3. DESIGN OF STRUCTURES, COMPONENTS, EQUIPMENT, AND SYSTEMS

3.1 Conformance with NRC General Design Criteria

3.1.1 Regulatory Criteria

The applicant shall discuss the extent to which plant structures, systems, and components (SSCs) important to safety meet the U.S. Nuclear Regulatory Commission (NRC) criteria in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," Appendix A, "General Design Criteria for Nuclear Power Plants." For each applicable criterion, the applicant shall provide a summary showing how the principal design features meet the general design criterion (GDC) and shall identify and justify any exceptions to the GDC. The discussion of each criterion shall identify the sections of the design control document (DCD) that present more detailed information to demonstrate compliance with or exceptions to the GDC.

3.1.2 Summary of Technical Information

The applicant provided a general evaluation of the principal design criteria of the economic simplified boiling-water reactor (ESBWR) standard plant as compared to the NRC's GDC for nuclear power plants set forth in Appendix A to 10 CFR Part 50. The applicant discussed the applicability of each criterion to the ESBWR design and identified the sections in the DCD that discuss detailed design information pertinent to the criteria.

3.1.3 Staff Evaluation

The staff reviewed the information in the ESBWR DCD, Tier 2, Section 3.1, to verify that the ESBWR design meets the relevant GDC. The staff's review of SSCs relies in part on codes and standards that represent accepted industry practices. Each of the following sections in this safety evaluation identifies applicable GDC, codes, and standards and discusses their applicability to the ESBWR design and the basis for acceptability of the design.

3.2 Classification of Structures, Systems, and Components

3.2.1 Seismic Classification

3.2.1.1 *Regulatory Criteria*

The staff reviewed the ESBWR DCD, Tier 2, Section 3.2.1, Revision 7, in accordance with NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition" (hereafter referred to as the SRP), Section 3.2.1, Revision 2, issued March 2007, and the guidance in Regulatory Guide (RG) 1.29, "Seismic Design Classification," which is identified in SRP Section 3.2.1. The staff's acceptance of the design is based on compliance with the GDC and CFR parts discussed below.

In GDC 2, "Design Bases for Protection Against Natural Phenomena," of Appendix A to 10 CFR Part 50, the NRC requires, in part, that nuclear power plant SSCs important to safety be designed to withstand the effects of earthquakes without loss of capability to perform their safety functions. This requirement applies to both pressure-retaining and nonpressure-retaining SSCs that are part of the reactor coolant pressure boundary (RCPB) and other SSCs important to safety. SSCs that are important to safety ensure various safety functions, including the following safety-related functions:

- integrity of the RCPB

- capability to shut down the reactor and maintain it in a safe-shutdown condition

- capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures, comparable to the exposure requirements in 10 CFR 50.34(a)(1)

Appendix S, “Earthquake Engineering Criteria for Nuclear Power Plants,” to 10 CFR Part 50, defines the safe-shutdown earthquake (SSE) for which these safety-related plant features are designed. An evaluation of the maximum earthquake potential forms the basis of the SSE; the SSCs are designed to remain functional through an earthquake that produces the maximum vibratory ground motion.

RG 1.29, Revision 3, “Seismic Design Classification,” issued September 1978, designates those plant features designed to remain functional in the event of an SSE as seismic Category I. Regulatory Position C.1 of RG 1.29 states that applicants should apply the pertinent quality assurance (QA) requirements of Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants,” to 10 CFR Part 50 to all activities affecting the safety-related functions of seismic Category I SSCs. Position C.2 of RG 1.29 states that those portions of nonseismic (NS) SSCs whose continued function is not required, but whose failure could reduce the functioning of any seismic Category I SSC to an unacceptable level or could result in an incapacitating injury to occupants of the control room, should be designed and constructed so that an SSE could not cause such failure. Position C.3 of RG 1.29 provides guidelines for designing interfaces between seismic Category I and NS SSCs. Position C.4 of RG 1.29 states that the pertinent QA requirements of Appendix B to 10 CFR Part 50 should be applied to all activities affecting the safety-related functions of SSCs discussed in Positions C.2 and C.3. Revision 4 to RG 1.29, issued March 2007, includes new Regulatory Position C.5, which refers to RG 1.189, “Fire Protection for Nuclear Power Plants,” for seismic requirements applicable to fire protection systems (FPSs).

RG 1.143, “Design Guidance for Radioactive Waste Management Systems, Structures, and Components Installed in Light-Water-Cooled Nuclear Power Plants,” referenced in RG 1.29, provides guidance for establishing the seismic design requirements of radioactive waste management SSCs to withstand earthquakes, as set forth in GDC 2 and 60, “Control of Releases of Radioactive Materials to the Environment.” RG 1.143 identifies several radioactive waste SSCs requiring some level of design consideration.

3.2.1.2 *Summary of Technical Information*

ESBWR DCD, Tier 2, Revision 7, Section 3.2.1, Tables 3.2-1, 3.2-2, and 3.2-3, and Figures 3.2-1 and 3.2-2, identify the ESBWR seismic classification criteria and principal SSCs that are classified as seismic Category I, seismic Category II, or NS. These tables identify the pressure boundary components of both fluid systems and nonpressure boundary items, such as structures, cranes, and supports. DCD Table 3.2-1 also includes the seismic classification of electrical systems, although Chapter 8 of this report addresses the seismic classification of electrical systems. The descriptions of the various system safety functions and applicable simplified piping and instrumentation drawings (P&IDs) in other sections of DCD Tier 2 also include seismic classifications for fluid systems.

DCD, Tier 2, Revision 7, Table 3.2-1, initially identified the QA requirements as either “B” for the program under Appendix B to 10 CFR Part 50 for safety-related components or “E” for non-safety-related components. The designation “E” indicated that the QA requirements are applied commensurate with the importance of the safety function. This QA requirement designation has been replaced by the term “safety-related classification” and by Class Q, S, or N, depending on the appropriate level of QA.

DCD, Tier 2, Revision 7, Section 3.2, states that the ESBWR complies with GDC 2, as the safety-related SSCs are designed to withstand the effects of earthquakes without loss of capability to perform their safety-related functions. Section 3.2.1 of DCD, Tier 2, Revision 7, further states that the ESBWR meets the acceptance criteria of SRP Section 3.2.1 and the seismic classifications are consistent with the guidelines in RG 1.29. DCD, Tier 2, Revison 7, Table 1.9-3, is consistent with SRP Section 3.2.1, and Table 1.9-21b of DCD, Tier 2, Revision 7, initially identified no exceptions to RG 1.29, Revision 3, although an exception was subsequently included concerning the main steam (MS) piping.

Section 7.1.6.4 of DCD, Tier 2, Revision 7, states that the instrument sensing lines are designed to satisfy the requirements of RG 1.151, “Instrument Sensing Lines,” issued July 1983, and DCD, Tier 2, Revision 7, Section 7.7.7.3.3 specifically identifies that the sensing lines penetrating the containment meet the guidance of RG 1.151 and are seismic Category I.

3.2.1.3 *Staff Evaluation*

The staff review included evaluation of the criteria used to establish the seismic classification and the application of those criteria to the classification of principal components included in DCD, Tier 2, Revision 7, Table 3.2-1, except for electrical features, which are evaluated in Chapter 8 of this report. The following sections include a summary of GE Hitachi Nuclear Energy (GEH) responses to significant requests for additional information (RAIs) for each review topic required to complete this review. Section 3.2.2 of this report includes additional RAIs that address both seismic and quality group (QG) classification. DCD, Tier 2, Revision 7, includes changes that the applicant made in response to the RAIs. In July 2009, the staff also performed an audit of available classification design-basis documents for risk-significant components as documented in the “Summary of the July 20 to 24, 2009, Regulatory Audit of Design Specification of Risk Significant ESBWR Components at General Electric Hitachi (GEH) Office in Wilmington, NC,” issued September 1, 2009. The audit found that the detailed design is not complete and information is insufficient to validate the basis for each component classification. However, the applicant has established a process for the regulatory treatment of non-safety systems (RTNSS), which is evaluated in Chapter 22 of this report, to classify SSCs and define supplemental requirements for non-safety-related SSCs that are important to safety to ensure their reliability consistent with the assumed reliability in the probabilistic risk assessment (PRA). Although the final list of risk-significant RTNSS SSCs and specific supplemental requirements are to be determined during the detailed design, the design reliability assurance program (D-RAP) will be used to ensure that appropriate supplemental design and QA requirements are specified. The applicant identified an inspection, test, analysis, and acceptance criterion (ITAAC) for the D-RAP; subsequently revised the DCD; and completed appropriate design-basis documents, including an RTNSS requirements document. On the basis of the RTNSS process and these documents, sufficient information exists to demonstrate that the applicant has an appropriate classification process for SSCs important to safety and to conclude that the classification criteria and application of those criteria are generally consistent with the criteria in RG 1.29 or an equivalent alternative.

3.2.1.3.1 Classification Criteria

The staff reviewed the criteria identified in DCD, Tier 2, Revision 7, Section 3.2.1, that the applicant used to select the appropriate seismic classification in DCD Table 3.2-1 for principal components. The staff determined that the classification criteria for seismic Category I, Category II, and NS are basically consistent with RG 1.29, Revision 3, with an approved exception defined in SRP Section 3.2.1 for seismic classification.

One difference from the regulatory guidance is that RG 1.29 designates those portions of the boiling-water reactor (BWR) steam systems from the containment isolation valves to the turbine stop valve (TSV) to be seismic Category I, but SRP Section 3.2.2 (Branch Technical Position (BTP) 3-1) and the DCD, Tier 2, Revision 7, provide an acceptable alternative when the system is seismically analyzed. One difference in terminology is that RG 1.29 does not use the term "seismic Category II," but the basic methodology—seismic analysis of SSCs whose failure could adversely affect seismic Category I SSCs—is consistent.

Another difference related to terminology and GDC 2 is that certain components that may be important to safety, but perform no safety-related function, are considered NS and are evaluated in accordance with RTNSS, discussed in DCD, Tier 2, Revision 7, Chapter 19 and in Chapter 22 of this report. Systems that provide post-72-hour cooling and postaccident monitoring are examples of RTNSS that may include additional seismic requirements. Fire protection is another example of a non-safety-related system that may be important to safety and therefore has seismic requirements. Revision 4 to RG 1.29 changed this guidance to add Regulatory Position C.5, which refers to RG 1.189, "Fire Protection for Nuclear Power Plants," for seismic requirements applicable to FPSs. DCD, Tier 2, Revision 7, Table 1.9-21b and Section 9.5 identify no exceptions to RG 1.189 and Plant Systems Branch (SPLB) 9.5-1 for seismic requirements for the FPS. DCD, Tier 2, Revision 7, Table 3.2-1 classifies portions of the FPS as seismic Category I or II, which is consistent with regulatory guidance requiring a seismic analysis and is therefore acceptable. Also, the response to RAI 3.2-52 clarified that portions of the FPS that support makeup water to the isolation condenser/passive core cooling system (IC/PCCS) and spent fuel pools (SFPs) after 72 hours are seismic Category I in accordance with SRP Section 9.1.3. Section 3.2.2.3.4 of this report further addresses supplemental QA for the portions of FPSs that are classified as seismic Category I and II.

3.2.1.3.2 Use of Simplified Piping and Instrumentation Drawings

In RG 1.29, Regulatory Position C.3 identifies that, in regard to the interface between seismic Category I and NS Category I SSCs, the dynamic analysis requirements should be extended to the first anchor point in the NS system. SRP Section 3.2.1 indicates that the boundary limits are reviewed on the P&IDs. As identified in SRP Section 3.2.1, details of the seismic classification may be shown on plot plans, general arrangement drawings, and P&IDs. The simplified P&IDs in the DCD identify the main components in the fluid systems and the basic interconnecting piping and valve configurations, as well as the interface between the safety-related and non-safety-related portions of each system. These drawings are simplified schematics that do not exhibit the level of detail typically shown in P&IDs developed during the detailed design phase. Section 3.2.2.2.3.5 of this report discusses the staff's concern that the level of detail in the simplified P&IDs submitted with the DCD does not permit a detailed review, which the staff addressed in RAI 3.2-7. Also, based on a staff audit ("Summary of the July 20 to 24, 2009, Regulatory Audit of Design Specification of Risk Significant ESBWR Components at General Electric Hitachi (GEH) Office in Wilmington, NC," September 1, 2009), various detailed P&IDs show that seismic classifications are extended to the first anchor in the NS system to meet Regulatory Position C.3 of RG 1.29.

3.2.1.3.3 Seismic Classification for Restraints

In RAI 3.2-13, the staff requested that the applicant revise B21 Item 6 in Table 3.2-1 of the DCD to state that seismic restraints must be located in a seismic Category I structure. In its response, the applicant indicated that it will revise Table 3.2-1 to clarify that seismic interface restraints are located inside the seismic Category I building. The applicant added a note to Table 3.2-1 and included Figures 3.2-1 and 3.2-2 to provide the details showing that the seismic interface restraints are inside the seismic Category I building. In RAI 3.2-57, the staff requested that pipe whip restraints be at least seismic Category II. The response to RAI 3.2-57 indicated that the applicant will revise Table 3.2-2 to eliminate the reference to seismic Category NS for safety-related pipe whip restraints. The staff finds that the changes made in the DCD, Tier 2, Revision 7, resolve its concerns about seismic categorization of restraints, and therefore, RAIs 3.2-13 and 3.2-57 were closed.

3.2.1.3.4 Seismic Category I

Based on its review of DCD, Tier 2, Revision 7, Section 3.2.1; DCD, Tier 2, Revision 7, Tables 3.2-1, 3.2-2, and 3.2-3; and the other sections and P&IDs discussed above, the staff determined that, in general, the safety-related SSCs in the ESBWR are acceptably classified as seismic Category I, in accordance with Regulatory Position C.1 of RG 1.29, including the referenced RG 1.151. DCD, Tier 2, Revision 7, Table 1.9-21b identifies one exception to RG 1.29 regarding the classification of the MS system in the turbine building (TB). This exception to RG 1.29 Position C.1.e is acceptable on the basis that the turbine main steam system (TMSS) is to be analyzed according to SRP Section 3.2.2, BTP 3-1.

In multiple RAIs, the staff also requested that several SSCs with a potential safety function be designated seismic Category I in order to make this finding (i.e., Safety-related SSCs are classified as seismic Category I). The response to RAI 3.2-51 identified additional components in the reactor building (RB) heating, ventilation, and air conditioning (HVAC) as seismic Category I. The response to RAI 3.8-2 indicated that the applicant will update the fuel building (FB) HVAC to identify the isolation dampers and ducting penetrating the FB boundary as safety-related and seismic Category I. DCD, Tier 2, Revision 7, Table 3.2-1, now identifies these components as seismic Category I. The responses to RAIs 3.2-22, 3.2-23, 3.2-30, 3.2-31, 3.2-32, 3.2-43, 3.2-44, 3.2-45, 3.2-46, 3.2-47, 3.2-54, 3.2-55, and 3.2-56 explained that the system functions in question are not safety-related and, therefore, the SSCs supporting these functions need not be seismic Category I. Non-safety-related SSCs that are risk significant are considered RTNSS candidates to be evaluated for seismic requirements under Chapter 22 of this report. As explained in DCD, Tier 2, Revision 7, Chapter 19A, certain RTNSS candidates require augmented seismic design criteria. The staff evaluated the categorization and treatment, including augmented seismic design criteria for RTNSS candidates, under various RAIs, including 3.2-63, 22.5-4, 22.5-5, 22.5-7, and 22.5-16 addressed in Chapter 22 and Section 3.2.1.3.9 of this report. RTNSS components with augmented seismic design criteria may require an appropriate seismic classification other than NS or, alternatively, seismic requirements clearly denoted in the DCD, Tier 2, Revision 7, and design documents.

