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Subject: **Response to NRC Request for Additional Information Letter No. 16 Related to ESBWR Design Certification Application – Piping Design – RAI Numbers 3.12-1 through 3.12-37**

Enclosure 1 contains GE's response to the subject NRC RAIs transmitted via the Reference 1 letter.

If you have any questions about the information provided here, please let me know.

Sincerely,

Kathy Sedney for

David H. Hinds
Manager, ESBWR

D068

Reference:

1. MFN 06-103, Letter from U.S. Nuclear Regulatory Commission to David H. Hinds, *Request for Additional Information Letter No.16 Related to ESBWR Design Certification Application,* March 30, 2006

Enclosure:

1. MFN 06-119 – Response to NRC Request for Additional Information Letter No. 16 Related to ESBWR Design Certification Application – Piping Design – RAI Numbers 3.12-1 through 3.12-37

cc:	WD Beckner	USNRC (w/o enclosures)
	AE Cubbage	USNRC (with enclosures)
	LA Dudes	USNRC (w/o enclosures)
	GB Stramback	GE/San Jose (with enclosures)
	eDRF	0000-0053-6846

Enclosure 1

MFN 06-119

Response to NRC Request for Additional Information

Letter No. 16 Related to ESBWR Design Certification Application

Piping Design

RAI Numbers 3.12-1 through 3.12-37

<u>NRC RAI 3.12-1</u>

DCD Tier 2, Table 1.9-22, identifies that the 2004 edition of the ASME Code, Section III, is applicable to the ESBWR piping design. Explain how the requirements of 10 CFR 50.55a(b) will be satisfied.

<u>GE Response</u>

DCD Tier 2, Table 1.9-22 will be revised to identify the 2001 edition of the ASME Code, including Addenda through 2003, as being applicable to the ESBWR design. This change makes the DCD basis consistent with 10 CFR 50.55a(b) and the basis for Regulatory Guide 1.84, Revision 33, and Regulatory Guide 1.147, Revision 14, which discuss the applicability of specific ASME Codes cases.

The same change will also be made to DCD Tier 2 Tables 3.8-6 and 3.8-9.

Markups of the affected DCD pages are attached.

NRC RAI 3.12-2

(a) *DCD Tier 2, Table 5.2-1, Sections 3.7 and 3.9 include the following ASME Code Cases which have been annulled by the ASME as noted in the current Regulatory Guides (RGs) 1.84 and 1.147: N-247, N-411-1, N-420, N-463-1, N-476, N-479-1 and N-608. Discuss what alternatives are being considered to address the issues contained in these Code Cases.*

(b) *The staff approved, in RG 1.84, Code Cases N-71-18, N-122-2, and N-416-3 that are the revised versions of these Code Cases referenced in the DCD. Describe the changes in these revised Code Cases that may impact the design criteria presented in the DCD and how they were addressed.*

(c) *The staff's acceptance status of several Code Cases in DCD Tier 2, Table 5.2-1, have been changed. (i) The DCD indicates that Code Cases N-318-5 and N-416-2 were conditionally accepted, but they are now unconditionally endorsed by the staff. Note that Code Case N-416-3, not its previous revision, has been currently endorsed by the staff. (ii) The DCD also indicates that Code Case N-491-2 was not listed in RG 1.147, but it is now endorsed by the staff. Since the acceptance status of these Code Cases given in the DCD has been changed, address the changes in the applicability of these Code Cases in the DCD for ESBWR piping design.*

GE Response

(a) GE agrees to review the applicable code cases cited in RAI 3.12-2(a), but cannot accomplish this review effort by the 4/28/06 due date. Evaluation of the applicability of these ASME Code Cases will be completed by 7/1/06, with a revised RAI 3.12-2 response provided at that time.

(b) Code Case N-71-18 is for "Additional Material for Subsection NF, Class 1, 2, 3 and MC Supports Fabricated by Welding Section III, Division I". Since there is no additional material used in the ESBWR design, this Code Case does not impact the design criteria presented in the DCD.

Code Case N-122-2 provides the Procedure for the Design of Rectangular Cross Section Attachment on Class 1 Piping. The revised Code Case reduced the stress indices of C_T, C_L and C_N by 50% as compared to the previous version. The design results using the previous Code Case are conservative for lug attachment analysis. Therefore, this Code Case does not impact the design criteria presented in the DCD.

Code Case N-416-3 provides Alternative Test Requirement for Weld Repair. It does not impact the design criteria presented in the DCD. Revision 2 of the DCD will be revised to N-122-2.

(c) DCD Tier 2, Table 5.2-1 will be changed to allow unconditional use of Code Cases N-318-5, N-416-3 and N-491-2 in DCD Revision 2.

NRC RAI 3.12-3

The current staff position for the ISM method of analysis is presented in Volume 4, Section 2 of NUREG-1061, "Report of the USNRC Piping Review Committee." Some differences were noted between the ISM method of response combinations presented in the DCD Tier 2, Section 3.7.3.9, and the method given in NUREG-1061 (e.g., the SRSS method in the DCD and absolute sum method in NUREG-1061 for combining group responses for a given direction). Indicate whether all of the provisions contained in NUREG-1061 for the ISM method of analysis will be followed or provide the technical justification for any alternatives.

GE Response

NUREG-1503 paragraph 3.9.2.2, page 3-62 provides the guidelines for ISM analysis method.

As an alternative to the enveloped response spectrum method, GE chose to use the multiple-support excitation analysis method. When this method is used, the staff's position is that the response resulting from motions of supports between two or more different support groups may be combined by the SRSS method if a support group is defined by supports that have the same time history input. This usually means all supports located on the same floor or portion of a floor in a structure.

DCD Revision 2 will be revised to incorporate this guideline.

<u>NRC RAI 3.12-4</u>

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. DCD Tier 2, Section 3.7.2.1.1, 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. 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 or provide a technical justification for not considering this criterion along with the other criterion described above for seismic and hydrodynamic loading analyses.

<u>GE Response</u>

The convergence criterion of using ½ Δt to result in no more than a 10% change in response is part of the requirement for time history analysis. DCD Tier 2, Section 3.7.2.1.1 will be updated accordingly. Markups of the affected DCD pages are attached.

NRC RAI 3.12-5

DCD Tier 2, Section 3.7.2.1.1, states that for the frequency domain solution, the dynamic excitation time history is digitized with time steps no larger than the inverse of two times the highest frequency of significance. It appears that this criterion is related to the Nyquist frequency for selection of the appropriate time step. Provide the technical justification why this approach is sufficiently accurate to capture the piping system response at the Nyquist frequency.

GE Response

Frequency domain solution is not used in the piping system response analysis. This analysis methodology applies to structural evaluations.

NRC RAI 3.12-6

When developing seismic floor response spectra for use in a response spectrum analysis for piping and equipment analysis, the peaks of the spectra obtained from a time history analysis are generally broadened by plus and minus 15% to account for modeling uncertainties. When performing a time history analysis of piping and equipment for seismic and hydrodynamic loads, describe how the uncertainties in the material properties of the structure/soil and in the modeling techniques used in the analysis to develop the loading are accounted for in the time history analysis. Indicate whether the digitized time history is adjusted to account for the material/modeling uncertainties. Describe all of the dynamic loads for which the time history will be adjusted to account for modeling uncertainties and provide the basis for the amount of the adjustment. Also, indicate how the hydrodynamic building spectra are broadened to account for the modeling uncertainties.

GE Response

When the calculated floor acceleration time history is used in the time history analysis of piping and equipment, the uncertainties in the time history are accounted for by expanding and shrinking the time history within 1/(1±0.15) so as to change the frequency content of the time history within ±15%. Alternatively, a synthetic time history that is compatible with the broadened floor response spectra may be used. The methods of peak broadening are applicable to seismic and other building dynamic loads. DCD Tier 2, Section 3.7.2.9 will be updated accordingly and markups of the affected DCD pages are attached.

<u>NRC RAI 3.12-7</u>

DCD Tier 2, Section 3.7.2.1.3, provides a description of the static coefficient method of analysis. It states that the response loads are determined statically by multiplying the mass value by a static coefficient equal to 1.5 times the maximum spectral acceleration at the appropriate damping value of the input response spectrum. Indicate whether the use of the static coefficient method in the DCD also requires that (a) justification be provided that the system can be realistically represented by a simple model and the method produces conservative results and (b) the design and associated simplified analysis account for the relative motion between all points of support, as prescribed in SRP 3.9.2. If not, provide the technical justification.

