Cover thickness, ft	Surface load transmitted to pipe (lb/in^2)	
	Highway H20	Railway E80		Highway H20	Railway E80
1	12.50	-	16	Negl.	3.47
2	5.56	26.39	18	Negl.	2.78
3	4.17	23.61	20	Negl.	2.08
4	2.78	18.40	22	Negl.	1.91
5	1.74	16.67	24	Negl.	1.74
6	1.39	15.63	26	Negl.	1.39
7	1.22	12.15	28	Negl.	1.04
8	0.69	11.11	30	Negl.	0.69
10	Negl.	7.64	35	Negl.	Negl.
12	Negl.	5.56	40	Negl.	Negl.
14	Negl.	4.17			

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping

Service Condition	Service Level	Category	Loading or Stress Component	Acceptance Criteria[1]
Design	-	Primary Stress	Design Pressure, Deadweight, Steady State Flow Load and Dynamic Fluid Load[2] specified as Level A	Eq 9N NB-3652
Normal	A	Primary plus Second-ary Stress Intensity Range (S.I.R.)	Range of Level A: 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	Eq 10N NB-3653.1
		Peak S.I.R.	Same as for Level A Primary plus Secondary S.I.R. plus Range of Level A Thermal Radial Gradient Stress (linear and non-linear)	Eq 11N NB-3653.2
		Thermal S.I.R.[5]	Range of Level A: Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3], Cyclic Thermal Load[4]	Eq 12N NB-3653.6(a)
		Primary plus Second-ary Membrane plus Bending S.I.R.[5]	Same as for Level A Primary plus Secondary S.I.R. except Range of Level A Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3] and Cyclic Thermal Load[4] is not considered	Eq 13N NB-3653.6(b)
		Alternating Stress Intensity (S.I.) (Fatigue Usage)[6]	Same as for Level A Peak S.I.R.	Eq 14N NB-3653.6(c)
		Thermal Stress Ratchet	Range of Level A Linear Thermal Radial Gradient	NB-3653.7

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping

Service Condition	Service Level	Category	Loading or Stress Component	Acceptance Criteria[1]
Upset	B	Permissible Pressure	Maximum Level B Service Pressure	NB-3654.1
		Primary Stress	Coincident Level B Service Pressure, Deadweight, Steady State Flow Load, Dynamic Fluid Load[2]	Eq 9U NB-3654.2(a)
		Primary plus Secondary S.I.R.	Same as for Level A Primary plus Secondary S.I.R. (except Level B Load and Stress Ranges are used) plus Earthquake Inertial Load[7]	Eq 10U NB-3654.2(b)
		Peak S.I.R.[8]	Same as for Level B Primary plus Secondary S.I.R. plus Range of Level B Thermal Radial Gradient Stress (linear and non-linear)	Eq 11U NB-3654.2(b)
		Thermal S.I.R.[5]	Range of Level B: Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3], and Cyclic Thermal Load[4]	Eq 12U NB-3654.2(b)
		Primary plus Second-ary Membrane plus Bending S.I.R.[5]	Same as for Level B Primary plus Secondary S.I.R. except Range of Level B Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3] and Cyclic Thermal Load[4] is not Considered	Eq 13U NB-3654.2(b)
		Alternating S.I. (Fatigue Usage)[6]	Same as for Level B Peak S.I.R.	Eq 14U NB-3654.2(b)
		Thermal Stress Ratchet	Range of Level B Linear Thermal Radial Gradient	NB-3654.2(b)
		Deformation Limits	As Set Forth in the Design Specification	NB-3654.2(b)

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping

Service Condition	Service Level	Category	Loading or Stress Component	Acceptance Criteria[1]
Emergency[9]	C	Permissible Pressure	Maximum Level C Service Pressure	NB-3655.1
		Primary Stress	Coincident Level C Service Pressure, Deadweight, Steady State Flow Load, Dynamic Fluid Load[2]	Eq 9E NB-3655.2(a)
		Deformation Limits	As Set Forth in the Design Specification	NB-3655.3
Faulted	D	Permissible Pressure	Maximum Level D Service Pressure	NB-3656(a)(1)
		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)	Eq 9F NB-3656(a)(2)
		Secondary Stress[12]	MAX[Range of (Bending Moment 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]	6Sm[13]
Pressure Testing[14]	-	Primary Membrane S.I.	Test Pressure, Deadweight	NB-3657 NB-3226(b)
		Primary Membrane plus Bending S.I.	Test Pressure, Deadweight	NB-3657 NB-3226(c)

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping (Continued)

Notes:

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 150F.
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 and14).
7. The Earthquake Inertial Load considered in the Level B Primay plus Secondary Stress Intensity Range, Peak Stress Intensity Range and Alternating Stress Intensity calculations (Equations 10, 11 and 14) is taken as 1/3 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 is considered. If the earthquake inertial load is taken as 1/3 of the peak SSE inertial load then the number of cycles to be considered for earthquake loading is 300 (the equivalent number of 20 full SSE cycles as derived in accordance with Appendix D of IEEE Standard 344-1987).
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 which result in an alternating stress intensity (S_a) value greater than that for 10^6 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-excedance criteria given in NUREG-0484 is met. When the time phasing relationship cannot be established, or when the non-excedance criteria in NUREG-0484 is not met, dynamic loads are combined by absolute sum. SSE and High Energy Line Break loads are always combined using the SRSS method.

12. This secondary stress check is only necessary if the stresses (including those due to Earthquake Inertial Load) exceed the Equation 10U (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. Sm = 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 which result in an alternating stress intensity (S_a) value greater than that for 10^6 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.

Additional Revisions to ANP-10264NP
"U.S. EPR Piping Analysis and Pipe Support Design Topical Report"
(TAC No. MD3128)

The following change will be provided in the approved version of ANP-10264NP:

Page Number	Section	Description of Change	Reason
1-3 and 2-2	Table 1-1 (item 1) and 2.2	Deleted the Combined License (COL) action item for the COL applicant to identify any additional code cases that are not listed in the topical report for piping not included in the scope of the U.S. EPR design certification.	The COL applicant is permitted to use other code cases as long as they are listed in RG 1.84 as a conditionally or unconditionally accepted code case.

nrc·IC·08:010
received 4/2/08

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

March 26, 2008

Ms. Sandra M. Sloan
Manager of Regulatory Affairs
New Plants Deployment
AREVA NP Inc.
3315 Old Forest Road
Lynchburg, VA 24506-0935

SUBJECT: AREVA NP INC. - U.S. EPR STANDARD DESIGN CERTIFICATION APPLICATION REVIEW SCHEDULE

Dear Ms. Sloan:

By letter dated December 11, 2007, as supplemented by letters dated February 7 and February 20, 2008, AREVA NP Inc. (AREVA) submitted an application to the Nuclear Regulatory Commission (NRC) for a standard design certification (DC) of the U.S. Evolutionary Power Reactor (EPR), pursuant to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants." By letter dated February 25, 2008, the NRC staff docketed the application and informed AREVA of its intention to publish a schedule for the detailed review of the application within 30 days. This letter transmits that schedule.

The established review schedule reflects tasks for all six phases of the safety review, from the start of review until the final safety evaluation report (FSER) with no open items is issued. The review officially began on March 19, 2008, and the safety review supports the issuance of a FSER in May 2011. Milestones for the six phases of the DC review as well as the supporting topical reports that are currently under review are provided in the enclosure to this letter. As discussed in the March 13, 2008, public meeting, the following areas may introduce significant uncertainty into the review schedule if not adequately addressed in Phase 1 of the staff's review.

1. The U.S. EPR design does not rely on active containment cooling systems for post-accident containment mixing. As a result, to adequately justify the level of mixing in the containment and the level of steam condensation in the reactor coolant system credited in the post-accident analysis, the staff anticipates requesting additional information which may require long lead items to properly address the issue.

2. The proposed use of earthquake experience and/or test experience approach for seismic and dynamic qualification of mechanical and electrical equipment is highly dependent on the selection of equipment and the type of experience database proposed. AREVA will be requested to submit the database and the equipment to be qualified. Based on past experience with similar applications, it has taken longer than anticipated to complete the review. If AREVA chooses to proceed with this approach the scheduled may be impacted.

3. AREVA has proposed to use M5™ cladding material for the U.S. EPR fuel. M5™ fuel cladding material has exhibited unanticipated axial growth in current operating plants. Resolution of this issue and its impact on EPR design is unknown.

4. AREVA has submitted four topical reports that are incorporated by reference in the accident analyses and fuel design chapters of the U.S. EPR Final Safety Analysis Report. If issues arise regarding the use of new methodologies in these topical reports, they may impact the review schedule.

5. The staff will require additional information to address emergency core cooling system strainer downstream effects on post-loss-of-coolant accident long-term core cooling with recirculation flow. Based on past experience with operating plants, resolution of this issue may take longer than anticipated. This is an industry-wide issue and the resolution of it is uncertain.

The staff will evaluate this schedule when the safety evaluation report with open items is issued (i.e., at the end of Phase 2). At that point, the staff may establish new milestones in Phases 4 through 6 based on the number and complexity of the open items. The schedule assumes technically correct and complete responses within 30 days of receipt to NRC's requests for additional information (RAIs). For any RAIs that cannot be answered within 30 days, it is expected that a date for receipt of this information will be provided to the staff within the 30 day period so that the staff can assess how this information will impact the published schedule. In addition, any new and significant changes or additions to the DC application or supporting documentation could impact scheduled completion dates.

It is the staff's intent to establish a predictable review schedule and a review process that supports identification and resolution of complex issues as early in the review as possible. To that end, the staff intends to interact with AREVA as the review progresses to address open items, schedule details, and potential schedule refinements.

If you have any questions or comments concerning this matter, I can be reached at 301-415-3361 or via e-mail address at getachew.tesfaye@nrc.gov.

Sincerely,

Getachew Tesfaye, Sr. Project Manager
EPR Projects Branch
Division of New Reactor Licensing
Office of New Reactors

Docket No. 52-020

Enclosure:
As stated

cc: See next page

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AREVA NP Inc. – U.S. EPR Design Certification Application Review Milestones

Task	Target Date
Phase 1 - Preliminary Safety Evaluation Report (SER) and Request for Additional Information (RAI)	Jan 28, 2009
Phase 2 - SER with Open Items	Nov 20, 2009
Phase 3 – Advisory Committee on Reactor Safeguards (ACRS) Review of SER with Open Items	Mar 5, 2010
Phase 4 - Advanced SER with No Open Items	November 2010
Phase 5 - ACRS Review of Advanced SER with No Open Items	March 2011
Phase 6 – Final SER with No Open Items	May 2011

Topical Reports Draft Safety Evaluation

Topical Report	Target Date
ANP-10264(NP), Revision 0, "U.S. EPR Piping Analysis and Pipe Support Design"	May 30, 2008
ANP-10272, "Software Program Manual TELEPERM XS™ Safety Systems Topical Report"	Jul 14, 2008
ANP-10273P, "AV42 Priority Actuation and Control Module Topical Report"	Nov. 20, 2008
ANP-10278P, Revision 0, "U.S. EPR Realistic Large Break Loss of Coolant Accident Topical Report"	July 15, 2008
ANP-10279, "U.S. EPR Human Factors Engineering Program Topical Report"	Oct 15, 2008
ANP-10281P, "U.S. EPR Digital Protection System Topical Report"	Sep 05, 2008
ANP-10284, "U.S. EPR Instrumentation and Control Diversity and Defense-in-Depth Methodology Topical Report"	Nov 13, 2008
ANP-10285P, "U.S. EPR Fuel Assembly Mechanical Design Topical Report"	Aug 21, 2008
ANP-10286P, "U.S. EPR Rod Ejection Accident Methodology Topical Report"	May 31, 2009
ANP-10287P, "Incore Trip Setpoint and Transient Methodology for U.S. EPR Topical Report"	May 31, 2009

April 18, 2008
NRC:08:024

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U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Second Revised Response to an RAI on the Topical Report ANP-10264(NP) "U.S. EPR Piping Analysis and Pipe Support Design" (TAC No. MD3128)

Ref. 1: Letter, Ronnie L. Gardner (AREVA NP Inc.) to Document Control Desk (NRC), "Request for Review and Approval of ANP-10264(NP) Revision 0, 'U.S. EPR Piping Analysis and Pipe Support Design'," NRC:06:040, September 29, 2006.

Ref. 2: Letter, Getachew Tesfaye (NRC) to Ronnie L. Gardner (AREVA NP Inc), "Request for Additional Information Regarding Topical Report ANP-10264(NP), 'U.S. EPR Piping Analysis and Pipe Support Design' (TAC No. MD3128)," May 29, 2007.

Ref. 3: Letter, Ronnie L. Gardner (AREVA NP Inc.) to Document Control Desk (NRC), "Response to a Request for Additional Information Regarding ANP-10264NP 'U.S. EPR Piping Analysis and Pipe Support Design' (TAC No. MD3128)," NRC:07:028, July 13, 2007.

Ref. 4: Letter, Ronnie L. Gardner (AREVA NP Inc.) to Document Control Desk (NRC), "Revised Response to an RAI on the Topical Report ANP-10264(NP) 'U.S. EPR Piping Analysis and Pipe Support Design' (TAC No. MD3128)," NRC:07:064, November 20, 2007.

Ref. 5: Letter, Getachew Tesfaye (NRC) to Sandra M. Sloan (AREVA NP Inc.), "AREVA NP Inc. - U.S. EPR Standard Design Certification Application Review Schedule," March 26, 2008.

AREVA NP Inc. (AREVA NP) requested the NRC's review and approval of the topical report ANP-10264(NP) Revision 0 in Reference 1. The NRC provided a Request for Additional Information (RAI) regarding this topical report in Reference 2. The AREVA NP response to this RAI was provided in Reference 3. A revised RAI response was submitted to the NRC in Reference 4.

Based on discussions with the NRC on February 12, 2008, March 19, 2008, and April 10, 2008, Attachment A to this letter is a second revised response to Request for Additional Information – ANP-10264(NP), 'U.S. EPR Piping Analysis and Pipe Support Design Topical Report'." Attachment A to this letter only contains those RAI responses that are being revised as result of discussions with NRC. Additionally, Attachment B to this letter contains revised pages to the topical report. Changes to the RAI responses and the topical report are indicated in red with revision bars.

Reference 5 states that the NRC plans to complete its review of the topical report and issue the safety evaluation report by May 30, 2008. AREVA NP understands that this revised response resolves all remaining issues associated with this topical report. Therefore, the attached revised RAI responses support the NRC's schedule for issuance of the safety evaluation report with no open items. The revised pages to the topical report in attachment B will be incorporated into the approved version of the topical report subsequent to AREVA NP receiving the Final Safety Evaluation Report.

The revised RAI response as provided on the enclosed CD does not contain any information that AREVA NP considers to be proprietary.

If you have any questions related to this submittal, please contact Ms. Sandra M. Sloan, Regulatory Affairs Manager for New Plants Deployment. She may be reached by telephone at 434-832-2369 or by e-mail at sandra.sloan@areva.com.

Sincerely,

Ronnie L. Gardner

Ronnie L. Gardner, Manager
Site Operations and Corporate Regulatory Affairs
AREVA NP Inc.

Enclosures

cc: J. Rycyna
G. Tesfaye
Docket No. 52-020

Second Revised Response to Request for Additional Information – ANP-10264NP "U.S. EPR Piping Analysis and Pipe Support Design Topical Report" (TAC No. MD3128)

RAI EPR-8: *Independent Support Motion Method*

The current staff position for the Independent Support Motion (ISM) method of analysis is presented in Volume 4, Section 2 of NUREG-1061, "Report of the US NRC Piping Review Committee. "Some differences (e.g., modal combinations per RG 1.92 for uniform support motion (USM) only) were noted between the ISM method of response combinations (both methods and their sequence) presented in the TR Section 4.2.2.2.2, and the method given in NUREG-1061. Indicate whether all of the provisions (for groups, modes, spatial and inertial and SAM combination methods) contained in NUREG-1061 for the ISM method of analysis will be followed or provide the technical justification for any alternatives or methods described in the TR.

Response 8:

All of the provisions of NUREG-1061 for the ISM method of analysis will be followed. The following revisions to the TR will be made for clarification:

Section 4.2.2.2.1, the 2nd paragraph will be revised as follows:

> "The combinations of modal responses and spatial components for systems analyzed using USM are performed consistent with the guidance provided in RG 1.92. The modal and directional responses are combined as discussed in Sections ...."

Section 4.2.2.2.2 will be revised to include a reference to NUREG-1061, Volume 4 as follows:

> "The combinations of modal responses and spatial components for systems analyzed using ISM are performed consistent with the recommendations in NUREG-1061, Volume 4. Additionally, when using independent support motion, the seismic response of each mode is calculated by combining the responses of all support groups into one by using absolute summation method per the recommendations of NUREG-1061."

Section 4.2.2.3 will be revised as a result of the revised response to RAI EPR-27 regarding the use of Regulatory Guide 1.92, Revision 2. The following changes will be included in Attachment B to this response.

- New paragraphs (third and fourth) will be added to Section 4.2.2.3 to state that modal response combinations will be per the guidance of RG 1.92 as discussed in Sections 4.2.2.3.1 through 4.2.2.3.4 for USM analyses and per NUREG-1061 as discussed in Section 4.2.2.3.5 below for ISM analyses.
- Section 4.2.2.3.1, first sentence, will be revised as follows:

> "RG 1.92 provides guidance on combining the individual periodic modal results due to each response spectrum in a dynamic analysis performed using USM."

> ~~and the following text will be added to the end of this section:~~

~~"For piping systems analyzed using ISM methods, modal results are combined without the consideration of closely spaced modes, per NUREG-1061. Therefore, for these systems, modal results are combined by the SRSS method presented above."~~ (Note: the deleted text has been moved to new section 4.2.2.3.5)

- Sections 4.2.2.3.1 through 4.2.2.3.4: These sections will be revised or added to add clarification for modal response combination methods used for USM analyses, which will be performed using the methodologies provided in Regulatory Guide 1.92 Revision 2. See RAI EPR-27 and Attachment B to this response for details.

- Section 4.2.2.3.5: This section will be added to clarify the modal response combination methods for ISM analyses.

Section 4.2.2.5 will be revised to read as follows:

> "The analysis of these seismic anchor motions (SAM) will be performed as a static analysis with all dynamic supports active. The results of this analysis shall be combined with the piping system seismic inertia analysis results by absolute summation when an enveloped uniform support motion is used for the dynamic analysis, per SRP 3.7.3. When independent support motion is used in the inertial analysis, the responses due to the relative displacements and those due to inertia are combined by the SRSS method, per NUREG-1061."

RAI EPR-15: *Buried Piping*

TR Section 3.10 did not give details on the analysis method and how the criteria are to be applied in the design of buried piping.

A. Based on the criteria presented in the TR, describe the analysis method and design requirements that will be used for buried piping design (including buried pipe tunnel if used in the design). Explain how these methods compare to the analytical methods referenced in the recently published NRC Standard Review Plan 3.7.3, Rev. 3, (i.e., ASCE Standard 4-98, ASCE Report - Seismic Response of Buried Pipes and Structural Components, and NUREG/CR-1161).

B. Why doesn't TR Section 3.10 include consideration of ground-water effects and soil arching effects which could increase or decrease the stresses in the pipe due to the overlying soil plus the ground surface loads?

D. TR Table 3-4 provides the design conditions, load combinations and acceptance criteria for Class 2/3 buried piping. Explain clearly the term non-repeated anchor movement, Equation 9U (vs 9), and Equation 9E (vs 9). While the intent may be interpreted, it is important that these terms be clearly defined in the TR. For Equations 10M and 11M, which are identified as "modified to include axial friction forces," provide the equations to show how they are modified.

F. Confirm that Note 5 in the TR Table is applicable to all cases cited in TR Table 3-4 since it is not referenced in the Table like the other notes are. Also, explain how the criteria of

NC/ND-3133 of the ASME Code (Note 5 in the Table) will be implemented in conjunction with meeting the loads and loading conditions specified in Table 3-4.

Response 15:

A. Section 3.10 of the TR will be revised to include analysis methods and design requirements for buried piping, as shown in Attachment B to this response.

The methods developed for the U.S. EPR buried piping meet requirements in SRP 3.7.3, Rev. 3, ASCE Standard 4-98 and ASCE Report-Seismic Response of Buried Pipes and Structural Components.

The revised Attachment B also includes Tables 3-5 and 3-6 that are referred to in Section 3.10.1.4 of the TR.

B. Section 3.10 of the TR will be revised as shown in Attachment B to include buoyancy forces from ground-water, overburden, and surface traffic from trucks, rail and construction equipment, as shown in Attachment B to this response.

D. Non-repeated anchor movements, in the case of buried pipe, refers to building settlement at the point where the buried pipe enters the building. Equations 9U and 9F refer to upset and faulted respectively. These designations are used to distinguish the differences in plant events that occur during the upset or faulted plant conditions and must be combined per equation 9 and meet the allowable stresses as noted in the various section of NC/ND 3650.

The TR will be revised as shown in Attachment B to provide revised equations 10M and 11M and define the terms in these equations.

F. Note 5 will be added to Table 3-4 as appropriate. As shown in Attachment B, the external pressure of the soil overburden defined in NC/ND-3133 will be added to the discussion in 3.10. Note 5 applies to the equations that include a pressure term. The TR will be revised to include this term.

<u>RAI EPR-18:</u> *Piping Model Structural Boundaries*

TR Sections 5.4.1.2 and 5.4.1.3 describe two alternate approaches of separating a piping analysis model using an elbow or a tee within the piping model. While these approaches may be technically sound, no references or technical justifications are provided for each of these methods. Provide technical justifications and limitations (if any) for these two methods of establishing piping model terminations. Also, discuss the basis for selecting the dimensions of L1 and L2 in TR Figure 5-1 for a restrained elbow and Figure 5-2 for a restrained tee.

Response 18:

The TR will be revised as shown in Attachment B to delete sections 5.4.1.2 and 5.4.1.3 including Figures 5-1 and 5-2.

RAI EPR-25: *Piping Load Combinations*

The staff needs clarification of several items associated with TR Section 3.3 and Tables 3-1 and 3-2.

C. Note 8 to TR Table 3-1 states that the earthquake inertial load used in the Level D Primary Stress (Equation 9F) calculations shall be taken as the peak SSE inertial load. The earthquake anchor motion load used in the Level D Primary Stress (Equation 9F) calculations shall be taken as the peak SSE anchor motion load. The staff position on the use of a single-earthquake design in SECY-93-087 states that the effects of anchor displacements in the piping caused by an SSE be considered with the Service Level D limits. For simplified elastic-plastic discontinuity analysis, if Eq. 10 cannot be satisfied for all pairs of load sets, then the alternative analysis per NB-3653.6 for Service Level D should be followed. In addition, the combined moment range for either the resultant thermal expansion and thermal anchor movements plus ½ the SSE seismic anchor motion or the resultant moment due to the full SSE anchor motion alone, whichever is greater must satisfy the equation (known as Eq. 12a) given in NB-3656(b)(4). Clarify if this is applicable to EPR piping design. Also, justify why this anchor motion stress is categorized as a primary stress in the TR Table 3-1 for the faulted condition.

Response 25:

C. At the time that the Topical Report was written, portions of Section III NB-3600 in the 2004 Edition of the ASME Boiler and Pressure Code were not endorsed by the NRC, per the version of 10CFR50.55a in effect at that time. The proposed draft of 10CFR50.55a which was published in spring of 2007 indicates that restrictions on the use of the rules involving seismic loading have been removed. AREVA will therefore reference the equations from NB-3656(b)(4) for the treatment of SSE anchor motions. TR Table 3-1 will be revised as shown in Attachment B to provide further clarification of the Class 1 load combinations.

RAI EPR-26: *Piping Damping Values*

In TR Section 4.2.5, it is identified that Rev. 0 of the RG 1.61 values of damping will be used in the seismic analysis of structures, systems, and components (SSCs) using ISM response spectrum analysis or time history analysis. However, for piping systems analyzed using USM response spectrum analysis, 5% damping will be used provided that the system is not susceptible to stress corrosion cracking. Five percent damping will not be used for analyzing the dynamic response of piping systems using supports designed to dissipate energy by yielding.

B. For piping systems analyzed using uniform support motion response spectrum analysis and 5% damping, verify that all of the limitations specified in RG 1.84 for ASME Code Case N-411 (or RG 1.61, Rev.1) will be met.

