ArevaEPRDCPEm Resource

From: WELLS Russell D (AREVA NP INC) [Russell.Wells@areva.com]
Sent: Friday, February 27, 2009 6:32 PM
To: Getachew Tesfaye
Cc: Pederson Ronda M (AREVA NP INC); BENNETT Kathy A (OFR) (AREVA NP INC); DELANO Karen V (AREVA NP INC)
Subject: Response to U.S. EPR Design Certification Application RAI No. 108, FSAR Ch 3, Supplement 1
Attachments: RAI 108 Supplement 1 Response US EPR DC.pdf

Getachew,

AREVA NP Inc. (AREVA NP) provided responses to 4 of the 20 questions of RAI No.108 on November 21, 2008. The attached file, "RAI 108 Supplement 1 Response US EPR DC.pdf " provides technically correct and complete responses to the remaining 16 questions, as committed.

Appended to this file are affected pages of the U.S. EPR Final Safety Analysis Report in redline-strikeout format which support the response to RAI 108 Questions 03.07.03-1, 03.07.03-3, 03.07.03-4, 03.07.03-5, 03.07.03-9, 03.07.03-11, 03.07.03-12, 03.07.03-14, 03.07.03-16, 03.07.03-18, and 03.07.03-19.

The following table indicates the respective pages in the response document, RAI 108 Supplement 1 Response US EPR DC.pdf ," that contain AREVA NP's response to the subject questions.

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RAI 108 Supplement 1 — 03.07.03-1	2	3
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This concludes the formal AREVA NP response to RAI 108 and there are no questions from this RAI for which AREVA NP has not provided responses.

Sincerely,

(Russ Wells on behalf of)
Ronda Pederson
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Licensing Manager, U.S. EPR™ Design Certification
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From: Pederson Ronda M (AREVA NP INC)
Sent: Friday, November 21, 2008 6:14 PM
To: 'Getachew Tesfaye'
Cc: 'John Rycyna'; DELANO Karen V (AREVA NP INC); BENNETT Kathy A (OFR) (AREVA NP INC); VAN NOY Mark (EXT)
Subject: Response to U.S. EPR Design Certification Application RAI No. 108 (1345, 1463),FSAR Ch. 3

Getachew,

Attached please find AREVA NP Inc.'s response to the subject request for additional information (RAI). The attached file, "RAI 108 Response US EPR DC.pdf" provides technically correct and complete responses to 4 of the 20 questions.

Appended to this file are affected pages of the U.S. EPR Final Safety Analysis Report in redline-strikeout format which support the response to RAI 108 Questions 03.03.01-2 and 03.07.03-2.

The following table indicates the respective page(s) in the response document, "RAI 108 Response US EPR DC.pdf" that contain AREVA NP's response to the subject questions.

Question #	Start Page	End Page
RAI 108 — 03.03.01-2	2	3
RAI 108 — 03.07.03-1	4	4
RAI 108 — 03.07.03-2	5	5
RAI 108 — 03.07.03-3	6	6
RAI 108 — 03.07.03-4	7	7
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A complete answer is not provided for 16 of the 20 questions. The schedule for providing technically correct and complete responses to the remaining questions is provided below.

Question #	Response Date
RAI 108 — 03.07.03-1	February 27, 2009
RAI 108 — 03.07.03-3	February 27, 2009
RAI 108 — 03.07.03-4	February 27, 2009
RAI 108 — 03.07.03-5	February 27, 2009

RAI 108 — 03.07.03-6	February 27, 2009
RAI 108 — 03.07.03-7	February 27, 2009
RAI 108 — 03.07.03-9	February 27, 2009
RAI 108 — 03.07.03-10	February 27, 2009
RAI 108 — 03.07.03-11	February 27, 2009
RAI 108 — 03.07.03-12	February 27, 2009
RAI 108 — 03.07.03-13	February 27, 2009
RAI 108 — 03.07.03-14	February 27, 2009
RAI 108 — 03.07.03-15	February 27, 2009
RAI 108 — 03.07.03-16	February 27, 2009
RAI 108 — 03.07.03-18	February 27, 2009
RAI 108 — 03.07.03-19	February 27, 2009

Sincerely,

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From: Getachew Tesfaye [mailto:Getachew.Tesfaye@nrc.gov]
Sent: Tuesday, October 28, 2008 10:04 AM
To: ZZ-DL-A-USEPR-DL
Cc: David Jeng; Manas Chakravorty; Sujit Samaddar; Michael Miernicki; Joseph Colaccino; John Rycyna
Subject: U.S. EPR Design Certification Application RAI No. 108 (1345, 1463),FSAR Ch. 3

Attached please find the subject requests for additional information (RAI). A draft of the RAI was provided to you on October 20, 2008, and on October 28, 2008, you informed us that the RAI is clear and no further clarification is needed. As a result, no change is made to the draft RAI. The schedule we have established for review of your application assumes technically correct and complete responses within 30 days of receipt of RAIs. For any RAIs that cannot be answered within 30 days, it is expected that a date for receipt of this information will be provided to the staff within the 30 day period so that the staff can assess how this information will impact the published schedule.

Thanks,
Getachew Tesfaye
Sr. Project Manager
NRO/DNRL/NARP
(301) 415-3361

Hearing Identifier: AREVA_EPR_DC_RAIs
Email Number: 275

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MESSAGE	6238	2/27/2009 6:31:57 PM
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Response to

Request for Additional Information No. 108 Supplement 1 (1345, 1463), Revision 0

10/28/2008

U. S. EPR Standard Design Certification
AREVA NP Inc.
Docket No. 52-020
SRP Section: 03.03.01 - Wind Loading
SRP Section: 03.07.03 - Seismic Subsystem Analysis
Application Section: FSAR Ch. 3

QUESTIONS for Structural Engineering Branch 2 (ESBWR/ABWR Projects) (SEB2)

Question 03.07.03-1:

RG 1.122 provides the requirements for the development of amplified response spectra and peak broadening for use in subsystem seismic analysis. However, in FSAR Section 3.7.3.1.1 (pg 3.7-293), in addition to a peak broadening method, a peak shifting method is described using as a basis ASCE Standard 4-98. This standard has not been accepted as providing NRC guidance for methods of seismic analysis.

a. On page 3.7-294, it states that where three different ISRS curves are used to define the response of the structure, the peak shifting method is applied in each direction. Confirm that this is in reference to three orthogonal directions of motion for a single set of ISRS representing the combined results from the different soil cases used in the SSI analysis referenced in FSAR Section 3.7.2. If this is not the case, describe the basis for the three different ISRS curves. Provide examples of where three different ISRS curves would not be used.

b. It also states, the final results are obtained by enveloping the results of the separate analyses. Describe using examples how this enveloping process is accomplished including how the results account for seismic input in three orthogonal directions.

c. Provide justification for using this method of analysis including a comparison of margins-of-safety with the peak broadening method.

Response to Question 03.07.03-1:

a. As stated in U.S. EPR FSAR, Tier 2, Section 3.7.3.1.1, the three in-structure response spectra (ISRS) curves refer to the three orthogonal directions of motion for a single set of spectra. Each set of ISRS represents the combined results from the soil cases used in the soil structure interaction (SSI) analysis, as described in U.S. EPR FSAR, Tier 2, Section 3.7.2.5.

b. The enveloping process accompanying the Peak Shifting Method is described using an example in ASCE 4-98 Commentary, Section C 3.4.2.3, Figure C3.4.2. In general, for N fundamental subsystem frequencies located within the peak broadening range of the j^{th} mode, N+3 separate seismic analyses need to be performed. The combined responses of N+3 seismic analyses are then enveloped to determine the governing response for one orthogonal direction of seismic motion. This process is conducted for the three directions of seismic motion. Co-directional responses of interest are then combined by methods described in U.S. EPR FSAR, Tier 2, Section 3.7.3.6.

c. A technical position on the justification of the Peak Shifting Method in lieu of the Peak Broadening Method is provided by the Pressure Vessel Research Council in WRC Bulletin 300, “Technical Position on Response Spectra Broadening.” Recommendations made therein were adopted in the ASME Boiler and Pressure Vessel Code, Section III, Division I, Appendix N and in Section 3.4.2.3 of ASCE 4-98. While the intent is to use this method primarily for piping systems, conclusions are broadly applicable to other multi-mode commodity systems.

   Justification for use of the peak shifting method is provided by the Pressure Vessel Research Council in WRC Bulletin 300, “Technical Position on Response Spectra Broadening.” Results of these the parametric analyses showed that the Peak Shifting

Method can reduce structural responses by up to 30%, with an average reduction of approximately 10%, when compared to the Peak Broadening Method. Investigated subsystems that used the Peak Broadening Method were found to exhibit at least two times higher dynamic response than corresponding responses that used the Time History Method. Thus, responses based on the Peak Shifting Method are less conservative than those based on Peak Broadening, while providing sufficient conservatism compared to results from Time History Analysis.

The Peak Shifting Method as addressed in U.S. EPR FSAR, Tier 2, Section 3.7.3.1.1 is documented in Section 4.2.2.1.2 of AREVA NP Topical Report ANP-10264NP-A Rev. 0, "U.S. EPR Piping Analysis and Pipe Support Design," which was approved by the NRC. Reference 1 in U.S. EPR FSAR, Tier 2, Section 3.7.3.15—which cites the above report—will be updated to reflect the latest revision. Reference 2 in U.S. EPR FSAR, Tier 2, Section 3.7.3.15 will be deleted, as it has been incorporated in the revised Reference 1.

FSAR Impact:

U.S. EPR FSAR, Tier 2, Section 3.7.3.1.1, 3.7.3.14, and 3.7.3.15 will be revised as described in the response and indicated on the enclosed markup.