<u>GE Response</u>

The use of the static coefficient method satisfies SRP 3.7.2 and 3.9.2 requirements. DCD Tier 2, Section 3.7.2.1.3 will be updated accordingly and markups of the affected DCD pages are attached.

NRC RAI 3.12-8

The DCD did not provide any information on the use of inelastic analysis methods for the ESBWR piping design, except that discussed in DCD Tier 2, Section 3.9.1.4, for design of whip restraints against a postulated gross piping failure. Indicate if any ESBWR piping design, other than the whip restraints, includes any inelastic analysis method. Also, if such a method could be used, provide details of the analysis approach, its acceptance criteria, scope and extent of its application.

GE Response

Inelastic analysis methods are not used in the ESBWR piping design and analysis.

NRC RAI 3.12-9

DCD Tier 2, Section 3.7.3.13, did not give details on the analysis method and how the criteria are to be applied in the design of buried piping. Based on the criteria presented in DCD Tier 2, Section 3.7.3.13, describe the analysis method and design requirement that are used for buried piping. The design procedure should include the load components, categorization of seismic stress in the Code evaluation, and allowable stress limits.

GE Response

There is no buried seismic Category I piping in the ESBWR design.

NRC RAI 3.12-10

DCD Tier 2, Section 3.7.3, refers to the guidelines in Appendix N of the ASME Code, as being applicable to design/analysis of ESBWR subsystems. The NRC staff has not explicitly endorsed Appendix N in its entirety. Identify all Appendix N guidance used in the ESBWR piping design/analysis that differs from the guidance provided in the current SRPs and RGs. If any differences exist and are used in the ESBWR piping design/analysis, then provide technical justification for using the Appendix N guidance.

GE Response

For ESBWR analyses, the NRC SRPs and RGs are the first priority to use. Reference to Appendix N will be deleted from DCD Tier 2, Section 3.7.3 in Revision 2.

<u>NRC RAI 3.12-11</u>

DCD Tier 2, Appendix 3D, provides a description of the major computer programs used in the analysis and design of safety related components, equipment, and structures. According to this appendix, the quality of these programs and computer results is controlled. The 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. To facilitate the staff review of the computer programs used in the ESBWR design, provide the following additional information:

(a) Identify which computer programs will be used during the design certification phase and which programs may be used in the future during the COL application phase.

(b) Identify which programs have already 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.

<u>GE Response</u>

(a) The programs used in the certification phase are:

PISYS07 It is a computer code for analyzing piping systems subjected to both static and dynamic piping loads.

ANSI713 The program is for calculating stresses and cumulative usage factors for Class 1, 2 and 3 piping components in accordance with articles NB, NC and ND-3650 of ASME Code Section III. ANSI7 is also used to combine loads and calculate combined service levels A, B, C and D load on piping supports and pipe-mounted equipment.

All of the programs in Appendix 3D.4 may also be used in the future during the COL application phase.

(b) PISYS05 has been benchmarked against NRC piping models. The results are documented in GE report NEDO 24210, dated August 1979 (Reference 3D 1 of

Appendix 3D), for mode shapes and uniform support motion response spectrum analysis (USMA) options. The independent support motion response spectrum analysis (ISMA) option has been validated against NUREG/CR 1677.

The PISYS05 computer program has been reviewed by NRC, and the results are benchmarked with NUREG/CR-6049. PISYS07 USMA and ISMA analyses are the same as PISYS05. It has been benchmarked with NUREG/CR-6049.

(c) The computer programs listed in Appendix 3D are available for staff review. These programs are Level 2 programs. 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 are contained in the design record file of each program.

NRC RAI 3.12-12

DCD Tier 2, Section 3.7.3.3.2, provides criteria to model lumped-masses for equipment in a dynamic analysis. Clarify whether these criteria are also applied to the development of piping system mathematical models. If not, provide the criteria used for piping system mathematical models.

GE Response

The lumped-masses for equipment are modeled and included in the mathematical model when the effect on the piping cannot be uncoupled from the piping. For this case, the equivalent equipment properties with the associated lump masses are included in piping models.

NRC RAI 3.12-13

DCD Tier 2, Section 3.7.3.3.3, states that if special engineered pipe supports are used, the modeling and analytical methodology shall be in accordance with methodology accepted by the regulatory agency at the time of certification or at the time of application, per discretion of the applicant. Clarify whether the statement means that the modeling and analytical methodology will be determined at the COL application stage and will be submitted for review and approval by the staff. If this is the case, the DCD should be revised accordingly. Otherwise, additional clarification of this statement is needed.

GE Response

The use of special engineered pipe supports is exceptional, unless specified otherwise. The need to use it during the COL phase is not foreseen. If its use should be essential at any point during the development of detailed engineering, the modeling and analytical methodology will be adequately determined in accordance with methodology accepted by the regulatory agency at the time of certification or at the time of application, per discretion of the applicant.

NRC RAI 3.12-14

DCD Tier 2, Section 3D.4.1 of Appendix 3D, indicates that the PISYS program has been benchmarked against NRC piping models. The results are documented in GE report NEDO-24210, dated August 1979 (Reference 3D-1 of Appendix 3D), for mode shapes and uniform support motion response spectrum analysis (USMA) options. The independent support motion response spectrum analysis (ISMA) option has been validated against NUREG/CR-1677. With regard to the benchmarking of the PISYS program, provide the following information:

(a) The version of the PISYS program used for the ESBWR analysis should be benchmarked against NUREG/CR-6049, "Piping Benchmark Problems for the GE ABWR." The piping benchmark problems in NUREG/CR-6049 are more recent and more representative of the current piping systems in the ESBWR. If NUREG/CR□6049 will not be used to benchmark the piping computer code used by COL applicants, then provide an explanation.

(b) Indicate where the requirement for the COL applicant to benchmark the use of any piping analysis program(s) in accordance with the current DCD validation methods is located.

GE Response

(a) Appendix 3D paragraph 3D.4.1 last paragraph will add the following in DCD Revision 2:

"Subsequently, the PISYS07 program, which is used for ESBWR piping analysis, has been benchmarked against NUREG/CR-6049. If applicable, COL applicants are also required to benchmark piping computer codes against NUREG/CR-6049.

(b) Appendix 3D paragraph 3D.4.1 last paragraph will be modified in DCD Revision 2 as shown in the (a) response.

NRC RAI 3.12-15

DCD Tier 2, Section 3.7.3.17, indicates that where small, Seismic Category II piping is directly attached to Seismic Category I piping, it can be decoupled from Seismic Category I piping. However, the DCD did not describe how the small branch piping will be analyzed in the piping design for both inertial and Seismic Anchor Motion (SAM) responses (e.g., small bore handbook or like other (larger) piping, equivalent static method or dynamic analysis). Describe the seismic analysis methods and procedures, including the input floor response spectrum and input SAM displacements, that apply to the small branch piping design. The description should also describe how any amplification effects and SAM effects, from the main run pipe at the attachment to the small branch pipe, are considered.

GE Response

The non-safety related piping and components whose structural failure due to an SSE could hinder the operation of the safety-related piping components, shall be designed to withstand the SSE without loss of piping integrity. The load combination and acceptance criteria are as follows.

The load combination and criteria are as follows.

Seismic Category	Description	Load Combination	Acceptance Criteria
II	Sustained Loads	PD + WT	EQ 8 $\leq$ 1.5 S_h
	Occasional Loads	PD + WT + RV2I	EQ 9 $\leq$ 1.8 S_h or 1.5 Sy
	Thermal Range	TE	EQ 13 $\leq$ $S_A + f(S_h - S_L)$
	Structural Integrity	PD + WT + SSEI PD + WT + $[(CHUGI)^2 + (RV2I)^2]^{1/2}$ PD + WT + $[(CONDI)^2 + (RV2I)^2]^{1/2}$ PT + WT + API	ND 3600 EQ 9 < 3Sh and no greater than 2.0 Sy and Meet NUREG 1367

For dynamic and SAM analyses,

1. Decouple criteria is 25 to 1 in the ratio of "moment of inertia" of run pipe to branch pipe.
2. Linear spectrum with accelerations from the seismic and dynamic analyses used in the large bore piping analysis (run pipe) are applied to this interface point for the small branch piping design, as well as the seismic and dynamic displacements at the connection point.
3. Formal analysis methods and procedures similar to the main pipe should be used, or more conservative handbook analysis may also be used.