Response 26:

TR Section 4.2.5 will be revised as shown in Attachment B to this response, to specify that RG 1.61, Revision 1, damping values will be used for USM, ISM, and time-history analysis.

RAI EPR-27: *Modal Combinations*

In TR Section 4.2.2.3.1, it is stated that for the response spectrum method of analysis, the modal contributions to the inertial responses are normally combined by the SRSS method. If some or all of the modes are closely spaced, any one of the methods (Grouping method, 10% method, and Double Sum method, as well as the less conservative methods in revision 2 of the RG 1.92) is applicable for the combination of modal responses. This combination method is applicable to both USM and ISM methods of analysis.

A. If guidance given in Revision 2 of the RG 1.92 is used for the EPR piping design, then Revision 2 of the RG no longer recognizes the Grouping method, 10% method and Double Sum method for closely spaced modes. These methods are renamed and AREVA should identify them as noted in the RG.

B. TR states that for closely spaced modes AREVA may use less conservative methods discussed in the RG. Please identify which methods are less conservative methods and explain why they are less conservative with respect to the other method(s).

Response 27:

A. AREVA NP will use RG 1.92, Revision 2, methods of modal combination for piping analyzed using USM (Note: RAI EPR-8 addresses ISM method of analysis). TR Sections 4.2.2.3 and 4.2.5 will be revised as shown in Attachment B to this response.

B. See the response to item A above.

RAI EPR-37: *Inclusion of Support Self-Weight Excitation*

In TR Section 6.8, AREVA did not indicate if the criteria presented is also applicable to other dynamic loads and did not discuss how the damping value will be used in the response spectrum analysis.

A. Clarify whether the criterion presented in the TR is also applicable to other dynamic loads. If not, provide technical justification.

B. Since the piping and support structure damping value may be different per RG 1.61, discuss what damping value will be used in the response spectrum analysis when the support structure is also modeled as part of the piping analysis. See also RAI EPR-32.

Response 37:

A. Section 6.8 of the TR will be revised as shown in Attachment B to address other dynamic loads.

B. In most cases, Revision 1 of RG 1.61 calls for 4 percent damping for the piping analysis. Similarly, the RG allows for 4 percent damping for welded steel or bolted steel with friction connections and 7 percent for bolted steel with bearing connections, which would be applicable for the supports. If frequency dependent damping values are used in the piping analysis, the support structure will still utilize the 4 percent or 7 percent damping values.

In those analyses where the support\restraint stiffnesses are explicitly represented in the analysis model and where the support damping is judged to be different than the piping damping, one of two approaches may be taken: 1) the lower of the support\restraint and piping damping may be applied to both support\restraints and piping, or 2) composite modal damping (as described in AREVA response to RAI EPR-32) may be used.

Description of Changes to the Piping Topical Report

Page number	Section	Description of Change
Att. B, pages 2 and 3	Table 1-1 and section 2.3	Based on discussion with NRC, the term “as-built” was changed to “as-designed” for the COL action item regarding development of design specifications and design reports.
Att. B, pages 4 through 11, pages 17 through 19, and page 25	Section 3.10 and Tables 3.4 through 3.6	Changed to reflect the revised response to RAI EPR-15.
Att. B, pages 12 through 16	Table 3-1	Changed to reflect the revised response to RAI EPR-25C.
Att. B, pages 20 through 24	Section 4.2.2.3	Changed to reflect the revised responses to RAI EPR-27 and RAI EPR-8.
Att. B, page 25 and 30	Section 4.2.5 and References	Changed to reflect the revised responses to RAI EPR-26 and RAI EPR-27. This section also includes the changes in response to RAI EPR-32.
Att. B, pages 26 through 28	Sections 5.4.1.2 and 5.4.1.3, Figures 5-1 and 5-2	Deleted sections 5.4.1.2 and 5.4.1.3, Figures 5-1 and 5-2 per the revised response to RAI EPR-18
Att. B, page 29	Section 6.8	Changed to reflect the revised response to RAI EPR-37.

Table 1-1: Analysis and Design Responsibilities for COL Applicants

ITEM	COL Applicant Responsibility	Applicable Section
1	COL applicant will identify any additional Code Cases used that are not listed in this Topical Report for piping not included in the scope of the U.S. EPR Design Certification.	2.2
2	The COL applicant will develop the design specification and the design reports using requirements outlined in the Code and demonstrate and document that as-~~built~~ designed piping and support configurations adhere to the requirements of the design specification.	2.3
3	Should the COL applicant find it necessary to route Class 1, 2 and 3 piping not included in the U.S. EPR Design Certification in such a manner that it is exposed to wind and/or tornadoes, it must be designed to withstand the plant design basis loads for this event	3.3.1.6
4	The COL applicant will confirm that thermal deflections do not create adverse conditions on the pressurizer surge line during hot functional testing.	3.7.2
5	A review of the impact of contributing mass of supports on the piping analysis will need to be performed by the COL applicant(s) following the final support design to confirm that the mass of the support is no more than 10% of the mass of the adjacent pipe span.	5.2
6	Pipe stress and support analysis will be performed by the COL applicant(s). A COL applicant choosing to use a piping analysis program other than those listed in Section 5.1 will implement the U. S EPR benchmark program using models specifically selected for the U.S. EPR.	5.3
7	The COL Applicant will verify proper installation and operation of snubbers utilizing visual inspections, hot and cold position measurements, and observance of thermal movements during plant startup.	6.6

- ASME Code Case N-318-5, ‘Procedure for Evaluation of the Design of Rectangular Cross Section Attachments on Class 2 or 3 Piping, Section III, Division 1.’
- ASME Code Case N-319-3, ‘Alternate Procedure for Evaluation of Stresses in Butt Welding Elbows in Class 1 Piping Section III, Division 1.’
- ASME Code Case N-391-2, ‘Procedure for Evaluation of the Design of Hollow Circular Cross Section Welded Attachments on Class 1 Piping, Section III, Division 1.’
- ASME Code Case N-392-3, ‘Procedure for Evaluation of the Design of Hollow Circular Cross Section Welded Attachments on Class 2 and 3 Piping, Section III, Division 1.’

Other ASME Code Cases may be used in the Design Certification if they are either conditionally or unconditionally approved in Regulatory Guide (RG) 1.84[4]. In addition, new Code Cases may be used by the Combined Construction Permit and Operating License (COL) applicant if they are included in RG 1.84[4].

2.3 Design Specification

A design specification is required by Section III of the ASME Code[2] for ASME Class 1, 2 and 3 piping. In addition, the ASME Code requires design reports for all Class 1, 2 and 3 piping demonstrating and documenting that as-designed~~built~~ piping and support configurations adhere to the requirements of the design specification. It is the responsibility of the COL applicant or his agent to develop the design specification and the design reports using requirements outlined in the ASME Code.

3.10 *Seismic Category I Buried Pipe*

Class 2 and 3 Seismic Category I buried piping systems in the U.S. EPR will be analyzed for pressure, weight, thermal expansion and seismic loads using dynamic or equivalent static load methods. The acceptance criteria for buried piping systems are described in Table 3-4.

3.10.1 *Static Loads and Load Combinations for Buried Pipe*

Loads and Loading Conditions are similar to those outlined in 3.3 but are modified for additional considerations of strains and stresses induced by the motion of the pipe in the surrounding soil mass. Thermal loads are impacted by the friction between the pipe and soil due to expansion and contraction of the pipe per the guidance in Reference 13.

3.10.1.1 *Pressure*

Internal Design Pressure, P, is calculated as described in 3.3.1.1. However, there is an external pressure, P_V, for buried pipe associated with the overburden of soil and P_P for loads from surface loads. The allowable external pressure is calculated using the methods and formula in NC/ND-3133.

3.10.1.2 *Deadweight*

For buried pipe, deadweight loads must include the weight of the soil overburden. It must also include live loads from surface traffic such as trucks, rail and construction equipment.

3.10.1.3 *Soil Overburden*

Soil overburden pressure is dependent on the diameter of buried pipe as well as the burial depth relative to the ground water table. Buried pipes are designed for soil load corresponding to weight of the overlying soil prism.

$P_v = \gamma H$ This equation applies to pipes buried above the groundwater table.

Where P_v = overburden pressure on pipe due to soil, psi

γ = dry unit weight of backfill material, lbs/in^3

H = burial depth to top of pipe, inches

In the case where the pipe is located below ground water table or where seasonal change in ground water table is significant, the effect of buoyancy and increased weight of water should be considered. For such condition, soil pressure should be computed as follows:

$$P_v = \gamma H - 0.33\gamma h + \gamma_w h$$

Where h = depth of groundwater above pipe, inches

γ_w = unit weight of water, lbs/in^3

3.10.1.4 *Surface Loads*

Live loads such as those imposed by trucks, rail, and construction equipment or other construction conditions should be considered in the analysis and design. The pressure transmitted to the buried pipe under these loads may be computed as follows:

$$P_p = 0.48 \frac{P_s}{H^2\left[1+\left(\frac{d}{H}\right)^2\right]^{2.5}}$$

Where P_p = surface load transmitted to the buried pipe, psi

d = offset distance from the surface load to buried pipe, inches

H = thickness of soil cover above the pipe, inches

P_s = concentrated surface load, lbs

The magnitude of P_p above is multiplied by an impact factor which is dependent on the soil cover and type of surface load. Table 3-5 shows some recommended values of impact factors. The magnitude of P_p may be taken from Table 3-6 which is based on AASHTO HS-20 Truck and Copper E-80 railroad loads [13]. The values reported in Table 3-6 include an impact factor of 1.50.

COL applicants should perform detailed geotechnical engineering analysis to determine if the surface load will cause lateral and/or vertical displacement of bearing soil for the piping. Consideration should also be given to the effect of wide and extra heavy loads when evaluating the buried utility.

3.10.1.5 *Bouyancy Force*

For utilities buried below groundwater table, vertical force due to buoyancy should be considered and may be evaluated as follows:

$$F_b = W_w - W_p - P_v D + \gamma_w hD$$

The above equation conservatively assumes that the pipe is empty.

Where F_b = buoyancy force per unit length of pipe, lb/in

D = outside diameter of the pipe, inches

P_v = γH = overburden pressure due to soil, psi

W_w = weight of water displaced by pipe per unit length, lb/in

W_p = self weight of pipe per unit length, lb/in

The corresponding buoyancy stress on the utility may be computed as follows:

$$\sigma_b = \frac{F_b L^2}{10Z}$$

Where L = length of the utility in the buoyancy zone, inches

Z = section modulus of the utility, in^3

3.10.1.6 *Pipe Ovalization*

Under combined dead and live loads, buried pipes tend to ovalize thereby causing through-wall bending stresses. The allowable ovalization (Ref. [13]) of the pipe diameter may be evaluated using the following equation:

$$\text{Pipe ovality} = \frac{\Delta}{D} = \frac{D'KP}{\left[\frac{(E_{sct} I)_{eq}}{R^3} + 0.061E'\right]}$$

$$\sigma_b = 4E_{sct} \frac{\Delta}{D} \frac{t}{D}$$

Where

E' = modulus of soil reaction, psi

K = bedding constant (typically taken to be 0.1)

R = outside radius of pipe, inches

Δ = vertical deflection of the utility/pipe, inches

P = pressure due to soil overburden, surface loads, flooding, and snow load, psi

$(E_{sct} I)_{eq}$ = equivalent pipe wall stiffness per unit length of pipe, lb-in^2/in~~in./lb~~

σ_b = through-wall bending stress, psi

~~D = diameter of the pipe~~

t = thickness of the pipe, inches

E_{sct} = secant Modulus of the pipe material, psi (Note: E_{sct} = E if pipe is fabricated from steel)

D' = deflection lag factor (typically taken to be between 1.0 and 1.50)

I = $t^3/12$ = moment of inertia, in^4/in~~, in~~^{4}

Pipe must be buried deep enough such that crushing of side wall of the pipe is eliminated. Soil, surface, and other credible event loads must not be excessive so as to cause buckling of the pipe. To avert ring buckling, the magnitude of the total vertical pressure should be limited to equation below.

$$P(as\ defined\ for\ ovality) \leq \frac{1}{FS}\sqrt{32R_w B'E' \frac{(E_{sct}I)_{eq}}{D^3}}$$

FS = factor of safety with value dependent on relative magnitude of thickness of cover soil, H and external pipe diameter, D. For $H/D < 2.0$, FS = 3.0 and for $H/D \geq 2$, FS = 2.5

R_W = water buoyancy factor with magnitude $1 - 0.33h/H$ (0<h<H)

h = height of ground water table above the top of the buried utility, inches

B' = dimensionless empirical coefficient of elastic support.

$$B' = \frac{1}{1 + 4e^{\left(-0.065\frac{H}{D}\right)}}$$

All the other parameters in above equation have been defined previously.

The effects of pressure (P, P_P, P_v), dead and live loads and loads from the effects of ovality must meet the requirements of Table 3-4 as follows for Equation 8:

$$S_{SL} = \frac{B_1 PD}{2t_n} + \frac{B_2 M_A}{Z} + \frac{F_b L^2}{10Z} + 4E_{sct}\frac{\Delta}{D}\frac{t}{D} \leq 1.5S_h$$

Where S_{SL} = Stress from sustained loads, psi

P = Internal pressure + ABS Sum (P_P +P_V), psi

B_1, B_2 = Stress indices

~~D_O = Pipe outside diameter~~

t_n = Pipe nominal wall thickness, inches

M_A = Moment due to weight, in-lbs

S_h = Allowable stress (hot), psi

3.10.2 *Thermal Expansion and Contraction*

Depending on the relative temperature of the soil in which the pipe is buried and the temperature of the fluid contained in the pipe, a pipe that is fully restrained by the surrounding soil may experience contraction or expansion. This thermal-induced stress (due to friction between the pipe and soil) should be considered and may be evaluated as follows:

$$\sigma_A = E_{sct}\alpha(T_2 - T_1)$$

Where

σ_A = axial compressive stress, psi, in fully restrained pipe due to difference in temperature between soil and pipe content.

α = coefficient of thermal expansion of the pipe, in/in/°F

T_2 = maximum operating temperature of fluid in the pipe, °F

T_1 = burial installation temperature, °F

The effects of restrained thermal expansion/contraction forces in buried pipe are evaluated against the requirements of NC/ND-3653.2(a) by using a modified Equation 10 or NC/ND-3653.2(c) by using a modified Equation 11. From Reference 2, the equations are as follows:

$$S_E = \frac{iM_C}{Z} + E_{sct}\alpha(T_2 - T_1) \le S_a \qquad \text{Equation 10M}$$

Where S_a = Allowable stress range for thermal expansion, psi

M_C = range of resultant bending moment due to restrained thermal expansion, in-lb

Or

$$S_{TE} = \frac{PD}{4t_n} + 0.75i\frac{M_A}{Z} + i\frac{M_C}{Z} + E_{sct}\alpha(T_2 - T_1) \le (S_h + S_a) \qquad \text{Equation 11M}$$

Where S_E = Stress from restrained thermal expansion, psi

S_{TE} = Stress from pressure, weight and thermal expansion, psi

3.10.3 *Seismic Loads*

Seismic-induced damage to buried piping is largely due to wave propagation or permanent ground deformation resulting from fault movement, landslide, and liquefaction-induced lateral spread. Where buried piping enters a structure, the seismic anchor movements of the structure must be accounted for in the design of the piping. Other forms of damage related to ground movement such as elastic and consolidation settlement (total and differential), freeze-thaw induced settlement, and seismic-induced settlement due to soil compaction and rearrangement should be considered on a case-by-case basis. For the case of piping anchored to an adjacent building, strain development in the utility due to settlement of the building should be evaluated. The seismic effects on buried piping are self limiting in that strains are limited by the surrounding soil. Therefore the stresses due to these strains are secondary in nature.
COL applicants shall carry out site investigation to assess the best route for the underground piping. During this field investigation, sites that are vulnerable to fault movement and liquefaction-induced landslide and lateral spread should be avoided. If a pipe must be buried in loose saturated cohesionless soil susceptible to liquefaction, rigorous linear and non-linear pipe-soil interaction analysis should be carried out to evaluate the integrity of the pipe under settlement and lateral spread conditions that may be caused by the liquefiable soil. If the result of the soil-pipe interaction is not acceptable, any of the following options recommended in Reference [14] may be adopted:

(1) Re-route the pipe to avoid areas of liquefiable loose saturated cohesionless soils;

(2) Modify the strength of the soil by using appropriate stabilizing agent;

(3) Excavate liquefiable soil and replace with competent structural fill materials; or

(4) Support the pipe in soil that is not susceptible to failure.

3.10.3.1 *Axial and Bending Strains Due to Propagation of Seismic Waves*

Typically, the magnitude of axial and bending strains on buried piping due to propagation of seismic wave is dependent on several factors such as the buried material and soil properties and pipe-soil interfacial properties. Conservatively, axial and bending strains on the buried piping are taken to be the same as those of the seismic wave if there is no site specific field instrumentation to measure the strain level experienced by the buried piping. Based on the axial and bending strains developed in the buried piping assuming long, linear runs remote from anchors or bends, the corresponding axial load and bending stress can be computed as follows:

$$F_a = \varepsilon_a A E_{sct}$$

$$M_b = \sigma_b Z$$

Where $\sigma_b = \varepsilon_b E_{sct}$

In above equations,

E_{SCT} = Secant modulus of the buried piping, psi

ε_a = Axial strain in the buried piping due to wave propagation

ε_b = Bending strain in the buried piping due to wave propagation

Z = Section modulus of the buried piping, in^3

A = Cross-sectional area of the pipe, in^2

For the computation of loads developed at elbows, the simplified procedures outlined in reference [14] are recommended for flexible and rigid conditions. At site locations where the differential settlement is significant, flexible anchors may be used in lieu of rigid anchors. All support structures (anchors) should be designed to resist the resulting axial loads and bending stresses.

The general axial and bending strains due to seismic wave propagation may be found as follows:

$$\varepsilon_a = \pm \frac{V}{\alpha_\varepsilon c}$$

$$\varepsilon_b = \pm \frac{Ra}{(\alpha_k c)^2}$$

Where V = maximum velocity of the soil layer (particle) in which the piping is embedded, ft/sec

a = maximum acceleration of the soil layer (particle) in which the piping is embedded, ft/sec^2

c = apparent velocity relative to ground surface, ft/sec

R = radius of the pipe, ft

ε_b = bending strain

ε_a = axial strain

α_e = wave velocity axial coefficient (compression & rayleigh=1.0, shear=2.0)

α_k = wave velocity bending coefficient (compression = 1.6, shear & rayleigh = 1.0)

In reference [15], it is noted that axial and bending strains are a result of three types of seismic waves, (1) compression, (2) shear and (3) surface or Rayleigh. The strain for each wave is calculated using the general form for axial and bending noted above.

As noted in Table 3-2 for above ground piping, the effects of seismic loads on above ground piping must meet the requirements of NC/ND-3655. As further indicated in Table 3-2, and in compliance with the guidance in SECY-93-087, page 23, the effect of SSE seismic anchor displacements (which produce secondary stresses) together with normal loads would be evaluated to a Service Level D limit. This has been done for above ground piping in the secondary stress equation shown in Table 3-2 for Level D. Since the seismic effects in buried pipe produce secondary stresses, to be consistent with Table 3-2 and the guidance provided, the two equations shown below for buried pipe must be evaluated and the worse of the two met. The use of the two equations allows for two possible cases: thermal expansion plus the amplitude of the buried pipe SSE effects or the range (= twice the amplitude) of the buried pipe SSE effects, whichever is larger. The use of the larger of the two results is consistent with the methodology in the example provided in Reference 14, Appendix 3, pages 45 and 46.

$$S_{NSSE} = \frac{iM_C}{Z} + \frac{iM_{SSE}}{Z} + \varepsilon_b E_{sct} + \varepsilon_a E_{sct} + E_{sct}\alpha(T_2 - T_1) \le 3.0S_h \text{ but not > than } 2.0S_y$$

$$S_{SSE} = \frac{2iM_{SSE}}{Z} + 2\varepsilon_a E_{sct} + 2\varepsilon_b E_{sct} \le 3S_h \text{ but not > than } 2.0S_y$$

Where S_{NSSE} = buried pipe stress due to normal plus the amplitude of SSE loads

S_{SSE} = buried pipe stress due to the range of SSE loads

M_{SSE} = amplitude of moments due to earthquake moment loading and anchor movements; earthquake moment loading is induced in the pipe near bends, intersections, and anchor points as described in Reference 15, Section 3.5.2.2(b)

S_y = yield stress

The allowable stress, $3.0S_h$ or $2.0S_Y$, is based on service level D limits due to the fact that only SSE load case is evaluated in the piping design for the U.S. EPR.

The value of M_{SSE}, ε_b and ε_a represent the amplitude of the seismic moment and seismic strains.

~~. In addition to the above equation, the following equation, which checks the range of seismic motion, shall also be evaluated:~~

$$S_{OL} = \frac{2iM_{SSE}}{Z} + 2\varepsilon_a E_{sct} + 2\varepsilon_b E_{sct} \le 3S_h \text{ but not>than } 2.0S_y$$

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping

Service Condition	Service Level	Category	Loading or Stress Component	Acceptance Criteria[1]
Design	-	Primary Stress	Design Pressure, Deadweight, Steady State Flow Load and Dynamic Fluid Load[2] specified as Level A	Eq 9N NB-3652
Normal	A	Primary plus Second-ary Stress Intensity Range (S.I.R.)	Range of Level A: 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	Eq 10N NB-3653.1
		Peak S.I.R.	Range of Level A: 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,~~Same as for Level A Primary plus Secondary S.I.R. plus Range of Level A~~ Thermal Radial Gradient Stress (linear and non-linear)	Eq 11N NB-3653.2
		Thermal S.I.R.[5]	Range of Level A: Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3], Cyclic Thermal Load[4]	Eq 12N NB-3653.6(a)
		Primary plus Second-ary Membrane plus Bending S.I.R.[5]	Range of Level A: Service Pressure, Steady State Flow Load, Dynamic Fluid Load[2], Material Discontinuity Stress~~Same as for Level A Primary plus Secondary S.I.R. except Range of Level A Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3] and Cyclic Thermal Load[4] is not Considered~~	Eq 13N NB-3653.6(b)
		Alternating Stress Intensity (S.I.) (Fatigue Usage)[6]	Range of Level A: 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, Thermal Radial Gradient Stress (linear and non-linear)~~Same as for Level A Peak S.I.R.~~	Eq 14N NB-3653.6(c)
		Thermal Stress Ratchet	Range of Level A Linear Thermal Radial Gradient	NB-3653.7

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping

Service Condition	Service Level	Category	Loading or Stress Component	Acceptance Criteria[1]
Upset	B	Permissible Pressure	Maximum Level B Service Pressure	NB-3654.1
		Primary Stress	Coincident Level B Service Pressure, Deadweight, Steady State Flow Load, Dynamic Fluid Load[2]	Eq 9U NB-3654.2(a)
		Primary plus Secondary S.I.R.	Range of Level B: 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,Same as for Level A Primary plus Secondary S.I.R. (except Level B Load and Stress Ranges are used) plus Earthquake Inertial Load[7]	Eq 10U NB-3654.2(b)
		Peak S.I.R.[8]	Range of Level B: 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]Same as for Level B Primary plus Secondary S.I.R. plus, Range of Level B Thermal Radial Gradient Stress (linear and non-linear)	Eq 11U NB-3654.2(b)
		Thermal S.I.R.[5]	Range of Level B: Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3], and Cyclic Thermal Load[4]	Eq 12U NB-3654.2(b)
		Primary plus Second-ary Membrane plus Bending S.I.R.[5]	Range of Level B: Service Pressure, Steady State Flow Load, Dynamic Fluid Load[2], Material Discontinuity Stress, Earthquake Inertial Load[7]Same as for Level B Primary plus Secondary S.I.R. except Range of Level B Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3] and Cyclic Thermal Load[4] is not Considered	Eq 13U NB-3654.2(b)
		Alternating S.I. (Fatigue Usage)[6]	Range of Level B: 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], Level B Thermal Radial Gradient Stress (linear and non-linear)Same as for Level B Peak S.I.R.	Eq 14U NB-3654.2(b)
		Thermal Stress Ratchet	Range of Level B Linear Thermal Radial Gradient	NB-3654.2(b)

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping

Service Condition	Service Level	Category	Loading or Stress Component	Acceptance Criteria[1]
		Deformation Limits	As Set Forth in the Design Specification	NB-3654.2(b)
Emergency[9]	C	Permissible Pressure	Maximum Level C Service Pressure	NB-3655.1
		Primary Stress	Coincident Level C Service Pressure, Deadweight, Steady State Flow Load, Dynamic Fluid Load[2]	Eq 9E NB-3655.2(a)
		Deformation Limits	As Set Forth in the Design Specification	NB-3655.3
Faulted	D	Permissible Pressure	Maximum Level D Service Pressure	NB-3656(a)(1)
		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)	Eq 9F NB-3656(a)(2)
		Secondary Stress[12]	MAX[Range of (Bending Moment 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]	6Sm[13]
Pressure Testing[15]	-	Primary Membrane S.I.	Test Pressure, Deadweight	NB-3657 NB-3226(b)
		Primary Membrane plus Bending S.I.	Test Pressure, Deadweight	NB-3657 NB-3226(c)

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping

Notes:

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 150F.
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 Primay plus Secondary Stress Intensity Range, Peak Stress Intensity Range and Alternating Stress Intensity calculations (Equations 10, 11 and 14) is taken as 1/3 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 is considered. If the earthquake inertial load is taken as 1/3 of the peak SSE inertial load then the number of cycles to be considered for earthquake loading is 300 (the equivalent number of 20 full SSE cycles as derived in accordance with Appendix D of IEEE Standard 344-1987).
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 which result in an alternating stress intensity (S_a) value greater than that for 10^6 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-excedance criteria given in NUREG-0484 is met. When the time phasing relationship cannot be established, or when the non-excedance criteria in NUREG-0484 is not met, dynamic loads are combined by absolute sum. SSE and High Energy Line Break loads are always combined using the SRSS method.