Question 03.07.03-3:

In FSAR Section 3.7.3.1.2 (pg 3.7-295) under the description for the time history method, it states that to account for uncertainties in the structural analysis one of two methods may be used. One of the methods described is to use a method similar to the peak shifting method used in response spectrum analysis.

a. Describe how this method meets the intent of the requirements in RG 1.122 to account for uncertainties in the structural seismic analysis.

b. Provide the basis for considering only three separate input time histories and describe how the time steps are modified so as to achieve an equivalent +/- 15 percent peak shifting used in the response spectrum method.

c. Provide justification for using this method of analysis including a comparison of margins-of-safety with the peak broadening method.

d. It is not clear from the discussion what the second method is that is used to account for uncertainties or how it is applied. A discussion of the second method should be provided for review.

Response to Question 03.07.03-3:

a. The intent of Regulatory Guide 1.122 intent is to broaden computed in-structure response spectra peaks to account for uncertainties in structural modeling due to uncertainties in structure and soil approximations used in seismic analyses. Regulatory Guide 1.122 provides an approach for determining the value ($\pm \Delta f_j$) for which each reference structural modal frequency (f_j) is broadened. Using this approach, the minimum calculated value of Δf_j is required to be $0.1f_j$, or 10 percent of the reference peak frequency. Regulatory Guide 1.122 also states that if Δf_j is not determined using the formulated approach described above, Δf_j should be taken as the minimum of $\pm 0.15f_j$ or 15 percent. Regulatory Guide 1.122 also notes that “Time history motions that will give results comparable to the floor design response spectra are also acceptable.”

   ASCE 4-98, Section 3.4.3.1 describes two methods for generating in-structure time history motions. The first method is to obtain the in-structure time histories from time history analysis of the supporting soil-structure system analysis. The second method is to generate synthetic in-structure time history motions.

   For the first method, time steps of the structural response are modified so that frequency content of the time history data is varied by a minimum of ±15 percent. This method is based on ASCE 4-98, Section 3.4.3.2 provisions and associated commentary. A similar approach is presented in ASME Boiler & Pressure Vessel Code, Section III, Division I, Appendix N, Subsection N-1222.3, “Time History Broadening,” which was adopted by ASCE 4. Both publications state that this approach is similar to broadening spectral peaks of a smoothed response spectrum. Therefore, the first method, which uses input time histories from the structure dynamic analysis with modified time steps, meets the intent of Regulatory Guide 1.122.

   U.S. EPR FSAR, Tier 2, Section 3.7.3.1.2 will be revised to identify ASCE 4-98, Section 3.4.3.2 as the basis for the proposed approach that uses input time histories from the structure dynamic analysis with modified time steps.

b. When using the Time History Method of seismic analysis, time history frequency content is varied a minimum of ±15%, per ASCE 4-98, Section 3.4.3.2. This variation produces three separate structural responses for each orthogonal direction (two horizontal and one vertical) for total of nine time histories. The minimum three input time histories for each orthogonal direction include the reference time history and two additional time histories with modified time steps to represent the lower and upper bound conditions (i.e., the frequency content shifted to capture ±15 percent of the reference time history).

   As identified in Part (a) above, this approach is provided in ASCE 4-98, Section 3.4.3.2, and associated commentary. According to ASCE 4-98, time steps of the reference time history can be modified to vary frequency content by ±15 percent by considering at least three different time intervals for the same time history data, where:

   - Δt is the reference interval
   - $\Delta t/(1 \pm 0.15)$ are the modified time steps.

   This results in three separate time history motions for input to the subsystem analysis. In addition, ASCE 4-98 Commentary, Section C3.4.3.2 recommends that if one of the subsystem frequencies (f_e) is within the broadened frequency range of $(1 \pm 0.15)f_j$ (where f_j is the fundamental frequency of the supporting structure), the time history also be used with additional scaled time intervals of: $\Delta t/[1+(f_e - f_j)/f_j]$. This additional time step requirement ensures that any subsystem mode within the broadened peak bandwidth will be excited by the peak acceleration.

   U.S. EPR FSAR, Tier 2, Section 3.7.3.1.2 will be revised to identify how time steps are to be modified to adequately vary the frequency content of the computed time history and to identify the additional time step requirement.

c. The Peak Broadening Method as presented in Regulatory Guide 1.122, and the first method described in (a) above that uses input time histories from the soil-structure dynamic analysis with modified time steps, are different analytical methods. Depending on the subsystem being analyzed, these analyses will yield different results due to differences in the input motion used and subsystem dynamic characteristics. As such, direct comparison of the two analytical methods cannot be explicitly made in terms of "Margin-of-Safety." However, peak broadening is the more conservative approach, as multiple subsystem modes may be excited by the acceleration associated with the broadened peak frequency range. When using the time history method with modified time steps, the analysis is slightly refined as only one subsystem modal frequency is considered to match a modal frequency of the supporting structure, and hence is subject to the peak acceleration in the broadened region under consideration.

   Note that the response spectrum analysis (RSA) method is preferred for subsystems seismic analysis. Time history analysis (THA) is only used when it is necessary to reduce the conservatism associated with RSA.

d. The second method referred to in the question ("The time histories at the attachment points may be derived considering variations in the concrete stiffness") will be removed from US EPR FSAR, Tier 2, Section 3.7.3.1.2. It will be replaced by the alternate method presented in ASCE 4-98, Section 3.4.3.1.b as "Synthetic time history motions consistent with the in-structure response spectra may also be specified." The alternate approach uses a generated synthetic time history as a subsystem forcing function and is more conservative than the first method, which uses the calculated time history with modified time steps. When the synthetic time history approach is used, uncertainties are considered if the in-structure response spectra (ISRS) computed from the synthetic time history envelop the broadened ISRS. Furthermore, when this method is used additional variation of the frequency content is not required, as the ISRS are broadened in accordance with Regulatory Guide 1.122 prior to generating the synthetic time history.

FSAR Impact:

U.S. EPR FSAR, Tier 2, Section 3.7.3.1.2 will be revised as described in the response and indicated on the enclosed markup.

Question 03.07.03-4:

In FSAR Section 3.7.3.1.2, (pg 3.7-295), the third paragraph states that "The time step is to be no larger than one-tenth of the cut-off frequency period, without justification." While for most of the commonly used integration methods, the maximum time step is limited to one-tenth of the smallest period of interest, which is generally the reciprocal of the cutoff frequency, industry practice also requires that (Section 3.2.2.1(c) of ASCE 4-98) the time step (Δt) used shall be small enough such that the use of one-half of Δt does not change the response by more than 10 percent. Provide the technical justification for not considering common industry practice in determining the maximum time step when time history integration methods are used.

Response to Question 03.07.03-4:

ASCE 4-98 (Reference 4 in U.S. EPR, FSAR, Tier 2, Section 3.7.3.15) Table 3.2-1 provides recommended maximum time step (Δt) values for time history analysis using various numerical integration methods. For the Newmark and Wilson θ integration methods, which are two of the most commonly used methods, the recommended maximum Δt is 1/10 of the shortest period of importance (i.e., the reciprocal of the cutoff frequency) for the subsystem in question. However, the one-tenth rule is a guideline for establishing an initial time step, and as such is considered an upper bound. For solution convergence, the acceptance criterion in ASCE 4-98 Section 3.2.2.1(c) is used; that Δt is sufficiently small that using 1/2 Δt does not change the response by more than 10 percent.

U.S. EPR, Tier 2, Section 3.7.3.1.2 will be revised to clarify selection of the appropriate time step.

FSAR Impact:

U.S. EPR FSAR, Tier 2, Section 3.7.3.1.2 will be revised as described in the response and indicated on the enclosed markup.

Question 03.07.03-5:

FSAR Section 3.7.3.1.4 (pg 3.7-295) describes an equivalent static method of analysis for subsystems where the mass of the subsystem components are considered as lumped masses at their center of gravity locations. It states that the seismic response forces from these masses are determined by multiplying the contributing mass by an appropriate seismic acceleration coefficient at each location.

a. How is the seismic acceleration coefficient determined?

b. Is the acceleration that is applied to each contributing mass the same value?

c. How does this method compare to the response spectrum method in terms of resultant seismic loads?

d. Describe the methods that will be used to justify the use of the equivalent static method over the use of other methods.

e. Describe how the methods meet the requirements of SRP 3.7.2-SAC-1.B for the equivalent static load method including how this method meets the requirements for accounting for the relative motion between points of support.

Further down in Section 3.7.3.1.4 (pg 3.7-295), a seismic acceleration equal to the peak acceleration multiplied by 1.5 is discussed as being appropriate for many subsystems to account for multi-modal participation. This is normally conservative for only simple systems and may not be conservative in which the maximum response results are derived from more than one direction. Under what situations and for what systems will the use of an equivalent static method be considered? It also states that the results from three directions of seismic input motions are combined by the SRSS method. Since the method is static, how are out-of-plane responses obtained from this analysis?

Response to Question 03.07.03-5:

a. The seismic acceleration coefficient at each node with a contributing mass within the multi-degree-of-freedom (MDOF) system is determined from the appropriate in-structure response spectrum (ISRS) based on the fundamental frequency. Either the peak acceleration or the frequency-dependent acceleration may be used to determine the appropriate seismic acceleration coefficient.

b. When using the equivalent static method (ESM), the same acceleration is applied to each node within the MDOF system. Studies on simple frame-type piping models (Reference 1) provide a basis for applying the same acceleration to each node within the MDOF system.

c. Various publications (References 1–5) compare the resultant seismic loads obtained from the equivalent static method (ESM) and the response spectrum method (RSM). Studies on simple frame-type piping models (References 1 and 2) showed that the ESM, in combination with a multi-mode factor (MMF) ≤1.2, produced the same seismic resultant forces as the RSM. Further studies on a representative piping system (References 4 and 5) produced conservative maximum ESM resultant seismic forces considerably higher than the RSM-calculated forces. When properly applied, the ESM always yields conservative results for simple frame-type structures. This is based on using the peak acceleration for all nodes within the MDOF system and the upper bound value of 1.5 for the MMF.

d. Justification for using the ESM to perform seismic analysis of subsystems is provided in the acceptance criteria specified in SRP 3.7.2-SAC-1.B. When ESM analysis is performed in lieu of a detailed dynamic analysis, justification will be provided that the subsystem to be analyzed is realistically represented by a simple structural model and that the calculated responses using the ESM produces conservative results. Typical examples or published results of analyzed subsystem structures similar to those under consideration may be cited as justification for using the ESM. A partial list of published results on simple subsystem structures is addressed in part c. of this response and presented in the References section below.

e. Using the ESM in lieu of a detailed seismic subsystem analysis is in accordance with SRP 3.7.2-SAC-1.B. The criteria justifying the use of the ESM to comply with Subsection i of SRP 3.7.2-SAC-1.B are addressed in part d. of this response.