NRC RAI 3.12-16

DCD Tier 2, Section 3.9.3.3, indicates that the main steam ASME Class 1 piping thermal loads are less than 2.4 Sy per equation 12 of NB-3600. Describe how the stress of 2.4 Sy satisfies the ASME Code Equation 12 allowable limit of 3 Sm.

GE Response

It is a typo. The last sentence of the first paragraph of 3.9.3.3 should read:

"The Main Steam ASME Class 1 piping stress range due to thermal loads per Equation 12 of NB-3600 are less than 2.4 S_m, and are more limiting than the dynamic loads that are required to be analyzed per Equation 13 of NB-3600."

Likewise, in 3.9.3.4 under the "ASME Class 1,2 and 3 Piping" heading, S_y will be changed to S_m.

The purpose of specifying this limit is to satisfy the pipe break criteria of MEB 3-1. The ASME Code for Equation 12 specifies an allowable limit of 3 S_m.

These corrections will be made in DCD Revision 2.

<u>NRC RAI 3.12-17</u>

Note 3 to DCD Tier 2, Table 3.9-2 indicates that the method used in the combination of dynamic responses of piping loadings is in accordance with NUREG-0484, Revision 1. Table 3.9-9 specifies a number of load combinations that specify an SRSS load combination. Describe how the NUREG-0484 criteria were satisfied for the Service Level D load combinations.

<u>GE Response</u>

The technical approach is a linear elastic analysis for Level D. According to that established criteria in Section 5 of NUREG-0484, SRSS combination specified in Table 3.9-9 is suitable for earthquake combinations with LOCA.

NRC RAI 3.12-18

Note 12 to DCD Tier 2, Table 3.9-2 provides a modification to the ASME Class 2 and 3 criteria to address SSE seismic anchor motion stresses. However note 12 did not include any additions/changes to the Class 1 piping requirements of ASME Code Section III, Subsection NB-3600, for equations 10, 11 and 12 (similar to the additions/changes made for Class 2 and 3 piping). Clarify whether there are any additions or changes for the Class 1 piping requirements and what earthquake level (for inertia and SAM) will be used to satisfy the ASME Code equations.

GE Response

Table 3.9-2 specifies SSE load. This includes the inertia and the anchor motion effect. This is the same designation as other dynamic loads. The SAM is included in Equation 10, 12, 13 and 14 evaluations. The piping design specification for Service Level A&B is shown below as an example.

Table 2. Main Steam Piping System

Condition	**Load Combination for All Terms**(1)(2)(3)	**Acceptance Criteria**(7)
Service Levels A & B	PP, TE, ΔT1(4), ΔT2(5), TA-TB(6), RV_1, RV_2I, RV_2D, TSV, SSEI, SSED	Eq 12 & 13 ≤2.4 S_m Fatigue - NB-3653 U < 0.1

NRC RAI 3.12-19

DCD Tier 2, Section 3.7.1.2 and Table 3.7-1 specify damping values to be used in the seismic analysis of SSCs. The DCD indicates that ASME Code Case N-411-1 may be used as permitted by RG 1.84 in place of Regulatory Guide 1.61 damping values. As indicated in RAI 3.12-2, Code Case N-411 has been annulled by the ASME. The DCD also indicates that ASME Code Case N-411-1 damping cannot be used for analyzing linear energy absorbing supports designed in accordance with ASME Code Case N-420. Indicate whether the damping values, corresponding to Code Case N-411-1 and meeting the conditions listed in Table 4 of RG 1.84, Rev. 33, will be used for the independent support motion (ISM) method. If the Code Case N-411-1 will be used, then provide the technical basis for using these damping values with the ISM method.

GE Response

References to ASME Code Case N-411-1 are being deleted from Section 3.7 in DCD Revision 2. To maintain this option in the ESBWR design, N-411-1 damping curve and associated conditions permitted by RG 1.84, including the limitations for use with the ISM method, will be explicitly described. Markups of the affected DCD pages are attached.

NRC RAI 3.12-20

In DCD Tier 2, Section 3.7.2.7, the cutoff frequency for modal responses is defined as the frequency at which the spectral acceleration approximately returns to the ZPA of the input response spectrum. Define this cutoff frequency quantitatively for seismic and other building dynamic loads applicable to the piping analysis for the ESBWR.

GE Response

The ZPA cutoff frequency for modal response analysis of subsystems for seismic and other building dynamic loads is 100 Hz or the rigid frequency as defined as f2 in DG-1127, Proposed Revision 2 of Regulatory 1.92. DCD Tier 2, Section 3.7.2.7 will be updated accordingly and markups of the affected DCD pages are attached.

NRC RAI 3.12-21

For the analyses of vibratory loads (other than seismic) with significant high-frequency input (e.g., above 33 Hz), describe:

(a) The modal combination method to be used for the high frequency modes above the cutoff frequency for vibratory loads.

(b) The nonlinear analysis method to be used to account for large gaps between the pipe and its supports.

GE Response

(a) The modal combination to be used for the high frequency modes above the cutoff frequency for vibratory loads is performed according to Appendix A of SRP 3.7.2.

(b) In general, the clearance of the supports considered in the piping analysis is sufficiently small so that a non-linear analysis is not needed. If this case should happen, a detailed analysis would be carried out with finite elements using the appropriate evaluation tools.

NRC RAI 3.12-22

DCD Tier 1, Section 3.1, "Piping design," states that Class 1 piping systems will be analyzed for fatigue with environmental effects. Provide the analysis and design methods that will be used to perform the fatigue evaluation, including the environmental effects, for the ESBWR Class 1 piping systems.

GE Response

Requirements contained in ASME III NB-3653. The load combinations contained in Table 3.9-9, and the plant event cycles contained in Table 3.9-1 of the DCD, define the design conditions that are inputs to the fatigue analysis. Additionally, GE has additional design criteria for carbon steel and stainless steel materials that are intended to address environmental issues that have been applied to prior BWR applications, and are likewise being applied to the ESBWR piping design. Additionally, class 1 piping using a fatigue limit of 0.1 instead of the ASME Code acceptance limit of 1.0 in conjunction with a stress ratio limit of 0.80 for Equations 12 and 13 of the ASME Code in order to limit the number of pipe whip restraints within the containment. DCD paragraphs 3.9.3.3 and 3.9.3.4 will be revised in DCD Revision 2 to reflect this commitment as follows:

"Additionally, a fatigue usage limit of 0.10 is used as a design criteria for all Class 1 piping."

Evaluations have also determined that the ASME Code has conservative methods that provide additional margins. Specifically, the ASME Code adds stresses that include P, Ma, Mb, Mc, DT1, DT2, and Dtab by absolute sum when in actuality the direction and signs of the stresses are different. Reference (1) has performed a detail finite element analysis to compare against the results of a NB-3600 analysis and found that the fatigue usage based on NB-3600 is about 10 times more conservative.

This design criteria that is being used for ESBWR is consistent with the design methods used on previous BWR product lines that have successfully operated for the last 40 years without piping fatigue issues. Data from fatigue usage monitors from operating plants have also confirmed that the design criteria specified by GE in the original plant design was conservative.

The simplified NB-3600 analysis has been used for last 40 years successfully. If newly developed environmental fatigue curves are used, high fatigue usage factors are predicted and pipe break locations will be postulated throughout the plant. The economical cost to the plant is huge, and any gain of safety is questionable.

It is recommended that the environmental fatigue design curves should not be used without substantial simultaneous changes in analytical methodology and the ASME Code.

Ref.1. "Fatigue Usage Factor Evaluation For An Integrally Reinforced Branch Connection Using NB-3600 And NB-3200 Analysis Methods" by Henry L. Hwang, PE, General Electric Nuclear Energy, Jack R. Cole, PE, David M. Bosi, PE, Design Engineering, Washington Public Power Supply System. PVP Vol. 313-2, page 139 through 156.

NRC RAI 3.12-23

Provide the analysis method that will be used to perform the fatigue evaluation of ESBWR Class 2, 3, and Quality Group D piping systems that are subject to cyclic loadings. Also, discuss how the environmental effects are considered in the Code Class 2 and 3 piping for which a fatigue analysis is performed.