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping

12. This secondary stress check is only necessary if the stresses (including those due to Earthquake Inertial Load) exceed the Equation 10U (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. Sm = 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 which result in an alternating stress intensity (S_a) value greater than that for 10^6 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 3-4: Design Conditions, Load Combination and Stress Criteria for ASME Class 2&3 Buried Piping

Loading Condition	Service Levels	Loads	Stress Criteria
Design	-	Primary Stress Loads: Pressure[1], Weight Loads, Other Sustained Mechanical Loads	Equation 8[5] NC/ND-3652
Normal/ Upset	A/B	Occasional: Pressure[1], Weight Loads, Other Sustained Mechanical Loads, DFL	Equation 9U[5] NC/ND-3653.1 (Level B Only)
		Secondary Stress: Thermal Expansion, TAM, Thermal Friction Forces	Equation 10M[2] [4] NC/ND-3653.2(a)
		Non-Repeated Anchor Movement	Equation 10a NC/ND-3653.2(b)
		Sustained Plus Secondary Stress: Pressure[1], Weight Loads, Other Sustained Mechanical Loads, Thermal Expansion, TAM, Thermal Friction Forces	Equation 11M[3] [4][5] NC/ND-3653.2(c)
Emergency	C	Occasional Stress: Pressure[1], Weight Loads, DFL	Equation 9E[5] NC/ND-3654.2(a)
Faulted	D	Secondary Stress: SSE effects~~Inertia~~ & SAM(M_{SSE}), Thermal Expansion and TAM (M_C), Friction Axial Forces from Thermal Expansion	See note 6

Notes:

1. Pressure for buried pipe includes internal pressure and the soil overburden loads and loads due to motor vehicles and train cars.
2. Equation 10 modified to include stress due to axial friction forces caused by thermal expansion and soil interaction.
3. Equation 11 modified to include stress due to axial friction forces caused by thermal expansion and soil interaction.
4. Stresses must meet Equation 10M or 11M, not both.
5. Buried piping systems must be designed to meet the external pressure load criteria of NC/ND-3133 of the ASME Code.
6. $\frac{i(M_{SSE}+M_C)}{Z}+\varepsilon_a E_{sct}+\varepsilon_b E_{sct}+E_{sct}\alpha(T_2-T_1)\leq$ lesser of $3S_h$ or $2S_y$ Equation A.

   OR

   $\frac{2i(M_{SSE})}{Z}+2\varepsilon_a E_{sct}+2\varepsilon_b E_{sct}\leq$ lesser of $3S_h$ or $2S_y$ Equation B

   For definition of terms, see Section 3.10.3.1.

Table 3-5: Impact Factor for Surface Load Effect on Buried Pipes (Reference 13)

Cover thickness (ft)	Surface Load Condition	
	Highways	Railways
0 - 1	1.50	1.75
1 - 2	1.35	1.50
2 - 3	1.15	1.50
> 3.0	1.00	1.35

Table 3-6: Recommended Surface Load for Buried Pipe

(Reference 13)

Cover thickness, ft	Surface load transmitted to pipe (lb/in^2)		Cover thickness, ft	Surface load transmitted to pipe (lb/in^2)	
	Highway H20	Railway E80		Highway H20	Railway E80
1	12.50	-	16	Negl.	3.47
2	5.56	26.39	18	Negl.	2.78
3	4.17	23.61	20	Negl.	2.08
4	2.78	18.40	22	Negl.	1.91
5	1.74	16.67	24	Negl.	1.74
6	1.39	15.63	26	Negl.	1.39
7	1.22	12.15	28	Negl.	1.04
8	0.69	11.11	30	Negl.	0.69
10	Negl.	7.64	35	Negl.	Negl.
12	Negl.	5.56	40	Negl.	Negl.
14	Negl.	4.17			

4.2.2.3 Modal Combination

The inertial response of a piping system in a seismic response spectrum analysis is considered in two parts. The modal analysis calculates the peak response of the piping system for all natural frequencies of the system below a defined cutoff frequency. These low frequency (or non-rigid) modes consistThis analysis consists of all modes with seismic excitation frequencies up to the frequency at which spectral accelerations return to the zero period acceleration (ZPA). This frequency is referred to as the ZPA cutoff frequency. For the U.S. EPR, the ZPA cutoff frequency is 40Hz for seismic analysis or as defined by figure 2 and 3 in RG 1.92[20], Rev. 2. Higher ZPA cutoff frequencies may be required for other dynamic load cases.

At modal frequencies above that corresponding to the ZPA, pipe members are considered rigid. The acceleration associated with these rigid modes is usually small. However, in certain situations the response to high frequency modes can significantly affect support loads, particularly axial restraints on long piping runs. To account for these effects of the residual rigid response, a missing mass correction is applied.

When performing response spectrum analyses using USM, the inertial response from the modal analysis is also divided into two types of response, periodic or rigid. At low frequencies, in the amplified regions of the response spectrum, the total inertial response is considered as a periodic response. Beyond this region but below the ZPA cutoff frequency (intermediate frequencies), the modal response consists of both periodic and rigid components. The total inertial solution is then determined by combining the individual modal responses, both periodic and rigid, and the residual rigid response per the guidance of RG 1.92 as discussed in Sections 4.2.2.3.1 through 4.2.2.3.4.

For analyses performed using ISM, all modal response at frequencies below the ZPA cutoff frequency is treated as periodic while the response above this frequency is rigid. The treatment and combination methods of these responses to obtain the total inertial solution will be performed per NUREG-1061 as discussed in Section 4.2.2.3.5 below.

4.2.2.3.1 USM Periodic Modal ResponsesLow Frequency (Non-Rigid) Modes

RG 1.92 provides guidance on combining the individual periodic modal results due to each response spectrum in a dynamic analysis performed using USM.

~~The combination method used shall consider the effects of closely spaced modes. Modes are defined as being closely spaced if their frequencies differ from each other by 10 percent or less of the lower frequency.~~

For piping systems with no closely spaced modes, the square root of the sum of the squares (SRSS) method is applied to obtain the representative maximum response of each element, as shown in the following equation:

$$R = \left[\sum_{k=1}^{N} R_k^2 \right]^{\frac{1}{2}}$$

Where R = the representative maximum response due to the input component of the earthquake,

R_k = the peak response due to the k[th] mode,

N = the number of significant modes.

This method may produce unconservative results for piping systems with closely spaced modes. Therefore, the double sum approved methods for combining closely spaced modesthe periodic modal responses considering either the Rosenblueth or Der Kiureghian correlation coefficients provided in RG 1.92 will be used to obtain a more accurate modal response for frequencies below the rigid range. These include the Grouping, Ten Percent and Double Sum methods, as well as the less conservative methods in Revision 2 of RG 1.92[16].

For piping systems analyzed using ISM methods, modal result s are combined without the consideration of closely spaced modes, per NUREG-1061[18]. Therefore, for these systems, modal results are combined by the SRSS method presented above.

4.2.2.3.2 USM Rigid Components of Modal Response

In the intermediate frequency region where modal responses consist of both periodic and rigid components, these components are separated using either the Gupta Method or Lindley-Yow method as presented in RG 1.92.

The rigid individual modal responses will then be combined by algebraic summation.

4.2.2.3.24.2.2.3.3 High Frequency (Residual Rigid) Modes Response

Piping system modes with frequencies greater than the ZPA cutoff frequency are considered as high frequency or rigid range modes. For flexible piping systems, the high frequency response may not be significant since a significant portion of the system mass is excited at frequencies below the ZPA. However, for piping systems, or portions of piping systems, which are more rigidly restrained or have lumped masses near rigid restraints, a significant portion of the system mass may not be accounted for in the low frequency modal analysis. This mass which is not excited at the lower frequencies is termed the "missing mass" of the system. While high frequency modes usually involve small displacement amplitudes and small pipe stresses, they can have a significant impact on support loads.

The response from high frequency modes must be included in the response of the piping system. Guidance for including the missing mass effects is provided in RG 1.92 for USM.

The peak modal responses of the system at frequencies above the ZPA are considered to be in phase. Thus, the responses of all high frequency modes are combined by algebraic summation.

The U.S. EPR will use the method presented in RG 1.92 or the left-out-force method described below for calculating and applying the response of the high frequency modes based on applying a missing mass correction. Although this method uses a different computational procedure than described in RG 1.92, Appendix A, the two methods produce the same result. The left-out-force method is used by SUPERPIPE and BWSPAN uses the method in Appendix A of RG 1.92.

The total inertia forces in a system considering a piping system under simple excitation, in a steady-state condition with a unit acceleration applied in a specified direction is mathematically represented by:

$$\{F_t\} = [M]\{r\}$$

Where	$\{F_t\}$	=	Total inertia forces in the specified direction
	$[M]$	=	Mass matrix
	$\{r\}$	=	Mass point displacement vector produced by a statically applied unit ground displacement

The sum of the inertia forces for all modes included in the modal analysis is calculated as:

$$\{F_s\} = \sum_{n=1}^{N} \{F_n\} = \sum_{n=1}^{N} [M]\{\phi_n\}\{\phi_n\}^T [M]\{r\}$$

Where	$\{F_s\}$	=	total inertia force seen by the system in the low frequency modal analysis
	$\{F_n\}$	=	inertia force of mode n
	$\{\phi_n\}$	=	mode shape

N = number of modes calculated in the modal analysis

Therefore, the missing, or left out, forces considering a unit ground acceleration in a specified direction are calculated as:

$$\{F_m\} = \{F_t\} - \{F_s\} = [M]\{r\} - \sum_{n=1}^{N} [M]\{\phi_n\}\{\phi_n\}^T [M]\{r\}$$

Or:

$$\{F_m\} = [M]\{r\}\left[1 - \sum_{n=1}^{N} [M]\{\phi_n\}\{\phi_n\}^T\right]$$

The missing inertia forces are calculated independently for all input components of earthquake motion (i.e., in each direction for each support group). The mode displacements, member end action, and support force corresponding to each missing force vector is determined with a modal acceleration equal to the ZPA.

As an alternative, when using the Lindley-Yow method, the Static ZPA method for calculating a total mass rigid response presented in RG 1.92 Section C.1.4.2 may be used.

~~These results are treated as an additional modal result in the response spectra analysis. This missing mass mode is considered to have a modal frequency and acceleration equal to the cut-off frequency used in the modal analysis. These modal results are combined by the SRSS method with the low frequency modal results using the methods described in Section 4.2.2.3.1.~~

~~For systems analyzed using USM, the rigid range (missing mass) results will be combined with the low frequency modal results in accordance with Regulatory Position C.1.5.1 of RG 1.92. For systems analyzed using ISM, the missing mass results will be combined with the low frequency modal results by SRSS, per NUREG-1061."~~

4.2.2.3.4 USM Complete Inertial Response

For USM response spectra analyses, the complete inertial response is calculated using the methodology provided in RG 1.92 Section C.1.5. In using these methods, the total rigid response will be calculated by algebraic summation of the applicable rigid response components and then combined with the total periodic response using the SRSS method.

4.2.2.3.5 ISM Combination of Modal Responses

For piping systems analyzed using ISM methods, modal results are combined without the consideration of closely spaced modes, per NUREG-1061. Additionally, the entire modal response for modes below the ZPA cutoff frequency is treated as a periodic response. Therefore, for these systems, modal results are combined by the SRSS method presented in Section 4.2.2.3.1 above.

The residual rigid response will be calculated using the missing mass method as that presented in Section 4.2.2.3.3. This missing mass response will then be combined with the low frequency modal results by SRSS, per NUREG-1061.

~~These results are treated as an additional modal result in the response spectra analysis. This missing mass mode is considered to have a modal frequency and acceleration equal to the cut-off frequency used in the modal analysis. These modal results are combined with the low frequency modal results using the methods described in Section 4.2.2.3.1.~~

4.2.2.4 Directional Combination

Following the modal combination of results, the responses of the piping system due to each of the three orthogonal earthquake motion inputs are combined. The collinear responses due to each of the input components of motion are combined using the SRSS method [20].

4.2.2.5 Seismic Anchor Motions

In addition to the dynamic inertia loads, the effects of differential displacements of equipment or structures to which the piping system attaches during a safe shutdown earthquake shall also be considered. The maximum relative displacement for each support location may be obtained from the results of the structural dynamic analysis for the supporting structure or calculated from the applicable floor response.

4.2.5 *Damping Values*

RG 1.61, Rev. 1 damping values will be used for Independent Support Motion response spectra and Time-History analysis. RG 1.61, Rev. 1 will also be used for piping systems analyzed using uniform support motion response spectra. Frequency dependent damping, as defined in Figure 1 of Regulatory position C.2 of RG 1.61, Rev. 1, may be used for a piping analysis provided the five (5) conditions defined in Regulatory Position C.2 are met.

For piping systems analyzed using a uniform enveloped response spectra analysis, RG 1.61, Rev 1 damping will be used in conjunction with RG 1.92, Rev. 2.

When composite modal damping is applied in a dynamic analysis (either time history or response spectrum), each model subgroup (piping, supports, equipment, etc) is assigned an appropriate damping value per RG 1.61 R1. The equivalent modal damping matrix, or composite modal damping matrix, is calculated for each mode by one of the two methods shown below:

Note: the highlighted text was provided to NRC in response to RAI EPR-32 and deemed acceptable by NRC

$$\bar{\beta}_j = \{\phi\}^T[\bar{M}]\{\phi\} \qquad (1)$$

$$\beta_j = \frac{\{\phi\}^T[\bar{K}]\{\phi\}}{K^*} \qquad (2)$$

Where:

K^* = $\{\varphi\}^T[K]\{\varphi\}$

[K] = assembled stiffness matrix

$\bar{\beta}_j$ = equivalent modal damping ratio of the j^{th} mode

$[\bar{K}],[\bar{M}]$ = the modified stiffness or mass matrix constructed from element matrices formed by the product of the damping ratio for the element and its stiffness or mass matrix

{φ} = j^{th} normalized modal vector

Note: Damping beyond 20% will not be used.

~~5.4.1.2 *Restrained Elbows*~~

~~In some instances where a single full anchor support is not feasible, a set of supports placed around an elbow may be used to separate analysis models. In this method, an elbow must be restrained as shown in Figure 5-1. This creates a structurally rigid zone around the elbow in which the piping effects from one end of the restrained section are not transmitted beyond the other end.~~

~~The piping within the restraints shown in Figure 5-1 is impacted by the piping on both sides of the restrained elbow. Therefore, the results from both analyses are combined to obtain pipe stresses and hanger loads for the restrained elbow section of the pipe.~~

~~5.4.1.3 *Restrained Tees*~~

~~A restrained tee is similar to a restrained elbow. The restrained tee is used to divide the branch and run pipe into separate models when the decoupling criteria in Section 5.4.2 are not met. The restraint configuration is shown in Figure 5-2.~~

~~The piping within the restraints shown in Figure 5-2 is impacted by both the branch and run pipe. Therefore, the results from both analyses are combined to obtain pipe stresses and hanger loads for the restrained tee section of the pipe.~~

Figure 5-1 Restrained Elbow

(DELETED)

Where L is equal to the recommended support span per Table 4-1 and L1 and L2 are defined as follows:

Dimension	Nominal	Minimum	Maximum
L1	6"	Fitting Weld Clearance	6"
L2	L/4	L/8	L/4

Figure 5-2 Restrained Tee

(DELETED)

~~Where L is equal to the recommended support span per Table 4-1 and L1 and L2 are defined as follows:~~

~~Dimension~~	~~Nominal~~	~~Minimum~~	~~Maximum~~
~~L1~~	~~6"~~	~~Fitting Weld Clearance~~	~~6"~~
~~L2~~	~~L/4~~	~~L/8~~	~~L/4~~

6.8 *Support Self-Weight Excitation*

6.8.1 *Seismic Loads*

The response of the support structure itself to SSE loadings is to be included in the pipe support analysis. In general, the inertial response of the support mass will be evaluated using a response spectrum analysis similar to that performed for the piping. Damping values for welded and bolted structures are given in Revision 1 to RG 1.61. This support self-weight SSE response, the piping inertial load SSE response and the SSE loads from SAM are to be combined by absolute sum.

6.8.2 *Other Dynamic Loads*

For the U.S. EPR Reactor Coolant Loop analysis, the support structures have been explicitly modeled with the piping. Due to this inclusion of the supports in the piping model, the dynamic effects of the support structures are inherently included in the overall results for all dynamic loadings (including seismic). For other Class 1, 2 or 3 piping system analyses, the support structures are not expected to be explicitly modeled in the piping analysis. The analyses will assume rigid support points in the piping model using the default stiffnesses in the analysis code, with support rigidity confirmed as discussed in Section 6.7. As also discussed in Section 6.7, if supports do not meet the requirements in Section 6.7, the actual support stiffnesses will be determined for all supports within that model and will be used in a reanalysis of the piping along with the mass of the support. Therefore, the dynamic characteristics of supports that are not rigid will be included in the piping analysis.

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U.S. EPR Piping Analysis and Pipe Support Design

Topical Report

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U.S. Nuclear Regulatory Commission

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Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1.	All	This is a new document

Contents

List of Tables

List of Figures

Nomenclature

Acronym	Definition
ACI	American Concrete Institute
AISC	American Institute of Steel Construction
ANSI	American National Standards Institute
ARS	Amplified Response Spectra
ASME	American Society of Mechanical Engineers
AWS	American Welding Society
CFR	Code of Federal Regulations
COL	Combined Construction Permit and Operating License
DBPB	Design Basis Pipe Break
DCD	Design Control Document
DFL	Dynamic Fluid Load
DLF	Dynamic Load Factor
GDC	General Design Criterion
ISM	Independent Support Motion
LBB	Leak-Before-Break
LOCA	Loss-of-Coolant Accident
MS/FWPB	Main Steam / Feedwater Pipe Break
NPS	Nominal Pipe Size
NRC	U.S. Nuclear Regulatory Commission
OBE	Operating Basis Earthquake
RCL	Reactor Coolant Loop
RG	Regulatory Guide

SAM	Seismic Anchor Motion
S.I.	Stress Intensity
SIF	Stress Intensification Factor
S.I.R.	Stress Intensity Range
SOT	System Operating Transient
SRP	Standard Review Plan
SRSS	Square Root of the Sum of the Squares
SSC	Structures, Systems and Components
SSE	Safe Shutdown Earthquake
TAM	Thermal Anchor Movement
USM	Uniform Support Motion
ZPA	Zero Period Acceleration

1.0 INTRODUCTION

This topical report presents the U.S. EPR Design Certification code requirements, acceptance criteria, analysis methods and modeling techniques for ASME Class 1, 2 and 3 piping and pipe supports. These structures and components are designed and analyzed as required to meet the U.S. Nuclear Regulatory Commission's (NRC) regulations provided in Title 10 of the Code of Federal Regulations (10 CFR). To meet these requirements, the design and analysis utilizes the additional guidance provided by Sections 3.7 and 3.9 of the NRC's Standard Review Plan (SRP), documented in NUREG-0800[1] and the requirements established in the American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section III, Division 1 (hereafter, ASME Code) for Code Class 1, 2 and 3 pressure retaining components and their supports. Pipe containing radioactive material will be classified as Quality Group D and designed to ASME B31.1 2004 edition, no addenda. The report focuses on Seismic Category I and Category II systems, but also addresses the interaction of non-seismic piping with Seismic Category I piping. The Reactor Coolant Loop (RCL) and Pressurizer Surge Line piping requirements, modeling techniques, analysis approaches and acceptance criteria are not specifically addressed in this document. They will be addressed in the Design Control Document.

Section 2.0 identifies the codes and standards applicable to the U.S. EPR design and analysis of piping and pipe supports. In addition, it identifies the Code Cases that will be used for piping analysis and support design.

Section 3.0 of this report presents the piping analysis acceptance criteria. It identifies the categorization of piping according to the guidance provided in Regulatory Guide 1.29, service level and load definitions and load combinations used in the qualification of piping. In addition, it discusses how the U.S. EPR piping will be designed to address additional issues related to pipe stress analysis.

Section 4.0 focuses on seismic analysis methods guided primarily by SRP 3.7.3. This section presents discussions on such topics as seismic input, response spectrum and time history analysis, damping values and equivalent static analysis. Seismic and non-seismic interactions are also discussed.

Section 5.0 presents pipe modeling techniques used in the qualification of piping for the U.S. EPR. Computer codes used in piping analysis are identified in this section with a brief description of each. Analysis boundaries, decoupling criteria and other modeling requirements are presented.

Section 6.0 presents the pipe support design criteria. Codes and standards and load combinations along with deflection criteria, stiffness and general support configurations are presented.

Conclusions are discussed in Section 7.0.

This topical also identifies some requirements and guidelines for which the COL applicant is responsible. The specific issues are identified in Table 1-1.

Table 1-1: Analysis and Design Responsibilities for COL Applicants

ITEM	COL Applicant Responsibility	Applicable Section
1	The COL applicant will develop the design specification and the design reports using requirements outlined in the Code and demonstrate and document that as-designed piping and support configurations adhere to the requirements of the design specification.	2.3
2	Should the COL applicant find it necessary to route Class 1, 2 and 3 piping not included in the U.S. EPR Design Certification in such a manner that it is exposed to wind and/or tornadoes, it must be designed to withstand the plant design basis loads for this event	3.3.1.6
3	The COL applicant will confirm that thermal deflections do not create adverse conditions on the pressurizer surge line during hot functional testing.	3.7.2
4	COL applicants should perform detailed geotechnical engineering analysis to determine if the surface load will cause lateral and/or vertical displacement of bearing soil for the piping.	3.10.1.4
5	COL applicants shall carry out site investigation to assess the best route for the underground piping.	3.10.3
6	A review of the impact of contributing mass of supports on the piping analysis will need to be performed by the COL applicant(s) following the final support design to confirm that the mass of the support is no more than 10% of the mass of the adjacent pipe span.	5.2
7	Pipe stress and support analysis will be performed by the COL applicant(s). A COL applicant choosing to use a piping analysis program other than those listed in Section 5.1 will implement the U.S. EPR benchmark program using models specifically selected for the U.S. EPR.	5.3
8	The COL Applicant will verify proper installation and operation of snubbers utilizing visual inspections, hot and cold position measurements, and observance of thermal movements during plant startup.	6.6

2.0 CODES AND STANDARDS

10 CFR Part 50, Appendix A, General Design Criterion (GDC) 1 requires that structures, systems and components (SSC) important to safety must be designed to quality standards “commensurate with the importance of the safety functions to be performed.” GDC 2 requires that SSCs important to safety be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes and floods without the loss of their safety function. Codes and standards used to show that safety-related piping and pipe supports for the U.S. EPR meet these GDCs are identified below.