   Relative motion between points of supports determined to be significant are considered in the seismic analysis using the ESM, in conformance with SRP 3.7.2-SAC-1.B(ii). Maximum relative support displacements are determined using conventional static analysis methods and then imposed in the most unfavorable combination onto the system.

   The MMF to be used in the seismic analysis using the ESM is determined in accordance with Subsection iii of SRP 3.7.2-SAC-1.B. Studies (References 1, 2, 4, and 5) have shown that for simple MDOF subsystem configurations, a MMF of 1.5 is conservative in capturing multi-mode effects and will lead, in combination with the appropriate acceleration, to a conservative response of the subsystem. For cases where a subsystem configuration can be demonstrated to respond as a single degree of freedom (SDOF) system with a known fundamental frequency, or as a rigid system with a fundamental frequency beyond the cut-off frequency, a MMF of 1.0 may be used in combination with the appropriate acceleration.

Response to questions raised by the NRC in the final paragraph of Question 03.07.03-5:

As stated in part d. of this response, the ESM is used for seismic analysis in situations where the subsystem to be analyzed can be represented by a simple structural model. A range of subsystem configurations suitable for seismic analysis using the ESM was investigated by the studies listed in the References section of this response, and may be used when applicable. Further guidance on system configurations that are adequate for seismic analysis using the ESM can be found in ASCE 4-98, Section C.3.2.5.3.

The maximum responses of a simple subsystem configuration will be determined by combining the three directions of seismic input motions using the square root of the sum of the squares method or the 100-40-40 percent rule. Subsystems suitable for seismic analyses using the ESM are limited to simple structural models. The off-axis seismic responses of these structural models will be negligible.

References for Question 03.07.03-5:

1. J.D. Stevenson and W.S. LaPay, “Amplification Factors to be Used in Simplified Seismic Dynamic Analysis of Piping Systems,” (1974).
2. C. W. Lin, “A Justification of the Static Coefficient of 1.5 for Equipment Seismic Qualification,” (1980).
3. C.W. Lin and T.C. Esselman, “Equivalent Static Coefficients for Simplified Analysis of Piping Systems,” (1983).
4. B.J. Hsieh and C.A. Kot, “A Structural Design and Analysis of a Piping System Including Seismic Load,” (1991)
5. B.J. Hsieh and C.A. Kot, “Observations on the Structural Design and Analysis of a Piping System,” (1991)

U.S. EPR, Tier 2, Sections 3.7.3.1.4 and 3.7.3.6 will be changed to clarify use of the Equivalent Static Load method.

FSAR Impact:

U.S. EPR FSAR, Tier 2, Section 3.7.3.1.4 and Section 3.7.3.6 will be revised as described in the response and indicated on the enclosed markup.

Question 03.07.03-6:

In FSAR Section 3.7.3.3 (pg 3.7-298), it states that in general three dimensional models are used for seismic analysis and six degrees-of-freedom exist for mass points. It then states that in most structures some of the dynamic degrees-of-freedom can be neglected or can be uncoupled from each other so that separate analyses can be performed for different types of motions. Provide the technical basis and criteria used for neglecting dynamic degrees-of-freedom and for uncoupling degrees-of-freedom such that a separate analysis can be performed for different types of motions.

Response to Question 03.07.03-6:

According to Chopra (A.K. Chopra, “Dynamics of Structures,” 2nd Edition, Prentice Hall), structures with distributed mass can be modeled with sufficient accuracy for purposes of dynamic analysis using lumped-mass representations, where mass is lumped at discrete nodes of a multi-degree-of-freedom structural model. Six degrees-of-freedom (DOF) exist for each nodal mass point (i.e., three translational DOF and three rotational DOF).

The rotational DOF and associated mass moment of inertia capture the local rotational responses during a dynamic analysis. For typical subsystems, these local rotational responses have negligible influence on the overall dynamic response of the system, provided that no external forces are applied in the local rotational DOF. When local rotational DOF are neglected, the rotational responses of the overall system are accounted for through translational dynamic responses at the nodal points.

For linear, frame-type sub-systems—such as straight runs of HVAC ducts, cable trays, or conduits—the three translational DOF can be considered independent of each other. Hence, they can be decoupled and the dynamic responses in the lateral, vertical, and axial directions for corresponding seismic excitations can be calculated separately.

The reduction and decoupling of dynamic DOF is evaluated on a case-by-case basis to ensure that correct seismic responses are obtained.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Question 03.07.03-7:

In FSAR Section 3.7.3.3 (pg 3.7-297), it states that it is sufficient to include degrees-of-freedom equal to twice the number of modes with frequencies below the ZPA frequency. This criterion does not meet the acceptance criteria for modeling described in SRP 3.7.2-SAC-1.A.iv. In addition, the stated criterion for establishing the cutoff frequency does not appear to satisfy the current Interim Staff Guidance (COL/DC-ISD-01) which requires that models used for dynamic analysis capture frequencies up to at least 50 Hz. Describe how the models developed for subsystem analysis meet the requirements of SRP 3.7.2 acceptance criteria and the Interim Staff Guidance or provide justification if they do not.

Response to Question 03.07.03-7:

With regard to the adequacy of the number of discrete mass degrees of freedom, Item 1 under SRP 3.7.2 (Rev. 3) SAC-1.A.iv states that the selected degrees of freedom should be able to predict a "sufficient" number of modes for each excitation direction. For sufficiency of number of modes the subject SAC stipulates that all significant modes with frequencies less than the zero period acceleration (ZPA) (or peak ground acceleration (PGA)) frequency of the corresponding spectrum be adequately represented in the dynamic solution. While the term "significant" is not specifically mentioned in SAC-1.A.iv, it is implied in the context of other SRP acceptance criteria, and the term "significant modes" is invoked in other places within the subject SRP.

One method of selecting a sufficient number of degrees of freedom is to make the number of degrees of freedom equal to at least twice the number of (significant) modes with frequencies below the ZPA frequency. This requirement is included in ASCE 4-98 Section 3.1.4.1(b) and SRP 3.7.2 (Rev. 2) SAC-1.a.iii. Although SRP 3.7.2 is more general and does not include this specific language, it is an accepted practice for ensuring that a sufficient number of degrees of freedom have been selected.

Regarding Interim Staff Guidance (COL/DC-ISG-01), which requires that models used for dynamic analysis capture frequencies up to at least 50 Hz, Section 3.1.1 indicates that the subject criterion for structural model refinement is intended to sufficiently capture high frequency (HF) content of horizontal and vertical ground motion response spectra (GMRS) and foundation input response spectra (FIRS) in structural responses. The terms GMRS and FIRS are used to describe site-specific design ground motion; as such, this requirement is not applicable to seismic models used for certified designs. The design spectra ZPA frequency used for the U.S. EPR standard plant is less than 50 Hz (U.S. EPR FSAR, Tier 2, Figure 3.7.1.1). Accordingly, models used for seismic analysis of the U.S. EPR are refined sufficiently to capture response up to the ZPA frequency.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Question 03.07.03-9:

In FSAR Section 3.7.3.3 (pg 3.7-298), it states that it is sufficient to include only the mass of the subsystem at the support point when the subsystem is rigid in comparison to the supporting system and is rigidly connected. Describe the criteria that are used to make this determination. Similarly for subsystems supported by flexible connections it states that the subsystem may be excluded from the primary model. Provide the criteria for making this determination. Is this true even when R_m is greater than .1? (See pg 3.7-298)

Response to Question 03.07.03-9:

U.S. EPR FSAR, Tier 2, Section 3.7.3.3 presents decoupling criteria consistent with SRP3.7.2-II-SAC-3-B requirements. The criteria (which are not quantitative) apply when a subsystem is decoupled from its primary system, and the treatment of the subsystem mass depends on whether the subsystem is rigidly or flexibly connected.

Guidelines on applying the decoupling criteria are in: T. W. Pickel, Jr., NE F 9-2T, “Seismic Requirements for Design of Nuclear Power Plants and Nuclear Test Facilities,” (Rev. 2), Oak Ridge National Laboratory, 1985. This document provides quantitative provisions, based on frequency ratios, for including and excluding a subsystem mass.

Based on guidelines presented in NE F 9-2T and SRP3.7.2-II-SAC-3-B, the following criteria are used for decoupling subsystems:

- When $R_m < 0.01$, the mass of a subsystem is included in the primary system model regardless of R_f.
- When $0.01 \le R_m \le 0.1$, decoupling may be done under two conditions:
    1. When $R_f \ge 1.25$, the subsystem mass is included in the primary system model at the support point.
    2. When $R_f \le 0.8$, the subsystem mass is not included in the primary system model.
- When $0.01 \le R_m \le 0.1$ and $0.8 < R_f < 1.25$ and when $R_m > 0.1$, a subsystem model is included in the primary system model and the effects of subsystem stiffness and mass are both considered.

Based on the above guidelines, criteria for treatment of a subsystem mass will be added to U.S. EPR FSAR, Tier 2, Section 3.7.3.3 and the statement concerning rigidly or flexibly connected subsystems will be removed.

Note: in the above discussion,

$$R_m = \frac{\text{Total mass of the supported subsystem}}{\text{Total mass of the supporting system}}$$

$$R_f = \frac{\text{Fundamental frequency of the supported subsystem}}{\text{Dominant frequency of the support motion}}$$

FSAR Impact:

U.S. EPR FSAR, Tier 2, Section 3.7.3.3 will be revised as described in the response and indicated on the enclosed markup.