GE Response

The Class 2 and Class 3 fatigue analyses are performed in accordance with the indications in NC-3611.2. The allowable stress reduction coefficient, *f*, is in accordance with Table NC-3611.2-1.

NRC RAI 3.12-24

NRC Bulletin 88-08 addresses unisolable sections of piping connected to the RCS (including the RPV) that may be subjected to temperature oscillations induced by leaking valves. Identify unisolable piping segments directly connected to the RCS and describe the analysis method to mitigate problems identified in Bulleting 88-08, including Supplements 1, 2 and 3.

GE Response

(1) NRCB 88-08 and NRCB, Supplement 1:

Theoretically, the problem of thermal fatigue in unisolable sections of piping connected to the RCS caused by cold water leaks through a normally closed block valve, with the pressure upstream of the valve greater than the RCS and the temperature upstream of the valve significantly lower than the RCS temperature, could occur in the following cases:

1.1 Condensate Isolation Valves of the Isolation Condenser System (B32). In the ESBWR, the problem of thermal stratification has been reduced to a minimum by means of a loop seal by providing a reduction in the pipeline where the condensate block valves are installed of 0.5 m minimum below the RPV nozzle elevation. The piping downstream of the condensate block valves are not insulated except for the horizontal piping directly connected to the RPV nozzle. In addition, temperature elements strapped or magnetically attached to the top and bottom surface of the horizontal pipe are provided to detect temperature stratification in the piping.

1.2 Standby Liquid Control System (C41) Squib Valves. In this case the problem of leaks does not exist due to the design of the squib valves.

(2) NRC 88-08, Supplement 3

The problem of injection of cold water through the stem seal connection of a normally closed gate valve could theoretically occur in the following cases:

2.1 Nuclear Boiling System (B21) RPV head vent piping drain line isolation valves. In the ESBWR globe type valves with bellow seals are provided.

2.2 The Gravity-Driven Cooling System (E50) squib valves do not have a seal line either.

Therefore it can be concluded that initially the condensate return piping of the Isolation Condensate Systems could be affected by the problem mentioned in NRC Bulletin 88.08 and that the design of the system in the ESBWR has taken into account the necessary measures to reduce the risk of stratification and to detect it.

NRC RAI 3.12-25

The effects of thermal stratification have been observed in both BWR and PWR feedwater piping as discussed in NRC Information Notice (IN) 84-87 and NRC IN 91-38. Described the method of analysis used in the ESBWR feedwater piping design to include the thermal stratification effects.

GE Response

IN 84-87 and IN 91-38 deal with the thermal stratification in Washington Nuclear Plant Unit 2, WNP-2 (BWR) and in Beaver Valley Unit 1, BV-1 (PWR). As indicated in IN 91 38, the three-loop design of BV 1 is especially prone to global thermal stratification in the feedwater pipes, which typically include long horizontal sections. Additionally, BWR plants are sensitive to the stratification effect during start-up when cold water is fed through preheated pipes.

The ABWR feedwater piping circumferential temperatures has been measured at various locations during startup and shutdown tests. The testing also included various designed operation transients. These test data, plus conservatisms, have been incorporated into the design duty cycle diagrams. Therefore, all the stratifications data are parts of the feedwater design requirements.

PISYS computer program has been written to calculate the piping forces and moments due to stratification. The solution has been benchmarked with ANSYS computer program results and exact solution by hand calculation for simple cases. The results of the stratification are included in the thermal cases. For ABWR feedwater piping analyses, there are 46 thermal cases calculated. Therefore, the thermal stratification effects have been incorporated in Equations 10 through 14 of NB-3650.

Furthermore, ESBWR have been designed to minimize the thermal stratification. In the case of WNP-2 (IN 84-87), an unusual design feature of the WNP-2 plant allows the feedwater system to be heated by the reactor water cleanup system (RWCU). The RWCU return lines join two 24-inch feedwater lines upstream from two isolation check valves, but downstream from normally open motor-operated valves. In many boiling water reactors, the RWCU enters the feedwater system between the inboard and outboard isolation check valves so that reverse flow of the RWCUS into the feedwater system is impossible. In the case of the ESBWR, the RWCU/SDC feeds water into the Nuclear Boiler System (NBS) in the feedwater section between two check valves (Figure 5.1-2 Nuclear Boiler System Schematic Diagram), so reverse flow of the RWCU/SDC into the feedwater system is impossible. {See NEDC-33084P Revision 1 page 3.1-27, GE proprietary information}.

In the case of the BV-1 (IN 91-38), the longest horizontal section in the ESBWR design is of approximate 50 ft. In addition, this section has the anti-stratification RWCU/SDC connection. Furthermore, within the containment, the feedwater line has seven direction changes before the connection to the RPV.

NRC RAI 3.12-26

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 SRVs purchased and installed at the COL applicant stage will match the test and design parameters used at the design certification state. 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.

GE Response

GE & BWR owner has performed SRV tests at Wyle in Huntsville, Alabama in August, 1981. The forces due to SRV discharge had been measured. It confirms that 20 msec opening time should be used. The results were presented in a paper "Comparison of the Performances of the Strut and Snubber Subject to Dynamic Load", by H. L. Hwang and E. O. Swain, Proceedings of International Nuclear Power Plant Thermal Hydraulics and Operations Topical Meeting, page J1 to J10. Taipei, Taiwan, Republic of China, October 22-24, 1984."

The computer program, RVFOR, is described in Appendix 3D paragraph 3D.4.4.1. This program is available for COL applicant to use whenever needed. Example input and output will be also available in the User's manual.

NRC RAI 3.12-27

DCD Tier 2, Section 3.7.3.12, discusses the effect of differential building movement on piping systems that are anchored and restrained to floors and walls of buildings that may have differential movements during a dynamic event. SRP 3.9.2 Section II.2.g states that the responses due to the inertial effect and relative displacement for multiply-supported equipment and components with distinct inputs should be combined by the absolute sum method. Provide the combination methods that are to be used in the design of ESBWR piping systems for the inertial responses and SAM responses caused by relative displacements for all analysis methods (including ISM).

GE Response

DCD Tier 2, Section 3.7.3.12, discusses the effect of differential building movement on piping systems that are anchored and restrained to floors and walls of buildings that may have differential movements during a dynamic event. In general, the piping systems are anchored and restrained to floors and walls of buildings that may have differential movements during a seismic event. The movements may range from insignificant differential displacements between rigid walls of a common building at low elevations to relatively large displacements between separate buildings at a high seismic activity site.

Piping system is different from multiply-supported equipment. For piping system, the induced displacements in compliance with NB 3653 are treated differently than the inertia displacements. The SRSS method is a standard industrial practice to combine the inertial responses and SAM responses caused by relative displacements.

NRC RAI 3.12-28

The DCD did not indicate whether piping thermal analyses of piping systems will be performed for all temperature conditions above ambient. If this is not the case, then provide the minimum temperature at which an explicit piping thermal expansion analysis would be required. Also, provide the technical basis for the selected minimum temperature.

GE Response

For Class 1 piping, all the operating temperatures above ambient or below ambient are included in the fatigue analysis. Even the ambient temperature is included as a load set with defined cycles. The stress free state of a piping system is defined as a temperature of 21°C (70°F). For Class 2, 3 or B31.1 piping, no thermal expansion analysis will be performed for piping with system operating temperature of 65°C (150°F) or less.

<u>NRC RAI 3.12-29</u>

DCD Tier 2, Appendix 3K, Section 3K.2, acknowledges that, as part of the resolution of the intersystem LOCA issue, the staff requires in addition to other requirements, that periodic surveillance and leak rate testing of the pressure isolation valves via Technical Specifications, as part of the ISI program. Indicate where in the DCD is the requirement that the COL applicant must perform this periodic surveillance and leak rate testing.

<u>GE Response</u>

DCD Tier 2 Appendix 3K, Section 3K2 describes NRC positions related to the design of low pressure piping system that interface with reactor coolant pressure boundary. These positions, which were developed during NRC review of ABWR, were taken into consideration in the development of ESBWR design.

The statement describes an NRC requirement on surveillance and leak rate testing of the pressure isolation valve between reactor coolant pressure boundary and a low pressure system. Because there is no such kind of pressure isolation valves identified in ESBWR, this NRC requirement is not applied in the ESBWR design.