2.1 *ASME Boiler and Pressure Vessel Code*

Piping analysis and pipe support design for the U.S. EPR addressed in this topical report use the 2001 ASME Code, Section III, Division 1, 2003 addenda[2] as the base code with limitations identified in the Code of Federal Regulations, 10 CFR 50.55a(b)(1). Accordingly, the 2001 Edition of the ASME Code, 2003 addenda, will be the design code for Class 1, 2, and 3 piping with the restriction that the treatment of dynamic loads, including seismic loads, in the pipe stress analyses will be according to sub-articles NB/NC/ND-3650 of the 1993 Addenda of the ASME Code[3]. Class 1 piping greater than one inch Nominal Pipe Size (NPS) will be analyzed to NB-3600. Class 1 piping one inch NPS and smaller and Class 1 piping meeting the requirements of NB-3630(d)(2) may be analyzed to NC-3600. Class 2 piping will be analyzed to NC-3600. Class 3 piping will be analyzed to ND-3600. Quality Group D piping will be analyzed to ASME B31.1, 2004 Edition, no addenda. Pipe supports will be designed to Subsection NF of the 2001 ASME Code, Section III, 2003 addenda. The requirements of ASME Section XI, 2001 Edition with 2003 addenda will be met in the design of piping and pipe supports.

2.2 *ASME Code Cases*

ASME Code Cases applicable to the U.S. EPR Design Certification for piping and pipe supports are as follows:

- ASME Code Case N-122-2, ‘Procedure for Evaluation of the Design of Rectangular Cross Section Attachments on Class 1 Piping, Section III, Division 1.’
- ASME Code Case N-318-5, ‘Procedure for Evaluation of the Design of Rectangular Cross Section Attachments on Class 2 or 3 Piping, Section III, Division 1.’
- ASME Code Case N-319-3, ‘Alternate Procedure for Evaluation of Stresses in Butt Welding Elbows in Class 1 Piping Section III, Division 1.’
- ASME Code Case N-391-2, ‘Procedure for Evaluation of the Design of Hollow Circular Cross Section Welded Attachments on Class 1 Piping, Section III, Division 1.’
- ASME Code Case N-392-3, ‘Procedure for Evaluation of the Design of Hollow Circular Cross Section Welded Attachments on Class 2 and 3 Piping, Section III, Division 1.’

Other ASME Code Cases may be used if they are either conditionally or unconditionally approved in Regulatory Guide (RG) 1.84[4].

2.3 *Design Specification*

A design specification is required by Section III of the ASME Code[2] for ASME Class 1, 2 and 3 piping. In addition, the ASME Code requires design reports for all Class 1, 2 and 3 piping demonstrating and documenting that as-designed piping and support configurations adhere to the requirements of the design specification. It is the responsibility of the COL applicant or his agent to develop the design specification and the design reports using requirements outlined in the ASME Code.

3.0 PIPING STRESS ANALYSIS CRITERIA

3.1 *Piping Seismic Classifications*

The U.S. EPR follows the guidance in RG 1.29, "Seismic Design Classification,"[5] in classifying structures, systems and components (SSCs) as Seismic Category I, Seismic Category II or non-seismic. The following definitions apply to these categories for piping:

- Seismic Category I piping is required to be designed to withstand the effects of a Safe Shutdown Earthquake (SSE) and remain functional during and after the event. These components must meet the requirements of Appendix B to 10 CFR Part 50.

- Piping that is not required to function during or after an SSE event, but its structural failure could reduce the functioning of Seismic Category I SSCs is classified as Seismic Category II piping. To prevent adverse impact to Seismic Category I SSCs, Seismic Category II piping will be designed to the same requirements as Seismic Category I piping.

- Piping that does not meet the criteria for Seismic Category I or II is considered non-seismic. Non-seismic pipe is routed away from safety equipment to prevent any interaction with Seismic Category I and II, where applicable. When it is not practical to route non-seismic pipe away from Seismic Category I and II piping, the non-seismic piping will be upgraded to Seismic Category II as defined above.

3.2 *Service Levels*

The U.S. EPR will utilize the four Service Levels used in the ASME Code, Levels A, B, C and D, and testing conditions, in its design of piping and pipe supports. These four service level designations also have the alternate naming convention of Normal, Upset, Emergency and Faulted, respectively. Based on the guidance in SRP 3.9.3[1], loading combinations of the various potential analysis load cases will be developed for the four defined levels. The general definitions of each of the four levels are as follows:

3.2.1 *Level A (Normal)*

Level A refers to sustained loadings encountered during normal plant/system start-up, operation, refueling and shutdown.

3.2.2 *Level B (Upset)*

Level B refers to occasional, infrequent loadings deviating from normal plant conditions, but having a high probability of occurrence. Piping and pipe supports will be designed to withstand these loading conditions without sustaining any damage or reduction in function.

3.2.3 *Level C (Emergency)*

Level C refers to infrequent loadings with a low probability of occurrence, which are considered as design basis loadings causing no significant loss of integrity. Such an occurrence requires the unit to be shut down for inspection and repair to any damaged components prior to re-start.

3.2.4 *Level D (Faulted)*

Level D refers to infrequent loadings with an extremely low probability of occurrence, associated with design basis accidents (such as Safe Shutdown Earthquake, Design Basis Pipe Break and Loss of Coolant Accident). Per RG 1.29[5], SSCs important to safety must retain their ability where required to “ensure:

- the integrity of the reactor coolant pressure boundary
- the capability to shut down the reactor and maintain it in a safe shutdown condition

- the capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures comparable to the guideline exposures of 10 CFR Part 100."

3.2.5 *Testing*

Pressure overload tests such as primary and secondary hydrotests and other leak rate tests are included in the piping analysis for primary membrane stresses and fatigue evaluation.

3.3 *Loadings and Load Combinations*

3.3.1 *Loadings*

3.3.1.1 *Pressure*

Internal design pressure, P, is used in the design and analysis of ASME Code Class 1, 2 & 3 piping. Minimum pipe wall thickness calculations are performed per ASME Code, Subsections NB-, NC-, ND-3640 utilizing design pressure. Design pressures and maximum service pressures are used in load combinations as noted in Tables 3-1 and 3-2 for calculating stresses for Design Conditions, Service Levels A, B, C and D and Testing.

3.3.1.2 *Deadweight*

Deadweight loads will be calculated by applying a 1g negative vertical acceleration to the pipe, contents, insulation and in-line components. The weight of water during hydrostatic testing shall be considered for piping systems carrying air, steam or gas.

3.3.1.3 *Thermal Expansion*

The effects on piping and supports from restrained thermal expansion and contraction shall be considered in the design. Various operating modes shall be considered in order to determine the most severe thermal loading conditions. Thermal anchor movements of equipment, support/restraints and run piping for decoupled branch lines shall also be considered. The zero thermal load temperature is taken as 70°F.

No thermal analysis is required for piping systems with an operating temperature equal to or less than 150°F[2]. Additionally, thermal anchor movements less than or equal to one sixteenth of an inch (1/16") may be excluded from the analysis since this represents the industry practice for acceptable gaps in pipe supports.[6]

3.3.1.4 *Seismic*

The effects of seismic inertial loads and anchor movements shall be included in the design analysis.

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. Per Appendix S to 10 CFR Part 50, the OBE load case does not require explicit design analysis. In the event of an earthquake which meets or exceeds the OBE ground motion, plant shutdown is required and Seismic Category I piping and supports are required to be inspected to ensure no functional damage has occurred. The design of the U.S. EPR Seismic Category I piping and supports includes analysis of the inertial and anchor movement (> 1/16") effects of the SSE event. These loads are Service Level D loads.

The consideration of fatigue effects due to seismic events is discussed in Section 3.4.

3.3.1.5 *Fluid Transient Loadings*

3.3.1.5.1 Relief Valve Thrust

Relief valve thrust loads, for open and closed systems, are functions of valve opening time, flow rate, fluid properties and flow area. 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 will be used when static analysis produces undesirably conservative results. These loads are considered in Service Level B, C or D load combinations.

3.3.1.5.2 Water and Steam Hammer

Water and steam hammer loads can be Service Level B, C or D loads and are dynamic in nature. Hammers usually involve 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.

3.3.1.6 *Wind/Tornado Loads*

Class 1, 2 and 3 piping for the U.S. EPR Design Certification is not exposed to wind or tornado loads. Should the COL applicant find it necessary to route piping outside the scope of the design certification in such a manner that it is exposed to wind and/or tornadoes, it must be designed to the plant design basis loads for these events.

3.3.1.7 *Design Basis Pipe Break (DBPB) Loads*

Loads due to high energy pipe breaks can take the form of pipe whip, jet impingement, elevated room temperatures and the dynamic effects in the system due to the break. These loads must be evaluated for the appropriate service condition. Breaks in the RCL, Main Steam and Pressurizer Surge lines which meet the Leak-Before-Break (LBB) size criteria are eliminated from consideration based on LBB analysis. However, DBPB loads do include the impact of small break LOCA, Main Steam and Feedwater line breaks outside the LBB analyzed zone.

3.3.1.8 *Thermal and Pressure Transient Loads*

Thermal and pressure transients are evaluated in the analysis of Class 1 piping by calculating the range of primary plus secondary stress intensities. For Class 2&3 piping, these transients are included as load cases in the appropriate ASME Code equations (8, 9 or 10).

3.3.1.9 *Hydrotests*

Piping systems are tested for leaks by filling the system with the test fluid and pressurizing to test pressures. Systems that are normally used for steam and gas services must have stops placed in spring hangers and temporary supports added as needed. Analysis of testing conditions for these lines must consider the temporary support configurations

3.3.2 *Load Combinations*

Using the methodology and equations from the ASME Code, pipe stresses shall be 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 Class 1 piping are given in Table 3-1. Class 2 and 3 load combinations are given in Table 3-2.

3.4 *Fatigue Evaluation*

3.4.1 *Code Class 1 Piping*

Class 1 piping shall be evaluated for the effects of fatigue as a result of pressure and thermal transients and other cyclic events including earthquakes. The fatigue analysis of Class 1 piping greater than 1 inch NPS is performed using the ASME Code requirements of NB-3653.

Per the guidance of SRP 3.7.3[1], Class 1 piping should be designed for a minimum of one SSE and five OBE events with ten maximum stress cycles per event. As discussed in Section 3.3.1.4, a detailed design analysis of the OBE loadcase is not performed for the U.S. EPR. Therefore, to meet this requirement, earthquake cycles included in the fatigue analysis are composed of 2 SSE events with 10 maximum stress-cycles each for a total of 20 full cycles of SSE stress range. Alternatively, as allowed by NRC memo SECY-93-087 [7], the methods of Appendix D of IEEE Standard 344-1987 [8] may be used to determine a number of fractional vibratory cycles equivalent to 20 full SSE cycles. When this method is used, the amplitude of the vibration is taken as one third of the amplitude of the SSE resulting in 300 fractional SSE cycles to be considered.

The effects of the reactor coolant environment on fatigue will be accounted for in the Class 1 piping fatigue analyses using methods acceptable to the NRC at the time of performance.

3.4.2 *Code Class 2 and 3 Piping*

Class 2 and 3 piping is evaluated for fatigue due to thermal cycles by following the requirements in NC-3611.2. This involves the reduction of ASME Code allowables for the thermal expansion stresses calculated to the requirements in NC/ND-3653.2(a) by a factor, *f*, as determined in Table NC/ND-3611.2(e)-1, “Stress Range Reduction Factors.” In addition, the stress intensification factors (SIFs) and stress indices used in ASME Code equations for calculating stresses at components are based on fatigue testing and, therefore, indirectly account for fatigue in Class 2 and 3 piping components. No cumulative usage factor is calculated for Class 2 & 3 piping.

Environmental impact on fatigue of Class 2 & 3 piping will follow guidelines established by the NRC at the time of analysis.

3.5 *Functional Capability*

General Design Criterion 2 of 10 CFR Part 50 requires that all Class 1, 2 & 3 piping systems essential for safe shutdown of the plant remain capable of performing their safety function for all Service Level D loading conditions. This criterion is met by meeting the recommendations in NUREG-1367, “Functional Capability of Piping Systems.” [9]

The NUREG-1367[9] provision that the dynamic moments be “calculated using an elastic response spectrum analysis with +/-15% peak broadening and with not more than 5% damping” will be considered met for piping analyzed by elastic time history methods as long as: 1) uncertainties in the applied time histories are accounted for, and 2) pipe damping used is not more than 5%.

Table 3-3 summarizes the criteria to be used to ensure that the functional capability requirement of GDC 2 is met.

3.6 *Welded Attachments*

Support and restraint designs that require welded attachments to the pipe for transfer of the pipe loads to the supporting structure will adhere to industry practices and ASME Code Cases identified in Section 2.2 of this document.

3.7 *Thermal Stratification (Thermal Stratification, Cycling and Striping)*

3.7.1 *NRC Bulletin 79-13 (Feedwater Lines)*

NRC Bulletin 79-13[10] was issued as a result of a feedwater line cracking incident at D.C. Cook Nuclear Plant Unit 2 which led to the discovery of cracks in numerous other plants. The primary cause of the cracking was determined to be thermal fatigue loading due to thermal stratification and high-cycle thermal striping during low flow emergency feedwater injection.

For the U.S. EPR, the steam generators and main feedwater lines are designed to minimize thermal stratification. There are separate nozzles on the steam generator for the main feedwater and emergency feedwater connections. Pipe runs are relatively short. The main feedwater nozzle is located in the conical section of the steam generator which aids in reducing thermal stratification.

The effects of thermal stratification and striping will be evaluated during the evaluation of the main feedwater system and the evaluation will confirm that all load cases meet the ASME Code allowables.

3.7.2 *NRC Bulletin 88-11 (Surge Line)*

NRC Bulletin 88-11[11] requires consideration of the effects of thermal stratification on the pressurizer surge line. The surge line on the U.S. EPR will be analyzed with the RCL piping and supports. The effects of thermal stratification and striping will be evaluated as part of this analysis or it will be demonstrated that the surge line is not subjected to significant stratification/striping effects due to design features that mitigate these effects. The COL applicant will confirm that thermal deflections do not create adverse conditions during hot functional testing.

3.7.3 *NRC Bulletin 88-08 (Unisolable piping due to leaking valves)*

Unisolable sections of piping connected to the RCL will be evaluated to determine if thermal stratification and striping caused by a leaking valve are plausible, as discussed in NRC Bulletin 88-08 [12]. Contributions to fatigue from thermal stratification and striping will be considered where it is determined that these phenomena are plausible.

3.8 *Design and Installation of Pressure Relief Devices*

3.8.1 *Design and Installation Criteria*

The design and installation of safety valves and relief valves for overpressure protection are performed to the criteria specified in Appendix O of the ASME Code, “Rules for the Design of Safety Valve Installations,” 2001 Edition, 2003 addenda. In addition, the following additional requirements must be met:

- Where more than one relief device is placed on the same header, instantaneous stresses in the pipe and support loads are calculated using the most adverse sequence of valve openings.

- Stresses are evaluated for all components, (pipe, valves, supports, welds and connecting systems) for the most adverse valve sequence.

- Stresses calculated as a result of valve reaction forces utilize dynamic or static calculation methods. If static methods are utilized, a Dynamic Load Factor (DLF) of 2.0 will be used.

- Stress and load combination requirements are specified in Table 3-1 and Table 3-2 for Class 1 and Class 2/3 piping, respectively.

3.8.2 *Analysis Requirements for Pressure Relieving Devices*

3.8.2.1 *Open Discharge*

Safety or Relief Valves that discharge directly to the atmosphere are considered open discharge configurations. Discharge forces are usually calculated using static methods with a DLF of 2.0. These static loads are then applied to the valve discharge in the piping analysis to evaluate stresses and support designs. Snubbers are considered engaged for this analysis.

3.8.2.2 *Closed Discharge*

Relief or safety valves with discharges piped to headers or tanks are analyzed with no steady state thrust forces but must be analyzed for intermediate forces acting on elbows and tees during the initial phase of the release. These forces are similar to water hammer and steam hammer due to the instantaneous opening of the valves and shall be evaluated with other load cases impacting the piping systems.

3.9 *Intersystem LOCA*

Low pressure piping systems that interface with the RCL and are thus subjected to the full RCL pressure will be designed for the maximum operating pressure of the RCL. The appropriate minimum wall thickness of the piping will then be calculated for each system using Equation 1 of NB-3640 of the ASME Code for Class 1 piping or Equation 3 of NC/ND-3640 for Class 2/3 piping. The piping will be analyzed to the requirements in NB/NC/ND-3650.

3.10 *Seismic Category I Buried Pipe*

Class 2 and 3 Seismic Category I buried piping systems in the U.S. EPR will be analyzed for pressure, weight, thermal expansion and seismic loads using dynamic or equivalent static load methods. The acceptance criteria for buried piping systems are described in Table 3-4.

3.10.1 *Static Loads and Load Combinations for Buried Pipe*

Loads and Loading Conditions are similar to those outlined in 3.3 but are modified for additional considerations of strains and stresses induced by the motion of the pipe in the surrounding soil mass. Thermal loads are impacted by the friction between the pipe and soil due to expansion and contraction of the pipe per the guidance in Reference 13.

3.10.1.1 *Pressure*

Internal design pressure, P, is calculated as described in 3.3.1.1. However, there is an external pressure, P_V, for buried pipe associated with the overburden of soil and P_P for loads from surface loads. The allowable external pressure is calculated using the methods and formula in NC/ND-3133.

3.10.1.2 *Deadweight*

For buried pipe, deadweight loads must include the weight of the soil overburden. It must also include live loads from surface traffic such as trucks, rail and construction equipment.

3.10.1.3 *Soil Overburden*

Soil overburden pressure is dependent on the diameter of buried pipe as well as the burial depth relative to the ground water table. Buried pipes are designed for soil load corresponding to weight of the overlying soil prism.

$P_v = \gamma H$. This equation applies to pipes buried above the groundwater table.

Where P_v = overburden pressure on pipe due to soil, psi

γ = dry unit weight of backfill material, lbs/in^3

H = burial depth to top of pipe, in.

In the case where the pipe is located below ground water table or where seasonal change in ground water table is significant, the effect of buoyancy and increased weight of water should be considered. For such condition, soil pressure should be computed as follows:

$$P_v = \gamma H - 0.33\gamma h + \gamma_w h$$

Where h = depth of groundwater above pipe, in.

γ_w = unit weight of water, lbs/in^3

3.10.1.4 *Surface Loads*

Live loads such as those imposed by trucks, rail, and construction equipment or other construction conditions should be considered in the analysis and design. The pressure transmitted to the buried pipe under these loads may be computed as follows:

$$P_p = 0.48 \frac{P_s}{H^2\left[1 + \left(\frac{d}{H}\right)^2\right]^{2.5}}$$

Where P_p = surface load transmitted to the buried pipe, psi

d = offset distance from the surface load to buried pipe, in.

H = thickness of soil cover above the pipe, in.

P_s = concentrated surface load, lbs.

The magnitude of P_p above is multiplied by an impact factor which is dependent on the soil cover and type of surface load. Table 3-5 [13] shows some recommended values of impact factors.

The magnitude of P_p may be taken from Table 3-6 which is based on AASHTO HS-20 Truck and Copper E-80 railroad loads [13]. The values reported in Table 3-6 include an impact factor of 1.50.

COL applicants should perform detailed geotechnical engineering analysis to determine if the surface load will cause lateral and/or vertical displacement of bearing soil for the piping. Consideration should also be given to the effect of wide and extra heavy loads when evaluating the buried utility.

3.10.1.5 *Buoyancy Force*

For utilities buried below groundwater table, vertical force due to buoyancy should be considered and may be evaluated as follows:

$$F_b = W_w - W_p - P_v D + \gamma_w h D$$

The above equation conservatively assumes that the pipe is empty.

Where F_b = buoyancy force per unit length of pipe, lb/in.

D = outside diameter of the pipe, in.

P_v = γH = overburden pressure due to soil, psi

W_w = weight of water displaced by pipe per unit length, lb/in

W_p = self weight of pipe per unit length, lb/in.

The corresponding buoyancy stress on the utility may be computed as follows:

$$\sigma_b = \frac{F_b L^2}{10Z}$$

Where L = length of the utility in the buoyancy zone, in.

Z = section modulus of the utility, in^3

3.10.1.6 *Pipe Ovalization*

Under combined dead and live loads, buried pipes tend to ovalize thereby causing through-wall bending stresses. The allowable ovalization (Ref. [13]) of the pipe diameter may be evaluated using the following equation:

Pipe ovality = $$\frac{\Delta}{D} = \frac{D'KP}{\left[\frac{(E_{sct} I)_{eq}}{R^3} + 0.061E'\right]}$$

$$\sigma_b = 4E_{sct} \frac{\Delta}{D} \frac{t}{D}$$

Where

E' = modulus of soil reaction, psi

K = bedding constant (typically taken to be 0.1)

R = outside radius of pipe, inches

Δ = vertical deflection of the utility/pipe, inches

P = pressure due to soil overburden, surface loads, flooding, and snow load, psi

$(E_{sct} I)_{eq}$ = equivalent pipe wall stiffness per unit length of pipe, lb-in^2/in

σ_b = through-wall bending stress, psi

t = thickness of the pipe, inches

E_{sct} = secant Modulus of the pipe material, psi (Note: E_{sct} = E if pipe is fabricated from steel)

D' = deflection lag factor (typically taken to be between 1.0 and 1.50)

I = $t^3/12$ = moment of inertia, in^4/in

Pipe must be buried deep enough such that crushing of side wall of the pipe is eliminated. Soil, surface, and other credible event loads must not be excessive so as to cause buckling of the pipe. To avert ring buckling, the magnitude of the total vertical pressure should be limited to equation below.

$$P(as\ defined\ \ for\ ovality) \leq \frac{1}{FS}\sqrt{32R_w B'E'\frac{(E_{sct}I)_{eq}}{D^3}}$$

FS = factor of safety with value dependent on relative magnitude of thickness of cover soil, H and external pipe diameter, D. For $H/D < 2.0$, FS = 3.0 and for $H/D \geq 2$, FS = 2.5

R_w = water buoyancy factor with magnitude $1 - 0.33h/H$ (0<h<H)

h = height of ground water table above the top of the buried utility, inches

B' = dimensionless empirical coefficient of elastic support.

$$B' = \frac{1}{1 + 4e^{\left(-0.065\ \frac{H}{D}\right)}}$$

All the other parameters in above equation have been defined previously.

The effects of pressure (P, P_P, P_V), dead and live loads from the effects of ovality must meet the requirements of Table 3-4 as follows for Equation 8:

$$S_{SL} = \frac{B_1 PD}{2t_n} + \frac{B_2 M_A}{Z} + \frac{F_b L^2}{10Z} + 4E_{sct}\frac{\Delta}{D}\frac{t}{D} \leq 1.5S_h$$

Where S_{SL} = Stress from sustained loads, psi

P = Internal pressure + ABS Sum (P_P +P_V), psi

B_1, B_2 = Stress indices

t_n = Pipe nominal wall thickness, in

M_A = Moment due to weight, in-ibs

S_h = Allowable stress (hot), psi

3.10.2 *Thermal Expansion and Contraction*

Depending on the relative temperature of the soil in which the pipe is buried and the temperature of the fluid contained in the pipe, a pipe that is fully restrained by the surrounding soil may experience contraction or expansion. This thermal-induced stress (due to friction between the pipe and soil) should be considered and may be evaluated as follows:

$$\sigma_A = E_{sct}\alpha(T_2 - T_1)$$

Where σ_A = axial compressive stress, psi, in fully restrained pipe due to difference in temperature between soil and pipe content.