Question 03.07.03-10:

In FSAR Section 3.7.3.3 (pg 3.7-298), it states “Seismic input for the subsystem and component design are the peak-broadened ISRS envelopes described in Section 3.7.2.5 or the floor acceleration time histories described in Section 3.7.2.4.” However, Section 3.7.2.4 does not provide a single set of floor time histories that envelope the peak-broadened ISRS. How does the applicant propose to use the various floor time histories generated from SSI analysis, which used a variety of soil conditions, in the subsystem analysis?

Response to Question 03.07.03-10:

The method of deriving in-structure response spectra (ISRS) from time history generation is provided in U.S. EPR FSAR, Tier 2, Section 3.7.2.5. The time history generation from the ISRS for piping is provided in U.S. EPR FSAR, Tier 2, Section 3.9 and in Section 3.2.4 for the piping subsystems.

If time history analyses are performed for the subsystems, the floor time histories from each soil condition are considered separately.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Question 03.07.03-11:

In FSAR Section 3.7.3.6 (pg 3.7-302) under "Time History Method," it states that analyses of subsystems may be performed separately for each of the three components of earthquake motion, or one analysis may be performed by applying all three components simultaneously. The FSAR then refers to free-field time histories that are used as input to the overall structural analysis models including SSI models. Given that the SSI analyses produces a separate time history motions for each direction and soil case evaluated, it is not clear from the FSAR discussion how time history analyses of subsystems are performed if time histories produced by the SSI analyses are to be used. Additionally, a description of how the time histories, which vary node by node, will be selected or applied to the model of the subsystem is not provided. If it is intended that an alternative approach to time history analyses which uses time histories developed to envelope the smoothed and broadened in-structure response spectra, the criteria used to develop these time histories should be specified. The staff is therefore requesting that additional information be provided on the source of the time histories, how they were developed, and how many sets of time histories are used in the analysis. If they are time histories that envelope the ISRS, provide the enveloping criteria, and if they are applied simultaneously, state whether or not they are statistically independent.

Response to Question 03.07.03-11:

The U.S. EPR seismic design basis includes twelve seismic analysis cases, each with characteristic soil properties and corresponding seismic inputs. Each case contains three components of earthquake motion, one in each of the three orthogonal directions. A soil-structure interaction (SSI) analysis is performed for each soil case and component of earthquake motion, where for each component the in-structure response time history is obtained for the primary direction and the two orthogonal off-directions. For a given case, the co-directional in-structure response for each orthogonal direction is then obtained by algebraically combining the primary in-structure response with the off-directional in-structure responses. Thus, SSI analyses result in twelve sets of co-directional in-structure response time histories for each of the three orthogonal directions.

Either of the following methods may be used to generate subsystem time history responses from the twelve sets of co-directional time histories:

1. One option consists of synthetic time histories developed to envelop the in-structure response spectra (ISRS). This process involves multiple steps. First, the twelve sets of co-directional time histories are converted into ISRS curves. Note that the spectra at a given floor envelop the response for the entire floor (i.e., one spectrum for each orthogonal direction per floor). Next, the enveloping ISRS (enveloped over 12 soil cases) for each orthogonal direction is developed, thereby reducing the number of ISRS curves to one ISRS per orthogonal direction per floor. The enveloped ISRS curves are then broadened by a minimum of ±15 percent in accordance with U.S. EPR FSAR, Tier 2, Section 3.7.3.1, and then smoothed response spectra curves for the enveloped and broadened ISRS are generated. Finally, response spectrum compatible, smoothed and broadened ISRS are developed in accordance with SRP 3.7.1. Thus, each floor will have three (one for each orthogonal direction) synthetic time histories for subsystem analysis. Because the synthetic time histories envelop the response for a given floor, each attachment point of a given subsystem at a given floor will use the same three time histories as input in the subsystem analysis. If a subsystem is supported at multiple

floors (i.e., multiple elevations) or spans between buildings, the uniform support motion method is used, as described in U.S. EPR FSAR, Tier 2, Section 3.7.3.9.1 for the response spectrum analysis.

2. Alternatively, an analysis for each of the twelve sets of co-directional time histories can be performed individually and the twelve results are then enveloped, provided uncertainties are accounted for. To account for uncertainties in the structural analysis of subsystems for seismic loading, a peak broadening approach is used, similar to that described for the response spectrum analysis in U.S. EPR FSAR, Tier 2, Section 3.7.3.1.1. This is accomplished by first converting the time histories into response spectra, and then proceeding through the methodology outlined in Section 3.7.3.1.1. Broadening is done by compressing or expanding the time step of the time histories to move the spectral peak accelerations to the desired frequencies. The subsystem model is then analyzed separately for the time histories using the original time step, the compressed time step and the expanded time step, which are defined by Δt, $(1 - \Delta f_1/f_1)\Delta t$, and $(1 + \Delta f_1/f_1)\Delta t$, respectively, where f_1 is the fundamental structural frequency. To capture peak accelerations within the broadened bandwidth ($f_j \pm \Delta f_j$), additional time steps are investigated with a time interval of $[1 – (f_e\text{-}f_j)/f_j]\ \Delta t$ when subsystem frequencies, f_e, are located within the broadened bandwidth. This process will be repeated for each time-history input at each attachment point of the subsystem being analyzed.

When using the time history analysis method with either of these two options, analyses may be performed separately for each of the three components of earthquake input motion, or one analysis may be performed by applying the three components simultaneously (provided the three components of earthquake input motion are demonstrated to be statistically independent in accordance with U.S. EPR FSAR, Tier 2, Section 3.7.1.1.2 requirements). Clarifications to U.S. EPR FSAR, Tier 2, Section 3.7.3.6 will be made to reflect this.

The above methodologies are in compliance with Regulatory Position C.2.2 and consistent with Section B of Regulatory Guide 1.92, Revision 2, and with Section 4.2.3 of NRC-approved AREVA NP Topical Report ANP-10264NP-A, “U.S. EPR Piping Analysis and Pipe Support Design,” Revision 0, for piping subsystems.

FSAR Impact:

U.S. EPR FSAR, Tier 2, Section 3.7.3.6 will be revised as described in the response and indicated on the enclosed markup.

Question 03.07.03-12:

In FSAR Section 3.7.3.7.1 (pg 3.7-304), it states the approved methods of RG 1.92 are used to obtain more accurate modal response for closely spaced modes. How does the combination of modal responses address each of the methods specified in Section C of RG 1.92, Rev. 2? In FSAR Section 3.7.3.7.1 (pg 3.7-304), it states that closely spaced modes are combined using the methods of RG 1.92, Revision 1 as well as the less conservative methods of RG 1.92, Revision 2. This revision was issued by the NRC after research in the U.S. resulted in improved methods for combining modal responses that provide a more accurate estimate of SSC seismic response while reducing unnecessary conservatism. The statement in the FSAR should be revised to more accurately reflect the basis for the methods in Revision 2 of the RG.

Response to Question 03.07.03-12:

U.S. EPR FSAR, Tier 2, Section 3.7.3.7.1, Low Frequency (Non-Rigid) Modes, will be revised to include the refined methods for combining modal responses described in Regulatory Guide 1.92, Revision 2.

U.S. EPR FSAR, Tier 2, Section 3.7.3.7.1 and Section 3.7.3.7.2 will be revised to address structures with single-point attachment, as well as multiply supported structures (i.e., subsystems analyzed by either the uniform support motion or the independent support motion method).

FSAR Impact:

U.S. EPR FSAR, Tier 2, Section 3.7.3.7.1 and Section 3.7.3.7.2 will be revised as described in the response and indicated on the enclosed markup.

Question 03.07.03-13:

In FSAR Section 3.7.3.7.2 (pg 3.7-304) at the bottom of the page, should the the mass point displacement vector {r} be identified as an acceleration vector?

Response to Question 03.07.03-13:

The vector {r} is a displacement vector for unit acceleration and is used in other equations in U.S. EPR FSAR, Tier 2, Section 3.7.3.7.2 to define mass participation (and is a displacement vector in that sense).

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Question 03.07.03-14:

In FSAR Section 3.7.3.8 (pg 3.7-306), it states that for non-seismic subsystems attached to seismic systems, the dynamic effects of the non-seismic subsystem are accounted for in the modeling of the seismic subsystem. It states that the non-seismic subsystem is precluded from causing failure of the seismic subsystem. What are the methods and design criteria that are used to assure that such failures do not occur and how do the methods in this FSAR section meet the acceptance criteria of SRP 3.7.3-SAC-8 which addresses the interaction of non-seismic systems with Seismic Category I systems?

Response to Question 03.07.03-14:

Non-seismic subsystems attached to seismic subsystems are classified as Category II. Accordingly, the attached non-seismic subsystems up to the first brace beyond the interface are analyzed and designed using the same methods and design criteria for seismic Category I subsystems. Applicable methods and design criteria are described in U.S. EPR FSAR, Tier 2, Section 3.7.3 and Appendix 3E, respectively. This approach meets the acceptance criteria of SRP 3.7.3.II-8 and SRP 3.7.2.II-8.C.

U.S. EPR, Tier 2, Section 3.7.3.1.3 and Section 3.7.3.8 will be revised to clarify the use of inelastic methods for subsystems.

FSAR Impact:

U.S. EPR FSAR, Tier 2, Section 3.7.3.1.3 and Section 3.7.3.8 will be revised as described in the response and indicated on the enclosed markup.

Question 03.07.03-15:

In FSAR Section 3.7.3.8.2 (pg 3.7-306), it states that safety-related subsystems or components which may be impacted by a non-seismic SSC are identified as interaction targets and are evaluated to establish that there is no loss of ability to perform their safety-related functions. In SRP 3.7.3-SAC-8, there are no acceptance criteria for the described situation. Provide justification as to why non-seismic SSCs which could interact with seismic Category I SSCs are not analyzed and designed to the same criteria as seismic Category I SSCs so that an interaction does not occur.

Response to Question 03.07.03-15:

Non-seismic structures, systems, and components (SSC) that are not classified as Category II may collapse as a result of a seismic event. If they are located in the adjacent to, or above, safety-related subsystems, their collapse may impact nearby safety-related subsystems. These safety-related subsystems, identified as interaction targets, are evaluated to establish that there is no loss of their ability to perform their safety-related functions if impacted by non-seismic SSC.