In the response to RAI 17.4-23 S02, the applicant referenced NEDO-33411 Risk Significance of Structures, Systems and Components for the Design Phase of the ESBWR, Revision 1, July 2009 for a list of all risk-significant SSCs and stated that it will revise DCD, Tier 2, Section 17.4, to clarify that the RTNSS and risk-significant SSCs are in the scope of the D-RAP. Also in the response to RAI 17.4-55, the applicant stated that the non-safety-related SSCs that perform safety-significant functions have QA requirements applied commensurate with the importance of that function and Table 3.2-1 identifies these SSCs. The applicant further agreed to revise DCD Table 3.2-1 to clarify that non-safety-related SSCs that are risk-significant but not designated as RTNSS are assigned to Quality Class S. It is understood that the term "quality class" has been replaced by the term "safety-related classification" and that the list of risk-significant SSCs within the scope of the D-RAP is preliminary. With these clarifications and changes, the staff concludes that, based on the evaluation of seismic requirements for RTNSS candidates addressed in Chapter 22 of this report and QA requirements for certain non-safety-related seismic Category I and Category II SSCs addressed in the D-RAP, the revised DCD, Tier 2, Revision 7, Table 3.2-1 is generally consistent with SRP Section 3.2.1 and RG 1.29 guidance for seismic Category I SSCs or the alternative classification in SRP Section 3.2.2 for the TMSS.

3.2.1.3.5 Seismic Category II

Regulatory Position C.2 of RG 1.29 states that those portions of NS SSCs whose continued function is not required, but whose failure could reduce the functioning of any seismic Category I SSC to an unacceptable level or could result in an incapacitating injury to occupants of the control room, should be designed and constructed so that an SSE could not cause such failure. In DCD, Tier 2, Revision 7, Section 3.2.1, the applicant classified such SSCs as seismic Category II, and the staff has determined that the necessary SSCs in the ESBWR are, in general, classified as seismic Category II.

The staff has questioned the seismic analysis methods for various seismic Category II SSCs and requested that several SSCs be designated as at least seismic Category II. In RAI 3.2-16, the NRC staff requested seismic analysis of the condenser anchorage and condenser nozzles. The RAI response clarified that the piping inlet nozzles and condenser anchorage are seismically analyzed for the SSE as shown in Figure 3.2-1, which the applicant planned to add to the DCD. Submitted with Revision 2 of DCD, Tier 2, Figure 3.2-1 shows this portion as seismic Category II. The response to RAI 3.2-16 S01 clarified that the seismic classification of the TMSS piping is an exception to RG 1.29 and that the applicant will revise DCD, Tier 2, Tables 1.9-21b and 17.0-1, accordingly. This approach is identified in SRP Sections 3.2.1 and 3.2.2 as an acceptable alternative to RG 1.29, therefore the staff concurs with the applicants' approach. The applicant revised Tables 1.9-21b and 17.0-1 to identify this as an exception to RG 1.29. The staff verified the changes to these tables in Revision 4 of the DCD. Therefore, RAI 3.2-16 was closed.

Regarding B21 Item 9, RAI 3.2-18 requested that the pipe whip restraints be categorized as at least seismic Category II, and the RAI response stated that the applicant will change seismic Category "NS or I" to "I or II." RAI 3.2-19 questioned the seismic analysis methods of the seismic Category II B21 Item 13 MS drains, and the response confirmed that the item will be analyzed according to the methods described in DCD, Tier 2, Revision 7, Section 3.7 and clarified that earthquake experience data are not the only basis for structural capability.

In RAI 3.2-40 staff requested the applicant to identify the turbine bypass piping as seismic Category II since it is seismically analyzed. The response to RAI 3.2-40 modified the turbine bypass system from NS to seismic Category II. Revision 1 to the S02 response to RAI 3.2-19 and 3.2-40 clarified that the seismic classification of the MS drains and turbine bypass will be revised, on the basis of the Chapter 10 review, from seismic Category II to NS, with a seismic analysis to demonstrate structural integrity. The DCD, Tier 2, Revision 7, shows that this piping is classified consistent with the revised RAI responses. This revised position requiring a seismic analysis with appropriate QA is acceptable on the basis that the seismic classification with a dynamic seismic analysis is consistent with SRP Section 3.2.2.

In RAI 3.2-23, staff requested the applicant to revise the ARI from NS to seismic Category I. The response to RAI 3.2-23 changed the seismic classification for alternate rod insertion (ARI) equipment from NS to seismic Category II and explained that the ARI classification is consistent with ABWR and as non-safety-related should be seismic Category II. In RAI 3.2-50, staff requested the applicant to revise the seismic classification of cranes hoists and elevators from NS to seismic Category II. The response to RAI 3.2-50 changed the seismic classification for the upper and lower drywell servicing hoists from NS to seismic Category I and the MS tunnel servicing hoists from NS to seismic Category II. In RAI 3.2-51, staff requested the applicant to revise the seismic classification of RB HVAC components from NS to seismic Category I or II. In response to RAI 3.2-51, the applicant revised the classification of the RB HVAC components in the U40 system from NS to seismic Category I or II. With the clarifications and changes discussed above, the staff concludes that the revised table is consistent with SRP Section 3.2.1 and RG 1.29 guidance for seismic Category II SSCs.

DCD, Tier 2, Revision 7, Section 3.7, "Seismic Design," discusses the design criteria for seismic Category II SSCs. In Regulatory Position C.3 of RG 1.29, the NRC recommends guidelines for designing interfaces between seismic Category I and NS SSCs. DCD, Tier 2, Revision 7, Section 3.7.3.8, "Interaction of Other Systems with Seismic Category I Systems," provides the ESBWR information relative to Positions C.2 and C.3. Sections 3.7 and 3.12 of this report discuss the staff's evaluations of this information for structures and piping, respectively.

Functionality of RTNSS Structures, Systems, and Components

SECY-96-128, "Policy and Key Technical Issues Pertaining to the Westinghouse AP600 Standardized Passive Reactor Design," dated June 12, 1996, established the Commission policy that RTNSS equipment must be protected from natural phenomena including seismic events (per GDC 2). Subsequently, a staff memo dated June 23, 1997, to the Commissioners pertaining to SECY-96-128, clarified that no dynamic qualification of active equipment was necessary for post-72-hour equipment. The definition of seismic Category II in DCD Sections 3.2.1 and 3.7 in earlier DCD revisions did not necessarily account for long-term functionality for RTNSS Criterion B SSCs. DCD Section 19A.8.3 notes that RTNSS B components are required to function following a seismic event and that they are designed to seismic Category II, at a minimum. However, the definition of seismic Category II in DCD Sections 3.2.1 and 3.7 does not include functionality requirements and states that the operational performance of these components was not required. For RTNSS B Category II SSCs, such as the control building air-handling units, that are required to function following a seismic event, the staff asked the applicant to explain how the classification as seismic Category II ensures that the SSCs will be functional following a seismic event. In RAI 3.2-68, the staff asked the applicant to identify an augmented seismic classification and/or revise the definition of seismic Category II in DCD Sections 3.2.1 and 3.7 accordingly.

In the response to RAI 3.2-68, the applicant stated that it will revise the definition of seismic Category II to clarify that RTNSS B SSCs are required to remain functional following a seismic event. The applicant is not relying solely on the classification of RTNSS Criterion B SSCs as seismic Category II to ensure their functionality following a seismic event, and DCD, Tier 2, Revision 7, Section 19A.8.3 notes that RTNSS Criterion B equipment is qualified to Institute of Electrical and Electronics Engineers (IEEE)-344-1987, “IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations—Description,” to demonstrate seismic performance and structural integrity. The functionality of RTNSS Criterion B SSCs following a seismic event is ensured by classifying them as Quality Class S (Special) in accordance with the ESBWR QA program as discussed in NEDO-33181, Revision 5, “NP-2010 COL Demonstration Project Quality Assurance Plan,” which is attached to the response to RAI 3.2-6 S01, Revision 1.

The response also stated that additional details on how the QA program requirements ensure the functionality of RTNSS Criterion B SSCs were being prepared and would be provided separately in response to RAI 3.2-6 S02. The response to RAI 3.2-6 S02 stated that the applicant will also modify Table 3.2-1 to replace the “QA Requirement” classification column with a “Quality Class” column. The term “quality class” was eventually replaced by the term “safety-related classification” in DCD Revision 6. DCD, Tier 2, Revision 7, Section 3.2.1 explains that seismic Category II SSCs that are also classified as RTNSS Criterion B in Tables 19A-2 and 19A-3 are required to remain functional following a seismic event. The staff concurs that additional requirements are needed to ensure the functionality of RTNSS SSCs following a seismic event, and DCD, Tier 2, Revision 7, Section 19A.8.3 notes that RTNSS Criterion B equipment is qualified to IEEE-344-1987 to demonstrate seismic performance and structural integrity. Based on the results of an audit (Summary or the July 20 to 24, 2009, Regulatory Audit of Design Specification of Risk Significant ESBWR Components at General Electric Hitachi (GEH) Office in Wilmington, NC), the) staff found that the applicant has a classification process in place to ensure that risk-significant SSCs are appropriately seismically classified and qualified to ensure functionality of RTNSS Criterion B equipment, but the basis for seismic considerations applicable to RTNSS SSCs other than Criterion B is unclear. In its audit response, dated September 21, 2009, the applicant identified certain actions to resolve this concern, including an RTNSS requirements document to be completed later in the year. The staff has confirmed that these actions have been completed.

Structures that house components or systems performing RTNSS B functions are to be a minimum of seismic Category II. DCD, Tier 2, Revision 7, Table 19A-3 shows that these structures are either seismic Category I or Category II. However, RTNSS SSCs and the structures that enclose these systems and components that perform RTNSS functions other than Type B are designated as NS. DCD, Tier 2, Revision 7, Section 19A states that RTNSS Criterion C is qualified to IEEE-344-1987 only to demonstrate structural integrity. The seismic classification and qualification of SSCs that perform RTNSS functions other than Criterion B, such as the plant service water system (PSWS), are evaluated in Section 3.2.1.3.7 of this report and are subject to the RTNSS process evaluated in Chapter 22 of this report. Therefore, the staff concludes that SSCs classified as seismic Category II satisfy Regulatory Position C.2 in RG 1.29..

3.2.1.3.6 Quality Assurance Requirements

Regulatory Positions C.1 and C.4 of RG 1.29 state that the pertinent QA requirements of Appendix B to 10 CFR Part 50 should be applied to all activities affecting the safety-related functions of (1) all seismic Category I SSCs and (2) those portions of SSCs that are covered under Positions C.2 and C.3 of RG 1.29.

The staff requested that several seismic Category I SSCs be required to meet Appendix B QA requirements in compliance with Position C.1. In its response to RAIs 3.2-6, 3.2-28, and 3.2-52, the applicant clarified its position by stating that the definition of equipment as seismic Category I does not in itself necessarily invoke a higher QG or QA classification. However, the application of QA requirements commensurate with the importance of the component's safety function is necessary. The staff concurs that the QA requirements depend on the component's safety function and that the conservative classification of SSCs as seismic Category I does not necessarily require application of the QA program described in Appendix B to 10 CFR Part 50. Section 3.2.2 of this report further evaluates as an RTNSS issue the acceptability of designating QA requirements as "E" for components that may have a function important to safety. The staff verified that all of the safety-related items (Safety Class 1, 2, and 3) listed in Table 3.2-1 as seismic Category I SSCs must meet the QA requirements of Appendix B to 10 CFR Part 50. The staff concludes that, for seismic classification of safety-related SSCs, this information is consistent with the regulatory position for such SSCs.

To satisfy Regulatory Position C.4 of RG 1.29, the pertinent QA requirements of Appendix B to 10 CFR Part 50 should also apply to safety-related functions of those portions of SSCs covered under Regulatory Positions C2 and C3 of RG 1.29 and defined by the applicant as seismic Category II. The staff reviewed the items listed in DCD, Tier 2, Revision 7, Table 3.2-1 that are seismic Category II SSCs to determine if they meet the requirements of Appendix B to 10 CFR Part 50 or an equivalent program. Certain safety-significant Category II SSCs have Appendix B quality requirements, such as the N11 TMSS. The staff requested that the applicant apply the Appendix B QA requirements to several other seismic Category II SSCs. Regarding the fuel storage facility fuel storage racks and other non-safety-related SSCs, the applicant explained in its response to RAI 3.2-6 that QA Requirement E is appropriate regardless of the seismic classification of the SSCs. In general, Table 3.2-1 shows that non-safety-related seismic Category II SSCs were initially identified as QA Requirement E. Since 10 CFR Part 50 Appendix B generally applies to SSCs that are important to safety, with emphasis on those that are safety-related the staff concurs that, in general, there is no need to apply the entire QA requirements of Appendix B to non-safety-related SSCs.

However, certain non-safety-related SSCs with a safety-significant function that fall into the category of seismic Category II or RTNSS components may require supplemental QA requirements based on the importance of their safety function. The staff was concerned that QA Requirement E was insufficient for seismic Category I or II and, subsequently, DCD, Tier 2, Revision 7, Table 3.2-1 showed non-safety-related seismic Category I and II SSCs identified as Safety-Related Class S. The resolution of Open Item 3.2-6 in Section 3.2.2.3.4 of this report addresses the technical concern about QA requirements for former QA Requirement E and current Safety-Related Class S. The QA requirement for the seismic Category I and Safety-Related Class S new and spent fuel racks is consistent with 10 CFR Part 50, Appendix B. Based on changes to identify Special Safety-Related Class S for non-safety-related seismic Category I and II and RTNSS SSCs, the staff concludes that application of a 10 CFR Part 50, Appendix B, program representing special QA requirements for non-safety-related seismic Category I and II SSCs and the inclusion of certain safety-significant SSCs under RTNSS is consistent with recent NRC policy and represents an acceptable position relevant to regulatory positions C.2 and C.3.

3.2.1.3.7 Nonseismic Evaluation

The staff reviewed DCD Table 3.2-1 to confirm that only non-safety-related SSCs are classified as NS. The staff determined that only non-safety-related SSCs are classified as NS, but the staff questioned the criteria applicable to specific NS SSCs that may have an important safety function. In RAI 3.2-42, the staff requested that the applicant identify a combined license (COL) action item to perform a walkdown of the nonseismically designed components in the vicinity of the alternate MS leakage path components. The following RAI response states that the applicant will add a COL item to DCD Section 10.3.7:

> A plant-specific walk-down of nonseismically designed systems, structures and components overhead, adjacent to, and attached to the main steamline (MSL) leakage path (i.e., the MS piping, the bypass line, and the main condenser) shall be conducted to confirm, by inspection, that the as-built MS piping, bypass to the condenser, and the main condenser, are not compromised by nonseismically designed systems, structures and components.

Subsequently, the applicant determined that an inspection is now a requirement of a Tier 1 Section 2.11.1 ITAAC, rather than a COL item. ITAAC 6 in Table 2.11.1-1 includes the following pertaining to seismic considerations for the main steam isolation valve (MSIV) leakage path:

> Inspections of nonseismically designed systems, structures and components overhead, adjacent to, and attached to the MSIV leakage path (i.e., the main steam piping, bypass piping, required drain piping and main condenser) will be performed.

On the basis of this ITAAC, all issues associated with RAI 3.2-42 were closed.