α = coefficient of thermal expansion of the pipe, in/in/°F

T_2 = maximum operating temperature of fluid in the pipe, °F

T_1 = burial installation temperature, °F

The effects of restrained thermal expansion/contraction forces in buried pipe are evaluated against the requirements of NC/ND-3653.2(a) by using a modified Equation 10 or NC/ND-3653.2(c) by using a modified Equation 11. From Reference 2, the equations are as follows:

$$S_E = \frac{iM_C}{Z} + E_{sct}\alpha(T_2 - T_1) \leq S_a \qquad \text{Equation 10M}$$

Where S_a = Allowable stress range for thermal expansion, psi

M_C = range of resultant bending moment due to restrained thermal expansion, in-lb

or

$$S_{TE} = \frac{PD}{4t_n} + 0.75i\frac{M_A}{Z} + i\frac{M_C}{Z} + E_{sct}\alpha(T_2 - T_1) \leq (S_h + S_a) \qquad \text{Equation 11M}$$

Where S_E = Stress from restrained thermal expansion, psi

S_{TE} = Stress from pressure, weight and thermal expansion, psi

3.10.3 *Seismic Loads*

Seismic-induced damage to buried piping is largely due to wave propagation or permanent ground deformation resulting from fault movement, landslide, and liquefaction-induced lateral spread. Where buried piping enters a structure, the seismic anchor movements of the structure must be accounted for in the design of the piping. Other forms of damage related to ground movement such as elastic and consolidation settlement (total and differential), freeze-thaw induced settlement, and seismic-induced settlement due to soil compaction and rearrangement should be considered on a case-by-case basis. For the case of piping anchored to an adjacent building, strain development in the utility due to settlement of the building should be evaluated. The seismic effects on buried piping are self limiting in that strains are limited by the surrounding soil. Therefore the stresses due to these strains are secondary in nature.

COL applicants shall carry out site investigation to assess the best route for the underground piping. During this field investigation, sites that are vulnerable to fault movement and liquefaction-induced landslide and lateral spread should be avoided. If a pipe must be buried in loose saturated cohesionless soil susceptible to liquefaction, rigorous linear and non-linear pipe-soil interaction analysis should be carried out to evaluate the integrity of the pipe under settlement and lateral spread conditions that may be caused by the liquefiable soil. If the result of the soil-pipe interaction is not acceptable, any of the following options recommended in Reference [14] may be adopted:

(1) Re-route the pipe to avoid areas of liquefiable loose saturated cohesionless soils;

(2) Modify the strength of the soil by using appropriate stabilizing agent;

(3) Excavate liquefiable soil and replace with competent structural fill materials; or

(4) Support the pipe in soil that is not susceptible to failure.

3.10.3.1 *Axial and Bending Strains Due to Propagation of Seismic Waves*

Typically, the magnitude of axial and bending strains on buried piping due to propagation of seismic wave is dependent on several factors such as the buried material and soil properties and pipe-soil interfacial properties. Conservatively, axial and bending strains on the buried piping are taken to be the same as those of the seismic wave if there is no site specific field instrumentation to measure the strain level experienced by the buried piping. Based on the axial and bending strains developed in the buried piping assuming long, linear runs remote from anchors or bends, the corresponding axial load and bending stress can be computed as follows:

$$F_a = \varepsilon_a A E_{sct}$$

$$M_b = \sigma_b Z$$

Where $\sigma_b = \varepsilon_b E_{sct}$

In above equations,

E_{sct} = Secant modulus of the buried piping, psi

ε_a = Axial strain in the buried piping due to wave propagation

ε_b = Bending strain in the buried piping due to wave propagation

Z = Section modulus of the buried piping, in^3

A = Cross-sectional area of the pipe, in^2

For the computation of loads developed at elbows, the simplified procedures outlined in reference [14] are recommended for flexible and rigid conditions. At site locations where the differential settlement is significant, flexible anchors may be used in lieu of rigid anchors. All support structures (anchors) should be designed to resist the resulting axial loads and bending stresses.

The general axial and bending strains due to seismic wave propagation may be found as follows:

$$\varepsilon_a = \pm \frac{v}{\alpha_\varepsilon c}$$

$$\varepsilon_b = \pm \frac{Ra}{(\alpha_k c)^2}$$

Where v = max. velocity of the soil layer (particle) in which the piping is embedded, ft/sec

a = max. acceleration of the soil layer (particle) in which the piping is embedded, ft/sec^2

c = apparent velocity relative to ground surface, ft/sec

R = radius of the pipe, ft

ε_b = bending strain

ε_a = axial strain

α_ε = wave velocity axial coefficient (compression=1.0, shear=2.0, Rayleigh=1.0)

α_k = wave velocity bending coefficient (compression = 1.6, shear & Rayleigh =1.0)

In reference [15], it is noted that axial and bending strains are a result of three types of seismic waves, (1) compression, (2) shear and (3) surface or Rayleigh. The strain for each wave is calculated using the general form for axial and bending noted above.

As noted in Table 3-2 for above ground piping, the effects of seismic loads on above ground piping must meet the requirements of NC/ND-3655. As further indicated in Table 3-2, and in compliance with the guidance in SECY-93-087, page 23, the effect of SSE seismic anchor displacements (which produce secondary stresses) together with normal loads would be evaluated to a Service Level D limit. This has been done for above ground piping in the secondary stress equation shown in Table 3-2 for Level D. Since the seismic effects in buried pipe produce secondary stresses, to be consistent with Table 3-2 and the guidance provided, the two equations shown below for buried pipe must be evaluated and the worse of the two met. The use of the two equations allows for two possible cases: thermal expansion plus the amplitude of the buried pipe SSE effects or the range (= twice the amplitude) of the buried pipe SSE effects, whichever is larger. The use of the larger of the two results is consistent with the methodology in the example provided in Reference 14, Appendix 3, pages 45 and 46.

$$S_{NSSE} = \frac{iM_C}{Z} + \frac{iM_{SSE}}{Z} + \varepsilon_b E_{sct} + \varepsilon_a E_{sct} + E\alpha(T_2 - T_1) \le 3.0S_h$$ but not > than $2.0S_y$

$$S_{SSE} = \frac{2iM_{SSE}}{Z} + 2\varepsilon_a E_{sct} + 2\varepsilon_b E_{sct} \le 3S_h$$ but not > than $2.0S_y$

Where S_{NSSE} = buried pipe stress due to normal plus the amplitude of SSE loads

S_{SSE} = buried pipe stress due to the range of SSE loads

M_{SSE} = amplitude of moments due to earthquake moment loading and anchor movements; earthquake moment loading is induced in the pipe near bends, intersections, and anchor points as described in Reference 15, Section 3.5.2.2(b)

S_Y = yield stress, psi

The allowable stress, $3.0S_h$ or $2.0S_Y$, is based on service level D limits due to the fact that only SSE load case is evaluated in the piping design for the U.S. EPR.

The value of M_{SSE}, ε_b and ε_a represent the amplitude of the seismic moment and seismic strains.

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping

Service Condition	Service Level	Category	Loading or Stress Component	Acceptance Criteria(1)
Design	-	Primary Stress	Design Pressure, Deadweight, Steady State Flow Load and Dynamic Fluid Load[2] specified as Level A	Eq 9N NB-3652
Normal	A	Primary plus Secondary Stress Intensity Range (S.I.R.)	Range of Level A: 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	Eq 10N NB-3653.1
		Peak S.I.R.	Range of Level A: 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, Thermal Radial Gradient Stress (linear and non-linear)	Eq 11N NB-3653.2
		Thermal S.I.R.[5]	Range of Level A: Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3], Cyclic Thermal Load[4]	Eq 12N NB-3653.6(a)
		Primary plus Secondary Membrane plus Bending S.I.R.[5]	Range of Level A: Service Pressure, Steady State Flow Load, Dynamic Fluid Load[2], Material Discontinuity Stress	Eq 13N NB-3653.6(b)
		Alternating Stress Intensity (S.I.) (Fatigue Usage)[6]	Range of Level A: 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, Thermal Radial Gradient Stress (linear and non-linear)	Eq 14N NB-3653.6(c)
		Thermal Stress Ratchet	Range of Level A Linear Thermal Radial Gradient	NB-3653.7

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping (Continued)

Service Condition	Service Level	Category	Loading or Stress Component	Acceptance Criteria[(1)]
Upset	B	Permissible Pressure	Maximum Level B Service Pressure	NB-3654.1
		Primary Stress	Coincident Level B Service Pressure, Deadweight, Steady State Flow Load, Dynamic Fluid Load[2]	Eq 9U NB-3654.2(a)
		Primary plus Secondary S.I.R.	Range of Level B: 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 10U NB-3654.2(b)
		Peak S.I.R.[8]	Range of Level B: 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], Level B Thermal Radial Gradient Stress (linear and non-linear)	Eq 11U NB-3654.2(b)
		Thermal S.I.R.[5]	Range of Level B: Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3], and Cyclic Thermal Load[4]	Eq 12U NB-3654.2(b)
		Primary plus Secondary Membrane plus Bending S.I.R.[5]	Range of Level B: Service Pressure, Steady State Flow Load, Dynamic Fluid Load[2], Material Discontinuity Stress, Earthquake Inertial Load[7]	Eq 13U NB-3654.2(b)
		Alternating S.I. (Fatigue Usage)[6]	Range of Level B: 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], Level B Thermal Radial Gradient Stress (linear and non-linear)	Eq 14U NB-3654.2(b)
		Thermal Stress Ratchet	Range of Level B Linear Thermal Radial Gradient	NB-3654.2(b)
		Deformation Limits	As Set Forth in the Design Specification	NB-3654.2(b)

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping (Continued)

Service Condition	Service Level	Category	Loading	Acceptance Criteria(1)
Emergency[9]	C	Permissible Pressure	Maximum Level C Service Pressure	NB-3655.1
		Primary Stress	Coincident Level C Service Pressure, Deadweight, Steady State Flow Load, Dynamic Fluid Load[2]	Eq 9E NB-3655.2(a)
		Deformation Limits	As Set Forth in the Design Specification	NB-3655.3
Faulted	D	Permissible Pressure	Maximum Level D Service Pressure	NB-3656(a)(1)
		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)	Eq 9F NB-3656(a)(2)
		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]	$6S_m$ [13]
Pressure Testing[14]	-	Primary Membrane S.I.	Test Pressure, Deadweight	NB-3657 NB-3226(b)
		Primary Membrane plus Bending S.I.	Test Pressure, Deadweight	NB-3657 NB-3226(c)

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping (Continued)

Notes:

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 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 1/3 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 is considered. If the earthquake inertial load is taken as 1/3 of the peak SSE inertial load then the number of cycles to be considered for earthquake loading is 300 (the equivalent number of 20 full SSE cycles as derived in accordance with Appendix D of IEEE Standard 344-1987[8]).
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 which result in an alternating stress intensity (S_a) value greater than that for 10^6 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 [16] 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 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping (Continued)

Notes (Continued):

12. This secondary stress check is only necessary if the stresses (including those due to Earthquake Inertial Load) exceed the Equation 10U (primary plus secondary stress intensity range for the Upset service condition) allowable stress. See Sections 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 which result in an alternating stress intensity (S_a) value greater than that for 10^6 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 3-2: Design Conditions, Load Combination and Stress Criteria for ASME Class 2&3 Piping

Loading Condition	Service Levels	Loads	Stress Criteria (4) (9)
Design	-	Primary Stress Loads: Pressure, Weight, Other Sustained Mechanical Loads	Equation 8 NC/ND-3652 (3)
Normal/ Upset	A/B	Occasional: Pressure, Weight, Other Sustained Mechanical Loads, Dynamic Fluid Loads (DFL)(1), Wind (7)	Equation 9U NC/ND-3653.1 (Level B Only) (6)
		Secondary Stress: Thermal Expansion, TAM	Equation 10 NC/ND-3653.2(a) (2)
		Non-Repeated Anchor Movement	Equation 10a NC/ND-3653.2(b)
		Sustained Plus Secondary Stress: Pressure, Weight, Other Sustained Mechanical Loads, Thermal Expansion, TAM	Equation 11 NC/ND- 3653.2(c) (2)
Emergency	C	Occasional Stress: Pressure, Weight, DFL (1), Tornado (7)	Equation 9E NC/ND-3654.2(a) (5)
Faulted	D	Occasional Stress: Pressure, Weight , DFL (1), SSE Inertia, Design Basis Pipe Break	Equation 9F NC/ND-3655(a) (5)
		Secondary Stress: Thermal Expansion, TAM, Seismic Anchor Movement (SSE)	$\frac{iM_c}{Z} \leq MIN(3.0S_h, 2.0S_y)$ (6,8)

Notes:

1 Dynamic Fluid Loads are occasional loads such as safety/relief valve thrust, steam hammer, water hammer, or other loads associated with Plant Upset, Emergency or Faulted Condition as applicable.
2 Stresses must 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 should be checked for weight loads during hydrostatic testing as well as normal operation weight loads.
4 ASME Boiler and Pressure Vessel Code, Section III.[2]
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 is met. When the causal relationship cannot be established, or when the non-exceedance criteria given in NUREG-0484 are not met, dynamic loads must 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 & 3 piping[7].
7 Wind and tornado loads are not combined with earthquake loading.
8 M_c = Range of resultant moments due to thermal moments due to expansion and TAMs (Level A and B only) and SSE Seismic Anchor Movements (SAM). M_c is equal to the maximum moment range of either (a) the full range of thermal plus 1/2 the range of SAM, or (b) the full range of SAM. S_h is equal to the pipe material allowable stress at the operating temperature. S_y is equal to the pipe material yield stress at the operating temperature.
9 ASME Code equations and paragraph numbers refer to the 2001 Edition through 2003 Addenda of the ASME Code. However, dynamic loads are treated in accordance with the applicable subarticles of the 1993 Addenda of the ASME Code per the limitations of 10 CFR 50.55a(b)(1).

Table 3-3: Functional Capability of Piping ASME Class 1, 2 & 3(1)

Criteria	Class 1		Class 2 & 3	
	Equation	Allowable	Equation	Allowable
Wall Thickness	$D_o/t \leq 50$	Meet	$D_o/t \leq 50$	Meet
Service Level D	Equation 9	Smaller of $2.0S_y$ or $3.0S_m$ (2)	Equation 9	Smaller of $2.0S_y$ or $3.0S_h$ (2)
External Pressure	$P_{external} \leq P_{internal}$	-	$P_{external} \leq P_{internal}$	-

Notes:

1. Applicable to Level D plant events for which the piping system must maintain an adequate fluid flow path.
2. Applicable to ASME Code Class 1, 2 & 3 when the following are met:
   - Dynamic loads are reversing
   - Steady-state bending stress from deadweight loads does not exceed:

$$\frac{B_2 M}{Z} \leq 0.25 S_y$$

   - When elastic response spectrum analysis is used, dynamic moments are calculated using a minimum of 15% peak broadening and pipe damping is not more than 5%. When elastic time history analysis is used, uncertainties in the applied time histories are accounted for and pipe damping is not more than 5%.

Table 3-4: Design Conditions, Load Combination and Stress Criteria for ASME Class 2&3 Buried Piping

Loading Condition	Service Levels	Loads	Stress Criteria
Design	-	Primary Stress Loads: Pressure(1), Weight Loads, Other Sustained Mechanical Loads	Equation 8(5) NC/ND-3652
Normal/ Upset	A/B	Occasional: Pressure(1), Weight Loads, Other Sustained Mechanical Loads, DFL	Equation 9U(5) NC/ND-3653.1 (Level B Only)
		Secondary Stress: Thermal Expansion, TAM, Thermal Friction Forces	Equation 10M(2) (4) NC/ND-3653.2(a)
		Non-Repeated Anchor Movement	Equation 10a NC/ND-3653.2(b)
		Sustained Plus Secondary Stress: Pressure(1), Weight Loads, Other Sustained Mechanical Loads, Thermal Expansion, TAM, Thermal Friction Forces	Equation 11M(3) (4)(5) NC/ND- 3653.2(c)
Emergency	C	Occasional Stress: Pressure(1), Weight Loads, DFL	Equation 9E(5) NC/ND-3654.2(a)
Faulted	D	Secondary Stress: SSE effects & SAM(M_{SSE}), Thermal Expansion and TAM (M_C), Friction Axial Forces from Thermal Expansion	See note 6

Notes:

1. Pressure for buried pipe includes internal pressure and the soil overburden loads and loads due to motor vehicles and train cars.
2. Equation 10 modified to include stress due to axial friction forces caused by thermal expansion and soil interaction.
3. Equation 11 modified to include stress due to axial friction forces caused by thermal expansion and soil interaction.
4. Stresses must meet Equation 10M or 11M, not both.
5. Buried piping systems must be designed to meet the external pressure load criteria of NC/ND-3133 of the ASME Code.
6. $\frac{i(M_{SSE}+M_C)}{Z}+\varepsilon_a E_{sct}+\varepsilon_b E_{sct}+E_{sct}\alpha(T_2-T_1)\leq$ lesser of $3S_h$ or $2S_y$ Equation A

   Or

   $\frac{2i(M_{SSE})}{Z}+2\varepsilon_a E_{sct}+2\varepsilon_b E_{sct}\leq$ lesser of $3S_h$ or $2S_y$ Equation B

   For definition of terms, see Section 3.10.3.1

Table 3-5: Impact Factor for Surface Load Effect on Buried Pipes

(Reference 13)

Cover thickness (ft)	Surface Load Condition	
	Highways	Railways
0 - 1	1.50	1.75
1 - 2	1.35	1.50
2 - 3	1.15	1.50
> 3.0	1.00	1.35

Table 3-6: Recommended Surface Load for Buried Pipe

(Reference 13)

Cover thickness, ft	Surface load transmitted to pipe (lb/in^2)		Cover thickness, ft	Surface load transmitted to pipe (lb/in^2)	
	Highway H20	Railway E80		Highway H20	Railway E80
1	12.50	-	16	Negl.	3.47
2	5.56	26.39	18	Negl.	2.78
3	4.17	23.61	20	Negl.	2.08
4	2.78	18.40	22	Negl.	1.91
5	1.74	16.67	24	Negl.	1.74
6	1.39	15.63	26	Negl.	1.39
7	1.22	12.15	28	Negl.	1.04
8	0.69	11.11	30	Negl.	0.69
10	Negl.	7.64	35	Negl.	Negl.
12	Negl.	5.56	40	Negl.	Negl.
14	Negl.	4.17			

4.0 PIPING ANALYSIS METHODS

4.1 *Experimental Stress Analysis*

Experimental Stress Analysis will not be used to qualify piping for the U.S. EPR Design Certification.

4.2 *Seismic Analysis Methods*

Seismic Category I piping systems shall be designed to withstand the effects of an SSE and maintain the capability of performing their safety functions. This design will be accomplished by performing a seismic analysis for all Seismic Category I subsystems using methods in accordance with SRP 3.7.3[1].

The seismic response of a piping system is determined by developing a mathematical model of the system suitable for calculating the response of the system to the seismic input. Dynamic equilibrium equations are formulated for the system using the direct stiffness method. In this method, the element stiffness matrices are formed according to virtual work principles and assembled to form a global stiffness matrix for the system relating external forces and moments to nodal displacements and rotations. Details on the dynamic piping model can be found in Section 5.2.

Once the mathematical model has been established, dynamic equilibrium equations are solved to determine the seismic response of the system by performing either a modal analysis by either the Response Spectrum Method or Time History Method. Alternatively, the Direct Integration Time History Method and, where applicable, the Equivalent Static Load Method may be used. These methods of seismic analysis are discussed below.

Non-seismic piping that interacts with seismic systems and seismic Category II piping will be analyzed by response spectra (RS) or equivalent static methods.

4.2.1 *Seismic Input*

The response spectra curves for the U.S. EPR are being developed to cover an appropriate range of possible soil conditions with the ground motion anchored to a peak ground acceleration of 0.3g. The ratio of the vertical design ground motion to the horizontal design ground motion is 1.0 for the U.S. EPR.

4.2.2 *Response Spectrum Method*

The effects of the ground motion during an SSE event are transmitted through structures to the piping systems at support and equipment anchorage locations. In the response spectrum method of analysis, peak values of response are determined for each mode of the piping system by application of floor response spectra, which represent the maximum acceleration response of an idealized single-degree-of-freedom damped oscillator as a function of natural frequency to the vibratory input motion of the structure.

The floor response spectra are applied to the piping system at locations of structural attachment, such as support or equipment locations. The response spectra analysis is performed using either enveloped uniform response spectra or independent support motion using multiple spectra.

Response spectrum analysis of piping systems subjected to dynamic seismic loads is performed using a linear method of analysis based on normal mode – modal superposition techniques. In this approach, seismic analysis of linear systems is based on the solution of simultaneous differential equations subject to a set of initial conditions and forces.

The response of a multi degree-of-freedom linear system subjected to seismic excitation is represented by the following differential equation of motion:

$$[M]\{\ddot{X}\}+[C]\{\dot{X}\}+[K]\{X\}=-[M]\{\ddot{u}\}$$

Where: $[M]$ = mass matrix (n x n);

$[C]$ = damping matrix (n x n);

$[K]$ = stiffness matrix (n x n);

$\{X\}$ = column vector of relative displacements (n x 1);

$\{\dot{X}\}$ = column vector of relative velocities (n x 1);

$\{\ddot{X}\}$ = column vector of relative accelerations (n x 1);

$\{\ddot{u}\}$ = input acceleration vector

n = number of degrees of freedom

The response spectrum method of analysis uses modal-superposition methods where the mode shapes are used to transform X in the equations of motion into a generalized coordinate system by substitution of the following:

$$\{X\} = [\phi]\{Y\}$$

Where: $[\phi]$ = mass normalized mode shape matrix; $[\phi]^T[M][\phi]$ = $[1]$

$\{Y\}$ = vector of normal, or generalized, coordinates

This transformation decouples the equation of motion above when each term is multiplied by the transposition of the mode shape matrix. This solution assumes that the mode shapes are normal (orthogonal) and also assumes orthogonality of the damping matrix.

The decoupled equation of motion for a system subjected to input acceleration due to seismic motion, $\ddot{u}$, for the nth mode is:

$$\ddot{Y}_n + 2\lambda_n\omega_n\dot{Y}_n + \omega_n{}^2Y_n = -\Gamma_n\ddot{u}$$

Where: Y_n = generalized coordinate of n[th] mode;

λ_n = damping ratio for the n[th] mode expressed as fraction of critical damping;

ω_n = circular frequency of n[th] mode of the system (radians/second);

Γ_n = modal participation factor of the n[th] mode

= $\{\phi_n\}^T[M]\{r\}/(\{\phi_n\}^T[M]\{\phi_n\})$

where $\{r\}$ = influence coefficient vector due to a unit input displacement

If all support points in a piping system move in phase (i.e., uniform excitation), then $\{r\}$ consists of ones and zeros to reflect the direction of input excitation. If all support points do not move in phase (i.e., multiple excitation), $\{r\}$ is calculated to reflect the attenuation of the effect of motion of one support group through the other support groups and a unique influence coefficient matrix is developed for each support group. The magnitude of the influence coefficient at a given point in the system is equivalent to the motion at the point of interest due to a statically applied unit displacement of the support group subjected to the excitation.

For the response spectrum method, the generalized response of each mode is determined from the expression below.

$$Y_n(\max) = \Gamma_n\left(\frac{S_{an}}{\omega_n^{\ 2}}\right)$$

Where: S_{an} = Spectral acceleration corresponding to frequency ω_n

The maximum displacement of node *j* relative to the base due to mode *n* is then:

$$X_{jn}(\max) = \phi_{jn} Y_n(\max)$$

This expression gives the maximum displacement from which other modal response quantities, such as forces, can be calculated. In performing these calculations for response quantities of interest, the signs of the participation factor, Γ, the maximum generalized coordinate, $Y_{jn}(\max)$, the maximum displacement of node *j* relative to the base due to mode j, $X_{jn}(\max)$, and other response quantities are retained.

The acceleration of a mass point and the associated inertia force are calculated in a similar manner as follows:

$$\ddot{Y}_n = \omega_n^2 Y_n = \Gamma_n S_{an}$$

and the acceleration of node j due to mode n, a_{jn}, equals:

$$a_{jn} = \ddot{Y}_n \phi_{jn}$$

and the inertia force at node j due to mode n, F_{jn}, equals:

$$F_{jn} = M_j a_{jn} = M_j \ddot{Y}_n \phi_{jn}$$

The floor response spectra are applied to the piping system in each of 3 orthogonal directions. Each of the directional components of earthquake motion input will in turn produce responses in the piping system in all three directions at each natural frequency of the piping system. The total seismic response of the system is determined by combining the modal and spatial results using the methods below.

4.2.2.1 *Development of Floor Response Spectrum*

In the response spectrum method of analysis, the design floor response spectra for the structures shall be generated according to RG 1.122 [17]. The development of the floor response spectra will consider simultaneous earthquake accelerations acting in three orthogonal directions (two horizontal and one vertical).