The above evaluations satisfy the acceptance criteria of SRP 3.7.2, subsection II.8, which is referred to in the second paragraph of SRP 3.7.3.-SAC-8. Under the provisions of Option B of SRP 3.7.2, Section II.8, it is acceptable to show that the collapse of non-Category I structures will not impair the integrity of the Category I structures.

For piping subsystems, U.S. EPR FSAR, Tier 2, Section 3.7.2.8.2, “Interaction Evaluation” is identical to Section 4.4.2 of NRC-approved AREVA NP Topical Report ANP-10264NP-A, “U.S. EPR Piping Analysis and Pipe Support Design.”

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Question 03.07.03-16:

FSAR Section 3.7.3.9 (pg 3.7.3-307) addresses distribution subsystems supported at multiple locations within a structure or at multiple locations in different structures. The acceptance criteria of SRP 3.7.3-SAC-9 states that the relative displacements of support points should be considered in the analysis of these systems. Describe how the methods of analysis account for these displacements and how the methods include the effects of the application of three orthogonal seismic inputs.

Response to Question 03.07.03-16:

The relative displacements of support points are obtained from the dynamic analysis of the supporting structure or—as a conservative alternative—determined from the in-structure response spectra, in accordance with SRP-3.9.2-II-SAC-2-G. For the latter option, the maximum displacement of the support points are calculated and imposed on the supported system in the most unfavorable combination.

There are earthquake components in the three global directions. Earthquake input in each direction results in three relative displacement values in the three global directions. If the relative displacements at support points are obtained from the time history analysis of the supporting structure with simultaneous input motions, the effects of the three orthogonal earthquake components are combined automatically. Otherwise, co-directional relative displacement values are combined by either the square root of the sum of the squares (SRSS) or the 100-40-40 rule (see Regulatory Guide 1.92). A response in the subsystem (moment, shear, stress, etc.) due to the relative support displacement is then determined, using conventional static analysis techniques.

The responses due to the inertia effect are combined with the responses due to relative displacements by absolute sum when the uniform support motion method is used (see SRP 3.7.3), or by SRSS when the independent support motion method is used (see NUREG-1061).

U.S. EPR, Tier 2, Section 3.7.3.9 will be revised to clarify methods used to analyze distribution subsystems that span between multiple locations within a structure or between locations in different structures.

FSAR Impact:

U.S. EPR FSAR, Tier 2, Section 3.7.3.9 will be revised as described in the response and indicated on the enclosed markup.

Question 03.07.03-18:

In FSAR Section 3.7.3.9.2 (pg 3.7-307), it states that independent support motion (ISM) may be used when distribution subsystems are supported by multiple support structures or at multiple support levels within a structure. When this approach is used, are the guidance and criteria given in NUREG 1061 related to ISM followed ?

Response to Question 03.07.03-18:

At the end of the first paragraph of U.S. EPR FSAR, Tier 2, Section 3.7.3.9.2, a statement will be added that the guidance and criteria given in NUREG-1061, Volume 4, Section 2 are followed when the independent support motion method is used.

FSAR Impact:

U.S. EPR FSAR, Tier 2, Section 3.7.3.9.2 will be revised as described in the response and indicated on the enclosed markup.

Question 03.07.03-19:

FSAR Section 3.7.3.2 (pg 3.7-296) describes various methods to account for seismic induced fatigue. To qualify electrical and mechanical equipment, the FSAR states that consideration of low level seismic effects is required by IEEE Standard 344-2004 with the equivalent of five OBE events followed by one SSE event (with 10 maximum stress cycles per event). It further states that this consideration includes the seismic qualification process based on the approach outlined in SRP 3.10-SAC-3.C. The FSAR states that earthquake cycles included in the fatigue analysis are composed of five one-third SSE events followed by one full SSE event. However, SRP 3.10-SAC-3.C states electrical equipment should be qualified with five one-half SSE events followed by one full SSE event. Provide justification for using a different method of analysis than that described in the SRP.

In referencing the IEEE Standard 344, the FSAR states that the 2004 version is being used while the SRP acceptance criteria reference the 1987 version of the Standard. The FSAR further states in a footnote on the bottom of page 3.7-296 that justification for use of the latest version of the IEEE Standards is provided in FSAR Section 3.11. A comparison of the two revisions of IEEE 344 for fatigue evaluation could not be found in FSAR Section 3.11. As a result, the staff is asking for reconciliation between the two versions of the Standard as it applies to fatigue evaluation.

Response to Question 03.07.03-19:

The method for fatigue evaluation is discussed in Section 3.4.7 and Section 3.4.8 of AREVA NP Topical Report ANP-10264NP-A, "U.S. EPR Piping Analysis and Pipe Support Design," Rev. 0, November 2008, and the methodology includes the fractional use of the safe shutdown earthquake (SSE) for cyclic evaluations.

Earthquake cycles for fatigue analysis will include five one-half SSE events followed by one full SSE event, as outlined in SRP 3.10.III.3.C. U.S. EPR FSAR, Section 3.7.3.2, fourth sentence of the second paragraph will be revised as follows:

> "To meet this requirement, earthquake cycles included in the fatigue analysis are composed of five one-half SSE events followed by one full SSE event."

A comparison between the versions of IEEE Standard 344 is provided in U.S. EPR FSAR. Tier 2, Section 3.11.2.3.4

FSAR Impact:

U.S. EPR FSAR, Tier 2, Section 3.7.3.2 will be revised as described in the response and indicated on the enclosed markup.

U.S. EPR Final Safety Analysis Report Markups

3.7.3 Seismic Subsystem Analysis

Seismic analysis methodology for U.S. EPR standard plant structural subsystems is described in this section. The plant structural subsystems include heating, ventilation, and air conditioning (HVAC) duct, cable tray, conduit, and tubing distribution systems; equipment and component supports; platforms and support frame structures; buried piping, tunnels, and conduits; yard structures; and atmospheric tanks. Structural subsystems include structural items that are not directly impacted by seismic forces imparted through the soil, but are directly impacted by seismic forces as they are transmitted through the building structure.

Seismic analysis for piping subsystems is outside the scope of this section and is addressed in Sections 3.9.2 and 3.12. Seismic and dynamic qualification methods for mechanical equipment are addressed in Section 3.10. Section 3.11 addresses seismic qualification of electrical equipment. Design criteria for distributed subsystem supports for piping, HVAC ducts, cable trays, and conduits are contained in Appendix 3A. Appendix 3C addresses seismic and dynamic analysis of supports for the reactor coolant system.

As addressed in Section 3.7, the design of the U.S. EPR does not consider explicit design analysis for the operating basis earthquake (OBE). The requirement for seismic fatigue through a cyclic load basis of one safe shutdown earthquake (SSE) and five OBEs is met for the U.S. EPR by consideration of full and fractional SSE events.

Seismic Category I subsystems are designed to withstand the effects of an SSE and maintain the capability to perform their safety functions. This design is accomplished by performing seismic analyses for Seismic Category I subsystems using methods in accordance with 10 CFR Part 50, GDC 2 and 10 CFR Part 50, Appendix S, per SRP 3.7.3 (Reference 6). These methods, as described in the following sections, include the response spectrum method, time history method or, where applicable, the equivalent static load method.

3.7.3.1 Seismic Analysis Methods

3.7.3.1.1 Response Spectrum Method

03.07.03-1

The effects of the ground motion during an SSE event are transmitted through structures to the subsystem at support and equipment anchorage locations. In the response spectrum method of analysis, ~~peak~~ values ~~of response~~ are determined for each mode of the subsystem ~~by applying~~ from the in-structure response spectra (ISRS). The ISRS 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 ISRS are developed as described and are applied to the subsystem at locations of structural attachment, such as support or equipment locations (see Section 3.7.2.5). The response spectra analysis is performed using either enveloped uniform response spectra or independent support motion (ISM) using multiple spectra input.

ISRS for each of the three directional components of earthquake motions are applied separately to the subsystem. Modal responses are determined by accelerating each mode with the spectral acceleration corresponding to the frequency of that mode. The modal and co-directional responses are then combined by the methods described in Sections 3.7.3.7 and 3.7.3.6, respectively.

~~The ISRS are applied to the subsystem in each of three orthogonal directions. Each of the directional components of earthquake motion input produces response in the subsystem in the three directions at each natural frequency of the subsystem. The total seismic response of the subsystem is determined by combining the modal and spatial results using the peak broadening, peak shifting, and time history methods, as described in the following sections.~~

03.07.03-1

Peak Broadening Method

ISRS are generated from the seismic structural analysis using the methods provided in Section 3.7.2 and following guidance from RG 1.122. ISRS are peak broadened by a minimum of ±15 percent to account for uncertainties in the structural response, as described in Section 3.7.2.5. ~~In addition to peak broadening, an alternative method of peak shifting, which is described in ASCE 4-98 (Reference 4), is employed in the seismic analysis of certain subsystems to account for uncertainties. The use of the peak shifting method in both response spectrum and time history methods of analysis, and the application of ISRS to the analysis of multiply-supported subsystems are provided as follows.~~

Peak Shifting Method

Peak shifting ~~analysis~~ as described in ASCE 4-98 (Reference 4) may be used in place of peak broadening to obtain a more realistic ~~reduce unnecessary conservatism in the~~ design. Similar to broadening, peak shifting considers a minimum of ±15 percent uncertainty in the peak structural frequencies. However, spectral shifting ~~reduces the amount of conservatism~~ refines the analysis by considering ~~that the structural natural frequency is defined by a single value, not a range of values. Therefore,~~ only one mode of the distribution subsystem ~~can~~to respond at the peak acceleration.

In the peak shifting method, the ~~natural~~ structural frequencies of the distribution subsystem within the maximum peak acceleration, broadened spectral frequency range are determined. If no distribution subsystem natural frequencies exist within this frequency range, successively lower acceleration peaks are broadened until the first range containing at least one natural frequency of the subsystem is found.