In RAI 3.2-63, the staff questioned the non-safety-related and NS classification of the R11, R12, and R21 electrical systems that recharge the batteries after 72 hours postaccident. The applicant's response indicated that the RTNSS equipment needed to recharge the safety-related batteries will be designed to withstand seismic effects without formal classification of these components as seismic Category I. The staff is concerned that, based on SECY-94-084, "Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems in Passive Plant Designs," dated March 28, 1994, and SECY-95-132, "Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems (RTNSS) in Passive Plant Designs (SECY-94-084)," dated May 22, 1995, systems that are RTNSS and required after 72 hours should be evaluated for their risk significance and seismically designed to appropriate standards. The application of the International Building Code (IBC) to the seismic design of the RTNSS components is evaluated under RAI 22.5-6 and 22.5-7 in Section 22 of this report. Also, refer to the evaluation of RAI 3.2-63 in Section 3.2.1.3.9 and Chapter 22 of this report which addresses the staff's concern about seismic qualification of RTNSS systems needed after 72 hours. Section 3.2.2 of this report, under RAI 3.2-6, specifically discusses supplemental requirements for risk-significant RTNSS SSCs.

In regard to RTNSS SSCs that do not perform a Criterion B post-72-hour safety function, the staff was also concerned that the NS classification may not be adequate to ensure that this equipment will be functional during and after an SSE. The RTNSS process evaluated in Chapter 22 of this report further describes the seismic requirements for RTNSS SSCs, such as the PSWS. GEH Topical Report NEDO-33411, Revision 1, issued July 2009, states that SSCs meeting RTNSS Criterion C or D are considered risk significant. Staff guidance in a memorandum dated July 18, 1994, pertaining to the AP600, identified a proposed review approach for equipment designated as important by the RTNSS process. The proposed approach used a qualification of electrical and mechanical equipment by experience on a case-by-case basis. A subsequent NRC memorandum dated June 23, 1997, concerning SECY-96-128, stated that, for equipment required post-72-hours (Category B), anchorages must be consistent with the SSE design of equipment anchorages of seismic Category I items, but no dynamic qualification of active equipment is necessary. In regard to RTNSS SSCs other than Criterion B, DCD, Tier 2, Revision 7, Section 19A.8.3 and the response to RAI 22.5-25 clarified that RTNSS Criterion A, C, D, or E does not require augmented design standards, and RTNSS C components are not required to remain functional following a seismic event on the basis of the seismic margins analysis. Systems and components in seismic Category NS are designed to the seismic requirements of the 2003 IBC, and DCD, Tier 2, Revision 7, Section 19A states that RTNSS Criterion C is qualified to IEEE-344-1987 only to demonstrate structural integrity. The staff's evaluation of augmented requirements for RTNSS SSCs is in Section 22.5 of this report. A staff audit ("Summary of the July 20 to 24, 2009, Regulatory Audit of Design Specification of Risk Significant ESBWR Components at General Electric Hitachi (GEH) Office in Wilmington, NC," September 1, 2009) further reviewed the basis for seismic requirements for RTNSS SSCs. The staff found that the applicant has a design process to consider appropriate seismic requirements for RTNSS SSCs, and the D-RAP addressed in DCD, Tier 1, Revision 7, Section 3.6, includes a D-RAP ITAAC to provide reasonable assurance that the ESBWR plant is designed and constructed in a manner consistent with the key assumptions in the PRA and the risk insights for the risk-significant SSCs in the D-RAP.

3.2.1.3.8 Structures

DCD Table 3.2-1 identifies the seismic designation of structures as either seismic Category I, seismic Category II, or nonseismic (NS). Both seismic Category I and seismic Category II structures are required to be seismically analyzed for the SSE. Structures designated NS are designed for seismic requirements in accordance with requirements for Category IV of the IBC. In RAIs 3.8-2, 3.2-54 and 3.2-55, the staff questioned the seismic designation of several structures.

The response to RAI 3.8-2 clarified that the portions of the FB and control building structure are seismic Category I and that only those non-safety-related portions of the FB and control building structures that contain non-safety-related equipment have been classified as seismic Category II. The NRC staff concurs that seismic Category II is the correct seismic category for portions of structures that do not support safety-related components but, in the event of a structural failure caused by an SSE, could adversely affect seismic Category I components. The RAI 3.8-2 response also clarified that the initially not-in-scope intake and discharge structures are to be classified as NS, andthe DCD, Tier 2, Revision 7, identifies these non-safety-related structures as NS.

The responses to RAIs 3.2-54 and 3.2-55 clarified that the PSWS performs no safety-related functions and the service water building structure and the intake and discharge structures are NS. The staff determined that these structures are correctly classified as NS on the basis that they do not support or enclose any safety-related components and their failure because of an SSE could not adversely impact seismic Category I components. Information on the PSWS was revised to show that the system no longer has a long-term cooling function post-72-hours. DCD Table 19A-2 includes the PSWS as a Criterion C RTNSS system to support Reactor Component Cooling Water System (RCCWS), with seismic requirements for the structure consistent with the IBC. In its resolution of RAI 22.5-7 and 22.5-25, Chapter 22 of this report, which concerns the design of structures, presents an evaluation of the acceptability of the application of the IBC for the seismic design of non-safety-related NS structures in regard to

RTNSS. DCD Revision 6, Table 19A-3, identifies structures that house RTNSS Criterion B functions as either seismic Category I or II, consistent with staff positions.

Turbine Building Seismic Classification

In Revision 5 to DCD Table 3.2-1, the applicant changed the TB seismic classification from seismic Category II to NS. The TB is adjacent to the seismic Category I control building, and Table 3.2-1 shows that the TB contains seismic Category I components, including portions of the reactor protection system and seismic Category II MS piping. In addition, the TB encloses RTNSS SSCs important to safety. Considering that a collapse or failure of the building structure could adversely affect these SSCs, this NS classification appears to be inconsistent with RG 1.29, Regulatory Position C.2. This position states that those portions of SSCs of which continued function is not required but of which failure could reduce the functioning of any plant feature included in RG 1.29 Regulatory Position C.2, items 1.a through 1.q to an unacceptable safety level, or could result in incapacitating injury to occupants of the control room, should be designed and constructed so that the SSE would not cause such failure. Section 3.2.1 of the application does not explain the basis for the change in seismic classification of the TB or the technical justification as to how the TB is designed and analyzed so that seismic interaction effects are precluded from adversely affecting seismic Category I SSCs, the seismic Category II MS piping, and RTNSS SSCs that are relied on after an SSE. In RAI 3.2-66, the staff asked the applicant to provide additional information to justify the reclassification of the TB.

The response to RAI 3.2-66 did not include an adequate basis for reclassification of the TB as NS. The staff asked the applicant to identify each of the criteria considered and explain how the reclassification and building design methodology meet these criteria. RG 1.29 provides the necessary guidance on criteria selection. If the applicant's evaluation concludes that reclassification of the TB as NS does not represent an exception to RG 1.29, the applicant is expected to provide specific information to justify that this exception does not adversely affect the functionality of SSCs important to safety within and adjacent to the building, by interaction with the TB when subjected to SSE loadings. The staff found that fail safe is not an adequate justification, unless all failure modes resulting from a seismic event have been considered and evaluated.

The applicant's supplemental response stated that the TB has been reclassified as seismic Category II as described in DCD, Tier 2, Section 3.7.2.8, Option (3), thereby preventing adverse seismic interaction with seismic Category I SSCs, in compliance with the guidance in RG 1.29. The applicant will revise DCD, Tier 2, Table 3.2-1, Figures 3.2-1 and 3.2-2, Sections 1.2.2.16.8, 3.3.2.3, 3.7.2.8, and 19A.8.3, to reflect the reclassification of the TB as a seismic Category II structure. In DCD Table 3.2-1, the TB structure is now classified as seismic Category II. The staff concludes that seismic Category II is appropriate since this classification ensures that the building is seismically analyzed to prevent collapse. All issues related to RAI 3.2-66 were closed.

3.2.1.3.9 Electrical Systems

In RAI 3.2-63, the staff questioned the NS classification of the medium-voltage distribution system, the low-voltage distribution system, and the standby alternating current (ac) power supply (diesel generators) designated as R11, R12, and R21 systems, which are used to recharge the safety-related batteries to support post-72-hour functions. In its response to RAI 3.2-63, the applicant indicated that the R11, R12, and R21 systems in DCD, Tier 2, Revision 7, Table 3.2-1 are classified as non-safety and NS and are designed and qualified to the seismic provisions of and the standards referenced in the IBC. Also, the applicant's response to the original RAI 3.2-63 indicates that the electric building, which houses this equipment, is also designed to the seismic provisions of the IBC.

The staff recognizes that the maximum earthquake level considered in the IBC provisions is an event with a recurrence period of 2,500 years, which is further reduced by a factor of 2/3 to obtain the design-level earthquake. SSCs designed to the IBC provisions are intended to satisfy their performance criteria at that design-level earthquake, which is significantly lower than the SSE ground motion. The RTNSS systems may be called into service as a result of an SSE event and, under these conditions, the RTNSS components will have experienced an SSE event. The staff is concerned that SSCs designed to the IBC provisions are likely to experience significant damage and could lose functionality when subjected to an SSE-level seismic event. Furthermore, the structures housing such equipment, if also designed to the IBC provisions, are likely to be severely damaged from an SSE event to the extent that the housed equipment could be incapacitated.

In regard to RTNSS for passive plant designs, SECY-94-084 and related documents identified criteria to address SSC functions relied on to resolve long-term safety (beyond 72 hours) and seismic events. This document states that the designer will use the PRA to determine the non-safety SSCs important to risk. Also, in SECY-96-128 and a subsequent memorandum dated June 23, 1997, outlining its policy on technical issues pertaining to the design of the AP600, the staff stated that "the equipment required after 72 hours need not be in automatic standby response mode, but must be readily available for connection and protected from natural phenomena including seismic events (per GDC 2)."

Based on the staff's understanding of the IBC limitations, and consistent with previous staff positions, the staff found that the classification of the standby diesel generators and their distribution systems in the DCD, Tier 2, Revision 7, as NS was inconsistent with staff positions regarding RTNSS using the IBC seismic provisions to ensure the availability of diesel generators and their distribution systems when required. This finding considered that the diesel generators are required to recharge the safety-related batteries to power the required direct current (dc) load demand of the dc system, as well as the load demand of the Class 1E uninterruptible power supply (UPS) 120-volt ac (VAC) system beyond 72 hours during a loss of offsite power. Therefore, the design of the standby diesel generators, the medium-voltage distribution system, and the low-voltage distribution system should have been qualified to withstand the effects of the SSE. The staff identified this as an open item. To resolve it, the applicant made design changes, including the addition of an ancillary diesel generator, in the DCD. DCD, Tier 2, Revision 7, Table 3.2-1 includes the ancillary diesel generators and associated equipment and identifies them as seismic Category II. Further, DCD, Tier 2, Revision 7, Section 19A.8.3 states that RTNSS Criterion B equipment is qualified to IEEE-344-1987 to demonstrate seismic performance and structural integrity. Based on staff and Commission positions summarized in NRC memoranda dated July 24, 1995, and June 23, 1997, this seismic classification is considered appropriate for RTNSS Criterion B SSCs that are needed to support post-72-hour functions.

RAI 3.2-63 was being tracked as an open item in the safety evaluation report (SER) with open items. The response to RAI 3.2-63 S02 stated that a special Quality Class S applies to RTNSS Criterion B equipment. Subsequently, the applicant changed the term "quality class" to "safety-related class," and the DCD, Tier 2, Revision 7, identifies seismic Category II SSCs as "Special Safety-Related Class." Safety-Related Class S is applicable to seismic Category II and other RTNSS SSCs for which a complete safety-related program as described in Appendix B to

10 CFR Part 50 is not required, although pertinent QA requirements of Appendix B are to be applied to SSCs considered important to safety. The staff concluded that the design changes and the inclusion of the ancillary diesel generators as seismic Category II located in a seismic Category II building with augmented IEEE-344 qualification, combined with the safety-related Class S shown in DCD, Tier 2, Revision 7, Table 3.2-1, and all issues associated with RAI 3.2-63 were closed. Also, refer to the resolution of RAI 3.2-6 in Section 3.2.2.3.4 and RAI 22.5-7 in Section 22.5.6.3.1 of this report, which also address the resolution of this concern.

3.2.1.4 *Conclusions*

On the basis of its review of DCD, Tier 2, Revision 7, Section 3.2.1, Tables 3.2-1, 3.2-2, and 3.2-3, and Figures 3.2-1 and 3.2-2, the applicable simplified P&IDs, and other supporting information in DCD, Tier 2, Revision 7, the staff concludes that the ESBWR safety-related SSCs, including their supports, are properly classified as seismic Category I, in accordance with Regulatory Position C.1 of RG 1.29, or alternatively with SRP Section 3.2.2 for the TMSS. In addition, the staff finds that DCD, Tier 2, Revision 7, includes acceptable commitments to Positions C.2, C.3, and C.4 of RG 1.29, and that, with the resolution of seismic requirements for RTNSS SSCs in Chapter 22 of this report, the necessary SSCs are properly classified as seismic Category II. A staff audit found that the applicant has a process in place to perform the final classification of SSCs during the detailed design, and the D-RAP addressed in DCD, Tier 1, Revision 7, Section 3.6, includes a D-RAP ITAAC to provide reasonable assurance that the ESBWR plant is designed and constructed in a manner that is consistent with the key assumptions in the PRA and the risk insights for the risk-significant SSCs in the D-RAP. This constitutes an acceptable basis for satisfying, in part, the portion of GDC 2 that requires that all SSCs important to safety be designed to withstand the effects of natural phenomena, including earthquakes.

This conclusion is based on the following:

- The applicant has, in part, met the requirements of GDC 1, “Quality Standards and Records,” by providing a commitment in the DCD, Tier 2, Revision 7, that safety-related seismic Category I SSCs will be designed, constructed, and operated under a QA program in compliance with the requirements of 10 CFR Part 50, Appendix B.

- The applicant has, in part, met the requirements of GDC 2 and 10 CFR Part 50 Appendix S, by having properly classified safety-related SSCs as seismic Category I items in accordance with the regulatory positions of RG 1.29 (with one acceptable exception for the MS system), RG 1.151, and RG 1.189. The identified safety-related SSCs are those plant features necessary to ensure (1) the integrity of the RCPB, (2) the capability to shut down the reactor and maintain it in a shutdown condition, and (3) the capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures comparable to the guideline exposures of 10 CFR 52.47, “Contents of Applications; Technical Information.” RTNSS candidates evaluated in Chapter 22 of this report include those important-to-safety SSCs not identified as seismic Category I, but providing a defense-in-depth safety function. Those SSCs whose failure could reduce the functioning of any seismic Category I feature to an unacceptable safety level, or result in incapacitating injury to control room personnel, are

- evaluated in Section 3.7 of this report and are identified for analysis or otherwise qualified to ensure that they will not fail during an SSE.

- The applicant has included a special safety-related classification applicable to seismic Category II and other RTNSS SSCs that are not required to apply a complete program as described in 10 CFR Part 50, Appendix B, but to which pertinent QA requirements of Appendix B apply.

- The applicant has identified radioactive waste systems and fire protection SSCs requiring seismic design considerations consistent with the positions of RGs 1.143 and 1.189.

- The applicant has properly classified the MS and associated systems in accordance with the guidance in BTP 3-1 of SRP Section 3.2.2.

3.2.2 Quality Group Classification

3.2.2.1 *Regulatory Criteria*

The staff reviewed ESBWR DCD Section 3.2.2, Revision 7, in accordance with SRP Section 3.2.2, Revision 2, and the guidance in RG 1.26, Revision 3, “Quality Assurance Programs,” issued February 1976, which is cited in SRP Section 3.2.2. The staff’s acceptance of the design is based on compliance with the GDC and CFR sections presented below.