For clarification, the following statement will be added in Section 3K2 of the next revision of DCD Tier 2. "The periodic surveillance and leak rate testing requirements for high-pressure to low-pressure isolation valves are not applicable to the ESBWR, because, as shown in this appendix, the ESBWR design does not contain a pressure isolation valve between the reactor coolant pressure boundary and a low pressure piping system."

NRC RAI 3.12-30

DCD Tier 2, Section 3.9.3.7.1, states: "The building structure component supports are designed in accordance with ANSI/AISC N690, Nuclear Facilities-Steel Safety-Related Structures for Design, Fabrication and Erection, or the AISC specification for the Design, Fabrication, and Erection of Structural Steel for buildings, correspond to those used for design of the supported pipe." Clarify what this sentence means, particularly the phrase "correspond to those used for design of the supported pipe." Also, identify the edition of these specifications because the titles do not match the corresponding specifications given in Tables 3.8-6 and 3.8-9 of the DCD.

GE Response

The paragraph "The building structure...supported pipe" will be modified in DCD Revision 2 as shown below.

"Supports and their attachments for ASME Code Class 1, 2 and 3 piping are designed in accordance with Subsection NF[1] up to the interface of the building structure, with jurisdiction boundaries as defined by Subsection NF. The loading combinations for various operating conditions correspond to those used for design of the supported pipe."

NRC RAI 3.12-31

(1) *DCD Tier 2, Section 3.9.3.7, states that concrete anchor bolts used in pipe supports are designed to the factors of safety defined in IE Bulletin 79-02, Revision 1 and pipe support base plate flexibility will be accounted for in accordance with IE Bulleting 79-02. Clarify that all aspects of the anchor bolt design (not just the factor of safety) will follow IE Bulletin 79-02, Revision 2 (not Revision 1).*

(2) *Indicate whether the design and installation of all anchor bolts will also be performed in accordance with Appendix B to ACI 349-01- "Anchoring to Concrete," subject to the conditions and limitations specified in RG 1.199.*

(3) *Define the term Seismic Category IIA used in DCD Tier 2, Section 3.9.3.7, and explain how it differs from Category II.*

GE Response

(1) Concrete expansion anchor bolts, with regard to safety factor and anchor plates flexibility, will follow all aspects IE Bulletin 79-02 Rev 2 dated November 8, 1979. Expansion anchor bolts shall not be used for any safety related system components.

(2) The design and installation of all other anchor bolts will be performed in accordance with Appendix B to ACI 349-01 "Anchoring to Concrete", subject to the conditions and limitations specified in RG 1.199.

(3) Seismic Category IIA does not exist. DCD will be changed from "IIA" to "II" in DCD Revision 2.

NRC RAI 3.12-32

DCD Tier 2, Section 3.7.3.3.1, provides some limited information about modeling the stiffness of guides and snubbers by using representative stiffness values. Some additional information about snubbers is provided in DCD Tier 2, Section 3.9.3.7.1, which describes the procedures to ensure that the spring constant achieved by the snubber supplier matches the spring constant used in the piping system model. However, the DCD does not adequately describe how the representative stiffness values are developed for all supports other than snubbers. Therefore, 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.

GE Response

(1) Standard practice is to consider the minimum stiffness values stated in Welding Research Council (WRC)-353. These are obtained in such a way that the support is a stiff point for the pipe in the restricted direction; in general, a minimum value of $200EI/L^3$ is accepted. For struts and snubbers, the stiffness to consider is the combine stiffness of Strut/Snubber, Pipe Clamp and piping support steel.

(2) Standard stiffness values developed for Lungmen project will be used. Pipe support will be designed to satisfy stiffness used in piping analysis.

(3) In general, pipe support component weights, which are directly attached to a pipe such as a Clamp, Strut, Snubber are considered in piping analysis.

(4) The stiffness for the building steel/structure (i.e., beyond the NF jurisdictional boundary) are not considered in pipe support overall stiffness because the stiffness is much higher than the pipe support steel.

NRC RAI 3.12-33

DCD Tier 2, Section 3.7.3 and 3.9.3 do not provide a description of the analysis methods or design requirements needed to evaluate the effects of seismic and other dynamic (support) self-weight excitation for ESBWR pipe supports. Provide this information, which is especially important for the larger and more massive type supports. The description should consider these effects on the support structure and anchorage. In addition, the description should consider all loads transmitted from the piping to the support and the support internal loads caused by self-weight, thermal, and inertia effects due to the support mass.

GE Response

The ESBWR pipe supports meet WRC Bulletin 353 stiffness criteria to preclude self-weight excitation.

In general, pipe support weight, such as snubber clamp or strut clamp on the pipe, is considered in piping analysis. The larger and more massive type supports will be evaluated in detail.

NRC RAI 3.12-34

DCD Tier 2, Section 3.9.3.7, describes the criteria and design requirements for piping supports of ESBWR piping. However, the DCD does not describe how friction loads imparted on pipe

GE Response

There are no sliding supports used for ESBWR.

The friction loads caused by unrestricted motion of the piping are considered to act on the support with a friction coefficient of 0.3, in the case of steel-to-steel friction. For stainless steel, Teflon, and other materials, the friction coefficient could be less. The friction stresses are not considered during seismic or dynamic loadings.

NRC RAI 3.12-35

DCD Tier 2, Section 3.9.3.7, describes the criteria and design requirements for piping supports of ESBWR piping. The DCD does not provide any description of the development and specification of hot and cold gaps to be used between the pipe and the box frame type supports. Provide this information.

GE Response

Current industry practice is to limit the total gap on frame type pipe supports in the range of 1/8 in. depending on the location of the application. In general this gap will be adequate for the radial thermal expansion of the pipe to avoid any thermal binding. For large pipe with much higher temperature, this gap will be evaluated to assure no thermal binding.

<u>NRC RAI 3.12-36</u>

DCD Tier 2, Section 3.9.3.7, describes the criteria and design requirements for piping supports of ESBWR piping. However, the DCD does not provide any information on the analysis and design criteria for instrumentation line supports. Provide this information

<u>GE Response</u>

The instrumentation lines will be supported taking into account the flexibility and thermal and dynamic motion requirements of the pipe to which they connect. The supports on the instrumentation lines are located/positioned by taking into account the characteristics of said lines (self weight, temperature, seismic or dynamic loads as a function of their location, etc.).

NRC RAI 3.12-37

DCD Tier 2, Section 3.9.3.7, describes the criteria and design requirements for piping supports of ESBWR piping. The DCD indicates that maximum calculated static and dynamic deflections of the piping at support locations do not exceed the allowable limits specified in the "suspension design specification". The purpose of the allowable limits is to preclude failure of the pipe supports due to piping deflections. Provide an additional discussion of the "suspension design specification." Also, describe how the deflection limits are developed.

GE Response

Standard practice in calculating piping supports is to consider a deflection limit of 1.6 mm for erection and operation loadings, based on WRC-353 paragraph 2.3.2. For the consideration of loads due to SSE and in the cases of springs, the deflection limit is increased to 3.2 mm. "Suspension Design Specification" will be changed to "Piping Design Specification" in the DCD Revision 2.

Table 1.9-22

Industrial Codes and Standards[2] Applicable to ESBWR

Code or Standard Number	Year	Title
PTC 25-2001	2001	Pressure Relief Devices
PTC 26-1962	1962	Speed Governing Systems for Internal Combustion Engine Generator Units
TDP-1-1998	1998	Recommended Practices for the Prevention of Water Damage to Steam Turbines Used for Electric Power Generation (Fossil)
TDP-2-1985	1985	Recommended Practices for the Prevention of Water Damage to Steam Turbines Used for Electric Power Generation (Nuclear)
BPVC Sec I	2001 including Addenda through 2003	Boiler & Pressure Vessel Code (BPVC) Section I, Power Boilers
BPVC Sec II	2001 including Addenda through 2003	BPVC Section II Part A Ferrous Material Part B Non-Ferrous Material Part C Welding Rods, Electrodes, and Filler Metals Part D Properties
BPVC Sec III	2001 including Addenda through 2003	BPVC Section III, Rules for Construction of Nuclear Power Plant Components Division 1: NB, NC, NCA, ND, NE, NF, NG Division 2: CC, NCA Code for Concrete Reactor Vessels and Containments
BPVC Sec V	2001 including Addenda through 2003	BPVC Section V: Nondestructive Examination
BPVC Sec VIII	2001 including Addenda through 2003	BPVC Section VIII: Div. 1 Rules for Construction of Pressure Vessels Div. 2 Pressure Vessel, Alternative Rules
BPVC Sec IX	2001 including Addenda through 2003	BPVC Section IX, Qualification Standard for Welding and Brazing Procedures Welder, Brazers and Welding and Brazing Operators
BPVC Sec XI	2001 including Addenda through 2003	BPVC Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components
BPVC OM Code	2001 including Addenda through 2003	BPVC Code for Operation and Maintenance of Nuclear Power Plants
ASME Steam Tables	1967	Thermodynamic and Transport Properties of Steam