Considering that the peak structural frequency may lie at any one frequency within the broadened range, N+3 separate response spectra analyses are then performed, where N is the number of subsystem modes within the broadened frequency range. The first analysis uses the unbroadened response spectrum. The second and third analyses use the unbroadened spectrum modified by shifting the frequencies associated with each spectral value by $-\Delta f_j$ and $+\Delta f_j$, where Δf_j is the amount of peak shifting required to account for the uncertainties of the structural response. The remaining N analyses also use the unbroadened spectrum modified by shifting the frequencies associated with each spectral value by a factor of:

$$1+\frac{(f_e)_n - f_j}{f_j}$$

Where:

$(f_e)_n$ = Subsystem natural frequency occurring within the broadened range, for n = 1 to N,

f_j = frequency at which the peak acceleration occurs (for the peak under consideration).

03.07.03-1

For each response spectra analysis performed in the peak shifting method, the modal results are combined separately to obtain responses of interest by the methods described in Section 3.7.3.7. The peak shifting method is preformed for each orthogonal direction of earthquake input motion resulting in three sets of analysis results. Each set of analysis results includes thereby N+3 responses. The governing response for each direction of earthquake input motion is obtained by enveloping the N+3 separate analysis results in each set. The co-directional responses are then determined using the combination methods described in Section 3.7.3.6.

~~The modal results of each of these analyses are then combined separately using the combination procedures: where three different ISRS curves are used to define the response of the structure, the peak shifting method is applied in each direction. The final results are obtained by enveloping the results of the separate analyses.~~

Multiply-Supported Systems

Section 3.7.3.9 describes the uniform support motion (USM) and ISM for subsystems supported at multiple locations within one or more buildings.

3.7.3.1.2 Time History Method

Seismic analyses may be performed using time history analysis methods in lieu of response spectrum analysis. The modal superposition method of time history analysis is used for seismic analysis of U.S. EPR subsystems. This method is based on decoupling of the differential equations of motion, considering a linear elastic system. The total response of the system is determined by integrating the decoupled equations for each mode and combining the results of the modes at each time step using algebraic addition.

Mode shapes and frequencies are determined in the response spectrum analysis method. The cutoff frequency for determining modal properties is selected to account for the principal vibration modes of the subsystem based on mass and stiffness properties, modal participation factors, and the frequency content of the input forcing function. The missing mass effects of high frequency modes are included based on the same principles described in Section 3.7.3.7. The cutoff frequency is determined so that the number of modes calculated does notwill produce dynamic analysis results within 10 percent of the same results of the dynamic analysis including combined with the next higher mode.

03.07.03-4

The time step is set to be no larger than one-tenth of the shortest period of importance (e.g., the reciprocal of the cutoff frequency). cutoff frequency period, without justification. Other factors that are considered in the selection of an acceptable time step are the fundamental frequency of the subsystem being analyzed and the input time history.

03.07.03-3

To account for uncertainties in the structural analysis, one of two methods may be used following the guidance of ASCE-4-98 (Reference 4). Similar to peak shifting in the response spectrum method of analysis, three separate input time histories from the structure dynamic analysis may be analyzed with modified time steps. In this approach, the frequency content of the input data is varied by minimum ±15 percent to account for uncertainties in the analysis of the supporting structure. Variation in the frequency content is done by using the same time history date with at least three different time steps, the initial time step Δt and $\Delta t(1 \pm 0.15)$. Additional variations of the time step shall be determined based on consideration of the subsystem frequencies and the frequency content of the excitation data.

Alternatively, a more conservative approach using a generated synthetic time history may be used as a subsystem forcing function. This approach conservatively accounts for uncertainties in the structure frequencies if the response spectra computed from the synthetic time history envelop the broadened ISRS. When this method is used, the additional variation of frequency content is not required because the effects of uncertainties in the supporting structure are included in the broadened ISRS.

Damping values and procedures are addressed in Section 3.7.3.5.

The total response of the subsystems due to excitation in three directions is calculated by methods described in Section 3.7.3.6.

03.07.03-3

~~To account for uncertainties in the structural analysis, one of two methods may be used. Similar to peak shifting in the response spectrum method of analysis, three separate input time histories with modified time steps may be analyzed. The time histories at the attachment points may be derived considering variations in the concrete stiffness.~~

~~Damping values and procedures are addressed in Section 3.7.3.5.~~

~~Subsystems are analyzed for each of the three mutually orthogonal directions of input motion. The three directional time history inputs may be applied simultaneously in one analysis. The total response at each time step is calculated as the algebraic sum of the three directional results. The three time histories may be applied individually combining the responses using the square root sum of the squares (SRSS) method.~~

3.7.3.1.3 Inelastic Analysis Methods

03.07.03-14

Inelastic analysis is not used to qualify seismic subsystems for the U.S. EPR standard plant.

3.7.3.1.4 Equivalent Static Load Method

An alternate method of analyzing the effects of the SSE on a subsystem is to use an equivalent static load method. This simplified analysis considers the mass of subsystem components as lumped masses at their center of gravity locations. The seismic response forces from these masses are then statically determined by multiplying the contributing mass by an appropriate seismic acceleration coefficient ~~from each location~~. The seismic acceleration coefficient is determined from response spectrum based on the system natural frequency. ~~based on the dynamic properties of the system. When the equivalent static load method is used, justification is provided that the use of a simplified model is realistic and the results are conservative.~~

03.07.03-5

When the equivalent static load method is used, justification is provided that the use of a simplified model is realistic and the results are conservative. Additionally, relative motion between all points of support, where determined to be significant, are considered in the analysis. Maximum relative support displacements may be determined using conventional static analysis methods and then imposed in the most unfavorable combination. Every support is considered active in the analysis.

In general, many subsystems, and especially distribution subsystems, are multiple degree-of-freedom systems and have a number of significant modal frequencies in the amplified region of the response spectrum curve below the zero period acceleration (ZPA). For these systems, the peak response system may be conservatively used. When the subsystem frequency is not determined analytically, or is determined to be equal to or less than the peak frequency of the appropriate ISRS, the seismic acceleration coefficient is taken as the peak acceleration of the ISRS.

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Alternatively, the frequency determination method may be used when the subsystem frequency is greater than the peak frequency of the appropriate ISRS. In the frequency determination method, the subsystem frequency is greater than the peak frequency and the corresponding seismic acceleration is less than the ISRS peak acceleration. For ISRS with multiple peaks, the seismic acceleration coefficient shall not be less than the accelerations corresponding to subsequent ISRS peaks at frequencies higher than the subsystem frequency, as all subsequent modes will have higher frequencies and lower seismic acceleration coefficients.

The seismic acceleration coefficient, from both the peak response method and the frequency determination method is multiplied by a multi-mode factor of 1.5 to acount for multi-modal participation. A multi-mode factor less than 1.5 may be used, where applicable, with adequate technical justification.

This analysis is performed for the three directions of seismic input motion. The results of these three analyses are combined as described in Section 3.7.3.6.

~~the seismic acceleration coefficient is equal to the peak acceleration of the appropriate ISRS multiplied by 1.5, to account for the multi-modal participation. A multi-mode factor less than 1.5 is used in instances where technical justification is provided to support the reduced factor.~~

~~This analysis is performed for the three directions of seismic input motion. The results of these three analyses are then combined using the SRSS method, as in the response spectrum analyses. Relative motion of support locations, when determined to be significant, is considered. Every seismic support is considered active in this analysis.~~

3.7.3.2 Determination of Number of Earthquake Cycles

Criteria are established for the evaluation of distribution subsystems and for mechanical and electrical equipment for the effects of seismic-induced fatigue when fatigue is expected to have a significant effect on the design. Because the U.S. EPR design does not consider OBE load cases, the effects of seismic-induced fatigue are evaluated in accordance with SECY 93-087 (Reference 5) and SRP 3.7.3 of NUREG-0800 (Reference 6).

03.07.03-1

Seismic-induced fatigue of piping systems is described in the AREVA NP Topical Report ANP-10264NP-A~~10264-NP~~ (Reference 1)~~ and the AREVA NP letter NRC:07:028 (Reference 2)~~. The consideration of low-level seismic effects (i.e., fatigue) is required by IEEE Std 344-2004[1] (Reference 7) to qualify electrical and mechanical

1. Section 3.11 provides the justification for the use of the latest version of the IEEE standards referenced in this section that have not been endorsed by existing Regulatory Guides. AREVA NP maintains the option to use current NRC-endorsed versions of the IEEE standards.

equipment with the equivalent of five OBE events followed by one SSE event (with 10 maximum stress cycles per event). This consideration includes the seismic qualification process based on the approach provided in Reference 5 and outlined in SRP 3.10.III.3.C of Reference 6. To meet this requirement, earthquake cycles included in the fatigue analysis are composed of five one-half ~~third~~ SSE events followed by one full SSE event. A number of fractional peak cycles equivalent to the maximum peak cycles for five one-half SSE events may be used in accordance with Appendix D of Reference 7 when followed by one full SSE event. This approach results in consideration of fractional peak cycles.

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The effects of seismic-induced fatigue on distributed subsystems other than piping and electrical and mechanical equipment are evaluated, and when determined as appropriate the effects are evaluated using the same guidance from Reference 5 and SRP 3.7.3 of Reference 6 for piping systems. To meet this requirement, earthquake cycles included in the fatigue analysis are composed of two SSE events, with 10 maximum stress-cycles each, for a total of 20 full cycles. This is considered equivalent to the cyclic load basis of one SSE and five OBEs. Alternatively, the methods of Appendix D of Reference 7 may be used to determine a number of fractional vibratory cycles equivalent to 20 full SSE cycles. When this method is used, the amplitude of the vibration is taken as one-third of the amplitude of the SSE resulting in 300 fractional SSE cycles to be considered.

3.7.3.3 Procedures Used for Analytical Modeling

For dynamic analysis, the subsystem is idealized as a three dimensional framework using specialized finite element analysis programs. The analysis model consists of a sequence of nodes connected by beam elements with stiffness properties representing the subsystem components. Nodes are typically modeled at points required to define the subsystem geometry as well as lumped mass locations, support locations, and locations of structural or load discontinuities. Subsystem supports are idealized as springs with appropriate stiffness values.