In GDC 1, the NRC requires, in part, that nuclear power plant SSCs important to safety be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety function to be performed. This requirement is applicable to both pressure-retaining and nonpressure-retaining SSCs that are part of the RCPB and other SSCs important to safety. SSCs that are important to safety ensure various safety functions, including the following safety-related functions:

- integrity of the RCPB

- capability to shut down the reactor and maintain it in a safe-shutdown condition

- capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures, comparable to the exposure requirements in 10 CFR 50.34(a)(1)

The requirements in 10 CFR 50.55a, “Codes and Standards,” state, in part, that components that are part of the RCPB must meet the requirements for Class 1 components in Section III of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (hereafter referred to as the ASME Code). For components that are connected to the RCPB, there is an exception from ASME Code Class 1 requirements for components whose failure would not exceed reactor coolant makeup or components that can be isolated from the reactor coolant system (RCS) by two valves in series (both closed, both open, or one open and one closed) where each open valve is capable of automatic closure. The QG A standards required for pressure-containing components of the RCPB are consistent with ASME Code, Section III, Class 1. In addition, 10 CFR 50.55a also states that QG B and QG C must meet the requirements for Class 2 and Class 3, respectively, in the ASME Code, Section III. RG 1.26, Revision 3, identifies those fluid systems or portions of systems and system functions classified as QG B, C, and D and their applicable quality standards. Revision 4 to RG 1.26, issued March 2007, after preparation of the initial DCD, updated the guidance. The only significant technical changes to this guidance are the added reference to RG 1.143 for radioactive waste management systems and the deletion of footnote b to Table 1, which stated, “ASME Code N-Symbol need not be applied,” relative to QG B and C. This evaluation addresses both of these changes.

3.2.2.2 *Summary of Technical Information*

DCD, Tier 2, Section 3.2.2, “System Quality Group Classification,” and Tables 3.2-1, 3.2-2, and 3.2-3 identify the system QG classification criteria and the safety-related ESBWR fluid systems and components that are classified as QG A, B, or C. Non-safety-related fluid systems that do not fall within QG A, B, or C also appear in these tables as QG D. Table 3.2-1 initially identified the safety designation as “Q” or “N,” but DCD Revision 2 replaced this designation with the term “safety class” based on American Nuclear Society (ANS) 58.14, “Safety and Pressure Integrity Classification Criteria for Light Water Reactors.” In addition to the QG for pressure-retaining components, revised tables submitted in DCD, Tier 2, Revision 3, also identified ANS 58.14 safety class and QA requirements as either “B” or “E.” In subsequent revisions, the DCD classification tables have been extensively revised to replace QA requirements and quality class with Safety-Related Classification Q, S, or N, depending on the appropriate level of QA. DCD, Tier 2, Revision 7, Table 3.2-3, identifies codes and industry standards applicable to the different QGs for various pressure-retaining components and supports. The applicable chapters on various systems, together with simplified P&IDs in other sections of DCD, Tier 2, Revision 7, also identify applicable codes and industry standards, as well as quality and safety classifications for fluid systems.

DCD, Tier 2, Revision 7, Section 3.1.1.1, states that, in regard to GDC 1, the QA program ensures implementation of recognized codes and standards in fabrication and construction. Section 3.1.1.1 further explains that relevant codes and standards are applied to equipment commensurate with its safety-related function and that the QA program and records meet GDC 1. This section indicates that Sections 3.2.2 and 3.2.3 identify the methodology for QG and safety classifications, respectively. The definitions of safety classes are based on their safety importance, and DCD Revision 7, Table 3.2-2 shows the corresponding safety class, ASME Section III Code Class, and QA minimum requirements for each QG. DCD, Tier 2, Revision 7, Section 3.2.2, states that the ESBWR meets the acceptance criteria of SRP Section 3.2.2. DCD, Tier 2, Revision 7, Table 1.9-3, is consistent with SRP Section 3.2.2. Table 1.9-21b of DCD Tier 2 initially identified no exceptions to RG 1.26, Revision 3, for the ESBWR, but an exception is included for the control rod drive (CRD) system in response to an RAI. DCD, Tier 2, Revision 7, Section 7.1.6.4, states that the instrument sensing lines are designed to satisfy the requirements of RG 1.151, and Section 7.7.7.3.1.2 specifically identifies that the sensing lines penetrating the containment meet RG 1.151 and are QG B.

3.2.2.3 *Staff Evaluation*

The staff reviewed the ESBWR DCD, Tier 2, Revision 7, in accordance with SRP Section 3.2.2 and the guidance in RG 1.26, Revision 3, identified in SRP Section 3.2.2. The review included evaluation of the criteria used to establish the QG classification and the application of those criteria to the classification of principal components included in DCD, Tier 2, Revision 7, Table 3.2-1. The following sections summarize the applicant’s responses to significant RAIs under each review topic required to complete this review. Revisions of DCD Tier 2 included changes that the applicant made in response to the RAIs. One classification change was the inclusion of the term “safety class” based on ANS 58.14. Although SRP Section 3.2.2 allows safety class to be cross-referenced with the classification groups in RG 1.26, the NRC has not endorsed ANS classification standards. In July 2009, the staff performed an audit (“Summary of the July 20 to 24, 2009, Regulatory Audit of Design Specification of Risk Significant ESBWR Components at General Electric Hitachi (GEH) Office in Wilmington, NC,” September 1, 2009) of available classification design-basis documents for risk-significant components selected by the applicant. Based on the results of the audit, the detailed design is not complete, and the information is insufficient to validate the basis for each component classification. However, there is sufficient information to conclude that the classification criteria are consistent with RG 1.26 or an equivalent alternative.

3.2.2.3.1 Classification Criteria

The staff reviewed the criteria/methodology identified in DCD, Tier 2, Sections 3.2.2 and 3.2.3, which the applicant used to select the appropriate quality classification and safety classification, respectively, in Table 3.2-1 for principal components. The staff determined that the classification criteria were not entirely consistent with GDC 1 and RG 1.26 for QG classification and that the DCD did not appear to address supplemental requirements or special treatment for RTNSS components. One difference is that certain components that may be important to safety but are not safety-related were considered QA Requirement E rather than QA Requirement B. An evaluation of these RTNSS candidates appears in the discussion of RAI 3.2-6 in Section 3.2.2.3.4 of this report and under RTNSS in DCD, Tier 2, Revision 7, Chapter 19 and Chapter 22 of this report. The staff also determined that ANS 58.14, which is referenced in Revision 3 of the DCD and used to identify safety classification, has not received the NRC’s endorsement. Table 1.9-21b of DCD, Tier 2, Tier 2, Revision 7, addresses the compliance with RG 1.143 for radwaste systems. Sections 11.2, 11.3, and 11.4 of DCD, Tier 2, Revision 7, address the classification of radwaste systems relative to RG 1.143 guidance, and an evaluation appears in the corresponding sections of this report. The sections below further address specific concerns with the classification criteria under the respective review topics.

3.2.2.3.2 Code N-Symbol

Revision 4 to RG 1.26 eliminates the option to apply the stamp denoting compliance with ASME Code, Section III, to QG B and C systems and components, consistent with 10 CFR 50.55a and the NRC’s Regulatory Issue Summary (RIS) 2005-17, “Clarification of Requirements for Application of the ASME Code Symbol Stamp on Safety-Related Components,” dated August 8, 2005. In RAI 3.2-1, the staff requested confirmation that all pressure-retaining components designed to meet ASME Code requirements for Class 1, 2, and 3 components will bear the Code N-symbol stamp (N stamp), in accordance with 10 CFR 50.55a.

The response to RAI 3.2-1 clarified that the applicant will apply the N stamp to ASME Code, Section III, Class 1, 2, and 3 components. However, the resubmitted Table 3.2-1 for the N11 system shows that TMSS piping designed to ASME Code, Section III, Class 2, is not code stamped and does not require ASME inspections. In RAI 3.2-01 S01, the staff asked the applicant to correct or clarify the basis for this apparent discrepancy. The applicant’s response clarified that the non-safety-related QG B MS piping and components downstream of the seismic interface anchor do not require the N stamp. The applicant identified this in the notes for N11 Item 1 in Table 3.2-1 of DCD Tier 2 and further noted that this piping does not require ASME-authorized inspection.

The practice to not N-stamp or apply ASME-authorized inspection to this QG B piping is contrary to the requirement in 10 CFR 50.55a relative to QG B components and the guidance in RG 1.26, Revision 4, which specifies that components classified as QG B must meet the requirements for Class 2 components in the ASME Code, Section III. Further explanation of the basis for requiring an N stamp appears in NRC RIS 2005-17, which clarifies that compliance with 10 CFR 50.55a is expected to be a Tier 1 requirement. In RAI 3.2-1 S02, the staff asked requested the applicant to review Tier 1 and 2 commitments relevant to 10 CFR 50.55a and modify its position or explain why such piping and components do not need an N stamp or an ASME-authorized inspection.

The applicant's response to RAI 3.2-1 S02 modified the applicable DCD Tier 1 and 2 sections to remove an exception from requirements for N-stamping QG B MS piping and DCD Table 3.2-1, Revision 5, identifies that the N11 TMSS is classified as QG B, with no exception to N-stamping. Also, DCD Section 3.2.3.4, Revision 5, clarifies that non-safety-related SSCs that are classified as seismic Category I and II and QG B or C are subject to ASME Code, Section III, requirements (including N-stamping) and ASME Code Section XI, inspection requirements. Based on the applicant's changes to not take an exception to N-Stamp, this is consistent with ASME Section III and acceptable to staff. All issues related to RAI 3.2-1 concerning the ASME Code stamp were resolved.

3.2.2.3.3 Main Steam, Feedwater, and Connected Components

SRP Section 3.2.2 provides specific guidelines on the classification and analysis required for the MSLs, feedwater lines, and other connected components outside containment that are credited with controlling MSL leakage. To determine that these components are consistent with regulatory guidance, the staff asked the applicant to change the QG and QA designation and analysis of several MSLs, feedwater lines, and other connected components outside containment to meet the SRP Section 3.2.2 guidance and to make the COL action identified in Section 3.2.1.3.7 of this report mandatory. In RAI 3.2-15, the staff asked the applicant to revise Table 3.2-1 to show B21 Item 8 for the feedwater piping as QG B and thus make it consistent with SRP Section 3.2.2 and RG 1.26 guidance. The RAI response states that the applicant will revise Table 3.2-1 to designate this piping as QG B, and DCD Revision 3 identifies this piping as QG B.

Regulatory Position C.1.c in RG 1.26 specifies that those portions of the steam systems of BWRs extending from the outermost containment isolation valve up to but not including the turbine stop and bypass valves or shutoff valves and connected piping be classified as QG B. Although Table 3.2-1 correctly classified this piping as QG B, Section 3.2.2.2 did not include the classification criteria. In RAI 3.2-1 S01, the staff requested that the applicant add the classification criteria as a basis for identifying the QG for the N11 system piping, including connected piping. Revision 3 to the DCD revised Section 3.2.2.2 to include the specific classification criteria for the N11 MS piping to be consistent with SRP Section 3.2.2. All issues related to RAI 3.2-1 were therefore resolved.

The ESBWR design eliminates the MSIV leakage control system. Instead, the design relies on the use of an alternative leakage path that takes advantage of the large volume and surface area in the MS piping, MS drainlines, turbine bypass line, and condenser to hold up and plate out the release of fission products following core damage. In this manner, the ESBWR design uses the alternative leakage path and condenser to mitigate the consequences of an accident, and this path and condenser must remain functional during and after an SSE. To address the classification and analysis of the alternative leakage path, the staff developed a position, which the NRC discussed in Section II.E of SECY-93-087, “Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs,” dated April 2, 1993, and approved by the Commission in a staff requirements memorandum (SRM) dated July 21, 1993. The position states that the MS piping beyond the outermost isolation valve up to the seismic interface restraint and connecting branch lines up to the first normally closed valve should be classified as QG B (Safety Class 2) and seismic Category I. The MSL from the seismic interface restraint up to but not including the TSV (including branch lines to the first normally closed valve) should be classified as QG B and inspected in accordance with the applicable parts of the ASME Code, Section XI. An applicant may classify this portion of the MSL as non-Category I if it has performed a dynamic seismic analysis to demonstrate the component’s structural integrity under SSE loading conditions. However, all pertinent QA requirements of Appendix B to 10 CFR Part 50 are applicable to ensure that the quality of the piping material is commensurate with its importance to safety during normal operational, transient, and accident conditions.

To ensure the integrity of the remainder of the proposed alternative leakage path, the staff position is that (1) the MS piping between the TSV and the turbine inlet, the turbine bypass line from the bypass valve to the condenser, and the MS drainline from the first valve to the condenser need not be classified as safety-related or as seismic Category I but should be analyzed using a dynamic seismic analysis method to demonstrate their structural integrity under SSE loading conditions, (2) the condenser anchorage should be seismically analyzed to demonstrate that it is capable of sustaining the SSE loading conditions without failure, and (3) before commercial operation, the COL holder should conduct plant-specific walkdowns of nonseismically designed SSCs overhead, adjacent to, and attached to the alternative leakage path to assess potential failures. The staff has verified that the QG and QA designations for these components meet the SRP Section 3.2.2 guidance and that the DCD, Tier 2, Revision 7, includes the COL action requirement to perform plant-specific walkdowns of the nonseismically designed components in the vicinity of the alternative leakage path, as discussed in Section 3.2.1.3.7 of this report.

RAI 3.2-19 requested that the second drain isolation valve in the MS drains beyond the outermost MSIV be a normally closed valve. The RAI response confirmed that this valve is a normally closed valve.

DCD Table 3.2-1 shows that the MSIV drains beyond the outermost MSIV are designated as QG D. The response to RAI 3.2-19 indicates that the second isolation valve in the MS drains beyond the MSIV is a normally closed valve, and the applicant confirmed that B21 Item 13, in Table 3.2-1 will be analyzed according to the methods described in DCD Section 3.7. Since Figure 3.2-1 shows an open orifice in this line that bypasses the closed valve, the staff requested in RAI 3.2-19 S01 that the applicant confirm that the offsite radiation dose caused by a failure in this Safety Class D piping will not exceed the acceptance criteria of 0.5 rem identified in RG 1.26. Otherwise, this line should be under the QG C classification to be consistent with RG 1.26. The applicant’s response to RAI 3.2-19 S01 identified a second normally closed valve that is in series with and upstream of the orifice in the bypass line. This valve is not reflected in the simplified schematic in DCD Figure 3.2-1 but does appear on the detailed nuclear boiler system P&ID. This normally closed valve is important to the classification, and it should appear on the simplified diagram. In RAI 3.2-19 S02, the staff requested that the applicant submit a revised DCD Figure 3.2-1 to show this normally closed valve in the MS drains. RAI 3.2-19 was being tracked as an open item in the SER with open items.

DCD Figure 3.2-1 in Revision 5 shows normally closed valves in the MSIV drains, but based on the results of a staff audit in July 2009 ("Summary of the July 20 to 24, 2009, Regulatory Audit of Design Specification of Risk Significant ESBWR Components at General Electric Hitachi (GEH) Office in Wilmington, NC," September 1, 2009), the DCD figure should be updated to reflect the configuration shown on the detailed P&IDs. Also, the revised response to RAI 3.2-19 S02 and RAI 3.2-40 identified changes to Table 3.2-1 concerning the seismic classification addressed in Section 3.2.1.3.5 of this report. The applicant's response to the audit identified certain planned actions to eliminate the inconsistencies, including updating the DCD figures and P&IDs to show the correct configuration. DCD Figure 3.2-1 was updated in Revision 6, to be consistent with the P&ID and SRP 3.2.2 guidance such that the QG classification is consistent with RG 1.26. All issues associated with RAI 3.2-19 were closed.