The uncertainties in the structural frequencies due to uncertainties and approximations in the material and structural properties and modeling methods used in the development of the floor response spectrum shall be considered in the response spectrum analysis in one of two ways. Either the raw floor spectra will be smoothed and then peak broadened or, where a reduction in unnecessary conservatism is desired, the peak shifting method of analysis will be used.

4.2.2.1.1 Peak Broadening Method

Peak broadened response spectra shall be generated using the methods of RG 1.122[17]. In order to account for uncertainties in the structural response, response spectra will be peak broadened by a minimum of ±15%.

4.2.2.1.2 Peak Shifting Method

Peak shifting analysis may be used in place of peak broadening in order to reduce unnecessary conservatism in the design. Similar to broadening, peak shifting will consider a minimum of ±15% uncertainty in the peak structural frequencies. However, spectral shifting reduces the amount of conservatism by considering that the structural natural frequency is defined by a single value, not a range of values. Therefore, only one mode of the piping system can respond at the peak acceleration. [18]

In the peak shifting method, the natural frequencies of the piping system within the maximum peak acceleration broadened spectral frequency range defined above are determined. If no piping system natural frequencies exist within this frequency range, successively lower acceleration peaks are broadened until the first range containing at least one natural frequency of the piping is found.

Considering that the peak structural frequency may lie at any one frequency within the broadened range, N+3 separate response spectra analyses are then performed, where N is the number of piping modes within the broadened frequency range. The first analysis uses the unbroadened response spectrum. The second and third analyses use the unbroadened spectrum modified by shifting the frequencies associated with each spectral value by $-\Delta f_j$ and $+\Delta f_j$, where Δf_j is the amount of peak shifting required to account for the uncertainties of the structural response. The remaining N analyses also use the unbroadened spectrum modified by shifting the frequencies associated with each spectral value by a factor of:

$$1 + \frac{(f_e)_n - f_j}{f_j}$$

Where $(f_e)_n$ = Piping system natural frequency occurring within the broadened range, for n = 1 to N,

f_j = frequency at which the peak acceleration occurs (for the peak under consideration).

The modal results of each of these analyses are then combined separately using the combination procedures below. The final results are obtained by enveloping the results of the separate analyses.

Where three different floor spectrum curves are used to define the response of the structure, the peak shifting method is applied in each direction.

4.2.2.2 *Multiply Supported Systems*

4.2.2.2.1 Uniform Support Motion

Piping systems supported by multiple elevations within one or more buildings may be analyzed using Uniform Support Motion (USM). This analysis method applies a single set of spectra at all support locations which envelops all of the individual response spectra for these locations. An enveloped response spectrum is developed and applied for each of the three orthogonal directions of input motion.

The combinations of modal responses and spatial components for systems analyzed using USM are performed consistent with the guidance provided in RG 1.92. The modal and directional responses are combined as discussed in Sections 4.2.2.3 and

4.2.2.4, respectively. See Section 4.2.2.5 for consideration of relative displacements at support locations.

4.2.2.2.2 Independent Support Motion

Independent Support Motion (ISM) may be used when piping systems are supported by multiple support structures or at multiple levels within a structure. In this method of analysis, supports are divided into support groups with different seismic excitation applied to each group. A support group is made up of supports that have the same time-history input. Typically, a support group is made up of supports attached to the same structure, floor or portion of a floor.

The combinations of modal responses and spatial components for systems analyzed using ISM are performed consistent with the recommendations in NUREG-1061, Volume 4. Additionally, when using independent support motion, the seismic response of each mode is calculated by combining the responses of all support groups into one by using absolute summation method per the recommendations of NUREG-1061, Volume 4[19]. The modal and directional responses are then combined as discussed in Sections 4.2.2.3 and 4.2.2.4, respectively. See Section 4.2.2.5 for consideration of relative displacements at support locations.

Analyses performed using ISM shall use the RG 1.61[20] damping values (See Section 4.2.5).

4.2.2.3 *Modal Combination*

The inertial response of a piping system in a seismic response spectrum analysis is considered in two parts. The modal analysis calculates the peak response of the piping system for all natural frequencies of the system below a defined cutoff frequency. This analysis consists of all modes with seismic excitation frequencies up to the frequency at which spectral accelerations return to the zero period acceleration (ZPA). This frequency is referred to as the ZPA cutoff frequency. For the U.S. EPR, the ZPA cutoff frequency is 40Hz for seismic analysis or as defined by figure 2 and 3 in RG 1.92, Rev. 2. Higher ZPA cutoff frequencies may be required for other dynamic load cases.

At modal frequencies above that corresponding to the ZPA, pipe members are considered rigid. The acceleration associated with these rigid modes is usually small. However, in certain situations the response to high frequency modes can significantly affect support loads, particularly axial restraints on long piping runs. To account for the effects of the residual rigid response, a missing mass correction is applied.

When performing response spectrum analyses using USM, the inertial response from the modal analysis is also divided into two types of response, periodic or rigid. At low frequencies, in the amplified regions of the response spectrum, the total inertial response is considered as a periodic response. Beyond this region but below the ZPA cutoff frequency (intermediate frequencies), the modal response consists of both periodic and rigid components. The total inertial solution is then determined by combining the individual modal responses, both periodic and rigid, and the residual rigid response per the guidance of RG 1.92 as discussed in Sections 4.2.2.3.1 through 4.2.2.3.4.

For analyses performed using ISM, all modal response at frequencies below the ZPA cutoff frequency is treated as periodic while the response above this frequency is rigid. The treatment and combination methods of these responses to obtain the total inertial solution will be performed per NUREG-1061 as discussed in Section 4.2.2.3.5 below.

4.2.2.3.1 USM Periodic Modal Responses

RG 1.92[21] provides guidance on combining the individual periodic modal results due to each response spectrum in a dynamic analysis performed using USM.

For piping systems with no closely spaced modes, the square root of the sum of the squares (SRSS) method is applied to obtain the representative maximum response of each element, as shown in the following equation:

$$R = \left[\sum_{k=1}^{N} R_k^2 \right]^{\frac{1}{2}}$$

Where R = the representative maximum response due to the input component of the earthquake,

R_k = the peak response due to the kth mode,

N = the number of significant modes.

This method may produce unconservative results for piping systems with closely spaced modes. Therefore, the double sum method for combining the periodic modal responses considering either the Rosenblueth or Der Kiureghian correlation coefficients provided in RG 1.92[21] will be used to obtain a more accurate modal response for frequencies below the rigid range.

4.2.2.3.2 USM Rigid Components of Modal Response

In the intermediate frequency region where modal responses consist of both periodic and rigid components, these components are separated using either the Gupta Method or Lindley-Yow method as presented in RG 1.92[21].

These rigid individual modal responses will then be combined by algebraic summation.

4.2.2.3.3 Residual Rigid Response

Piping system modes with frequencies greater than the ZPA cutoff frequency are considered as high frequency or rigid range modes. For flexible piping systems, the high frequency response may not be significant since a significant portion of the system mass is excited at frequencies below the ZPA. However, for piping systems, or portions of piping systems, which are more rigidly restrained or have lumped masses near rigid restraints, a significant portion of the system mass may not be accounted for in the low frequency modal analysis. This mass which is not excited at the lower frequencies is termed the "missing mass" of the system. While high frequency modes usually involve small displacement amplitudes and small pipe stresses, they can have a significant impact on support loads.

The response from high frequency modes must be included in the response of the piping system. Guidance for including the missing mass effects is provided in RG 1.92[21] for USM.

The peak modal responses of the system at frequencies above the ZPA are considered to be in phase. Thus, the responses of all high frequency modes are combined by algebraic summation.

The U.S. EPR will use the method presented in RG 1.92[21] or the left-out-force method described below for calculating and applying the response of the high frequency modes based on applying a missing mass correction. Although this method uses a different computational procedure than described in RG 1.92, Appendix A, the two methods produce the same result. The left-out-force method is used by SUPERPIPE and BWSPAN uses the method in Appendix A of RG 1.92.

The total inertia forces in a system considering a piping system under simple excitation, in a steady-state condition with a unit acceleration applied in a specified direction is mathematically represented by:

$$\{F_t\} = [M]\{r\}$$

Where $\{F_t\}$ = Total inertia forces in the specified direction

$[M]$ = Mass matrix

$\{r\}$ = Mass point displacement vector produced by a statically applied unit ground displacement

The sum of the inertia forces for all modes included in the modal analysis is calculated as:

$$\{F_s\} = \sum_{n=1}^{N} \{F_n\} = \sum_{n=1}^{N} [M]\{\phi_n\}\{\phi_n\}^T [M]\{r\}$$

Where $\{F_s\}$ = total inertia force seen by the system in the low frequency modal analysis

$\{F_n\}$ = inertia force of mode n

$\{\phi_n\}$ = mode shape

N = number of modes calculated in the modal analysis

Therefore, the missing, or left out, forces considering a unit ground acceleration in a specified direction are calculated as:

$$\{F_m\} = \{F_t\} - \{F_s\} = [M]\{r\} - \sum_{n=1}^{N} [M]\{\phi_n\}\{\phi_n\}^T [M]\{r\}$$

Or:

$$\{F_m\} = [M]\{r\}\left[1 - \sum_{n=1}^{N} [M]\{\phi_n\}\{\phi_n\}^T\right]$$

The missing inertia forces are calculated independently for all input components of earthquake motion (i.e., in each direction for each support group). The mode displacements, member end action, and support force corresponding to each missing force vector is determined with a modal acceleration equal to the ZPA.

As an alternative, when using the Lindley-Yow method, the Static ZPA method for calculating a total mass rigid response presented in RG 1.92 Section C.1.4.2 may be used.

4.2.2.3.4 USM Complete Inertial Response

For USM response spectra analyses, the complete inertial response is calculated using the methodology provided in RG 1.92 Section C.1.5. In using these methods, the total rigid response will be calculated by algebraic summation of the applicable rigid response components and then combined with the total periodic response using the SRSS method.

4.2.2.3.5 ISM Combination of Modal Responses

For piping systems analyzed using ISM methods, modal results are combined without the consideration of closely spaced modes, per NUREG-1061[19]. Therefore, for these systems, modal results are combined by the SRSS method presented in Section 4.2.2.3.1 above. Additionally, the entire modal response for modes below the ZPA cutoff frequency is treated as a periodic response.

The residual rigid response will be calculated using the missing mass method as that presented in Section 4.2.2.3.3. This missing mass response will then be combined with the low frequency modal results by SRSS, per NUREG-1061.

4.2.2.4 *Directional Combination*

Following the modal combination of results, the responses of the piping system due to each of the three orthogonal earthquake motion inputs are combined. The collinear responses due to each of the input components of motion are combined using the SRSS method. [21]

4.2.2.5 *Seismic Anchor Motions*

In addition to the dynamic inertia loads, the effects of differential displacements of equipment or structures to which the piping system attaches during a safe shutdown earthquake shall also be considered. The maximum relative displacement for each support location may be obtained from the results of the structural dynamic analysis for the supporting structure or calculated from the applicable floor response.

If the support locations are within a single structure, the seismic displacements are considered to be in-phase and the relative displacement between locations is generally small and may be neglected from the analysis. However, where supports are located within different structures or at flexible equipment connections, the displacements of these locations are conservatively assumed to move 180 degrees out-of-phase and the relative displacements between supported locations must be considered. The analysis of seismic movements at decoupled branch line locations is discussed in Section 5.4.2.

The analysis of these seismic anchor motions (SAMs) will be performed as a static analysis with all dynamic supports active. The results of this analysis shall be combined with the piping system seismic inertia analysis results by absolute summation when an enveloped uniform support motion is used for the dynamic analysis, per SRP 3.7.3[1]. When independent support motion is used in the inertial analysis, the responses due to the relative displacements and those due to inertia are combined by the SRSS method, per NUREG-1061[19].

4.2.3 *Time History Method*

Seismic analyses may be performed using time history analysis methods in lieu of response spectrum analysis. Time history analysis may also be used for the dynamic analysis of water/steam hammer effects, relief/safety valve thrust loads, jet force loads or other hydraulic transient loadings. The time history analyses of piping systems for the U.S. EPR may be performed using BWSPAN or SUPERPIPE (See Section 5.1 for discussion on computer codes).

The modal superposition method of time history analysis is used for seismic piping analyses with acceleration time history seismic input. This method is based on decoupling of the differential equations of motion, considering a linear elastic system, using the same method as that described in Section 4.2.2. The total response of the system is determined by integrating the decoupled equations for each mode and combining the results of the modes at each time step using algebraic addition.

The mode shapes and frequencies are determined as in the response spectrum analysis. The cutoff frequency for the determination of modal properties is 40 Hz or as defined in figures 2 and 3 of RG 1.92, Rev. 2 as this is expected to encompass all of the important response frequencies of the system. Missing mass effects of the high frequency modes beyond the cutoff frequency are included via the Missing Mass Method described in Regulatory Position C.1.4.1 and Appendix A of RG 1.92, Rev. 2.

Time step studies will be performed for three of the Class 1 attached piping problems that are slated to be analyzed during the detailed design effort for the U.S. EPR. The smallest integration time step required for convergence in these sample analyses will be used for all of the Class 1 piping analyses. Convergence will be determined by halving the integration time step until it can be shown that halving it further will not increase the response of the system by more than 10%. If time history analysis of Class 2/3 piping problems is performed, the integration time step will be established in a similar manner, that is, through time step studies on a representative sample of Class 2/3 piping problems.

To account for uncertainties in the structural analysis for seismic loading, a peak shifting approach, similar to that described in Section 4.2.2.1.2 for response spectrum analysis, is used. This is accomplished by first converting the seismic time history excitations into response spectra, and then proceeding through the methodology outlined in Section 4.2.2.1.2. Note that shifting of the input excitation peaks is accomplished by adjusting the time step of the time histories which represent the excitations.

Damping values are discussed in Section 4.2.5.

The direct integration time history analysis method may be used as an alternative to the modal superposition time history analysis. In this method the differential equation of motion, as provided in Section 4.2.2, is solved directly on the uncoupled equations without transformation. Rayleigh damping, or mass and stiffness damping, is used when direct integration time history analysis is performed.

Input time histories are analyzed for each of the three mutually orthogonal directions of input motion. The three directional time history inputs are statistically independent and they are applied simultaneously in one analysis. The total response at each time step is calculated as the algebraic sum of the three directional results. Alternatively, the three time histories may be applied individually and the responses combined by the SRSS method.

4.2.4 *Equivalent Static Load Method*

An alternate method of analyzing the effects of the SSE on a piping system is to use an equivalent static load method. This simplified analysis considers the mass of piping and components as lumped masses at their center of gravity locations. The seismic response forces due to these masses are then statically determined by multiplication of the contributing mass by an appropriate seismic acceleration coefficient at each location. The seismic acceleration coefficient is determined based on the dynamic properties of the system. When the equivalent static load method is used, justification will be provided that the use of a simplified model is realistic and the results are conservative.

In general, piping systems are multiple degree of freedom systems and have a number of significant modal frequencies in the amplified region of the response spectrum curve (below the ZPA). For multiple degree of freedom systems, the peak acceleration of the appropriate floor response spectra will be multiplied by 1.5. For cases where a piping configuration can be demonstrated to respond as a single degree of freedom systems with a known fundamental frequency or rigid system with fundamental frequency beyond the cutoff frequency, a factor of 1.0 may be used with the highest spectral accelerations at that frequency or any higher frequency (as may be the case for multiple peak input spectra).

Mathematically the seismic force F_1 on a mass point in one (1) direction is represented as:

$$F_1 = kmS_a$$

where:

k = 1.0 for single degree of freedom or rigid system

1.5 for multiple degree of freedom system

m = mass in direction 1

S_a = value of acceleration from response spectrum

The forces from each of the three orthogonal directions of earthquake are applied to calculate seismic stresses and then combined by SRSS to calculate overall seismic stresses.

This analysis is performed for all three directions of seismic input motion. The results of these three analyses are then combined using the SRSS method, as in the response spectrum analyses. The relative motion of support locations (seismic anchor motions) are considered as in Section 4.2.2.5.

All seismic supports are considered active in this analysis.

4.2.5 *Damping Values*

RG 1.61, Rev. 1 damping values will be used for Independent Support Motion response spectra and Time-History analysis. RG 1.61, Rev. 1 will also be used for piping systems analyzed using Uniform Support Motion response spectra. Frequency dependent damping, as defined in Figure 1 of Regulatory positions C.2 of RG 1.61, Rev. 1, may be used for a piping analysis provided the five (5) conditions defined in Regulatory Position C.2 are met.

For piping systems analyzed using a uniform enveloped response spectra analysis, RG 1.61, Rev. 1 damping will be used in conjunction with RG 1.92, Rev. 2.

When composite modal damping is applied in a dynamic analysis, each model subgroup (piping, supports, equipment, etc) is assigned an appropriate damping value per RG 1.61, Rev. 1. The equivalent modal damping matrix, or composite modal damping matrix, is calculated for each mode by one of the two methods shown below:

$$\overline{\beta_j} = \{\phi\}^T [\overline{M}] \{\phi\} \qquad (1)$$

$$\beta_j = \frac{\{\phi\}^T [\overline{K}] \{\phi\}}{K^*} \qquad (2)$$

Where:

$K^* = \{\varphi\}^T [K] \{\varphi\}$

$[K] =$ assembled stiffness matrix

$\overline{\beta_j} =$ equivalent modal damping ratio of the j^{th} mode

$[\overline{K}], [\overline{M}] =$ the modified stiffness or mass matrix constructed from element matrices formed by the product of the damping ratio for the element and its stiffness or mass matrix

$\{\varphi\} =$ j^{th} normalized modal vector

Note: Damping beyond 20% will not be used.

4.3 *Inelastic Analysis Methods*

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

4.4 *Non-Seismic/Seismic Interaction*

The U.S. EPR utilizes state-of-the-art computer modeling tools for design and location of structures, equipment and piping. These same tools are used to minimize the interactions of seismic and non-seismic components, making it possible to protect Seismic Category I piping systems from adverse interactions with non-seismic piping and components. In the design of the U.S. EPR, the primary method of protection for seismic piping is isolation from all non-seismically analyzed piping. In cases where it is not possible, or practical, to isolate the seismic piping, adjacent non-seismic piping is classified as Seismic Category II and analyzed and supported such that an SSE event will not cause an unacceptable interaction with the Seismic Category I piping. Alternatively, an interaction evaluation may be performed to demonstrate that the interaction will not prevent the Seismic Category I piping system from performing its safety related function.

For non-seismic piping attached to seismic piping, the dynamic effects of the non-seismic piping are accounted for in the modeling of the seismic piping. The attached non-seismic piping up to the analysis boundary is designed to preclude its causing failure of the seismic piping during a seismic event.

4.4.1 *Isolation of Seismic and Non-Seismic Systems*

Isolation of seismic and non-seismic systems is provided by either geographical separation or by the use of physical barriers. Isolation minimizes the interaction effects that must be considered for the seismic systems and minimizes the number of non-seismic systems requiring more rigorous analysis.

Several routing considerations are used to isolate seismic and non-seismic systems. When possible, non-seismic piping is not routed in rooms containing safety-related piping or equipment. Non-seismic piping which cannot be completely separated from seismic systems must be shown to have no interaction with the seismic systems based on separation distance or an intermediate barrier, or be classified as Seismic Category II piping.

4.4.2 *Interaction Evaluation*

Non-seismic piping and components may be located in the vicinity of safety-related piping without being qualified as Seismic Category II provided an impact evaluation is performed to verify that no possible adverse impacts will occur. In this evaluation, the non-seismic components are assumed to fall or overturn as a result of a seismic event. Any safety-related piping system or component which may be impacted by the non-seismic component is identified as an interaction target and evaluated to ensure that there is no loss of ability to perform its safety-related function.

The following assumptions and guidelines are used to evaluate non-seismic/seismic interactions:

- All non-seismic hangers on the non-seismic piping system are assumed to fail instantaneously.
- All flanges on bolted connections on the non-seismic piping system are assumed to fail, thus allowing each section of piping to fall independently.
- Welded non-seismic piping supported by a seismic structure or component is assumed to fail at all rigidly constrained locations.

4.5 *Small Bore Piping*

Small bore piping (including instrumentation lines) for the U.S. EPR is defined as ASME Class 1 piping that is 1” NPS and smaller and Class 2, 3 and QG D that is 2” NPS and smaller. This piping may be analyzed using response spectrum methods described in Section 4.2.2 of the topical report or the equivalent static method described in 4.2.4.

Table 4-1: Suggested Deadweight Pipe Support Spacing

Nominal Pipe Size, NPS Inches	Suggested Maximum Span			
	Water Service		Steam, Gas, or Air Service	
	ft	m	ft	m
1	7	2.1	9	2.7
2	10	3.0	13	4.0
3	12	3.7	15	4.6
4	14	4.3	17	5.2
6	17	5.2	21	6.4
8	19	5.8	24	7.3
12	23	7.0	30	9.1
16	27	8.2	35	10.7
20	30	9.1	39	11.9
24	32	9.8	42	12.8

(Reference ASME B31.1 and Subsection NF of the ASME Code)

5.0 PIPING MODELING TECHNIQUES

5.1 *Computer Codes*

The following computer programs are used in the analysis of safety-related piping systems.

5.1.1 *SUPERPIPE*

SUPERPIPE is a comprehensive computer program for the structural design and analysis of piping systems. This program is used to analyze piping for both static and dynamic loads and performs design checks for ASME Class 1, 2 and 3 and B31.1 piping. SUPERPIPE is being used during design certification for the analysis of ASME Class 2 and 3 piping. It may be used for Class 1 piping.

Static analyses performed by SUPERPIPE include deadweight, distributed loads, thermal, internal pressure and applied forces, moments or displacements. Dynamic analysis methods include both response spectrum analysis and time-history analysis using either modal superposition or direct integration methods.

SUPERPIPE is developed and maintained by AREVA NP and has been verified and validated to U.S. NRC standards.

5.1.2 *BWSPAN*

BWSPAN is an AREVA NP developed code which performs structural analysis of piping and structural systems. Deadweight, thermal expansion, response spectrum, time history and thermal stratification loading can be analyzed. Output includes displacements, loads, accelerations and displacement time histories, as appropriate. BWSPAN also performs pipe stress and fatigue calculations to a variety of design codes including B31.1, B31.7 and the ASME Code. BWSPAN also calculates stresses for linear type supports according to Subsection NF of the ASME Code. BWSPAN is being used for analysis of the RCL piping during the design certification phase.

5.1.3 *GT STRUDL*

GT STRUDL is a general purpose structural analysis program used for the design and analysis of pipe supports structures. The program has the capability to perform both static and dynamic analyses using simple beam elements as are found in most pipe support structures. GT STRUDL is being used to determine member stresses, weld stresses, forces and moments applied to the building structures, and deflections used to validate the rigid support assumptions used in design of the piping. The program is being used for ASME Class 1, 2 and 3 supports, as well as supports meeting ANSI/AISC N690 and the AISC Manual.

GT STRUDL is owned and maintained by Georgia Tech. Verification of the GT STRUDL computer is accomplished by executing verification cases and comparing the results to those provided by Georgia Tech. Each document that describes a GT STRUDL analysis includes information regarding the verification analysis and its results. Error notices from Georgia Tech are processed and records pertaining to error notification, tracking and disposition are available for NRC inspection.

5.2 *Dynamic Piping Model*

For dynamic analysis, the piping system is idealized as a three dimensional framework using specialized finite element analysis programs. The analysis model consists of a sequence of nodes connected by beam elements with stiffness properties representing the piping and other inline components. Nodes are typically modeled at points required to define the piping system geometry as well as lumped mass locations, support locations, locations of structural or load discontinuities and at other locations of interest along the piping. System supports are idealized as springs with appropriate stiffness values for the restrained degrees of freedom.

In the dynamic mathematical model, the distributed mass of the system, including pipe, contents and insulation weight, is represented either as a consistent (distributed) mass or as lumped masses placed at each node. For the latter case, in order to adequately determine the dynamic response of the system, elements may be subdivided and additional mass points added. The minimum number of degrees of freedom in the model is to be equal to twice the number of modes with frequencies below the ZPA frequency. Maximum mass point spacing may be no greater than one half of the span length of a simply supported beam with stiffness properties and distributed mass equal to that of the piping cross-section and a fundamental frequency equal to the cutoff frequency. This maximum span between mass locations is mathematically represented as:

$$S_m = \frac{1}{2}\left(\frac{\pi}{2f_m}\right)^{0.5}\left(\frac{EIg}{w}\right)^{0.25}$$

Where, S_m = Maximum mass point spacing span

f_m = Dynamic properties analysis cut-off frequency

E = Young's Modulus

I = Moment of Inertia of the pipe

g = Gravitational Acceleration

w = Weight of the pipe per unit length

Concentrated weights of in-line components, such as valves, flanges and instrumentation, are also modeled as lumped masses. Torsional effects of eccentric masses are included in the analysis. For rigid components (those with natural frequencies greater than the ZPA cutoff frequency) the lumped mass is modeled at the center of gravity of the component with a rigid link to the pipe centerline. Flexible components (those with natural frequencies less than the ZPA cutoff frequency) are included in the model using beam elements and lumped mass locations to represent the dynamic response of the component.

