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.

<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.

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."

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.*

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.

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

$$S_{TE} = \frac{PD_O}{4t_n} + 0.75i\frac{M_A}{Z} + i\frac{M_C}{Z} + E\alpha(T_2 - T_1) - \upsilon\frac{PD}{2t} \le (S_h + S_a)$$ 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.

<u>RAI EPR-16:</u> *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.

<u>RAI EPR-17:</u> *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."

<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 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."*

<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 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.

<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:

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.

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:

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."

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.*

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.

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.

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 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 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.

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

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:

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

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, $Y_{jn}(\text{max})$, the maximum displacement of node *j* relative to the base due to mode j, $X_{jn}(\text{max})$, 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:

$$S_{SL} = \frac{B_1 P D_O}{2t_n} + \frac{B_2 M_A}{Z} + \frac{F_b L^2}{10Z} \leq 1.5 S_h$$

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

$$S_{TE} = \frac{PD_O}{4t_n} + 0.75i\frac{M_A}{Z} + i\frac{M_C}{Z} + E\alpha(T_2 - T_1) - \upsilon\frac{PD}{2t} \le (S_h + S_a)$$ 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 ($F_{a(SSE)}$)	$\frac{i(M_{SSE} + M_c)}{Z} + \varepsilon_a + \varepsilon_b + E\alpha(T_2 - T_1) \leq 3.0 S_h$ 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.