Table 3.8-6

Codes, Standards, Specifications, and Regulations Used in the Design and Construction of Seismic Category I Internal Structures of the Containment

Specification Reference Number	Specification or Standard Designation	Title
1	ACI 301-99	Specifications for Structural Concrete for Builders
2	ACI 307-88	Recommended Practice for Concrete Formwork
3	ACI 305-99	Recommended Practice for Hot Weather Concreting
4	ACI 211.1-91	Recommended Practice for Selecting Proportions for Normal Weight Concrete
5	ACI 315-99	Manual of Standard Practice for Detailing Reinforced Normal Weight Concrete
6	ACI 306-88	Recommended Practice for Cold Weather Concreting
7	ACI 309-96	Recommended Practice for Consolidation of Concrete
8	ACI 308-98	Recommended Practice for Curing Concrete
9	ACI 212-86	Guide for use of Admixtures in Concrete
10	ACI 214-02	Recommended Practice for Evaluation of Compression Test results of Field Concrete
11	ACI 311-88	Recommended Practice for Concrete Inspection
12	ACI 304-00	Recommended Practice for Measuring, Mixing, Transporting, and Placing Concrete
13	ACI 349-01	Code Requirements for Nuclear Safety-Related Concrete Structures
14	ASME-2001 through 2003 Addenda	Boiler and Pressure Vessel Code Section III, Division 2, Subsection CC.
15	ANSI/AISCN690-1994s2 (2004)	Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities
16	AWS D1.1-04	Structural Welding Code
17	EPRI NP-5380, 1987	Visual Weld Acceptance Criteria for Structural Welding at Nuclear Power Plants (Nuclear Construction Institute Group) Rev. 2, Sep. 1987.
18	ANSI/ASME NQA-1-1989	Quality Assurance Program Requirements for Nuclear Facilities, with Addenda 1a-1989, 1b-1991, and 1c-1992 (Note: more recent revisions exist)
19	Not Used	

Table 3.8-9

Codes, Standards, Specifications, and Regulations Used in the Design and Construction of Seismic Category I Structures

Specification Reference Number	Specification or Standard Designation	Title
1	*ACI 349-01*	Code Requirements for Nuclear Safety-Related Concrete Structures
2	*ANSI/AISC-N690-1994s2(2004)*	Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities"
3	*ASME-2001 through 2003 Addenda*	Boiler and Pressure Vessel Code Section III, Division 2, Subsection CC
4	ASME-2001 through 2003 Addenda	Boiler and Pressure Vessel Code Section III, Subsection NE, Division 1, Class MC
5	ANSI/ASME NQA-1-1989	Quality Assurance Program Requirements for Nuclear Facilities, with Addenda 1a-1989, 1b-1991, and 1c-1992 (Note: more recent revisions exist)
6	AWS D1.1 -04	Structural Welding Code - Steel
7	AWS D1.4 -98	Structural Welding Code - Reinforcing Steel
8	AWS D1.6-99	Structural Welding Code for Stainless Steel
9	ASCE 4-98	Seismic Analysis of Safety-Related Nuclear Structures
10	ASCE 7-02	Minimum Design Loads for Buildings and Other Structures
11	AISC360-05	2005 AISC Specification for Structural Steel Building
12	SSPC-PA-1-00	Paint Application Specification No. 1, Shop, Field and Maintenance Painting of Steel
13	SSPC-PA-2-04	Paint Application Specification No. 2, Measurement of Dry Coating Thickness with Magnetic Gages
14	SSPC-SP-1-82	Surface Preparation Specification No. 1, Solvent Cleaning
15	SSPC-SP-5-00	Surface Preparation Specification No. 5, White Metal Blast Cleaning
16	SSPC-SP-6-00	Surface Preparation Specification No. 6, Commercial Blast Cleaning
17	SSPC-SP-10-00	Surface Preparation Specification No. 10, Near-White Blast Cleaning
18	Not Used	
19	Not Used	
20	Regulatory Guide 1.28	Quality Assurance Program Requirements" (Design and Construction), Aug. 1985
21	Regulatory Guide 1.29	Seismic Design Classification, Sep. 1978
22	Regulatory Guide 1.31	Control of Ferrite Content in Stainless Steel Weld Metal, Apr. 1978
23	Regulatory Guide 1.44	Control of the Use of Sensitized Stainless Steel, May 1973
24	Not Used	
25	Regulatory Guide 1.60	Design Response Spectra for Seismic Design of Nuclear Power Plants, Dec. 1973
26	Regulatory Guide 1.61	Damping Values for Seismic Design of Nuclear Power Plants, Oct. 1973
27	Regulatory Guide 1.69	Concrete Radiation-Shields for Nuclear Power Plants, Dec. 1973
28	Regulatory Guide 1.76	Design Basis Tornado for Nuclear Power Plants, Apr. 1974

n = number of modes considered in the analysis

If some or all of the modes are closely spaced, any one of the three methods (grouping method, 10% method, and double sum method) presented in Regulatory Guide 1.92 is applicable for the combination of modal responses.

For modal combination involving high-frequency modes, the following procedure applies:

Step 1 — Determine the modal responses only for those modes that have natural frequencies less than that at which the spectral acceleration approximately returns to the ZPA of the input response spectrum. The ZPA cutoff frequency is 100 Hz or the rigid frequency defined as f2 in DG-1127, Proposed Revision 2 of Regulatory Guide 1.92. It is applicable to seismic and other building dynamic loads. Combine such modes in accordance with the methods described above.

Step 2 — For each degree of freedom (DOF) included in the dynamic analysis, determine the fraction of DOF mass included in the summation of all of the modes included in Step 1. This fraction d_i for each DOFi is given by:

$$d_i = \sum_{n=1}^{N} \Gamma_n \times \phi_{n,i} \tag{3.7-11}$$

where

n = order of the mode under consideration

N = number of modes included in Step 1

$\phi_{n,i}$ = mass-normalized mode shape for mode n and DOFi

Γ_n = participation factor for mode n (see Equation 3.7-3 for expression).

Next, determine the fraction of DOF mass not included in the summation of these modes (e_i):

$$e_i = |d_i - \delta_{ij}| \tag{3.7-12}$$

where δ_{ij} is the Kronecker delta, which is one if DOFi is in the direction of the input motion and zero if DOFi is a rotation or not in the direction of the input motion. If, for any DOFi, the absolute value of this fraction e_i exceeds 0.1, one should include the response from higher modes with those included in Step 1.

Step 3 — Higher modes can be assumed to respond in phase with the ZPA and, thus, with each other; hence, these modes are combined algebraically, which is equivalent to pseudo-static response to the inertial forces from these higher modes excited at the ZPA. The pseudo-static inertial forces associated with the summation of all higher modes for each DOFi are given by:

$$P_i = ZPA \times M_i \times e_i \tag{3.7-13}$$

where P_i is the force or moment to be applied at DOFi, and M_i is the mass or mass moment of inertia associated with DOFi. The system is then statically analyzed for this set of pseudo-static

$\{P\}$ = column vector of time-dependent applied forces

= $-[M]\{\ddot{x}_g\}$ for support excitation in which $\{\ddot{x}_g\}$ is column vector of time-dependent support accelerations

The above equation can be solved by modal superposition or direct integration in the time domain, or by the complex frequency response method in the frequency domain. For the time domain solution, the numerical integration time step is sufficiently small to accurately define the dynamic excitation and to render stability and convergency of the solution up to the highest frequency (or shortest period) of significance. 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%. For most of commonly used numerical integration methods (such as Newmark β-method and Wilson θ-method), the maximum time step is limited to one-tenth of the shortest period of significance. For the frequency domain solution, the dynamic excitation time history is digitized with time steps no larger than the inverse of two times the highest frequency of significance and the frequency interval is selected to accurately define the transfer functions at structural frequencies within the range of significance.