A portion of the weight of component type supports (such as snubbers, struts, spring hangers, etc.) is supported by the pipe and must be considered in the piping analysis model. The mass contributed by the support is included in the analysis when it is greater than 10 percent of the total mass of the adjacent pipe span (including pipe, contents, insulation and concentrated masses). The adjacent span is defined as the piping including the applicable support and bounded by the adjacent restraint on each side of this support in each direction. Because the mass of a given support will not typically contribute to the piping response in the direction of the support, only the support mass in the unsupported directions need to be considered, unless the support is flexible in the supported direction. A review of the impact of contributing mass of supports on the piping analysis will need to be performed by the COL applicant(s) following the final support design to confirm that the mass of the support is no more than 10% of the mass of the adjacent pipe span.

5.3 *Piping Benchmark Program*

Pipe stress and support analysis will be performed by the COL applicant(s). If the COL applicant(s) chooses to use a piping analysis program other than those listed in Section 5.1, the applicant will implement the U.S. EPR benchmark program using models specifically selected for the U.S. EPR.

5.4 *Model Boundaries*

Piping system analysis models are typically terminated by one of three techniques. These include termination at structural boundaries, termination based on decoupling criteria, or termination by model isolation methods. Structural boundaries and the use of decoupling criteria are the preferred methods. However, after applying these first two methods, further division of the piping system may be desired to create more manageable models for analysis. This may be accomplished using the model isolation methods.

5.4.1 *Structural Boundaries*

The most preferable model boundary is at a rigid structural attachment restraining all six degrees of freedom for the piping, such as at an equipment nozzle or penetration.

Structural model boundaries provide isolation of the effects of the piping on one side of the boundary to the piping on the opposite side. For large piping systems, the following types of intermediate structural boundaries may be added to the system during design to allow for further division of the analysis model.

5.4.1.1 *In-line Anchors*

An in-line anchor is a pipe support which restrains the piping in all six degrees of freedom, thereby isolating the piping effects on each side of the support from the other. While an in-line anchor provides a clean model boundary for analysis purposes, it may not be practical in many situations. The addition of in-line anchors generally create stiffer piping systems and may cause significant increases in stress and support loads on lines with high thermal movements. Additionally, the use of in-line anchors on high energy lines adds additional postulated terminal end pipe rupture locations. Therefore, additional in-line anchors are only added if they are determined to be practical.

When in-line pipe anchors are used, anchor load results from seismically analyzed piping on both sides of an anchor are combined to obtain the design loads for the anchor.

5.4.2 *Decoupling Criteria*

Piping analysis models may be divided by the use of decoupling criteria. Unlike the isolation of effects at the termination point provided by the structural boundary methods, the decoupling criteria provide a model termination point where the effects from one side to the other are limited and can be accounted for using defined methods.

A branch line may be excluded from the analysis model of the run pipe if it is sufficiently small compared to the run pipe, such that the branch has little effect on the results of the run pipe analysis. Generally, branch lines and instrument connections may be decoupled from the analysis model of larger run piping provided that either the ratio of the branch pipe diameter to the run pipe diameter (D_b/D_r) is less than or equal to 1/3 or the ratio of the moment of inertia of the two lines (I_b/I_r) is less than or equal to 1/25.

The decoupling criteria may also be applied for in-line pipe size changes (such as at a reducer or reducing insert). In this case, the smaller diameter pipe would be treated as the branch line and the larger pipe would be treated as the run.

In addition to the size requirements, a decoupled branch line must be designed to accommodate the thermal and seismic movements of the run pipe without restraint. Therefore, no restraints are to be placed on the branch line near the run pipe connection. Adequate flexibility in the branch line is provided by maintaining a minimum length of pipe, perpendicular to the supported direction, from the run pipe to the first restraint of 1/2 of the pipe span in Table 4-1 for the branch line. If the branch line design does not meet this requirement, the branch line may not be decoupled from the analysis model of the run piping.

Because the decoupling criteria ensure that the branch line has little effect on the run pipe, only two additional items need to be included in the run pipe analysis. The run pipe analysis must include an appropriate SIF and/or stress indices at the point where the piping is decoupled. Additionally, mass effects of the branch line shall also be considered. The mass to be considered is the mass of 1/2 of the first span of the branch pipe, including concentrated weights and eccentric masses, in each direction.

Large concentrated masses should not be located within the first span of the branch pipe. 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 must be considered. In these cases, the branch piping will be modeled and analyzed with the run pipe, or a portion of the branch line shall be included in the run pipe analysis to adequately include the torsional effects of the eccentric mass.

The branch pipe analysis must include more consideration for the effects of the run piping. The branch point is considered as an anchor in the analysis of the branch pipe with the appropriate SIF and/or stress indices for the branch connection. The movements (displacements and rotations) of the run pipe at the branch intersection due to statically applied loads in the run pipe analysis (such as thermal and seismic anchor movements (SAM)) shall be applied as anchor movements with their respective load cases in the branch line analysis. Additionally, in the branch analysis, the applied SAMs at the decoupled location shall include the run pipe movements from both the run pipe SAM analysis and the run pipe SSE inertia analysis. The inertial effects of the run pipe on the branch line are considered in one of the following methods:

- For branch lines decoupled from the RCL, the inertial input to the branch line is generated from the analysis of the RCL. The analysis of the RCL yields time history responses at the branch connections and equipment nozzles. This time history response of the RCL, or a response spectrum generated from the time history response, is then applied as the input inertial excitation at the branch-to-RCL intersection. This method may also be used for decoupling pipe from flexible equipment if the response of the equipment is known.

- For other decoupled lines, branch piping analysis will include one of the following:

    1. The fundamental frequency of the run pipe at the branch location will be determined. If this frequency is at or above the ZPA cutoff frequency, the run pipe is considered as rigid and there will be no amplification of the building response spectra. Therefore, the applied inertial excitation at the branch-to-run pipe anchor shall include the envelope of building excitations for the nearest supports on both the branch and run pipes.

    2. If the fundamental frequency of the run pipe at the branch location is below the ZPA cutoff frequency, the run pipe at this location is considered to be flexible and therefore may amplify the input inertial effects. Where practical, in these cases, amplified response spectra will be developed from the run pipe analysis and applied at the branch-to-run pipe anchor in the branch pipe analysis.

3. As an alternative to a decoupled analysis, for branch lines connected to flexible run piping where amplified response spectra are not generated, the branch line analysis may include a portion of the run pipe meeting one of the model isolation methods described in Section 5.4.3 in order to capture the possible amplification of inertial input from the run pipe. Therefore, the applied inertial excitation shall include the envelope of building excitations for the nearest supports on both the branch and run pipes. In these cases, the run pipe analysis remains qualified by the decoupled analysis.

5.4.3 *Model Isolation Methods*

The Overlap Region and Influence Zone model isolation methods are used to divide large seismic piping systems that cannot be separated by structural methods or decoupling criteria. These methods are similar in technique in that a section of the piping system is used as the boundary of the models. This section of the system is defined such that the effects of the piping beyond one end of the region do not significantly affect the piping beyond the opposite end of the region. The difference in these methods is in the definition of the qualification boundary as shown in Figure 5-1.

5.4.3.1 *Overlap Region Methodology*

An overlap region consists of a section of the piping system that is modeled in two, or more, analyses. This region is defined to be large enough to prevent the transmission of motion due to seismic excitation from one end of the region to the other and must meet the following criteria which are consistent with the recommendations of NUREG/CR-1980[22].

.As a minimum, an overlap region must contain at least four (4) seismic restraints in each of three perpendicular directions and at least one change in direction. If a branch is encountered, the balance of restraints required beyond that point shall be included on all lines joining at the branch. An axial restraint on a straight run of pipe may be counted effective at each point of lateral restraint on that same run.

The overlap region should be selected in a rigid area of the piping system. A dynamic analysis of the overlap region shall be made with pinned boundaries extended beyond the overlap region either to the next actual support or to a span length equal to the largest span length within the region. The fundamental frequency determined from this analysis shall be greater than the frequency corresponding to the ZPA.

When using the overlap methodology, pipe stresses in the overlap region must be qualified separately in each piping model. Supports located in the overlap region, including the ends, are qualified for the enveloped loads and movements resulting from all models covering the overlap region.

5.4.3.2 *Influence Zone Modeling*

The Zone of Influence (ZOI) method is provided as an option when the requirement for a rigid section of piping can not be met in order to use the overlap methodology. In this method, all piping must be modeled to a point where boundary conditions and loadings no longer impact the piping being qualified. This will typically be more piping than is required by the overlap method and the validity of the boundary is required to be demonstrated during the analysis.

The main difference between the influence zone and the overlap region is that in using the influence zone, all piping and supports are qualified by a single model. This is achieved by first determining the qualification boundary between models. Each model is then extended to a termination point such that the response of the piping at the termination of the model will not influence the response of the piping within the qualification boundary. The influence zone is then defined by the section of piping between the qualification boundary and the model termination point.

Because the response of the piping at and beyond the termination point will not, by definition, influence the piping within the qualification region, the pipe stresses and supports are qualified by the results of one analysis only. However, when using this methodology versus the overlap region, a significantly larger section of piping may be required to be included in two or more models.

5.5 *Seismic/Non-Seismic Interface Boundaries*

The effects of non-seismic piping connected to Seismic Category I piping must either be isolated from the Seismic Category I piping or included in the analysis model. The model boundary at a non-seismic/ seismic piping interface may consist of structural isolation, decoupling or model isolation methods similar to those discussed in 5.4. However, additional considerations are required to ensure that the dynamic effects of the non-seismic piping are considered.

Seismic Category I design requirements extend to the first seismic restraint beyond the seismic system boundary. The non-seismic piping and supports beyond this location that impact the dynamic analysis of the Seismic Category I piping are reclassified as Seismic Category II and included in the model. The extent of piping classified as Seismic Category II may be bounded by the following methods.

- Any of the structural boundaries in Section 5.4.1 may be used to terminate the Seismic Category II region. In these cases, all piping and supports between the Seismic Category I design boundary and the structural anchor, or the final restraint of a restrained elbow or tee, are classified as Seismic Category II.

- Locations in the seismic/non-seismic interface region which meet the decoupling criteria in Section 5.4.2 are acceptable model boundaries. When this method is applied, all piping and restraints beyond the Seismic Category I boundary up to the decoupled location are classified as Seismic Category II.

- Alternatively, a series of piping restraints may be utilized to isolate the seismic response of non-seismically designed piping from seismically designed piping, similar to the model isolation methods discussed in Section 5.4.3. In this case, isolation of dynamic effects is provided by four seismic restraints in each of the three orthogonal directions beyond the Seismic Category I system boundary.

In all cases, the Seismic Category II portion of the system is analyzed with the Seismic Category I piping for the SSE load case as well as loads resulting from the potential failure of the non-seismic piping and pipe supports. This is accomplished by the application of a plastic moment in each of three orthogonal directions at the termination of the model. The plastic moment is calculated as:

$$M_P = S_Y Z_P \quad \text{and} \quad Z_P = \left(D^3 - d^3\right)/6$$

Where, M_P = Plastic moment to be applied

S_Y = Material Yield Strength at 70°F

Z_P = Plastic section modulus of the pipe

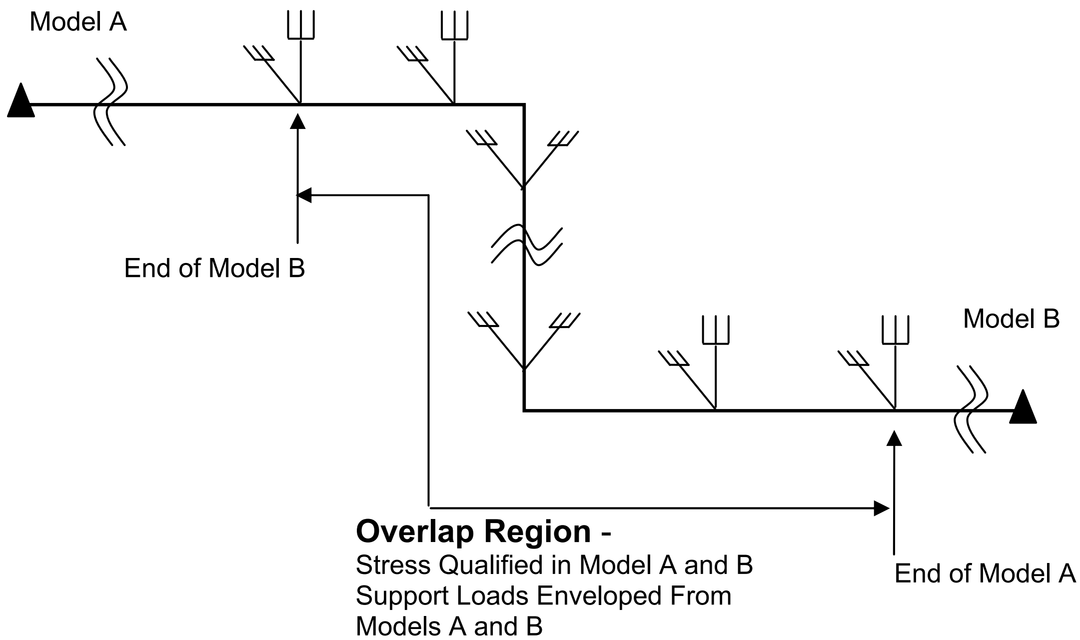
D = Outside diameter of the pipe

d = Inside diameter of the pipe

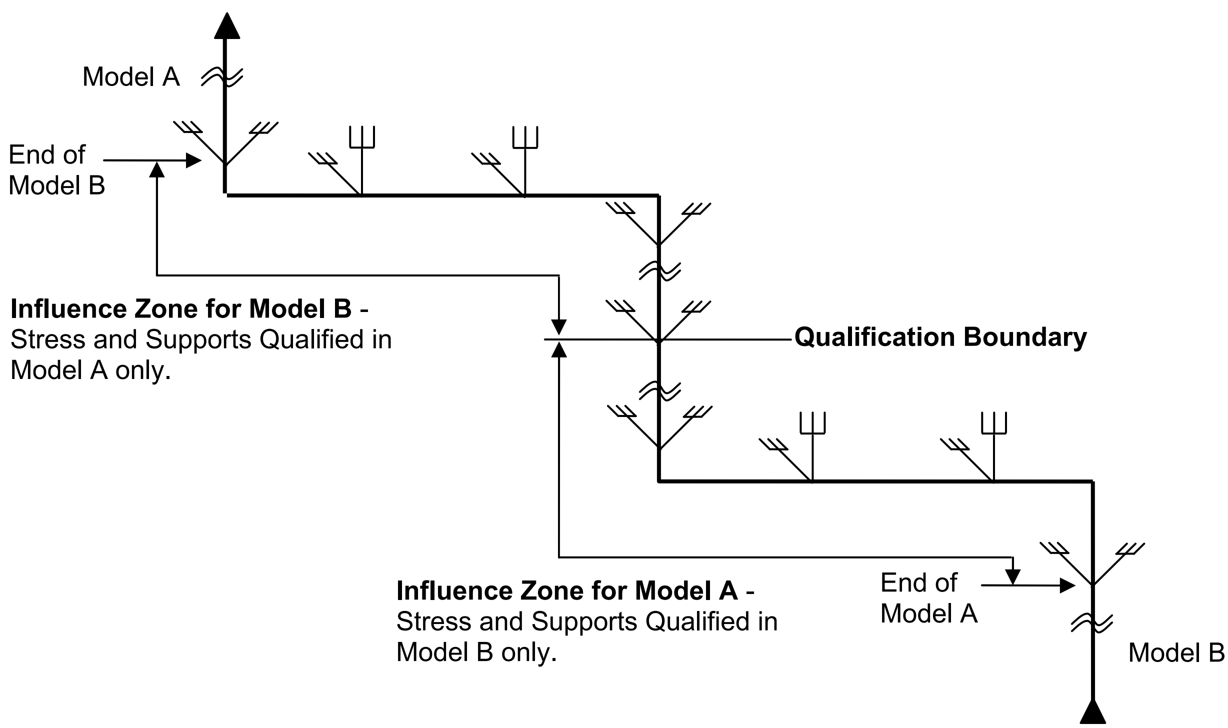
Each moment is applied and evaluated in a separate analysis and the results of each analysis are individually combined with the seismic inertia results by absolute summation methods. The results of these three analyses are then enveloped to obtain the design loads for the piping and supports.

Each moment is applied and evaluated in a separate analysis and the results of the three analyses are enveloped.

Figure 5-1: Model Isolation Methods of Division- Comparison of Qualification Boundaries



OVERLAP REGION METHODOLOGY



INFLUENCE ZONE METHODOLOGY

6.0 PIPE SUPPORT DESIGN CRITERIA

Pipe supports are designed for the loading, deflections and directionality of support required by the piping analysis, in order to provide for the proper functionality requirements of the piping itself. In addition, the pipe support elements must be designed to meet the requirements of the appropriate design codes, to again be consistent with the code requirements of the overall piping system. Pipe supports typically include structural elements, at times also coupled with standard manufactured catalog items developed specifically for pipe support usage.

The piping analysis usually makes idealized supporting assumptions as required by the specific analysis conditions. In turn, the supports are typically designed separately from the piping analysis, with design methods to match the assumed analysis constraints. As such, the supports should be designed to minimize their effects on the piping analysis, and must not invalidate the piping analysis assumptions.

6.1 *Applicable Codes*

The design codes for U.S. EPR piping supports are designated based on the seismic category of the support in question. Seismic Category I pipe supports shall be designed in accordance with Subsection NF of the ASME Code for Service Levels A, B, C and D [2] while using the acceptance limits of Subsection NF for Levels A, B and C and the acceptance limits of Appendix F of Section III for Level D. Subsection NF will be used for the manufacturing, installation and testing of all seismic Category I pipe supports. Subsection NF details varying requirements for ASME Class 1, 2 and 3 support structures, and is further delineated into plate and shell type supports, linear type supports and standard piping supports. In addition, the welding requirements for A500, Grade B tube steel from AWS D1.1 are utilized [23].

Plate and shell type supports, as defined in the ASME Code are supports such as skirts or saddles fabricated from plate elements and loaded to create a biaxial stress field. Linear type supports are essentially subjected to a single component of direct stress, but may also be subjected to shear stresses. Examples of linear type support elements would be beams, columns, frames and rings. Standard supports are made from typical support catalog items such as springs, rigid struts and snubbers. Standard support items are typically load rated items, but may be also qualified by plate and shell or linear analysis methods.

For all Seismic Category II pipe supports other than standard component supports, the design, manufacturing, installation, and testing meet the requirements of ANSI/AISC N690, “Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities” [24]. Standard component supports are designed, manufactured, installed and tested to Subsection NF of the ASME Code. Any structural members used as part of a pipe support also containing standard components are designed, manufactured, installed, and tested to ANSI/AISC N690.

For Non-seismic Category pipe supports supporting piping analyzed to B31.1, the requirements of B31.1 for supports (Sections 120 and 121) are met, where applicable. In addition, the structural elements are designed using guidance from the AISC Manual of Steel Construction [25]. For standard components used in these supports, vendor’s catalog requirements are utilized, which also meet B31.1 requirements.

For Non-seismic Category pipe supports supporting unanalyzed piping, the structural elements are designed using guidance from the AISC Manual, and standard components meet the vendor’s catalog requirements.

In addition to the pipe support design codes mentioned above, expansion anchors and other steel embedments in concrete shall be designed for concrete strength in accordance with ACI-349, “Code Requirements for Nuclear Safety Related Concrete Structures” [26].

6.2 *Jurisdictional Boundaries*

The jurisdictional boundaries for pipe supports fall into two categories. The first boundary is between the pipe and the support structure. The second boundary is between the support structure and the associated building structure. For the U.S. EPR, the pipe support jurisdictional boundaries will be as defined in the ASME Code.

The jurisdictional boundary between the pipe and its support structure will follow the guidance of Subsections NB-1132, NC-1132, or ND-1132, as appropriate for the ASME Class of piping involved. For piping analyzed to B31.1, the jurisdictional boundary guidance of ND-1132 will be utilized. In general, for attachments to the pipe which are not directly welded to the pipe, the jurisdictional boundary is at the outer surface of the pipe. For attachments which are welded directly to the pipe, the boundary will vary in accordance with the configuration of the attachment. For such welded attachments, the guidance in Subsections NB-1132, NC-1132 or ND-1132 will be utilized. In addition, local pipe stresses due to the welded attachments will be evaluated in accordance with the appropriate ASME Code Cases given in Section 2.2 of this document.

The jurisdictional boundary between the pipe support and the building structure will follow the guidance of Subsection NF-1130 of the ASME Code. 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.

6.3 *Loads and Load Combinations*

Load combinations for the U.S. EPR will be defined based on the four Service Levels used in the ASME Code; Levels A, B, C and D. These four level designations are defined in Section 3.2. Based on the guidance given in SRP 3.9.3[1], loading combinations of the various potential analysis load cases will be developed for the four defined levels.

Note that the load combinations used for all four levels will always include the normal plant operating loadings in effect for all conditions, i.e., deadweight and thermal. However, since signed thermal loadings may cancel other signed loadings, the cold condition must also always be considered for support loads.

The following sections (except Section 6.3.11) provide an explanation of the various analysis load cases used in the load combinations, and Table 6-1 provides the specific load combinations for pipe supports. The acceptance criteria associated with the Service Levels will be per ASME Code, Subsection NF, ANSI/AISC N690 or the AISC Manual of Steel Construction, as appropriate. Section 6.3.11 provides minimum design loads for pipe support design when the actual calculated design loads are very small. The symbol designations in parentheses in the section titles are used in the table to represent the corresponding loadings.

6.3.1 *Deadweight (D) Loads*

Deadweight loads for a pipe support are usually based on the deadweight load case of the associated piping analysis, and include the weight of the pipe and fittings, contents, insulation, and pipe support components directly supported by the pipe, such as clamps for spring supports (See Section 5.2 for specific details). In addition to gravity loads from the piping analysis, the deadweight of the support itself should be considered in the support qualification, if considered significant.

Note that gravity supports are either designed to be rigid or flexible supports based on the piping analysis thermal movements of the pipe. High thermal movements often require a flexible spring support to allow thermal growth while still supporting the pipe under the deadweight condition.

6.3.2 *Thermal (T_N, T_U, T_E, T_F) Loads*

Thermal loads for a pipe support will usually be calculated in one or more load cases in the associated piping analysis based on the thermal operating parameters of the piping system. Since there may be differing temperatures of the piping fluid for the various service levels, the subscripts of the symbol designations above represent the four service levels; normal, upset, emergency and faulted. The various temperatures in the piping system will cause the overall system to expand or contract, thereby applying loads to the pipe supports which are restricting the free expansion or contraction. In addition, anchor points for the piping system, such as equipment nozzles or branch connections, may also be moving thermally such that they apply thermal movements to the piping analysis. These are typically referred to as Thermal Anchor Movements (TAMs), which must also be considered in the overall piping analysis.

Along with the overall system effects mentioned above, consideration for local, radial thermal expansion of the pipe cross section must be made. This effect is often addressed by having small gaps around the pipe for such thermal growth, while still maintaining relatively tight constraints for seismic loadings (See Section 6.11).

One further consideration for the pipe support design is the environmental condition around the pipe support, including the pipe temperature. The air temperature around the support may cause expansion of the support structure itself, as well as affect the material properties of the support structure. In addition, an elevated pipe temperature may cause the support structure to undergo local expansion, or be subject to reduced material allowables near the vicinity of the pipe.

6.3.3 *Friction (F) Loads*

Friction loads to be applied to the pipe support are typically not calculated in the piping analysis, but instead are hand calculated during the support design. Such loads are developed when sliding of the pipe across the surface of a support member in the unrestrained direction(s) occurs under thermal expansion conditions. See Section 6.10 for further discussion of the development of these loads.