3.2.2.3.4 Quality Assurance Requirements

The staff reviewed quality classifications to determine if the applicant identified appropriate QA criteria for safety-related and non-safety-related components that have a safety-significant function. In RAI 3.2-6, the staff requested that the applicant designate as QA Requirement B several items that are classified as either seismic Category I or II.

Contrary to the guidance in RG 1.29, the response to RAI 3.2-6 indicated that QA Requirement E is appropriate for all non-safety-related SSCs regardless of their seismic classification. Note (5) to Table 3.2-1 identified QA Requirement E as involving QA requirements commensurate with the importance of the item's function. Note (4) to Table 3.2-2 also stated that elements of Appendix B to 10 CFR Part 50 are generally applied to non-safety-related equipment commensurate with the importance of the equipment's function. Because this QA Requirement E definition is so general, it was unclear which specific QA requirements apply to various components that are classified as QA Requirement E. For example, the DCD does not identify which supplemental requirements, if any, apply to non-safety-related SSCs, such as the steam dryer, reactor pressure vessel (RPV) insulation, and high-energy piping, whose failure may adversely affect safety-related SSCs. In addition, Section 17.4 on quality/reliability assurance or Section 19.6, subsequently revised as Appendix 19A, on RTNSS does not appear to address graded supplemental requirements applicable to QA Requirement E for important non-safety systems, such as the standby ac power system and the PSWS, that have a defense-in-depth function. In RAI 3.2-6 S01, the staff asked the applicant to clarify which graded requirements it applied to QA Requirement E for each component in Table 3.2-1 so classified, including the appropriate QA program, such as the commitment added for radwaste systems in response to RAI 3.2-38. If the requirements were not sufficiently defined, they would be subject to further review when design requirements and a design-specific, focused PRA were complete. RAI 3.2-6 was being tracked as an open item in the SER with open items.

In RAI 3.2-6 S02 the applicant was requested to submit a revision to DCD Table 3.2-1 to identify which components are classified as Quality Class S or Quality Class N and describe the special treatment requirements that apply to such SSCs. For example, define what supplemental design, inspection and installation requirements over and above commercial codes and standards are applicable to risk-significant SSCs defined by the RTNSS process that are defined as Quality Class S. If the selection of SSCs that are defined as Quality Class S and their supplemental requirements depend on the final PRA and the final deterministic selection process, the applicant was requested to advise when the scope of Quality Class S SSCs and their supplemental requirements will be final and complete. The response to RAI 3.2-6 S02 stated that the applicant would replace the "QA Requirements" column in DCD Tables 3.2-1 and 9.1-4 with the more descriptive "Quality Class" as defined in NEDO-33181. This change will clearly identify all non-safety-related SSCs that have any special QA requirements. Design changes, including the addition of an ancillary diesel generator, were also included in DCD Revision 5, and in the RAI 3.2-6 S02 response. This RTNSS equipment is identified as "QA Special Class." The DCD was subsequently updated to use the term "Safety-Related Classification S" for special QA requirements applied to all non-safety-related SSCs considered important to safety.

The DCD does not define specific supplemental design and QA requirements for each RTNSS SSC, and the staff further reviewed this area during an audit of detailed design-basis documents. Based on the results of the audit ("Summary of the July 20 to 24, 2009, Regulatory Audit of Design Specification of Risk Significant ESBWR Components at General Electric Hitachi (GEH) Office in Wilmington, NC," September 1, 2009), the staff finds that the applicant has a classification process in place to ensure that procurement documents for special class components include special treatment; however, all the specific supplemental requirements are not available at this time. Also, because DCD Table 3.2-2 does not identify QA requirements for Safety Class N, the staff recommended improvements that would more clearly identify QA requirements applicable to QG D special class and seismic Category II. In response to the September 1, 2009, audit report, the applicant identified planned actions to resolve the open item, among them a DCD revision to include a Safety-Related Classification S to identify SSCs that have special QA requirements, and an explanation of why they have received the "S" classification.

Revision 6 of the DCD changed the "QA Requirement" column to "Safety-Related Classification" and designated "Q" for safety-related SSCs to which Appendix B to 10 CFR Part 50 applies, "S" for special QA applied to non-safety-related SSCs including RTNSS, and "N" for standard non-safety-related QA requirements. The D-RAP addressed in DCD, Tier 1, Section 3.6, includes a D-RAP ITAAC to provide reasonable assurance that the ESBWR plant is designed and constructed in a manner that is consistent with the key assumptions in the PRA and the risk insights for the risk-significant SSCs in the D-RAP. Detailed QA requirements are not identified, but an RTNSS requirements document is in preparation. The audit response further stated that DCD Section 17.1.22 and NEDO-33181 describe special treatment. Based on the DCD, Tier 2, Revision 7, changes to include a special classification for RTNSS SSCs and D-RAP ITAAC, the staff concluded that all issues related to RAI 3.2-6 were closed.

In RAI 3.2-38, the staff requested that the applicant identify specific QA requirements for non-safety-related components in radioactive waste management systems K10, K20, and K30 designated as QA Requirement E that meet the guidelines of RG 1.143. The RAI response stated that the applicant will revise DCD Table 3.2-1 to refer to the ESBWR QA program described in DCD Chapter 17. DCD Chapter 17, Revision 5, identifies no exceptions to RG 1.143, and note (5)d. to DCD Table 3.2-1 states that a QA program meeting the guidance of RG 1.143 is applied to radioactive waste management systems. Table 3.2-1 identifies radioactive waste management systems as Safety-Related Classification S. DCD Table 3.2-1 indicates that the QA program applied to systems K10, K20, and K30 meets the guidance of RG 1.143. The QA program described in DCD Chapter 17 meets the guidance of RG 1.143, which references American National Standards Institute (ANSI)/ANS 55.6, "Liquid Radioactive Waste Processing System for Light Water Reactor Plants," for liquid radioactive waste processing systems. Therefore, the staff finds this change to be acceptable, and RAI 3.2-38 wasclosed.

In RAI 3.2-41, the staff requested that the applicant classify the main condenser and auxiliaries as QA Requirement B and seismic Category II. The RAI response identified the condenser as non-safety- related and NS, but the condenser anchorage is seismically analyzed for SSE. The applicant will correct DCD Section 15.4.4.5.2.4 and Table 3.2-1 accordingly. In DCD Revision 3, Table 3.2-1 indicates that the condenser anchorage in the N61 system is seismically analyzed for SSE, and Figures 3.2-1 and 3.2-2 show the system classification boundaries consistent with SRP Section 3.2.2. The RAI response also stated that determination of the QA requirements for the main condenser will occur during the detailed design phase. Based on the applicant's commitment in the DCD to appropriate application of the special QA requirements for analysis of the main condenser anchorage, the staff concluded RAI 3.2-41 was closed.

In RAI 3.2-52, the staff asked the applicant to classify FPS components as QA Requirement B. The RAI response clarified that the FPS components are non-safety- related and that the QA requirements of Appendix B to 10 CFR Part 50 apply only to safety-related components. The staff concurs that typically the requirements of Appendix B apply only to safety-related or seismic Category II SSCs, and therefore, QA Requirement E supplemented by a QA program meeting the guidance of NRC BTP SPLB 9.5-1 is appropriate for the FPS, provided that appropriate QA is included for seismic Category I RTNSS portions that support fuel pool cooling consistent with the D-RAP. DCD, Tier 2, Revision 7, Table 3.2-1 shows that supplemental QA is included for these RTNSS portions of the FPS. All issues associated with RAI 3.2-52 were therefore closed.

In RAI 3.2-55, the staff requested that the applicant classify the intake and discharge structures as QA Requirement B. The RAI response clarified that the intake and discharge structure components do not perform any safety-related functions and serve only as a defense-in-depth measure for heat removal. The staff concurs that QA Requirement B is generally not applicable to non-safety-related SSCs. However, RTNSS SSCs that support important safety functions may require special treatment. The resolution of Open Item 3.2-6 addressed quality requirements applicable to items with a defense-in-depth function. SRP Section 3.2.2 does not apply to structures, and DCD Revision 6 identifies the intake and discharge structures that house RTNSS Criterion C components as seismic Category NS, Safety-Related Class N, with standard QA requirements. DCD Section 19A, Tier 2, Revision 7, addresses special treatment requirements applicable to non-safety-related structures with a defense-in-depth function that house RTNSS components; Section 19A.8 present an evaluation of these structures. All issues associated with RAI 3.2-55 were therefore closed.

3.2.2.3.5 Simplified Piping and Instrumentation Drawings

The typical use for detailed P&IDs developed during the design stage is the identification of specific classification boundaries of interconnecting piping and valves. The P&IDs in DCD Tier 2 are simplified schematic diagrams rather then comprehensive detailed design drawings. These diagrams supplement DCD Table 3.2-1 and show the major system components, as well as the basic interconnecting piping and valve configurations, including the interface between the safety-related and non-safety-related portions of each system. The staff requested information to enable a more complete review of some system configurations to determine their proper classifications. In RAI 3.2-7, the staff requested that the applicant add a COL action item to provide complete, detailed P&IDs of all plant systems to ensure that the final design classifications and the classification boundaries are acceptable.

In response to RAI 3.2-7, the applicant agreed that some of the simplified P&IDs do not clearly describe the limits of the applied QG, QA, and seismic categories within the various systems. The applicant stated that it will correct these as they are discovered and update them in a future revision of the DCD. The applicant believes that a COL action is unnecessary to provide complete, detailed P&IDs and that detailed P&IDs can be provided under proprietary submittals.

Various regulatory documents have addressed the level of detail for system diagrams, and updated final safety analysis reports (FSARs) for operating reactors have accepted the use of simplified diagrams rather than detailed P&IDs. Because simplified diagrams are acceptable for the design certification and there is an ITAAC to address design reports that include final classification boundaries, the staff finds that the level of detail included with the simplified diagrams submitted in the DCD, Tier 2, Revision 7, is acceptable, and therefore, RAI 3.2-7 was closed.

3.2.2.3.6 Quality Group A

The staff reviewed DCD, Tier 2, Revision 7, Tables 3.2-1, 3.2-2, and 3.2-3, and the simplified P&IDs in accordance with SRP Section 3.2.2. SRP Section 3.2.2 references Revision 3 of RG 1.26 as the principal document used by the staff to identify, on a functional basis, the pressure-retaining components of those systems important to safety and their appropriate QG. Section 5.2 of this report discusses the conformance of ASME Code Class 1 RCPB components to the requirements of 10 CFR 50.55a. RG 1.26 designates these RCPB components as QG A. The staff determined that the applicant has properly classified RCPB components consistent with 10 CFR 50.55a.

3.2.2.3.7 Quality Group B

Based on its review of the information in DCD, Tier 2, Section 3.2.2, Tables 3.2-1, 3.2-2, and 3.2-3, and the relevant simplified P&IDs, the staff has determined that the classifications for QG B SSCs of the ESBWR are, in general, consistent with the guidelines in SRP Section 3.2.2 and RG 1.26, conform to GDC 1, and therefore are acceptable. To make this finding, the staff requested that the applicant revise numerous designations in Table 3.2-1 to conform to the guidance in SRP Section 3.2.2 and RG 1.26. These include several systems that perform safety-related functions discussed in the SRP Section 3.2.2 and RG 1.26 guidance, such as those systems that perform reactor shutdown; control reactivity; or provide decay heat removal (DHR), emergency core cooling water, postaccident DHR, or spent fuel cooling. The following paragraphs describe the significant Section 3.2 RAIs that address QG B SSCs. In RAI 3.2-3, the staff requested that the applicant revise Section 3.2.2.2 to add QG B systems, such as those that provide reactor shutdown, emergency core cooling, postaccident containment heat removal, postaccident fission product removal, or DHR.

In response to RAI 3.2-3, the applicant reclassified from QG C to QG B certain systems that perform a safety function identified in RG 1.26 as QG B. For example, after further review, the applicant designated the gravity-driven cooling system (GDCS), which was previously classified as QG C, as QG B. However, the applicant did not include in the revised DCD Section 3.2.2.2 the quality classification criteria for systems that provide an emergency core cooling function, such as the GDCS. The staff asked the applicant to submit revisions to Sections 3.2.2.2 and 3.2.2.3 that include the classification criteria for systems that perform an emergency core cooling function and other applicable safety functions to be consistent with revised Table 3.2-1 and RG 1.26. In general, the applicant's supplemental response resolved the staff's concern about consistency with RG 1.26 by revising Sections 3.2.2.2 and 3.2.2.3 in DCD, Tier 2, Revision 3. RAIs 3.2-1 and 3.2-21 address the staff's other questions regarding consistency with RG 1.26.

The applicant classified certain other RCPB components that meet the exclusion requirements of 10 CFR 50.55a(c)(2) as QG B. Although DCD, Tier 2, Revision 2, Section 3.2.3.2, states that Safety Class 2 includes pressure-retaining portions of pipes 2.54 centimeters (1 inch) in diameter and smaller that are part of the RCPB, it does not identify the basis for this classification, and Section 3.2.2 does not specify the exclusion criteria for quality class.

In its response to RAI 3.2-3, the applicant identified the safety classifications based on ANS 58.14 and included them in Table 3.2-1. DCD Section 3.2.3.1 designated Safety Class 1 as applicable to components of the RCPB (as defined in 10 CFR 50.2, “Definitions”) and their supports whose failure could cause a loss of reactor coolant at a rate in excess of the normal makeup system. The staff asked the applicant to clarify the maximum size of the piping connected to the RCPB that is excluded from Safety Class 1 on the basis of reactor coolant makeup capability. In addition, ANS 58.14 is currently withdrawn and has not received the NRC’s endorsement. Until this standard is updated and NRC endorsed, this document cannot be used as a basis for classification. The applicant has resolved the staff’s concern about the criterion that excludes certain piping from ASME Code, Section III, Class 1, requirements by clarifying that the maximum diameter of piping connected to the RCPB that is excluded from Safety Class 1 is 2.54 centimeters (1 inch) on the basis of reactor coolant makeup capability.

A supplemental response acknowledged that the applicant is aware that ANS 58.14 is withdrawn and that the NRC has not endorsed this standard. The applicant’s supplemental response stated that it will remove the reference to ANS 58.14-1993 and indicated that the applicant’s classification scheme is not dependent on ANS 58.14. The DCD, Tier 2, Revision 7, shows that reference to ANS 58.14 has been deleted from Section 3.2.5. Therefore, all issues related to RAI 3.2-3 were closed.

The staff reviewed fluid systems that are important to safety to ensure that their classification is correct. The staff questioned the classification in Table 3.2-1 of various SSCs that may have important safety functions.

C12 Control Rod Drive System

Regulatory Position C.1.b(1) in RG 1.26 states that systems or portions of systems important to safety that are used for reactor shutdown should be classified as QG B. DCD, Tier 2, Section 3.2.3.2, states that Safety Class 2 components include pressure-retaining portions of the CRD system that are necessary for emergency negative reactivity insertion. In RAI 3.2-21, the staff requested that the applicant designate safety-related, Safety Class 2 hydraulic control unit (HCU) assemblies, shown in Table 3.2-1 as C12 Item 3, and subcomponents as QG B components.