In the dynamic mathematical model, the distributed mass of the subsystem is represented either as a consistent (i.e., distributed) mass or as lumped masses placed at each node. For the latter case, in order to adequately determine the dynamic response of the system, elements may be subdivided and additional mass points added. The minimum number of degrees-of-freedom in the model is equal to twice the number of modes with frequencies below the ZPA frequency.

For equipment, components, and subsystems other than piping, the seismic analysis also requires the development of a model representative of the dynamic properties of the particular system. For simple systems, a single-mass model may be sufficient with the mass lumped at the center of mass of the system. Otherwise, a multiple-mass model is developed by concentrating the mass of the system at a sufficient number of locations including locations where mass concentration or a drastic change in stiffness or orientation occurs, and by connecting the lumped masses with beam elements or spring elements. In lieu of a lumped multiple-mass model, a finite element model may also be used for the seismic analysis of the system. Dynamic properties of the supporting structural elements such as floor slab, roof slab, walls, miscellaneous steel platforms, and framing on which the system is attached, are included in the analysis model of the system unless:

- Such structural element may be demonstrated to be dynamically rigid.
- The particular floor slab, roof slab, or wall is dynamically flexible but an amplified ISRS that accounts for both the mass of the system and the flexibility of the floor slab, roof slab, or wall is available.

When developing the dynamic model of such structural elements (i.e., floor slab, roof slab, wall, miscellaneous steel platform, or framing) supporting the system, masses equal to 25 percent of the floor live load or 75 percent of the roof snow load, whichever is applicable, are included.

In most cases, the subsystems, equipment, and components are analyzed (or tested) as a decoupled system from the primary structure. For the decoupling of the subsystem and the supporting system, the following criteria are used:

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- If R_m <0.01, decoupling can be done for any R_f. Mass of the subsystem is considered in the supporting system model through uniformly distributed load.
- If 0.01 ≤R_m ≤0.1, decoupling can be done if R_f ≤0.8 or R_f ≥1.25. When R_f ≥1.25, mass of the subsystem is included in the supporting system model. When R_f ≤0.8, mass of the subsystem is not included in the supporting system model.
- If R_m >0.1, an approximate model of the subsystem should be included in the primary system model.

Where:

R_m and R_f are defined as:

R_m = Ratio of total mass of the supported system to total mass of the supporting system.

R_f = Ratio of fundamental frequency of the supported subsystem to dominant frequency of the support motion.

~~It is sufficient to include only the mass of the subsystem at the support point in the primary system model when the subsystem is rigid in comparison to the supporting system, and is rigidly connected. On the other hand, in case of a subsystem supported by flexible connections, the subsystem may be excluded from the primary model.~~

R_I = 1, 2 and 3 is the response component for each of the two horizontal components and one vertical component of earthquake motion, respectively.

Time History Method

03.07.03-11

In a linear time history analysis, the analysis may be performed separately for each of the three components of earthquake motion, or one analysis may be performed by applying all three components simultaneously if the three components of earthquake motion are statistically independent. in accordance with Section 3.7.1.2. demonstrates the statistical independence of the free-field time histories used as input to the seismic structural models. When linear time history analyses are performed separately for each component, the combined response for all three components may be obtained using the SRSS rule to combine the maximum responses from each earthquake component, as illustrated above.

When the seismic analysis is performed using simultaneous application of the time history input, the responses may be obtained individually for each of the three independent components and combined algebraically at each time step to obtain the combined response time history:

$$R(t) = \sum R_i(t)$$

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Equivalent Static Load Method

The seismic loads from the three components of the earthquake motion are combined using the SRSS method or 100-40-40 percent spatial combination rule, as in response spectrum analysis.

3.7.3.7 Combination of Modal Responses

The inertial response of a distribution subsystem in a seismic response spectrum analysis is considered in two parts: low frequency mode and high frequency mode. The modal analysis calculates the peak response of the distribution subsystem for natural frequencies of the system below a defined cutoff frequency. The low frequency (or non-rigid) modes consist of every mode with seismic excitation frequencies up to the frequency at which spectral accelerations return to the ZPA. For seismic analysis of the U.S. EPR standard plant, this frequency, the ZPA cutoff frequency, is about 40 Hz, as shown in Figure 3.7.1-1. Higher ZPA cutoff frequencies may be required for other dynamic load cases.

At modal frequencies above the ZPA cutoff frequency, distribution subsystem members are considered rigid. The acceleration associated with these rigid modes is usually small. However, in certain situations the response to high frequency modes can significantly affect support loads, particularly axial restraints on long distribution system runs. To account for these effects, a missing mass correction is applied.

3.7.3.7.1 Low Frequency (Non-Rigid) Modes

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RG 1.92, Revision 2, provides guidance on combining the individual modal results of a response spectrum analysis for structure supported at a single point and for multiply supported structures analyzed due to each response spectrum in a dynamic analysis using the USM method. Guidance for modal combinations for the ISM method including the missing mass effects is provided in NUREG-1061, Volume 4. (Reference 8).

The combination method used considers the effects of closely spaced modes. Modes are defined as being closely spaced if their frequencies differ from each other by 10 percent or less of the lower frequency.

For distribution subsystems analyzed using the USM method and with no closely spaced modes, the SRSS method is applied to obtain the representative maximum response of each element, as shown in the following equation:

$$R = \left[\sum_{k=1}^{N} R_k^2\right]^{\frac{1}{2}}$$

Where:

R = the representative maximum response due to the input component of the earthquake motion in one direction. (This calculation is performed in each of the earthquake directions.)

R_k = the peak response due to the kth mode

N = the number of significant low frequency modes.

If modes with closely spaced frequencies exist, the SRSS method is not applicable, and one of the two methods presented in C.1.1.2 and C.1.1.3 of RG1.92, Revision 3 should be used instead.

The more conservative methods of the combining modal responses as described in RG 1.92, Revision 1 remain acceptable; however, when using the Revision 1 methods, the residual response provisions of Revision 2 for treatment of the missing mass modes (as discussed in C.1.4.1 and C.1.5.1 of RG 1.92, Revision 2) shall be implemented.

This method may produce unconservative results for distribution subsystems with closely spaced modes. Therefore, the approved methods for combining closely spaced modes provided in RG 1.92 are used to obtain a more accurate modal response. These

~~include the Grouping, Ten Percent, and Double Sum methods of RG 1.92, Revision 1, as well as the less conservative methods of RG 1.92, Revision 2.~~

3.7.3.7.2 High Frequency (Rigid) Modes

~~Distribution subsystem~~ Modes with frequencies greater than the ZPA cutoff frequency are considered as high frequency, or rigid range, modes. For flexible ~~distribution~~ subsystems, the high frequency response may not be significant since a significant portion of the system mass is excited at frequencies below the ZPA. For ~~distribution~~ subsystems, ~~or~~ portions of ~~distribution~~ subsystems that are more rigidly restrained or have lumped masses near rigid restraints, a significant portion of the system mass may not be accounted for in the low frequency modal analysis. This mass which is not excited at the lower frequencies is termed the missing-mass of the system. While high frequency modes usually involve small displacement amplitudes and small stresses, they can have a significant impact on support loads.

The response from high frequency modes must be included in the response of the subsystem. Guidance for including the missing mass effects is provided in SRP Section 3.7.3 of Reference 6, RG 1.92 for subsystems supported at a single point and for multiply supported subsystems analysed by USM. Guidance for subsystems analyzed by ISM is provided in Reference 8, Volume 4.

03.07.03-12

The peak modal responses of the system at frequencies above the ZPA are considered to be in phase. For subsystems supported at a single point and for multiply support subsystems analyzed by either USM or ISM methods of analysis, the responses of high frequency modes are combined by algebraic summation.

The U.S. EPR design calculates the response of the high frequency modes by including a missing mass correction.

~~The response from high frequency modes must be included in the response of the distribution subsystem. Guidance for including the missing mass effects is provided in SRP Section 3.7.3 of Reference 6, RG 1.92 for USM, and Reference 8, Volume 4 for ISM.~~

~~The peak modal responses of the system at frequencies above the ZPA are considered to be in phase. For either USM or ISM methods of analysis, the responses of high frequency modes are combined by algebraic summation.~~

~~The U.S. EPR uses the following method for calculating and applying the response of the high frequency modes based on applying a missing mass correction.~~

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The total inertia forces in a ~~distribution~~ subsystem under simple excitation in a steady-state condition with unit acceleration applied in a specified direction is mathematically represented by the following expression.

$$\{F_t\} = [M]\{r\}$$

Where:

$\{F_t\}$ = total inertia forces in the specified direction

$[M]$ = mass matrix

$\{r\}$ = mass point displacement vector produced by a statically applied unit ground displacement.

The sum of the inertia forces for each mode included in the modal analysis is calculated as:

$$\{F_s\} = \sum_{n=1}^{N} \{F_n\} = \sum_{n=1}^{N} [M]\{\phi_n\}\{\phi_n\}^T [M]\{r\}$$

Where:

$\{F_s\}$ = total inertia force seen by the system in the low frequency modal analysis

$\{F_n\}$ = inertia force of mode n

$\{\phi_n\}$ = mode shape

N = number of modes calculated in the modal analysis.

Therefore, the missing forces considering unit ground acceleration in a specified direction are calculated as:

$$\{F_m\} = \{F_t\} - \{F_s\} = [M]\{r\} - \sum_{n=1}^{N} [M]\{\phi_n\}\{\phi_n\}^T [M]\{r\}$$

or:

$$\{F_m\} = [M]\{r\}\left[1 - \sum_{n=1}^{N} [M]\{\phi_n\}\{\phi_n\}^T\right]$$

The missing inertia forces are calculated independently for all input components of earthquake motion (i.e., in each direction for each support group). The mode displacements, member end action, and support force corresponding to each missing force vector are determined.

For subsystems supported at a single point or for multiple supported systems analyzed by the USM method, these results are treated as an additional modal result in the response spectra analysis. This missing mass mode is considered to have a modal frequency and acceleration defined at the cut-off frequency used in the modal analysis. These modal results are combined with the low frequency modal results using the methods described in Section 3.7.3.7.1.