6.3.4 *System Operating Transient (R_{SOT}) Loads*

System operating transients are defined in SRP 3.9.3[1] as “the transients and their resulting mechanical responses due to dynamic occurrences caused by plant or system operation.” These dynamic loads will typically come from load cases analyzed in the computerized piping analysis, and are the result of transients such as safety/relief valve thrust, fast valve closure, water hammer and steam hammer.

6.3.5 *Wind (W) Loads*

If applicable (See Section 3.3.1.6), exposed piping and support structures will be analyzed for the design basis wind forces. This will typically be the result of a load case in the piping analysis performed for the piping system. Depending on the speed of application of the wind loading, snubber supports may or may not activate. Conservatively, both a static support (snubbers unlocked) and dynamic support (snubbers locked) configuration will be analyzed and the results enveloped.

6.3.6 *Tornado (W_T) Loads*

If applicable (See Section 3.3.1.6) exposed piping will also be analyzed for the design basis tornado. The tornado loads will consist of loads due to tornado wind speeds, differential pressures and tornado generated missiles, as appropriate. The tornado wind speeds are calculated from the translational velocity of the tornado added to the rotational velocity. As for the wind loadings, the support loads will typically be the result of a load case in the piping analysis and both a static support (snubbers unlocked) and dynamic support (snubbers locked) configuration will be analyzed and the results enveloped for the tornado wind loads. Missile loadings will be considered as a dynamic load case for support activation purposes.

6.3.7 *Design Basis Pipe Break (R_{DBPB}) Loads*

Design basis pipe breaks are defined in SRP 3.9.3[1] as “those postulated pipe breaks other than a LOCA or MS/FWPB. This includes postulated pipe breaks in Class 1 branch lines that result in the loss of reactor coolant at a rate less than or equal to the capability of the reactor coolant makeup system”. These loads would include loads applied to the piping from another nearby broken pipe (jet impingement or pipe whip), or loads in a pipe from a break in the same pipe (dynamic effects in the system due to the break).

6.3.8 *Main Steam / Feedwater Pipe Break ($R_{MS/FWPB}$) Loads*

These pipe break loads are the same type of loadings, determined in the same fashion as for the design basis pipe break, except that they are specifically for the two subject systems.

6.3.9 *Loss of Coolant Accident (LOCA) Loads*

Loss of coolant accidents are defined in Appendix A to 10 CFR Part 50 as "those postulated accidents that result from the loss of reactor coolant, at a rate in excess of the capability of the reactor coolant makeup system, from breaks in the reactor coolant pressure boundary, up to and including a break equivalent in size to the double-ended rupture of the largest pipe of the Reactor Coolant System." Leak-before-Break methodology will be used to eliminate double ended guillotine breaks in the RCL and Pressurizer Surge Line piping, but breaks in the smaller attached lines will be considered. Again, these loads would be determined in the same fashion as for the other pipe break scenarios.

6.3.10 *Safe Shutdown Earthquake (SSE) Loads*

The seismic loads to be applied to the pipe supports from the piping, due to the maximum potential earthquake expected in the area of the plant, are the SSE loads. These loads will include inertial loads from the piping, as well as seismic movements at anchor points such as piping anchor supports, equipment nozzles and branch line points.

In addition to the SSE loads from the piping, the seismic acceleration of the support structure itself must also be considered. This effect is called self-weight excitation, and is discussed further in Section 6.8.

6.3.11 *Minimum Design Loads*

Minimum design loads will be defined for all pipe supports such that uniformity is obtained in the load carrying capability of the supports. As such, all supports should be designed for the largest of the following three loads:

- 125% of the Level A condition load.
- The weight of a standard ASME B31.1 span of water filled, schedule 80 pipe.
- Minimum value of 150 pounds.

6.4 *Pipe Support Baseplate and Anchor Bolt Design*

Although the use of baseplates with expansion anchors is expected to be minimized in the U.S. EPR design, there will likely be some instances where baseplate designs must be utilized. For such designs, the concrete will be evaluated using ACI-349 [26], Appendix B subject to the conditions and limitations of RG 1.199 [27]. 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 utilized in the development of anchor bolt loads, as addressed in IE Bulletin 79-02, Revision 2 [28].

6.5 *Use of Energy Absorbers and Limit Stops (Non-Linear Response)*

The use of energy absorbers for pipe supports utilizing normal design loadings is not expected for the U.S. EPR design, but energy absorbing material may be used in the design of pipe whip restraints. The use of gapped rigid supports (limit stops) is not anticipated in the U.S. EPR design. However, should the need for such supports arise, the non-linear piping analysis will be solved using direct integration time history methods. If non-linear piping analysis is performed, the modeling and analysis methods must be submitted to and approved by the NRC prior to its use.

6.6 *Use of Snubbers*

Snubber supports for piping systems are utilized for situations requiring free thermal movements, while restraining movements due to dynamic loadings. An example of such a situation would be the need to relieve dynamic stresses at a piping fitting, while allowing thermal growth of the pipe, thereby minimizing the thermal loads/stresses at the same fitting. Many times this approach is used for the first support on piping adjacent to an equipment nozzle. Due to the rigidity of an equipment nozzle (usually modeled as a rigid piping anchor), care should be taken in the support design to assure that the pipe will have the required dynamic acceleration/movement to properly activate the snubber. Typical snubber components are manufactured standard hardware, and may be either hydraulic or mechanical in operation.

The size and location of snubbers in a piping system will be a function of the thermal and dynamic analyses requirements. Snubbers, in general should not be used where thermal movements are small. Also, use of snubbers should be minimized as much as reasonable due to the maintenance and testing requirements for these components. As such, accessibility of any snubbers utilized must also be a consideration in the design of the piping system.

Other design/analysis considerations for snubbers are related to the ability of the snubbers to properly activate for their design loadings. For snubbers which might experience high thermal growth rates, the analysis should ensure that such growth rates do not exceed the snubber lock-up velocity. Also, for parallel snubbers utilized in the same support, care must be taken to ensure that total fitting clearances are not mismatched between the tandem snubbers such that one will activate before the other. Other such load sharing considerations for tandem snubbers, such as significant stiffness differences, must also be a support design criterion.

The Design Specification(s) provided to the supplier(s) of snubbers should contain the following types of information:

- Applicable Codes and Standards

- Functional Requirements
- Operating Environment (Both Normal and Post Accident)
- Materials (Construction and Maintenance)
- Functional Testing and Certification
- Requirement for Construction to Meet ASME Code, Subsection NF

The proper installation and operation of snubbers will be verified by the COL applicant, utilizing visual inspections, hot and cold position measurements, and observance of thermal movements during plant startup.

6.7 *Pipe Support Stiffnesses*

Supports in the piping analysis model may be modeled with either the actual stiffness of the support structure, or an arbitrarily rigid stiffness. In general, rigid stiffnesses will be utilized for the piping supports, with a check on support deflection in the restrained direction(s) to verify the rigidity. The actual stiffness will be modeled for variable spring supports. If actual support stiffnesses are utilized for other than spring supports, the support should be designed such that the stiffness is approximately the same for both directions along a single axis. If the actual support stiffness is used for any support other than variable spring supports, all supports within the piping model shall use the actual support stiffnesses. Also, caution should be used in the support design to keep the unrestrained direction of the support from having a frequency which would tend to provide significant amplification of the support structure mass.

Two deflection checks will be performed for each support modeled as rigid in the piping analysis. The first check will compare the deflection in the restrained direction(s) to a maximum of 1/16 inch for SSE loadings or the minimum support design loadings of Section 6.3.11. The second check will compare the deflection in the restrained direction(s) to a maximum of 1/8 inch for the worst case deflection for any load case combination. Note that in the development of the support deflections, dynamically flexible building elements beyond the support jurisdictional boundaries will also be considered.

6.8 *Support Self-Weight Excitation*

6.8.1 *Seismic Loads*

The response of the support structure itself to SSE loadings is to be included in the pipe support analysis. In general, the inertial response of the support mass will be evaluated using a response spectrum analysis similar to that performed for the piping. Damping values for welded and bolted structures are given in Revision 1 to RG 1.61 [20]. This support self-weight SSE response, the piping inertial load SSE response, and the SSE loads from SAM are to be combined by absolute sum.

6.8.2 *Other Dynamic Loads*

For the U.S. EPR Reactor Coolant Loop analysis, the support structures have been explicitly modeled with the piping. Due to this inclusion of the supports in the piping model, the dynamic effects of the support structures are inherently included in the overall results for all dynamic loadings (including seismic). For other Class 1, 2 or 3 piping system analyses, the support structures are not expected to be explicitly modeled in the piping analysis. The analyses will assume rigid support points in the piping model using the default stiffnesses in the analysis code, with support rigidity confirmed as discussed in Section 6.7. As also discussed in Section 6.7, if supports do not meet the requirements in Section 6.7, the actual support stiffnesses will be determined for all supports within that model and will be used in a reanalysis of the piping along with the mass of the support. Therefore, the dynamic characteristics of supports that are not rigid will be included in the piping analysis.

6.9 *Design of Supplemental Steel*

As discussed in Section 6.1, all Seismic Category I and II pipe supports for the U.S. EPR will be designed to Subsection NF of the ASME Code or to ANSI/AISC N690, respectively. This will include any supplemental steel required to connect the main support structure to the building structure. As is also discussed in Section 6.2, the jurisdictional boundaries of the support structures to the building structures will likewise follow the guidance of Subsection NF. This guidance would include any such supplemental steel within the support boundary. Thus, the supplemental steel will be designed to Subsection NF of the ASME Code or ANSI/AISC N690 for Seismic Category I and II pipe supports, respectively. For non-seismic pipe supports, the AISC Manual of Steel Construction will be utilized for the supplemental steel, as it will for the main support structure.

6.10 *Consideration of Friction Forces*

As discussed in Section 6.3.3, friction forces develop in the pipe support when sliding of the pipe across the surface of a support member in the unrestrained direction(s) occurs under thermal expansion conditions. Since friction is due to the gradual movement of the pipe, loads from friction will only be calculated using the deadweight and thermal loads normal to the applicable support member. Friction due to other piping loads will not be considered.

Specifically, to calculate the friction forces, a force will only need to be calculated if the thermal movement in the applicable unrestrained direction(s) is greater than 1/16 inch. If this threshold is met, the force will be calculated using the product of CN, where C is the appropriate coefficient of friction and N is the total force normal to the movement. The coefficient of friction will be taken as 0.3 for steel-to-steel conditions and 0.1 for low friction slide/bearing plates. If support stiffness information is readily available, this calculated force can be reduced by using the force of KX (if less than CN), where K is the support stiffness in the movement direction and X is the movement.

6.11 *Pipe Support Gaps and Clearances*

For rigid guide 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. Excessive gaps in these supports would lead to a non-linear condition, which will not be the normal design for the U.S. EPR, as stated in Section 6.5. The normal design practice for the U.S. EPR will be to use a nominal cold condition gap of 1/16 inch on each side of the pipe in the restrained direction. This will lead to a maximum total cold condition gap around the pipe for a particular direction of 1/8 inch.

For gaps around the pipe in an unrestrained direction, the gap magnitudes should be specified large enough to accommodate the maximum movement of the pipe.

6.12 *Instrumentation Line Support Criteria*

The design and analysis loadings, load combinations and acceptance criteria to be used for instrumentation line supports will be similar to those used for pipe supports. The applicable design loads will include deadweight, thermal expansion and seismic loadings (where appropriate). The applicable loading combinations will similarly follow those used for the ASME Levels in Table 6-1, utilizing the design loadings mentioned above. The acceptance criteria will be from ASME Code, Subsection NF for Seismic Category I instrumentation lines, ANSI/AISC N690 for Seismic Category II instrumentation lines and the AISC Manual of Steel Construction for non-seismic instrumentation lines.

6.13 *Pipe Deflection Limits*

For pipe supports utilizing standard manufactured hardware components, the manufacturer’s recommendations for limitations in its hardware will be followed. Examples of these 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 will be made in the initial designs for tolerances on such limits. This is especially important for snubber and spring design where the function of the support can be changed by an exceeded limit.

The check for travel range limitation for spring hangers will utilize the “working range” given in the standard Load Table for Selection of Hanger Size typically given in the vendor catalogs. This working range already provides a deflection tolerance beyond each end limit of the range (with the magnitude dependent on the spring type), provided the hot and cold loads fall within the working range.

The project guidance for stroke limit checks for snubbers is to allow at least ½ inch of stroke at each end for the initial design checks.

The check of swing angle for rods, struts and snubbers, for current analyses, utilizes ANVIL, International’s limit of 4 degrees. AREVA applies a tolerance of 1 degree to this, thus checking to 3 degrees for initial design.

The check for alignment angles of strut and snubber paddles and their associated clamps or end brackets uses ANVIL’s limit of 5 degrees. AREVA applies a tolerance of 1 degree to this, thus checking to 4 degrees for initial design.

The check for the spring variability recommended by Anvil is 25%. AREVA applies a tolerance of 5% to this, thus checking to 20% for initial design.

Table 6-1: Loading Combinations for Piping Supports

Condition	Load Combination(1), (2), (3)
Normal (Level A)	$D + T_N + F$
Upset (Level B)	$D + T_U + R_{SOT}$ $D + T_U + W$
Emergency (Level C)	$D + T_E + R_{SOT}$ $D + T_E + W_T$ $D + T_E + R_{SOT} + R_{DBPB}$ (4)
Faulted (Level D)	$D + T_F + R_{SOT}$ $D + T_F + R_{SOT} + R_{DBPB}$ (4) $D + T_F + R_{SOT} + R_{MS/FWPB}$ (4) $D + T_F + R_{SOT}$ + LOCA (4) $D + T_F + R_{SOT}$ + SRSS (R_{DBPB} + SSE) (4) $D + T_F + R_{SOT}$ + SRSS ($R_{MS/FWPB}$ + SSE) (4) $D + T_F + R_{SOT}$ + SRSS (LOCA + SSE) (4)

Notes:

1. OBE inertia and SAM loads are not included in the design of Class 1, 2 & 3 piping[7]

2. The acceptance criteria for the load combinations are discussed in Section 6.3.

3. SSE includes inertia and SAM loads combined by absolute sum.

4. Loads due to dynamic events 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 SRSS method, provided it is demonstrated that the non-exceedance criteria given in NUREG-0484 are 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 (i.e., Loss-Of-Coolant-Accident and Secondary Side Pipe Rupture) loads are always combined using the SRSS method.

7.0 SUMMARY/CONCLUSIONS

The piping analysis and support design for the U.S. EPR adheres to the requirements of Title 10 of the Code of Federal Regulations and the ASME Code. This is accomplished by utilizing industry guidance in NUREGs, Regulatory Guides, and NRC and industry bulletins. These codes and standards, acceptance criteria and modeling techniques are generally the same as those used in existing plant designs updated only as a result of industry experiences and increased knowledge.

Adhering to the guidance provided by this topical for piping analysis and support design will result in these structures and components in the U.S. EPR being designed to industry requirements while providing adequate levels of safety to the public.

8.0 REFERENCES

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2. ASME Boiler & Pressure Vessel Code, Section III, Division 1, 2001 Edition through 2003 addenda.

3. ASME Boiler & Pressure Vessel Code, Section III, Division 1, 1992 Edition through 1993 addenda.

4. Regulatory Guide 1.84, "Design, Fabrication and Materials Code Case Acceptability, ASME Section III," Revision 33.

5. Regulatory Guide 1.29, "Seismic Design Classification," Revision 3.

6. WRC Bulletin 353, "Position Paper on Nuclear Plant Pipe Supports," May 1990.

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

8. IEEE 344-1987, "Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations."

9. NUREG-1367, "Functional Capability of Piping Systems," November 1992.

10. NRC Bulletin 79-13, "Cracking in Feedwater System Piping," Revision 2.

11. NRC Bulletin 88-11, "Pressurizer Surge Line Thermal Stratification."

12. NRC Bulletin 88-08, with Supplement 3, "Thermal Stresses in Piping Connected to Reactor Coolant System."

13. Guideline for the Design of Buried Steel Pipe; Report by American Lifelines Alliance, 2001.

14. Seismic Response of Buried Pipes and Structural Components; ASCE Committee on Seismic Analysis of Nuclear Structures and Materials, New York, 1983.

15. ASCE Standard 4-98, “Seismic Analysis of Safety-Related Nuclear Structures and Commentary, American Society of Civil Engineers,” copyright © 2000 by the American Society of Civil Engineers

16. NUREG-0484, “Methodology for Combining Dynamic Responses,” Revision 1.

17. Regulatory Guide 1.122, "Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components," Revision 1.

18. WRC Bulletin 300, "Technical Position on Criteria Establishment; Technical Position on Damping Values for Piping - Interim Summary Report; Technical Position on Response Spectra Broadening; Technical Position on Industry Practice," December 1984.

19. NUREG-1061, Volume 4,"Report of the U.S. Nuclear Regulatory Commission Piping Review Committee, Evaluation of Other Loads and Load Combinations," December 1984.

20. Regulatory Guide 1.61, Rev. 1, "Damping Values for Seismic Design of Nuclear Power Plants," March 2007

21. Regulatory Guide 1.92, "Combining Modal Responses and Spatial Components in Seismic Response Analysis," Revision 2.

22. NUREG/CR-1980, "Dynamic Analysis of Piping Using the Structural Overlap Method," March 1981.

23. AWS D1.1/D1.1M:2004, "Structural Welding Code - Steel."

24. ANSI/AISC N690-1994, "Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities" including Supplement 2 (2004).

25. AISC Manual of Steel Construction, 9th Edition.

26. ACI-349-2005, Appendix B, "Code Requirements for Nuclear Safety Related Concrete Structures."

27. Regulatory Guide 1.199, "Anchoring Components and Structural Supports in Concrete," November 2003.

28. NRC Bulletin 79-02, "Pipe Support Base Plate Designs Using Concrete Expansion Anchor Bolts," Revision 2.

List of Changes for ANP-10264NP-A

Section	Page	Change Description	Reference
Contents	ii through vi	Revised Table of Contents, List of Tables, and List of Figures	N/A
1.0	1-1	Revised in response to RAI EPR-2	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1
Table 1-1	1-3	Deleted COL information item 1 and renumbered the remainder of the COL information items	AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a, Att. D
Table 1-1	1-3	Renumbered COL information 1 was revised to change “as-built” to “as-designed”	AREVA NP letter NRC:08:024, dated 4/18/08, ANP-10264Q1b, Att. B
Table 1-1	1-3	Added COL information item 4 which was previously contained in Section 3.10.1.4	N/A
Table 1-1	1-3	Added COL information item 5 which was previously contained in Section 3.10.3	N/A
Table 1-1	1-3	Renumbered COL information item 7 was revised in response to RAI EPR-20	AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
2.1	2-1	Revised in response to RAI EPR-2 and RAI EPR-3	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1 AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
2.2	2-2	Revised last paragraph	AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a, Att. D

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Section	Page	Change Description	Reference
2.3	2-2	Changed “as-built” to “as-designed”	AREVA NP letter NRC:08:024, dated 4/18/08, ANP-10264Q1b, Att. B
3.10	3-11	Entire section revised in response to RAI EPR-8 and RAI EPR-15	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1 AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a AREVA NP letter NRC:08:024, dated 4/18/08, ANP-10264Q1b
Table 3-1	3-22	Table 3-1 and corresponding notes were revised in response to RAI EPR-25	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1 AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a AREVA NP letter NRC:08:024, dated 4/18/08, ANP-10264Q1b
Table 3-2	3-27	Note 5 was revised in response to RAI EPR-25	AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
Table 3-4	3-29	Table 3-1 and corresponding notes were revised in response to RAI EPR-15	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1 AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a AREVA NP letter NRC:08:024, dated 4/18/08, ANP-10264Q1b

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Section	Page	Change Description	Reference
Tables 3-5 and 3-6	3-30 and 3-31	New tables added in response to RAI EPR-15	AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
4.2	4-1	Revised in response to RAI EPR-4	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1 AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
4.2.2	4-2	Revised in response to RAI EPR-5	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1
4.2.2.2.1	4-7	Revised in response to RAI EPR-8	AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
4.2.2.2.2	4-8	Revised in response to RAI EPR-8	AREVA NP letter NRC:08:024, dated 4/18/08, ANP-10264Q1b
4.2.2.3	4-8	Revised in response to RAI EPR-6, RAI EPR-8, and RAI EPR-27	AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a AREVA NP letter NRC:08:024, dated 4/18/08, ANP-10264Q1b
4.2.2.3.1 and 4.2.2.3.2	4-9 and 4-10	Revised in response to RAI EPR-8	AREVA NP letter NRC:08:024, dated 4/18/08, ANP-10264Q1b

List of Changes for ANP-10264NP-A

Section	Page	Change Description	Reference
4.2.2.3.3, 4.2.2.3.4, 4.2.2.3.5	4-10 through 4-13	Revised in response to RAI EPR-8 and RAI EPR-28	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1 AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a AREVA NP letter NRC:08:024, dated 4/18/08, ANP-10264Q1b
4.2.2.5	4-14	Revised in response to RAI EPR-8	AREVA NP letter NRC:08:024, dated 4/18/08, ANP-10264Q1b
4.2.3	4-14	Revised in response to RAI EPR-5, RAI EPR-9, RAI EPR-10, and RAI EPR-11	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1 AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
4.2.4	4-16	Revised in response to RAI EPR-5 and RAI EPR-12	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1 AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
4.2.5	4-17	Revised in response to RAI EPR-26, RAI EPR-27, and RAI EPR-32	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1 AREVA NP letter NRC:08:024, dated 4/18/08, ANP-10264Q1b
4.4.1	4-19	Revised in response to RAI EPR-14	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1

List of Changes for ANP-10264NP-A

Section	Page	Change Description	Reference
4.4.2	4-20	Revised in response to RAI EPR-14	AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
4.5	4-20	Revised in response to RAI EPR-13	AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
5.1.1 and 5.1.2	5-1	Revised in response to RAI EPR-16	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1
5.1.3	5-2	New Section added in response to RAI EPR-36	AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
5.2	5-3	Last paragraph revised in response to RAI EPR-17	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1
5.3	5-4	Revised in response to RAI EPR-20	AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
5.4.1.2 and 5.4.1.3	N/A	These sections were deleted in response to RAI EPR-18	AREVA NP letter NRC:08:024, dated 4/18/08, ANP-10264Q1b
5.4.2	5-6	Revised in response to RAI EPR-7, RAI EPR-21, and RAI EPR-22	AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
5.4.3.1	5-8	First paragraph revised in response to RAI EPR-19	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1
5.4.3.2	5-9	First paragraph revised in response to RAI EPR-19	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1
5.5	5-10	Revised in response to RAI EPR-23	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1

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Section	Page	Change Description	Reference
Figure 5-1	5-12	Deleted old figures 5-1 and 5-2; Figure 5-3 renumbered as Figure 5-1 and revised in response to RAI 18 and RAI 19	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1 AREVA NP letter NRC:08:024, dated 4/18/08, ANP-10264Q1b
6.1	6-1	Revised in response to RAI EPR-33	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1 AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
6.3.5 and 6.3.6	6-6	Revised in response to RAI EPR-34	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1 AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
6.3.11	6-8	Revised the first bullet in response to RAI EPR-34	AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
6.5	6-8	Revised the first bullet in response to RAI EPR-29	AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
6.8	6-11	Revised in response to RAI EPR-37	AREVA NP letter NRC:08:024, dated 4/18/08, ANP-10264Q1b
6.8.1	6-11	Revised in response to RAI EPR-29	AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
6.8.2	6-11	Revised in response to RAI EPR-37	AREVA NP letter NRC:08:024, dated 4/18/08, ANP-10264Q1b

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Section	Page	Change Description	Reference
6.12	6-13	Revised in response to RAI EPR-38	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1
6.13	6-14	Revised in response to RAI EPR-39	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1
Table 6-1	6-15	Revised in response to RAI EPR-34	AREVA NP letter NRC:07:028, dated 07/13/07, ANP-10264Q1 AREVA NP letter NRC:07:064, dated 11/20/07, ANP-10264Q1a
8.0	8-1 and 8-2	Revised in response to RAI EPR-26 and RAI EPR-27	AREVA NP letter NRC:08:024, dated 4/18/08, ANP-10264Q1b