The response to RAI 3.2-21 explained that the HCU classifications have been well established and accepted for many decades for both the entire BWR operating fleet and the advanced boiling-water reactor (ABWR) certified design. The applicant believes that the same classification is appropriate for the ESBWR and is consistent with industry practice. The staff concurs that the HCU classification has been standard industry practice and accepted by the NRC and that no change in classification is required, but DCD Section 1.9 should specifically identify this industry practice as an exception to RG 1.26. In RAI 3.2-21 S01, the staff asked the applicant to confirm that this represents an exception to RG 1.26 and to submit a revision to DCD Section 1.9. The response to RAI 3.2-21 S01 clarified that the classification of the HCU is an exception to RG 1.26 and that the applicant will revise DCD, Tier 2, Tables 1.9-21b and 17.0-1, accordingly. The staff confirmed that the applicant has revised Tables 1.9-21b and 17.0-1 in DCD Revision 4 to identify this as an exception to RG 1.26. Although the staff recognizes that the HCU classification has been standard industry practice, in RAI 3.2-21 S02, it requested that the applicant provide technical justification establishing this as an acceptable alternative to QG B and ASME Code, Section III, Class 2, requirements identified in RG 1.26. Justification should include information such as alternative equivalent industry standards, supplemental nondestructive examination, inservice inspection (ISI), QA practices, and operating experience to demonstrate the reliability of the HCU pressure boundary.

The applicant's response to RAI 3.2-21 S02 identified additional information to demonstrate the reliability of the HCU pressure boundary and the appropriateness of the standard classification. This information included alternate industry codes and standards, supplemental nondestructive examination requirements, ISI for valves, QA practices consistent with Appendix B to 10 CFR Part 50, and sound operating experience applicable to the HCU pressure boundary. Therefore, staff concludes that it is reasonable to expect the CRD HCU to continue to provide a reliable pressure boundary with the supplemental requirements identified. All issues concerning the quality classification of the CRD HCUs in RAI 3.2-21 were closed.

In RAI 3.2-22, the staff asked the applicant to classify DCD Table 3.2-1, C12 Items 6 and 7, as QG B, QA Requirement B, and seismic Category I. The response stated that, as explained in the response to RAI 4.6-1, the QG, QA, and seismic category is consistent with the classification of the CRD system high-pressure makeup function as non-safety-related. The staff agrees that, based on the response to RAI 4.6-1, the CRD high-pressure makeup function is non-safety-related and no change to the DCD is required. Therefore, RAI 3.2-22 was closed.

In RAI 3.2-23, the staff asked the applicant to classify DCD Table 3.2-1, C12 Item 10, for the ARI equipment as QG B, QA Requirement B, and seismic Category I. The response noted that the seismic category classification has been changed from NS to seismic Category II, and Table 3.2-1 in DCD Revision 3 shows this as seismic Category II. Because the function and design of the ESBWR ARI are the same as in the approved ABWR design and are in conformance with Licensing Topical Report (LTR) NEDE-31096-P-A, "Anticipated Transients Without Scram – Response to NRC ATWS Rule 10 CFR 50.62," February 1987, the applicant considered the same classification to be appropriate and correct for the ESBWR and consistent with accepted industry practice. The staff concurs that this classification is consistent with accepted standard industry practice defined in Generic Letter (GL) 85-06, "Quality Assurance Guidance for ATWS Equipment That Is Not Safety-Related," dated April 16, 1985; therefore, RAI 3.2-23 was closed.

E50 Gravity-Driven Cooling System

In RAI 3.2-26, the staff requested that the applicant classify the GDCS as QG B rather than QG C. The RAI response stated that the applicant will change the QG from C to B for Items 2 and 3 in Table 3.2-1 under system E50, and the applicant revised Table 3.2-1 in DCD Revision 3 accordingly. On the basis of the DCD change, RAI 3.2-26 is closed.

G31 Reactor Water Cleanup/Shutdown Cooling System

In RAI 3.2-34, the staff asked the applicant to designate the reactor water cleanup/shutdown cooling (RWCU/SDC) system as safety-related QG B and QA Requirement B or to justify the current classification.

The response to RAI 3.2-34 indicated that non-safety-related portions of the RWCU systems are correctly classified and are considered a defense-in-depth feature rather than a safety-related function. The staff concurs that non-safety-related SSCs with no safety function need not be QG B or QA Requirement B, provided that risk-significant systems are addressed under RTNSS. The RWCU/SDC system is considered risk significant on the basis of the PRA identified in the NRC's "Risk Insights to Support NRC Review of ESBWR COL Applications," Revision 0. However, DCD Table 19A-2 does not include this non-safety-related, risk-significant system as an RTNSS system. Chapter 22 of this report contains an assessment of risk-significant systems relative to seismic requirements and special treatment.

For portions of systems classified as both Safety Class N and either QG B or C, it is not clear which ASME Code Class applies. DCD Table 3.2-2 identifies that Safety Class N does not require the application of ASME Code, Section III. However, to be consistent with RG 1.26 and Table 3.2-3, the ASME Code, Section III, Class 2 or 3, applies to QG B and C, respectively. In RAI 3.2-34 S01, the staff asked the applicant to clarify the criteria in Table 3.2-2 to define the ASME Code Class for non-safety-related QG B and C components such as MS drains and the RWCU system.

The response to RAI 3.2-34 S01 revised DCD Table 3.2-2 to show the minimum design requirements for each individual safety class and clarified that it was prudent for the applicant to upgrade the QG and seismic classification for the non-safety-related RWCU/SDC piping outside containment. For Safety Class N, Table 3.2-2 shows QG D as the minimum requirement, with an option to design such non-safety-related SSCs to QG B or C requirements. It is not clear if selecting the option to design these components as QG B or C and to the ASME Code, Section III, standards represents a confirmation to also construct to the ASME Code, Section III, standards and perform ISI in accordance with ASME Code, Section XI, for such non-safety-related SSCs designed to ASME Code, Section III. In RAI 3.2-34 S02, the staff asked the applicant to clarify whether all systems that are optionally designed to ASME Code, Section III, are also constructed to ASME Code, Section III, and subject to all ASME Code, Section XI, ISI requirements. If selecting this optional upgrade does not represent a commitment to construct to ASME Code, Section III, standards, including N-stamping and inspecting to ASME Code, Section XI, the applicant needs to clarify which supplemental construction and inspection requirements, if any, are imposed to upgrade the quality and ISI of such SSCs. The staff also requested a detailed comparison of the supplemental construction requirements and ISI requirements with the requirements of ASME Code, Sections III and XI. The staff also asked the applicant to clarify whether the DCD will include upgraded non-safety-related SSCs in systems such as the RWCU and TMSS as RTNSS candidates. RAI 3.2-34 was being tracked as an open item in the SER with open items.

The applicant's subsequent response amended the previous position and commits to the construction of non-safety-related SSCs that are assigned QG B or C to the standards of the ASME Code, Section III, including N-stamping. This position is consistent with the response to RAI 3.2-1 S02 for the TMSS piping. The applicant also stated that ASME Code, Section XI, will be applied to portions of non-safety-related seismic Category I piping in the fuel and auxiliary pool cooling system (FAPCS) and RWCU/SDC system. The staff agrees that application of N-stamping and ASME Code, Section XI, is appropriate to ensure the integrity of SSCs designated as QG B or C and seismic Category I. The applicant has revised DCD Section 3.2.3.4 accordingly for those QG B and C components. Subsequently, in Revision 6, Table 3.2-1 identifies the non-safety-related portions of the RWCU system as QG C or D and Safety-Related Classification S with special QA requirements. All issues related to RAI 3.2-34 were therefore closed.

P51 Service Air System and P52 Instrument Air System

In RAI 3.2-46, the staff requested that the applicant classify components with safety-related functions within the P51 and P52 systems as QG B or C, QA Requirement B, and seismic Category I. The RAI response identified no safety-related functions for the service air system (SAS) and instrument air system other than the portion forming the containment boundary. Revision 2 of DCD Tier 2 shows the SAS containment penetration with a locked closed valve correctly classified as QG B, QA Requirement B, and seismic Category I. The staff concurs that Revision 2 of DCD Tier 2 correctly classifies the containment boundary; that other components with no safety-related function need not be QG B or C, QA Requirement B, or seismic Category I; and that QG D with standard QA requirements is appropriate, provided that risk-significant systems are addressed under RTNSS.

3.2.2.3.8 Quality Group C

Based on its review of the information in DCD, Tier 2, Section 3.2.2, Tables 3.2-1, 3.2-2, and 3.2-3, and the applicable simplified P&IDs, the staff has determined that the classifications for QG C SSCs of the ESBWR are, in general, consistent with the guidelines in SRP Section 3.2.2 and RG 1.26 and comply with GDC 1. Therefore, they are acceptable. To satisfy this finding, the staff asked the applicant to revise numerous designations in Table 3.2-1 to conform to the SRP Section 3.2.2 and RG 1.26 guidance. These included designations for several systems that perform safety-related functions discussed in the SRP Section 3.2.2 and RG 1.26 guidance, such as those systems that perform reactor shutdown or control reactivity or systems that provide DHR, emergency core cooling water, postaccident DHR, or spent fuel cooling. The following paragraphs discuss the significant Section 3.2 RAIs that address QG C SSCs.

In RAI 3.2-4, the staff requested that the applicant revise Section 3.2.2.3 to add important system functions to the QG C description. The request includes those functions that provide cooling water to systems for reactor shutdown, emergency core cooling, postaccident containment heat removal, or DHR, or those containing radioactive waste. The response to RAI 3.2-4 stated that the applicant has added the requested discussion to a new Section 3.2.3.3 for Safety Class 3. This response also clarified that the ESBWR does not require that cooling water be provided to safety-related systems for reactor shutdown, emergency core cooling, postaccident containment heat removal, or DHR, or to those systems containing radioactive waste, during the first 72 hours after an initiating event. As noted earlier, ANS 58.14 for safety classification is currently withdrawn and has not received the NRC's endorsement, but the applicant's classification scheme is not dependent on this standard. The applicant has stated that it will delete the reference to ANS 58.14 for safety class, and in Revision 6 of the DCD, this reference is deleted. Non-safety-related cooling water systems, such as the PSWS, are considered RTNSS systems rather than safety-related systems and their classification as QG D is appropriate for a non-safety-related RTNSS system, provided that supplemental requirements are included to ensure reliability. Chapter 22 of this report further reviews special treatment for RTNSS SSCs. All issues related to RAI 3.2-4 were closed.

G21 Fuel and Auxiliary Pools Cooling System

In RAI 3.2-30, the staff requested that G21 Item 8 be safety-related QG C, QA Requirement B, and seismic Category I. The RAI response identified that the GDCS pool suction and return lines do not meet any of the criteria in RG 1.26, Section C.2, and that GDCS cooling is not a safety-related function. The response explained that QA Requirement E is appropriate for a non-safety-related system that performs a defense-in-depth function. The staff concurs that components with no safety-related function need not be QG C, QA Requirement B, or seismic Category I and that QG D and standard QA are appropriate, provided that risk-significant systems are addressed under RTNSS. The resolution of Open Item 3.2-6 addresses the issue of supplemental QA requirements for non-safety-related important defense-in-depth functions, such as the FAPCS. Subsequently, in Revision 6, Table 3.2-1 identifies the non-safety-related portions of the FAPCS as QG C or D and Safety-Related Classification S with special QA requirements. All issues related to RAI 3.2-30 were closed.

In RAI 3.2-31, the staff requested that G21 Item 9 be safety-related QG C, QA Requirement B, and seismic Category I. The RAI response stated that the FAPCS isolation condenser/primary containment cooling (IC/PCC) pool cooling is not a safety-related function and that G21 Item 3 provides the safety-related makeup water. The response explained that QA Requirement E is appropriate for a non-safety-related system that performs a defense-in-depth function. The staff concurs that components with no safety-related function need not be QG C, QA Requirement B, or seismic Category I and that QG D and standard QA are appropriate, provided that risk-significant systems are addressed under RTNSS. The resolution of Open Item 3.2-6 addresses the issue of supplemental QA requirements for non-safety-related important defense-in-depth functions, such as the FAPCS. Subsequently, in Revision 6, Table 3.2-1 identifies the non-safety-related FAPCS Item 9 as QG D and Safety-Related Classification S with special QA requirements. All issues related to RAI 3.2-31 were closed.

In RAI 3.2-32, the staff requested that G21 Item 10 be safety-related QG C, QA Requirement B, and seismic Category I. The RAI response stated that the auxiliary pool return lines do not have a safety-related function. The response explained that QA Requirement E is appropriate for a non-safety-related system that performs a defense-in-depth function. The staff concurs that components with no safety-related function need not be QG C, QA Requirement B, or seismic Category I, and that QG D and standard QA are appropriate, provided that risk-significant systems are addressed under RTNSS. The resolution of Open Item 3.2-6 addresses the issue of supplemental QA requirements for non-safety-related important defense-in-depth functions, such as the FAPCS. Subsequently, in Revision 6, Table 3.2-1 identifies the non-safety-related FAPCS Item 10 as QG D and Safety-Related Classification S with special QA requirements. All issues related to RAI 3.2-32 were closed.

G31 Reactor Water Cleanup/Shutdown Cooling System

In RAI 3.2-35, the staff requested that G31 Item 8 be safety-related QG C and QA Requirement B. The RAI response identified that the RWCU/SDC system heat exchanger and cooling water do not have a safety-related function. The response explained that QG D is acceptable for a non-safety-related system in accordance with RG 1.26. The staff concurs that QG D with standard QA is appropriate for a non-safety-related system, provided that risk-significant systems are addressed under RTNSS. The resolution of Open Item 3.2-6 addresses the issue of supplemental QA requirements for non-safety-related SSCs that may be risk significant. Subsequently, in Revision 6, Table 3.2-1 identifies the non-safety-related RWCU/SDC system Item 8 as QG D and Safety-Related Classification S with special QA requirements. All issues related to RAI 3.2-35 were closed.

P10 Makeup Water System

In RAI 3.2-43, the staff requested that the classification of makeup water system (MWS) components be QG C, QA Requirement B, and seismic Category I. The RAI response stated that, other than the containment isolation function, the MWS is a non-safety-related system and has no safety design basis. The IC/PCC and SFPs depend on the FPS for any emergency makeup water. The staff concurs that components with no safety-related function need not be QG C, QA Requirement B, or seismic Category I, and that classification as QG D and standard QA is appropriate, provided that risk-significant systems are addressed under RTNSS. The resolution of Open Item 3.2-6 addresses the issue of supplemental QA requirements for non-safety-related SSCs that may be risk significant. Subsequently, in Revision 6, Table 3.2-1 identifies the non-safety-related MWS as QG D and Safety-Related Classification S with special QA requirements. All issues related to RAI 3.2-43 were closed.

P25 Chilled Water System

In RAI 3.2-44, the staff requested that the applicant classify the chilled water system (CWS) P25 Item 3 components as QG C, QA Requirement B, and seismic Category I. The RAI response stated that, other than the containment isolation function, the CWS is a non-safety-related system and does not perform or ensure any safety-related function. The staff concurs that components with no safety-related function need not be QG C, QA Requirement B, or seismic Category I and that classification as QG D with standard QA is appropriate, provided that risk-significant systems are addressed under RTNSS. The resolution of Open Item 3.2-6 addresses the issue of supplemental QA requirements for non-safety-related important defense-in-depth functions, such as those of the CWS. All issues related to RAI 3.2-44 were closed.

P41 Plant Service Water System

In RAI 3.2-45, the staff requested that the applicant classify PSWS P41 system components as QG C, QA Requirement B, and seismic Category I. The RAI response stated that the PSWS does not perform any safety-related function and does not interface with any safety-related component. The staff concurs that components with no safety-related function need not be QG C, QA Requirement B, or seismic Category I, and that classification as QG D with standard QA is appropriate, provided that risk-significant systems are addressed under RTNSS. The DCD identifies the PSWS as an RTNSS Criterion C system. The resolution of Open Item 3.2-6 addresses the issue of supplemental QA requirements for non-safety-related important defense-in-depth functions, such as those of the PSWS. Subsequently, in Revision 6, Table 3.2-1 identifies the non-safety-related PSWS as QG D and Safety-Related Classification S with special QA requirements. All issues related to RAI 3.2-45 were closed.