03.07.03-12

For multiply supported systems analyzed using ISM, the rigid range (missing mass) results will be combined with the low frequency modal results by SRSS, per Reference 8, Volume 4. All of the provisions of Reference 8 for the ISM method of analysis will be followed. For ISM, the responses in the rigid range are considered in phase and combined by algebraic summation and the total rigid response will then be combined with the modal results by SRSS.

~~For USM, these results are treated as an additional modal result in the response spectra analysis. This missing mass mode is considered to have a modal frequency and acceleration defined at the cut-off frequency used in the modal analysis. These modal results are combined with the low frequency modal results using the methods described in Section 3.7.3.7.1.~~

~~For systems analyzed using ISM, the rigid range (missing mass) results will be combined with the low frequency modal results by SRSS, per Reference 8, Volume 4. All of the provisions of Reference 8 for the ISM method of analysis will be followed. For ISM, the responses in the rigid range are considered in phase and combined by algebraic summation and the total rigid response will then be combined with the modal results by SRSS.~~

3.7.3.8 Interaction of Other Systems with Seismic Category I Systems

The U.S. EPR uses state-of-the-art computer modeling tools for design and location of structures, subsystems, equipment, and piping. These same tools are used to minimize interactions of seismic and non-seismic components, making it possible to protect Seismic Category I subsystems from adverse interactions with non-seismic subsystem components. In the design of the U.S. EPR, the primary method of protection for seismic ~~SSCs~~SSC is isolation from each non-seismically analyzed SSC. In cases where it is not possible, or practical to isolate the seismic ~~SSCs~~SSC, adjacent non-seismic ~~SSCs~~SSC are classified as Seismic Category II and analyzed and supported so that an SSE event does not cause an unacceptable interaction with the Seismic Category I items, in accordance with the provisions of SRP 3.7.2-SAC II-8. However, for non-seismic subsystems classified as Seismic Category II, inelastic analytical methods may be used, if necessary. An interaction evaluation may be performed to demonstrate

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that the interaction does not prevent the Seismic Category I distribution subsystem from performing its safety-related function.

For non-seismic subsystems attached to seismic subsystems, the dynamic effects of the non-seismic subsystem are accounted for in the modeling of the seismic subsystem. The attached non-seismic subsystem, ~~in relation to the analysis boundary~~classified as Seismic Category II, is designed to preclude the effect of causing failure of the seismic subsystem during a seismic event. Section 3.7.3.3 describes decoupling criteria used to determine if the flexibility of the non-seismic subsystem is included in the subsystem model.

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3.7.3.8.1 Isolation of Seismic and Non-Seismic Systems

Isolation of seismic and non-seismic subsystems is provided by either geographical separation or by the use of physical barriers. Isolation minimizes the interaction effects that must be considered for the seismic systems and minimizes the number of non-seismic subsystems requiring more rigorous analysis.

Several routing considerations are used to isolate seismic and non-seismic subsystems. When possible, non-seismic ~~SSCs~~SSC are not routed in rooms containing safety-related ~~SSCs~~SSC. Non-seismic ~~SSCs~~SSC that can not be completely separated from seismic ~~SSCs~~SSC 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. To the extent possible, non-seismic systems are not routed close to any safety-related components.

3.7.3.8.2 Interaction Evaluation

Non-seismic ~~SSCs~~SSC may be located in the vicinity of safety-related ~~SSCs~~SSC without being qualified as Seismic Category II, provided an impact evaluation is performed to verify that no possible adverse impacts occur. In this evaluation, the non-seismic components are assumed to fall or overturn as a result of a seismic event. Any safety-related subsystem or component which may be impacted by the non-seismic component is identified as an interaction target and is evaluated to establish that there is no loss of ability to perform its safety-related function.

The following assumptions and guidelines are used to evaluate non-seismic and seismic interactions:

As a result of the seismic event:

- Every non-seismic hanger on the non-seismic distribution subsystems is assumed to fail instantaneously.
- Every connection on the non-seismic distribution subsystem is assumed to fail, thus allowing each section of a subsystem to fall independently.

- Every flange on bolted connections on a non-seismic system and other distributed subsystems is assumed to fail, thus allowing each section of piping to fall independently.

3.7.3.9 MultipleMultiply-Supported Equipment and Components with Distinct Inputs

The criteria presented are primarily applicable to distribution subsystems that span between multiple locations within a structure or between locations in different structures and, as a result, experience non-uniform support motion. Two conventional methods are presented: the uniform support motion (USM) method and the independent support motion (ISM) method. For both methods: relative displacements at the support points are considered and determined by conventional static analyses are determined from floor response spectra, the maximum displacement is predicted by the following relationship:

$$S_d = \frac{S_a g}{\omega^2}$$

Where:

S_d = maximum displacement at each support.

S_a = spectral acceleration in "g's" at the ZPA cutoff frequency.

ω = fundamental frequency of the building (rad/sec).

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The support displacements are imposed on the subsystems in the most unfavorable combination. The responses due to support displacements are combined with inertial responses as described in Sections 3.7.3.9.1 or 3.7.3.9.2.

The criteria presented are primarily applicable to distribution subsystems that span between multiple locations within a structure or between locations in different structures and, as a result, experience non-uniform support motion. Two conventional methods are presented: the uniform support motion (USM) method and the independent support motion (ISM) method. For both methods, relative displacements at the support points are considered and determined by conventional static analyses.

3.7.3.9.1 Uniform Support Motion Method

Distribution subsystems supported at multiple elevations within one or more buildings may be analyzed using the USM method. This analysis method applies a single set of spectraum, called a uniform response spectrum, at each support location, This specturm which envelops the individual response spectra for these other locations. AnThe envelopinged response spectrum is developed and applied for each of the three orthogonal directions of input motion. The modal and directional responses are then

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combined as described in Sections 3.7.3.7 and 3.7.3.6, respectively. The responses due to relative displacements at the support points with the inertial responses by the absolute sum method.

3.7.3.9.2 Independent Support Motion Method

03.07.03-16
03.07.03-18

ISM may be used when distribution subsystems are supported by multiple support structures or at multiple levels within a structure. Distribution subsystems supported at multiple locations within one or more buildings with different seismic input response maybe analyzed using the ISM method. In this method of analysis, supports aremay be divided into support groups. A single ISRS is applied to all supports of each group, but different ISRS are applied to different groups. with different seismic excitation applied to each group. A support group is made up of supports that have the same time-history input. Typically, a support group is made up of supports attached to the same structure, floor, or portion of a floor. For distribution subsystems analyzed using the ISM method, criteria presented in NUREG-1061 (Reference 8) are followed.

In lieu of performing a response spectrum analysis with USM or ISM inputs, time histories of support motions may be utilizied as input excitations. The responses due to relative displacements at the support points are combined with the inertial responses by the SRSS method.

The modal and directional responses are combined as described in Sections 3.7.3.7 and 3.7.3.6, respectively. Analyses performed using ISM use the damping values of Table 3.7.1-1.

3.7.3.10 Use of Equivalent Vertical Static Factors

Equivalent vertical static factors are not used in the design of subsystems for the U.S. EPR design. Seismic loads are calculated assuming that the vertical seismic motion occurs simultaneously with the two horizontal motions.

3.7.3.11 Torsional Effects of Eccentric Masses

Torsional effects due to the effect of eccentric masses connected to a subsystem are included in that subsystem analysis. For rigid components (i.e., those with natural frequencies greater than the ZPA cutoff frequency of 40 Hz), the lumped mass is modeled at the center of gravity of the component with a rigid link to the subsystem member centerline. For flexible components having a frequency less than the ZPA, the subsystem model is expanded to include an appropriate model of the component.

3.7.3.12 Buried Seismic Category I Piping, Conduits, and Tunnels

Seismic Category I buried pipe, electrical conduit bank, and tunnels are used in the U.S. EPR design. Examples of such utilities include pipe encased in concrete box, electrical conduit bank, pipe encased in another pipe, and pipes buried in the soil. In

3.7.3.14 Methods for Seismic Analysis of Aboveground Tanks

03.07.03-1

Dynamic pressure on fluid containers in the in-containment refueling water storage tank (IRWST), spent fuel pool, and other fluid reservoirs due to the SSE are considered in accordance with ASCE 4-98 (Reference 4). ~~Section 3.7.1.3~~Section 3.7.1.2 presents damping values for seismic analysis of aboveground tanks. Damping values for concrete aboveground tanks are seven percent of critical for impulsive modes and 0.5 percent for sloshing mode. These damping values are taken from Table 3.7.1-1.

Seismic analyses of concrete above-ground tanks consider impulsive and convective forces of the water, as well as the flexibility of the tank walls and floor, and ceiling of the tank. For the spent fuel pool, cask loading pit, cask washdown pit, and fuel transfer canal, the impulsive loads are calculated by considering a portion of the water mass responding with the concrete walls (see Section 3.7.2.3). Impulsive forces are calculated by conventional methods for tanks determined to be rigid. For non-rigid tanks, the effect of tank flexibility on spectral acceleration is included when determining the hydrodynamic pressure on the tank wall for the impulsive mode.

The IRWST is analyzed using finite element methods by including it in the 3D FEM model of the internal structures described in Section 3.7.2 and detailed in Section 3.8.3.

3.7.3.15 References:

03.07.03-1

1. ANP-10264NP-A, Revision 0, "U.S. EPR Piping Analysis and Support Design Topical Report," AREVA NP Inc., ~~September 2006~~November 2008.

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

3. ASCE "Seismic Response of Buried Pipe and Structural Components," ASCE Committee on Seismic Analysis of Nuclear Structures and Material, American Society of Civil Engineers, 1983.

4. ASCE Standard 4-98, "Seismic Analysis of Safety-Related Nuclear Structures and Commentary," American Society of Civil Engineers, September 1986.

5. SECY-93-087, "Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water (ALWR) Designs," U.S. Nuclear Regulatory Commission, July 1993.

6. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," U.S. Nuclear Regulatory Commission, March 2007.