The modal superposition method is used when the equation of motion (Equation 3.7-1) can be decoupled using the transformation,

$$\{u\} = [\phi]\{q\} \tag{3.7-2}$$

where,

$[\phi]$ = mode shape matrix; often mass normalized, i.e., $[\phi]^T[M][\phi] = [1]$

$\{q\}$ = column vector of normal or generalized coordinates

Substituting Equation 3.7-2 into Equation 3.7-1 and multiplying each term by the transposition of the mode shape matrix results in the uncoupled equation of motion due to the orthogonality of the mode shapes (note that the orthogonality condition of the damping matrix is assumed). For systems subjected to base acceleration excitation, $\ddot{x}_g$, the equation of motion for the jth mode is

$$\ddot{q}_j + 2\lambda_j\omega_j\dot{q}_j + \omega_j^2 q_j = -\Gamma_j\ddot{x}_g \tag{3.7-3}$$

where

q_j = generalized coordinate of jth mode

λ_j = damping ratio of jth mode, expressed as fraction of critical damping

ω_j = undamped circular frequency of jth mode

Γ_j = modal participation factor of jth mode

3.7.2.9 Effects of Parameter Variations on Floor Response Spectra

Floor response spectra calculated according to the procedures described in Subsection 3.7.2.5 are peak broadened to account for uncertainties in the structural frequencies owing to uncertainties in the material properties of the structure and soil and to approximations in the modeling techniques used in the analysis. If no parametric variation studies are performed, the spectral peaks associated with each of the structural frequencies are broadened by ±15%. If a detailed parametric variation study is made, the minimum peak broadening ratio is ±10%. In lieu of peak broadening, the peak shifting method of Appendix N of ASME Section III, as permitted by Regulatory Guide 1.84, can be used.

When the calculated floor acceleration time history is used in the time history analysis for piping and equipment, the uncertainties in the time history are accounted for by expanding and shrinking the time history within 1/(1±0.15) so as to change the frequency content of the time history within ±15%. Alternatively, a synthetic time history that is compatible with the broadened floor response spectra may be used.

The methods of peak broadening described above are applicable to seismic and other building dynamic loads.

3.7.2.10 Use of Equivalent Vertical Static Factors

Equivalent vertical static factors are used when the requirements for the static coefficient method in Subsection 3.7.2.1.3 are satisfied. All Seismic Category I structures are dynamically analyzed in the vertical direction. No constant static factors are utilized.

3.7.2.11 Methods Used to Account for Torsional Effects

One method of treating the torsional effects in the dynamic analysis is to carry out a dynamic analysis that incorporates the torsional degrees of freedom. For structures having negligible coupling of lateral and torsional motions, a two-dimensional model without the torsional degrees of freedom can be used for the dynamic analysis and the torsional effects are accounted for in the following manner. The locations of the center of mass are calculated for each floor. The center of rigidity and torsional stiffness are determined for each story. Torsional effects are introduced in each story by applying a torsional moment about its center of rigidity. The torsional moment is calculated as the sum of the products of the inertial force applied at the center of mass of each floor above, and a moment arm equal to the distance from the center of mass of the floor to the center of rigidity of the story, plus 5% of the maximum building dimension at the level under consideration. To be conservative, the absolute values of the moments are used in the sum. The torsional moment and story shear are distributed to the resisting structural elements in proportion to each individual stiffness.

3.7.2.12 Comparison of Responses

Since only the time history method is used for the dynamic analysis of Seismic Category I structures, a comparison of responses with the response spectrum method is not necessary.

The timewise solution of Equation 3.7-8 can be obtained easily by using the standard normal mode solution technique. After obtaining the displacement response of the active degrees of freedom (U_a), Equation 3.7-7 can then be used to solve the support point reaction forces (F_s). Analysis can be performed using either the time history method or response spectrum method. Additional considerations associated with the ISM response spectrum method of analysis are given in Subsection 3.7.3.9.

3.7.2.1.3 Static Coefficient Method

This is an alternative method of analysis that allows a simpler technique in return for added conservatism. This method does not require determination of natural frequencies. The response loads are determined statically by multiplying the mass value by a static coefficient equal to 1.5 times the maximum spectral acceleration at appropriate damping value of the input response spectrum. A static coefficient of 1.5 is intended to account for the effect of both multi-frequency excitation and multi-mode response for linear frame-type structures, such as members physically similar to beams and columns, which can be represented by a simple model similar to those shown to produce conservative results (References 3.7-13 and 3.7-14). A factor of less than 1.5 may be used if justified. If the fundamental frequency of the structure is known, the spectral acceleration value at this frequency can be multiplied by a factor of 1.5 to determine the response. A factor of 1.0 instead of 1.5 can be used if the component is simple enough such that it behaves essentially as a single-degree-of-freedom system. When the component is rigid, it is analyzed statically using the Zero Period Acceleration (ZPA) as input. Structures, systems, and components are considered rigid when the fundamental frequency is equal to or greater than the frequency at which the input response spectrum returns to approximately the ZPA. Relative displacements between points of support are also considered and the resulting response is combined with the response calculated using the equivalent static method.

3.7.2.2 Natural Frequencies and Responses

Natural frequencies and SSE responses of Category I buildings are presented in Appendix 3A.

3.7.2.3 Procedures Used for Analytical Modeling

The mathematical model of the structural system is generally constructed as a stick model or a finite element model. The details of the model are determined by the complexity of the actual systems and the information required from the analysis. In constructing the primary structural system model, the following subsystem decoupling criteria are applicable:

- If $R_m < 0.01$, decoupling can be done for any R_f.
- If $0.01 \le R_m \le 0.1$, decoupling can be done if $R_f \le 0.8$ or $R_f \ge 1.25$.
- If $R_m > 0.1$, a subsystem model should be included in the primary system model

where R_m (mass ratio) and R_f (frequency ratio) are defined as:

R_m = total mass of the supported subsystem/total mass of the supporting system

3.7-8 ASCE 4-98, "Seismic Analysis of Safety-Related Nuclear Structures and Commentary."

3.7-9 R. W. Clough et al., "Dynamics of Structure," McGraw-Hill, 1975.

3.7-10 Electric Power Research Institute, "Guidelines for Nuclear Plant Response to an Earthquake," EPRI NP-6695, December 1989.

3.7-11 Electric Power Research Institute, "A Criterion for Determining Exceedance of the Operating Basis Earthquake," EPRI NP-5930, July 1988.

3.7-12 Electric Power Research Institute, "Standardization of Cumulative Absolute Velocity," EPRI TR-100082, December 1991.

3.7-13 Stevenson, J.D., and LaPay, W.S. "Amplification Factors to be Used in Simplified Seismic Dynamic Analysis of Piping Systems." Presented at the ASME Pressure Vessels and Piping Conference, Miami Beach, Fla., June 1974.

3.7-14 Lin, C.W. and Esselman, T.C. "Equivalent Static Coefficients for Simplified Seismic Analysis of Piping Systems." Proc., 7th International Conference on Structural Mechanics in Reactor Technology, August 1983.

The time histories of three spatial components are checked for statistical independency. The cross-correlation coefficient at zero time lag is 0.01351 between H1 and H2, 0.07037 between H1 and VT, and 0.07367 between H2 and VT. The cross-correlation coefficients are less than 0.16 as recommended in the reference of Regulatory Guide 1.92. Thus, H1, H2, and VT acceleration time histories are mutually statistically independent.

3.7.1.1.3 North Anna ESP Design Ground Motion

The ESBWR Reactor Building (RB) and Control Building (CB) foundations are embedded at depth of 20.15m (66 ft) and 15.05m (49 ft), respectively. The Fuel Building (FB) shares a common foundation mat with the RB. The corresponding foundation elevations at North Anna ESP site are EL. 205 ft for RB/FB and EL. 222 ft for CB. Since the low frequency parts of North Anna SSE ground spectra are enveloped by the 0.3g Regulatory Guide 1.60 generic site spectra with large margins, only the high frequency part needs to be explicitly taken into account. The high frequency SSE ground spectra and compatible time histories at elevations of CB and RB/FB foundation level are shown in Figures 3.7-24 to 3.7-35.