P54 Nitrogen Supply System

In RAI 3.2-47, the staff requested that the applicant classify the P54 Item 2 and 4 components as QG C, QA Requirement B, and seismic Category I. The RAI response indicated that, other than the containment isolation function, the components do not perform any safety-related functions. The staff concurs that components with no safety-related function need not be QG C, QA Requirement B, or seismic Category I and that classification as QG D with standard QA requirements is appropriate, provided that risk-significant systems are addressed under RTNSS. All issues related to RAI 3.2-47 were closed.

Y41 Station Water System

In RAI 3.2-56, the staff asked the applicant to classify components that provide cooling water to other systems for DHR, postaccident containment heat removal, and spent fuel pool cooling (SFPC) as QG C and QA Requirement B. The RAI response stated that the station water system does not provide makeup water to any safety-related components and its classification in Table 3.2-1 is appropriate. The staff concurs that a system that performs no safety-related function need not be classified as QG C or QA Requirement B and that classification as QG D with standard QA requirements is appropriate, provided that risk-significant systems are addressed under RTNSS.

3.2.2.3.9 Scope

The staff reviewed Table 3.2-1 to determine if the scope of components was complete regarding fluid systems important to safety and comprehensive for principal pressure-retaining components. The list of systems or portions of systems in Table 3.2-1 includes piping, pumps, and valves, as well as other mechanical and structural components. Together with the associated simplified P&IDs, this list identifies the component QG classification and system classification boundaries for portions of each system. In RAI 3.2-27, the staff requested that the applicant revise DCD Table 3.2-1 to include the GDCS pool splash guard. The RAI response stated that the applicant would add the GDCS splash guard to Table 3.2-1 as Item 5 for System E50; Revision 6 of the DCD correctly includes the splash guard as Safety-Related Classification Q. Therefore, all issues related to RAI 3.2-27 were closed.

In RAI 3.2-33, the staff asked the applicant to revise DCD Table 3.2-1 to include the FAPCS skimmer lines. The RAI response stated that the applicant would add skimmer lines to Table 3.2-1 as Item 10 for System G21; Revision 6 of the DCD correctly includes the non-safety-related auxiliary pool skimmer lines as QG D. Therefore, all issues related to RAI 3.2-33 were closed.

In RAI 3.2-48, the staff requested the addition to Table 3.2-1 of the vacuum breakers addressed in DCD Tier 2, Section 6.2.1.1.2. The response to RAI 3.2-48 clarified that the applicant would revise DCD Table 3.2-1 to include vacuum breakers. Revision 3 of the DCD correctly includes the vacuum breakers as QG B and Safety-Related Classification Q.

Because of omissions and other recent changes to Table 3.2-1, it was not evident that the applicant had thoroughly reviewed Table 3.2-1 and compared it to design documents to ensure the identification of all components important to safety. To ensure that the scope of items important to safety included in Table 3.2-1 is complete and consistent with the DCD, Tier 2, Section 3.2 classification criteria, the staff, in RAI 3.2-48 S01, asked the applicant to verify that it has performed or will undertake a comprehensive review of P&IDs and other design documents to identify any missing items. The staff also requested that the applicant identify the revision of the P&IDs and other design documents used for this review so that the detailed version of the plant design applicable to the design certification is documented. In response to RAI 3.2-48 S01, the applicant revised DCD Table 3.2-1 based on a review it performed to ensure that the system classifications are complete, consistent, and up to date. To assure that the scope of items important to safety included in Table 3.2-1 is complete and consistent with the classification criteria contained in Section 3.2, RAI 3.2-7 S02 specifically requested that the applicant verify that a comprehensive review of P&IDs and other design documents has or will be performed to identify any missing items. It was also requested that the revision of the P&IDs and other design documents used for this review be identified so that the detailed version of the plant design applicable to the design certification is documented. This commitment may be linked to the resolution of item 3.2-7 .In response to RAI 3.2-48 S02, the applicant submitted a revision to DCD Table 3.2-1 and confirmed that all safety-related systems are properly classified. The applicant also included a DCD revision to include the appropriate system assignment for the refueling bellows:

In the 3.2-48 S02 RAI response, the applicant further stated that DCD Table 3.2-1 is subject to change as the plant design progresses. The RAI response did not specifically address the request to identify the revision of P&IDs and other design documents used in the review so as to document the detailed version of the plant design examined in the design certification. RAI 3.2-7 indicated a similar concern regarding the identification of applicable P&IDs and design finality. Section 3.2.2.3.5 of this report discusses the resolution of this concern. On the basis that the applicant has reviewed and revised the DCD to establish that the system classifications are complete, consistent, and up to date, the staff finds that the scope of systems important to safety included in the DCD is sufficiently complete for design certification. In July 2009, the staff audited the design-basis documents used to establish the QG classification of systems and components during the detailed design, as documented in "Summary of the July 20 to 24, 2009, Regulatory Audit of Design Specification of Risk Significant ESBWR Components at General Electric Hitachi (GEH) Office in Wilmington, NC," issued September 1, 2009. Based on the results of the audit, the staff found that the detailed design is not complete, and the information is insufficient to validate the basis for each component classification. However, there is sufficient information to conclude that the scope of principal components is essentially complete and the classification criteria are consistent with RG 1.26 or an equivalent alternative. Staff concludes that all issues related to RAI 3.2-48 were resolved.

3.2.2.3.10 Systems Containing Radioactive Material

The staff reviewed miscellaneous systems that contain radioactive material to determine if their classification is correct. The applicant has not assigned a QG to certain components in the fuel transfer system (FTS) that contain radioactive material. In RAI 3.2-29, the staff requested that the applicant revise Table 3.2-1 to classify the FTS F42 Item 1 as at least QG D and QA Requirement B. The RAI response states that, since this component contains radioactive material, it falls into QG D, and the applicant will revise the table accordingly. Table 3.2-1 of DCD Revision 3 identifies FTS F42 Item 1 as QG D, seismic Category I, and QA Requirement E. The resolution of Open Item 3.2-6 addresses the supplemental QA requirements applicable to non-safety-related seismic Category I components with defense-in-depth functions such as the FTS. Subsequently, in Revision 6, Table 3.2-1 identifies the non-safety-related FTS as QG D and Safety-Related Classification S with special QA requirements. Therefore, staff concludes that all issues related to RAI 3.2-29 were closed.

In RAI 3.2-37, the staff requested that components in Systems K10, K20, and K30 that contain radioactive waste be classified as QG C. The RAI response identified that ESBWR radwaste systems are QG D in accordance with RG 1.26, as modified by RG 1.143, and that the applicant will revise DCD, Tier 2, Table 3.2-1, accordingly. Table 3.2-1 of DCD Revision 3 identified Systems K10, K20, and K30 as QG D and QA Requirement E with a QA program consistent with RG 1.143. Subsequently, in Revision 6, Table 3.2-1 identified the non-safety-related radwaste systems as QG D and Safety-Related Classification S with special QA requirements. The staff concurs that RG 1.143 is the appropriate reference for classification of radwaste systems, and DCD, Tier 2, Revision 2, Table 3.2-1, shows that the radioactive waste management system components conform to RG 1.143, Table 1. Although Table 1.9-21b in DCD, Tier 2, Revision 1, did not identify compliance with RG 1.143, Revision 3 of DCD Table 1.9-21b does state such compliance. Sections 11.2, 11.3, and 11.4 of DCD Tier 2 also show compliance for liquid, gaseous, and solid radwaste systems, respectively. Therefore, all issues related to RAI 3.2-37 were closed.

3.2.2.3.11 Codes and Standards

All pressure-retaining components and component supports designated as QG A, B, or C are constructed in accordance with ASME Code, Section III, Class 1, 2, or 3 rules, respectively. Construction, as defined in ASME Code, Section III, Subsections NB/NC/ND-1110(a), and used herein, is an all-inclusive term encompassing the design, materials, fabrication, examination, testing, inspection, and certification required in the manufacture and installation of components. Components classified as QG D are designed to the applicable standards identified in DCD, Tier 2, Table 3.2-3. SRP Section 3.2.2 states that SECY-93-087 directs the staff to review applications using the newest codes and standards endorsed by the NRC, with unapproved editions reviewed on a case-by-case basis. The staff determined that DCD, Tier 2, Table 3.2-1, footnote (9), does not specify an edition for the ASME Standard B31.1, “Power Piping,” relevant to the N32 turbine control system and that the NRC has not reviewed or approved International Organization for Standardization (ISO) 9001:2000, “Quality Management System (QMS)—Requirements,” for this purpose. In RAI 3.2-39, the staff requested that the applicant revise Table 3.2-1 N32 footnote (9) to conform to SRP Section 3.2.2 guidance or provide information demonstrating that the proposed alternative meets or exceeds the intent of SRP Section 3.2.2 guidance. The RAI response identified that DCD Table 1.9-22 lists footnote (9) for ASME B31.1 as code year 2004. The RAI response also noted that the applicant will insert a reference to GEZ-4982A, “General Electric Steam Turbine-Generator Quality Control Program,” and remove the reference to ISO 9001:2000. GEZ-4982A is consistent with the SRP, and application of ASME B31.1 for QG D is consistent with RG 1.26. Other sections of this report review the acceptability of the 2004 ASME B31.1 code and other code and standard editions identified in DCD, Tier 2, Section 1.9. Therefore staff concludes all issues related to RAI 3.2-39 were closed.

In DCD, Tier 2, Table 3.2-3, the applicant provided a correlation of the quality grouping with specific design codes and standards. The staff requested several changes to Table 3.2-3 to establish that the table is consistent with the SRP Section 3.2.2 and RG 1.26 guidance. In RAI 3.2-58, the staff requested that the applicant revise Table 3.2-3 to delete the Tubular Exchanger Manufacturers Association (TEMA) C reference or provide information demonstrating that the TEMA C standard meets or exceeds the requirements for QG A, B, C, and D components. The RAI response stated that the applicant would revise Table 3.2-3 to clarify that the requirements from both TEMA and the ASME Code must be considered. In DCD Revision 3, the applicant revised Table 3.2-3 accordingly. In RAI 3.2-59, the staff requested that the applicant also revise Table 3.2-3 to include pumps. The RAI response stated that the applicant would revise Table 3.2-3 to include pumps, and in DCD Revision 3, the applicant revised Table 3.2-3 accordingly. In RAI 3.2-60, the staff requested that the applicant also revise Table 3.2-3 to include non-ASME Code, Section III, component supports to ensure that ASME B31.1 or American Institute of Steel Construction (AISC) codes are listed for QG D supports. The RAI response added non-ASME Code, Section III, component supports that refer to the manufacturer’s standards such as ASME B31.1 and AISC codes for QG D. The applicant revised Table 3.2-3 in DCD Revision 3 accordingly. In RAI 3.2-61, the staff requested that the applicant also revise Table 3.2-3 to include core support structures and reactor internals to ensure that ASME Code, Section III, Subsection NG, is listed for QG B and C components. The RAI response revised Table 3.2-3 to include code information for core support structures and reactor internals. The applicant also revised Table 3.2-3 in DCD Revision 3 accordingly. In RAI 3.2-62, the staff requested that the applicant revise Table 3.2-3 to refer to ASME Code, Section III, Subsection NC, rather than Subsection NB, for the design of ASME Code Class 2 pressure vessels and heat exchangers. The RAI response revised the table accordingly.

During a July 2009 audit (Summary of the July 20 to 24, 2009, Regulatory Audit of Design Specification of Risk Significant ESBWR Components at General Electric Hitachi (GEH) Office in Wilmington, NC, September 1, 2009), the staff reviewed design-basis documents for risk-significant SSCs selected by the applicant and determined that DCD Table 3.2-2 should be revised to include a reference to ASME Section III CC, MC, or CS Code Class in addition to ASME Code Class 2 for QG B. DCD Revision 6 includes CC, MC, or CS in Table 3.2-2. The staff concludes that, with these changes, the revised DCD table is consistent with the guidance in SRP Section 3.2.2 and RG 1.26, and RAIs 3.2-58, 3.2-59, 3.3-60, 3.2-61, and 3.2-62 were therefore closed.

3.2.2.3.12 Nonpressure-Retaining Items

The guidance for QG classification in RG 1.26 is not applicable to nonpressure-retaining items, but SRP Section 3.2.2, Table 3.2.2-1, does include QG and construction codes for supports and core support structures. Table 3.2-1 of DCD Tier 2 includes supports and structures that are not pressure retaining, and the staff reviewed certain nonpressure-retaining items for application of the appropriate QG classification relative to basic QA requirements. The staff requested specific QG classifications for several nonpressure-retaining items in safety-related systems.

Supports

DCD, Tier 2, Section 3.2.2, states that the supports for piping and components have the same seismic and QG classifications as the component or piping supported. In RAI 3.2-3, the staff requested that the applicant revise the text in the DCD that states that the component supports are not addressed by RG 1.26. In the RAI response, the applicant agreed that component supports are included in the QG classifications; the applicant revised the DCD to delete the reference to supports in regard to RG 1.26.

B11 Reactor Pressure Vessel System

As identified in SRP Table 3.2.2-1, Section 3.9.3, and DCD Section 3.9.5.4, the ASME Code, Section III, Subsection NG, covers nonpressure-retaining core support structures. In RAI 3.2-10, the staff requested that the applicant revise Table 3.2-1 to identify QG B as applicable to core support structures, consistent with SRP Section 3.2.2. In its response to RAI 3.2-10, the applicant stated that it would revise Table 3.2-1 to add QG B to core support structures. Revision 3 of the DCD shows the core support structures as QG B.

In RAI 3.2-11, the staff requested that the applicant assign QG and QA requirements to non-safety-related reactor internals such as the steam separators and dryers. The response to RAI 3.2-11 indicated that the BWR steam dryers and steam separators have traditionally been classified as non-safety-related. Since these components are not pressure retaining, the applicant did not assign them a QG. Therefore, the response stated that assigning these components a QG C and a QA Requirement B is not warranted. The resolution of Open Item 3.2-6 addresses the supplemental QA requirements for non-safety-related seismic Category II components with standard quality requirements, such as steam dryers. Non-safety-related reactor internals are identified as Safety-Related Classification S in DCD Table 3.2-1 with special QA requirements applied.

During a July 2009 audit (Summary of the July 20 to 24, 2009, Regulatory Audit of Design Specification of Risk Significant ESBWR Components at General Electric Hitachi (GEH) Office in Wilmington, NC, September 1, 2009), staff reviewed design-basis documents for risk-significant SSCs selected by the applicant and determined that DCD Table 3.2-2 or Table 3.2-3, or both, should be revised to include a reference to ASME Section III, Subsection NG, for internal structures. In DCD Revision 6, the applicant revised Table 3.2-2 to include Subsection NG for reactor internals. All issues associated with RAI 3.2-11 were closed.

F16 Fuel Storage Facility

In RAI 3.2-28, the staff requested that the applicant classify the fuel storage racks (F16 Item 1) as at least QG D and QA Requirement B to be consistent with SRP Sections 3.2.1 and 3.2.2 and the guidance in RGs 1.26 and 1.29. The RAI response clarified that the fuel storage racks are non-safety-related and seismic Category I, consistent with the ABWR DCD. In SECY-91-153, "Draft Safety Evaluation Report on General Electric Company ABWR Design Covering Chapters 1, 2, 3, 4, 5, 6, and 17 of the Standard Safety Analysis Report," dated May 24, 1991, the Commission identified the classification of fuel storage racks in RG 1.26 as a concern for the ABWR. The resolution explained in NUREG-1503, "Final Safety Evaluation Report Related to the Certification of the Advanced Boiling Water Reactor," issued July 1994, was to credit the Category I design of the fuel racks combined with elements of Appendix B to 10 CFR Part 50 commensurate with the importance of the component's function. The resolution of Open Item 3.2-6 addresses the supplemental QA requirements for non-safety-related seismic Category I components with standard QA, such as the fuel storage racks. Subsequently, in Revision 6, Table 3.2-1 identifies the non-safety-related fuel racks as Safety-Related Classification S with special QA requirements. All issues related to RAI 3.2-28 were closed.