Data	CB Base	RB/FB Base
Horizontal H1 target spectrum	Figure 3.7-24	Figure 3.7-30
Horizontal H1 time histories	Figure 3.7-25	Figure 3.7-31
Horizontal H2 target spectrum	Figure 3.7-26	Figure 3.7-32
Horizontal H2 time histories	Figure 3.7-27	Figure 3.7-33
Vertical target spectrum	Figure 3.7-28	Figure 3.7-34
Vertical time histories	Figure 3.7-29	Figure 3.7-35

The spectrum figures are associated with 5% damping. The PGA values, corresponding to the spectral acceleration at 100 Hz of the target spectra, are 0.492g at the CB base and 0.469g at the RB/FB base in both horizontal and vertical directions. The time histories are generated under the spectral matching criteria given in NUREG CR-6728 and the cross-correlations between the three individual components are all less than the 0.3 requirement.

3.7.1.2 Percentage of Critical Damping Values

Damping values of various structures and components are shown in Table 3.7-1 for use in SSE dynamic analysis. These damping values are consistent with Regulatory Guide 1.61 SSE damping except for the damping value of cable trays and conduits.

The damping values shown in Table 3.7-1 and Figure 3.7-36 for cable trays and conduits are based on the results of over 2000 individual dynamic tests conducted by Bechtel/ANCO for a variety of raceway configurations (Reference 3.7-5). The damping value of cable tray systems (including supports) depends on the level of input motion and the amount of cable fill. In the acceleration range of interest to the ESBWR design, the damping value is 7% for empty trays, and it increases to 20% for 50% to fully loaded trays. For trays loaded to less than 50% the damping value can be obtained by linear interpolation. The damping value of conduit systems (including supports) is 7% constant. For HVAC ducts and supports the damping value is 7% for companion angle or pocket lock construction and is 4% for welded construction.

For ASME Section III, Division 1 Class 1, 2, and 3, and ASME/ANSI B31.1 piping systems, alternative damping values specified in Figure 3.7-37 may be used. The damping values shown in Table 3.7-1 are applicable to all modes of a structure or component constructed of the same

3.7.3.5 *Analysis Procedure for Damping*

Damping values for equipment and piping are shown in Table 3.7-1 and are consistent with Regulatory Guide 1.61. For ASME Section III, Division 1 Class 1, 2, and 3, and ASME/ANSI B31.1 piping systems, alternative damping values specified in Figure 3.7-37 may be used. For systems made of subsystems with different damping properties, the analysis procedures described in Subsection 3.7.2.13 are applicable.

3.7.3.6 *Three Components of Earthquake Motion*

The applicable methods of spatial combination of responses due to each of the three input motion components are described in Subsection 3.7.2.6.

3.7.3.7 *Combination of Modal Responses*

The applicable methods of modal response combination are described in Subsection 3.7.2.7.

3.7.3.8 *Interaction of Other Systems with Seismic Category I Systems*

Each non-Category I (i.e., C-II or NS) system is designed to be isolated from any Seismic Category I system by either a constraint or barrier, or is remotely located with regard to the Seismic Category I system. If it is not feasible or practical to isolate the Seismic Category I system, adjacent non-Category I systems are analyzed according to the same seismic criteria as applicable to the Seismic Category I systems. For non-Category I systems attached to Seismic Category I systems, the dynamic effects of the non-Category I systems are simulated in the modeling of the Seismic Category I system. The attached non-Category I systems, up to the first anchor beyond the interface, are also designed in such a manner that during an earthquake of SSE intensity it does not cause a failure of the Seismic Category I system.

3.7.3.9 *Multiply-Supported Equipment and Components with Distinct Inputs*

For multi-supported systems (equipment and piping) analyzed by the response spectrum method for the determination of inertial responses, either of the following two input motions are acceptable:

- Envelope response spectrum with USM applied at all support points for each orthogonal direction of excitation; or
- ISM response spectrum at each support for each orthogonal direction of excitation.

When the ISM response spectrum method of analysis (Subsection 3.7.2.1.2) is used, a support group is defined by supports that have the same time-history input. This usually means all supports located on the same floor, or portions of a floor, of a structure. The responses caused by motions of supports in two or more different groups are combined by the SRSS procedure.

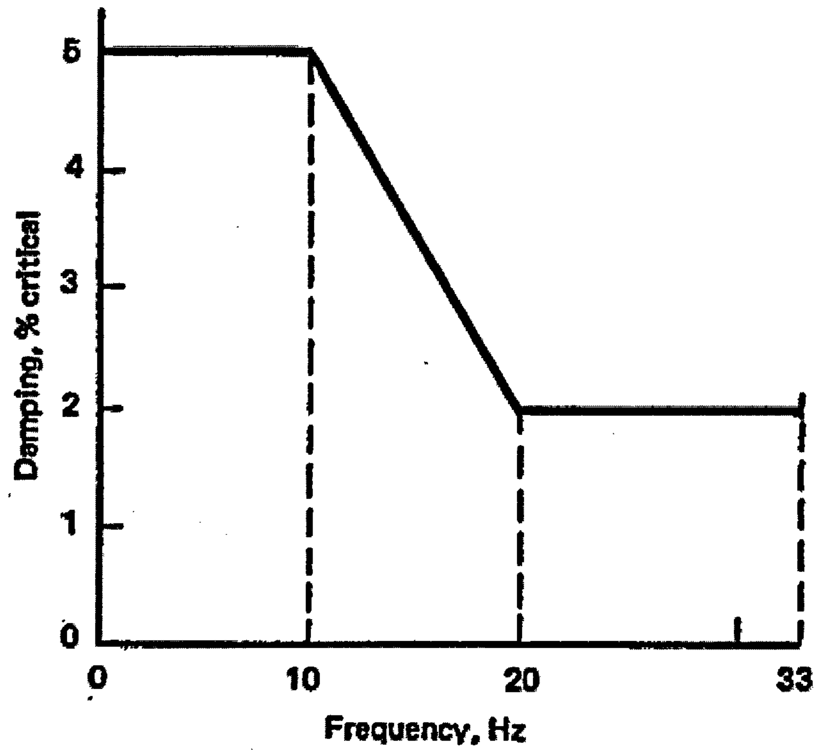
In addition to the inertial response discussed above, the effects of relative support displacements are considered. The maximum relative support displacements are obtained from the dynamic analysis of the building, or as a conservative approximation, by using the floor response spectra. For the latter option, the maximum displacement of each support is predicted by $S_d = S_a g/\omega^2$, where S_a is the spectral acceleration in "g's" at the high-frequency end of the spectrum curve (which, in turn, is equal to the maximum floor acceleration), g is the gravity constant, and ω is

Table 3.7-1

Damping Values for SSE Dynamic Analysis

Components	Percent of Critical Damping
Reinforced concrete structures	7.0
Steel frame structures	4.0
Welded steel assemblies	4.0
Bolted steel assemblies	7.0
Equipment	3.0
Piping systems [1]	
- diameter greater than 305 mm (12 in)	3.0
- diameter less than or equal to 305 mm (12 in)	2.0
RPV, skirt, shroud, chimney, and separators	4.0
Control rod guide tubes and CRD housings	2.0
Fuel assemblies	6.0
Cable Trays	20 (max) (See Figure 3.7-36)
Conduits	7.0
HVAC ductwork	
- companion angle	7.0
- pocket lock	7.0
- welded	4.0

[1] See Figure 3.7-37 for alternative damping values for response spectra analysis of ASME Section III, Division 1 Class 1, 2, and 3, and ASME/ANSI B31.1 piping systems.



Notes:

(1) The damping values specified should be used completely and consistently, if used at all.
(2) The damping values specified may be used only in those analyses in which current seismic spectra and procedures have been employed. Such use is to be limited only to response spectral analyses (similar to that used in the study supporting its acceptance, NUREG/CR-3526). The use with independent support motion method is not permitted.
(3) When used for reconciliation work or for support optimization of existing designs, the effects of increased motion on existing clearances and on-line mounted equipment should be checked.
(4) The damping values specified are not appropriate for analyzing the dynamic response of piping systems using linear energy absorbing supports designed to dissipate energy by yielding.
(5) The damping values specified are not applicable to piping in which stress corrosion cracking has occurred unless a case-specific evaluation is made and is reviewed by the NRC staff.
(6) The damping values specified are applicable in analyzing piping response for seismic and other dynamic loads filtering through building structures in high frequency range beyond 33 Hz.

Figure 3.7-37. Alternative Damping Values for Response Spectra Analysis of ASME Section III, Division 1 Class 1, 2, and 3, and ASME/ANSI B31.1 piping systems