J11 and J12 Nuclear Fuel and Fuel Channel

In RAI 3.2-36, the staff requested that the applicant classify the fuel and fuel channels as QG B. The RAI response stated that RG 1.26 applies only to pressure-retaining components and that the fuel and fuel channels are classified as Safety Class 3 to require a coolable geometry consistent with the ABWR DCD. The staff concurs that RG 1.26 applies only to pressure-retaining components and SRP Section 3.2.2, Table 3.2.2-1, does not include fuel and fuel channels. DCD Table 3.2-1 indicates that nuclear fuel and fuel channels are designed in accordance with NRC-approved methodology as described in DCD, Tier 2, Chapters 4 and 15 and DCD Ref 3.2-9: Global Nuclear Fuel, "GESTAR II General Electric Standard Application for Reactor Fuel," NEDE-24011-P-A-16, Class III (GE Proprietary) and NEDO-24011-A-16, Class I (Non-proprietary), Revision 16, October 2007.. Although industry consensus standard ANS 52.1 is withdrawn and has not received the NRC's endorsement, this industry standard specifically identifies Safety Class 3 for the fuel assemblies. For the ABWR, Safety Class 3 is identified as applicable to the fuel assemblies and fuel channel. Therefore, the staff concludes that QG B is not applicable to the fuel and fuel channels and, consistent with industry practice, Safety Class 3 rather than QG B is an appropriate classification.

3.2.2.4 *Conclusions*

On the basis of its review of the applicable information in the DCD and the above discussion, the staff concludes that the QG criteria and classifications of the pressure-retaining systems and components important to safety, as identified in DCD, Tier 2, Section 3.2.2, Tables 3.2-1, 3.2-2, and 3.2-3, and related P&IDs in the DCD, are, in general, consistent with RG 1.26 as supplemented by SRP Section 3.2.2 and therefore are acceptable. These tables and simplified P&IDs identify principal components in fluid systems and identify the classification boundaries of interconnecting piping and valves. All of the above SSCs are to be constructed in conformance with applicable ASME Code and industry standards. Conformance to RG 1.26 (with one acceptable exception for the HCUs as described above), RG 1.143, and applicable ASME Codes and industry standards provides assurance that component quality will be commensurate with the importance of the safety functions of these systems. This provides the basis for finding that pressure-retaining systems satisfy GDC 1 and are therefore acceptable.

This conclusion is based on the following:

- With one acceptable exception for the HCUs, the applicant has, in part, met the requirements of GDC 1 by having properly classified these pressure-retaining systems and components important to safety as QG A, B, C, or D in accordance with the positions of RGs 1.26 and 1.143.

- The identified safety-related pressure-retaining components and their supports are those that are necessary to ensure (1) the integrity of the RCPB, (2) the capability to shut down the reactor and maintain it in a shutdown condition, and (3) the capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures comparable to the guideline exposures in 10 CFR 52.47.

- Those pressure-retaining components and their supports that are important to safety but are considered non-safety-related are identified as Safety-Related Classification S with special treatment requirements determined by the RTNSS process addressed in Chapter 22 of this report.

3.3 <u>Wind and Tornado Loadings</u>

3.3.1 Wind Loadings

The staff reviewed Revision 7 of the ESBWR DCD, Section 3.3.1, in accordance with the guidance in NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition” (hereafter known as the SRP), Section 3.3.1, Revision 3, regarding the design of structures that must withstand the effects of the specified design wind speed for the ESBWR plant. The staff considered the applicant’s responses to requests for additional information (RAIs), open items, and confirmatory items. The following summarizes the results of the staff’s technical review of DCD, Tier 2, Section 3.3.1.

3.3.1.1 *Regulatory Criteria*

The design of structures that are important to safety and must withstand the effects of the design-basis wind load must comply with the relevant requirements of GDC 2, “Design bases for protection against natural phenomena,” of Appendix A to 10 CFR Part 50.

GDC 2 requires that SSCs important to safety be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions. GDC 2 further requires that the design bases reflect appropriate consideration of the most severe natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated. GDC2 also requires consideration of appropriate combinations of the effects of normal and accident conditions with the effect of natural phenomena and the importance of the safety functions to be performed.

To ensure compliance with the requirements of GDC 2, the NRC staff reviewed the following areas relating to the design of structures that have to withstand the effects of the design wind specified for the plant:

- the design wind speed and its recurrence interval, the speed variation with height, and the use of applicable gust factors in defining the input parameters for the structural design criteria appropriate to account for wind loadings;

- the procedures used to transform the design wind speed into an effective pressure applied to structures, taking into consideration the geometrical configuration and physical characteristics of the structures and the distribution of wind pressure on the structures.

3.3.1.2 *Summary of Technical Information*

The applicant discussed the design wind loadings criteria for the ESBWR in DCD, Tier 2, Section 3.3.1 and Table 2.0-1. The applicant stated that the design wind velocity and its recurrence interval, the velocity variation with height, and the applicable gust factors as discussed in SRP Section 3.3.1 are used in defining the input parameters for the structural design criteria appropriate to account for wind loadings. The procedures used to transform the wind velocity into an effective pressure applied to structures and parts, or portions of structures, follow those specified in American Society of Civil Engineers (ASCE) 7-02, “Minimum Design Loads for Buildings and Other Structures,” and ASCE Paper No. 3269, “Wind Forces on Structures,” in *Transactions of the ASCE*, published 1961.

The applicant stated that for the ESBWR design, the basic wind speed is 67.1 meters per second (m/s) (150 miles per hour (mph)) at an elevation of 9.14 meters (m) (30 feet (ft)) above grade. This basic wind speed is to be scaled by an importance factor, as defined in ASCE 7-02, of 1.0 and 1.15 for non-safety-related and safety-related structures, respectively, based on Category IV buildings and Exposure Category D.

3.3.1.3 *Staff Evaluation*

The staff reviewed the information provided by the applicant in DCD, Tier 2, Section 3.3.1, and determined that it needed additional information to complete its review.

In RAI 3.3-1, the staff requested that the applicant provide the following information:

> Section 3.3.1 of the DCD states that the procedures utilized to transform the wind velocity into an effective pressure applied to structures and parts, or portion of structures are as delineated in Reference 3.3-1. Reference 3.3-1 lists ASCE Standard 7-02, “Minimum Design Loads for Buildings and Other Structures,” Committee A.58.1, ANSI. Since the above referenced standard is still under NRC staff review, the applicant is requested to confirm that the procedures utilized to transform the wind velocity into an effective pressure applied to structures provided in the reference is consistent with those stipulated in Reference 2 of SRP Section 3.3.1 (Rev. 2, 1981), otherwise, identify and justify pertinent deviations from the provisions of the SRP section.

In its response to RAI 3.3-1, the applicant stated the following:

> ANSI A58.1 has been superseded by ASCE Standards. Further, 3-sec gust speed has become the basis for wind design codes since 1995. For the ESBWR standard plant a basic wind speed of 140 mph (3-sec gust) at a height of 33 feet and exposure category C was chosen based on Figure 6-1 of ASCE 7-02 as it bounds nearly all the US. The corresponding basic wind speed per ANSI A58.1 (Table 1) is 110 mph (fastest mile wind). The velocity pressure for 140 mph (3-sec gust) bounds the velocity pressure for 110 mph (fastest mile wind) for the same height and exposure category C. For category I buildings, an additional margin is provided by choosing a more severe exposure category D versus exposure category C specified in SRP Section 3.3.1.II.3. Therefore, the DCD requirements exceed the SRP requirements. Table 2.0-1 and Section 3.3.1.2 will be clarified in the next update as noted in the attached markups.

The staff reviewed the applicant's response to RAI 3.3-1 and the updates to Section 3.3.1.1 and Table 2.0-1 in DCD, Tier 2, Revision 3, and found that the design wind speed (3-second gust) for seismic Category I and II structures is identified as 67.1 m/s (150 mph) with a scaling importance factor of 1.15 and an assignment of Exposure Category D. The staff finds the design wind speed, importance factor, and the exposure category in accordance with ASCE 7-02 to be acceptable. Also, in Revision 3 of SRP Section 3.3.1, the staff accepted the provisions of ASCE 7-05, "Minimum Design Loads for Buildings and Other Structures," which are consistent with ASCE 7-02 provisions, for transforming wind speed into equivalent pressure to be applied to structures and portions of structures. Accordingly, the staff considers RAI 3.3-1 resolved.

Based on its review, the staff determined that the ESBWR design for wind loads, including the procedures for transforming the wind velocity into an effective pressure on structures and selecting pressure coefficients corresponding to the geometry and physical configuration of the structures, is consistent with the staff's positions in SRP Section 3.3.1, Revision 3.

The applicant's use of these procedures provides reasonable assurance that design-basis winds will not impair the structural integrity of the plant structures whose design must protect against wind, and consequently, the safety-related systems and components located within these structures are adequately protected and will perform their intended safety functions.

3.3.1.4 *Conclusions*

The staff concludes that the applicant's compliance with the provisions of SRP Section 3.3.1 and applicable design standards provides reasonable assurance that the ESBWR safety-related SSCs will maintain their structural integrity and perform their intended safety functions when subjected to design-basis wind loads in combination with other applicable design-basis loads. This satisfies the requirements of GDC 2.

3.3.2 Tornado Loadings

The staff reviewed Revision 6 of the ESBWR DCD, Section 3.3.2, in accordance with the guidance in SRP Section 3.3.2, Revision 3, regarding the design of structures that must withstand the effects of the specified design-basis tornado (DBT) for the ESBWR and considered the applicant's responses to RAIs, open items, and confirmatory items. The following summarizes the results of the staff's technical review of DCD Section 3.3.2.

3.3.2.1 *Regulatory Criteria*

The design of structures that are important to safety and must withstand the effects of the DBT must comply with the relevant requirements of GDC 2.

GDC 2 requires that SSCs important to safety be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their intended safety functions. GDC 2 further requires that the design bases reflect appropriate consideration of the most severe natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated. GDC2 also requires consideration of appropriate combinations of the effects of normal and accident conditions with the effect of natural phenomena and the importance of the safety functions to be performed.

To ensure compliance with the requirements of GDC 2, the staff reviewed the following areas relating to the design of structures that must withstand the effects of the DBT specified for the plant:

- the design parameters applicable to the tornado, including the tornado wind translational and rotational velocities, the tornado-generated pressure differential and its associated time interval, and the spectrum of tornado-generated missiles, including their characteristics, from the standpoint of their use in defining the input parameters for the structural design criteria appropriate to account for tornado loadings;

- the procedures used to transform the tornado parameters into effective loads on structures; and

- the information demonstrating that failure of any structure or component not designed for tornado loads will not adversely affect the capability of other structures or components to perform their necessary safety functions.

3.3.2.2 *Summary of Technical Information*

The applicant described the DBT and applicable missiles in DCD, Tier 2, Section 3.3.2 and Table 2.0-1.

The applicant indicated that the maximum tornado speed is 147.5 m/s (330 mph) with a translational wind velocity of 31.3 m/s (70 mph). This also implies a maximum tangential (rotational) velocity of 116.2 m/s (260 mph). The applicant also specified a maximum atmospheric pressure drop of 16.6 kilopascals (kPa) (2.4 pounds per square inch (psi)), a rate of pressure drop of 11.7 kPa/s (1.7 psi/s), and a maximum radius of tornado of 45.7 m (150 ft). The applicant indicated that the ESBWR missile spectra are in accordance with Spectra I of SRP Section 3.5.1.4.

The applicant's procedures for transforming the tornado loading into effective loads and the distribution across the structures are in accordance with Bechtel Topical Report BC-TOP-3-A, Revision 3, "Tornado and Extreme Wind Design Criteria for Nuclear Power Plants," issued 1974. The velocity pressure used in the design was obtained from this report meets the SRP Section 3.3.2 provision. DCD, Tier 2, Section 3.5.3, gives the procedure for transforming the tornado-generated missile impact into an effective or equivalent static load on structures. The loading combinations of the individual tornado loading components and the load factors are in accordance with SRP Section 3.3.2.

The applicant indicated that the reactor building (RB), fuel building (FB) and control building (CB) are not a vented (enclosed) structure. The exposed exterior roofs and walls of this structure are designed for the full pressure drop. Tornado dampers are provided on all air intakes and exhaust openings. These dampers are designed to withstand the full negative pressure drop. The applicant further indicated that all safety-related systems and components are protected within tornado-resistant structures.

3.3.2.3 *Staff Evaluation*

RG 1.76, “Design Basis Tornado for Nuclear Power Plants,” issued April 1974, provides the staff’s position on DBTs. RG 1.76 delineates the maximum tornado wind speed as 579 kilometers per hour (km/h) (360 mph) for the contiguous United States (US). The staff reevaluated the regulatory position in RG 1.76 for the standard design of advanced light-water reactors (ALWRs) using tornado data that became available after development of RG 1.76. J.V. Ramsdell and J. P. Risher discussed this reevaluation in NUREG/CR-4461, Revision 2, “Tornado Climatology of the Contiguous United States,” issued January 1987. In a March 25, 1988, letter, “ALWR Design Basis Tornado,” to Edwin A. Kintner, GPU Nuclear Corporation, the staff provided its interim position related to RG 1.76. In this interim position, the staff concluded that the maximum tornado wind speed of 531 km/h (330 mph) is acceptable. However, in SECY-93-087, “Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs,” dated April 2, 1993, the staff recommended that the Commission approve its position that a DBT with a maximum tornado wind speed of 483 km/h (300 mph) be adopted for the design of evolutionary and passive ALWRs, since the 483-km/h (300-mph) tornado is suitable for most U.S. sites. In the associated staff requirements memorandum dated July 21, 1993, the Commission approved the staff’s position. The staff finds that by using the maximum wind speed of 483 km/h (330 mph), the ESBWR design meets the staff’s position and the intent of SRP Section 3.3.2, Revision 3. Therefore, the use of a maximum wind speed of 483 km/h (330 mph) for the ESBWR is acceptable. The staff reviewed the information provided by the applicant in Section 3.3.2 of DCD Tier 2 and determined that it needed additional information to complete its review.

In RAI 3.3-2, the staff asked the applicant to provide the following information:

> Section 3.3.2.1 of the DCD states that the DBT and applicable missiles are described in Subsection 2.3.1 and 2.3.2 and Table 2.0-1. Subsection 2.3.1 of Table 2.0-1 provides parameters defining a DBT for the ESBWR except the maximum rotational speed of the same. This is not consistent with the fact that Table I of RG 1.76, lists rotational speed as one of the parameters defining a DBT. Explicitly provide rotational wind speed information in Table 2.0-1 or discuss applicant’s basis for omitting the parameter in the Table.

In its response to RAI 3.3-2, the applicant stated that the rotational wind speed is 116.2 m/s (260 mph) and provided a markup of a revised DCD Table 2.0-1.

The staff reviewed the applicant’s response to RAI 3.3-2 and DCD Revision 3 updates and found that the rotational wind speed used in the ESBWR standard plant design is acceptable and that the applicant had updated the DCD accordingly. RAI 3.3-2 is considered resolved.

The total effect of the DBT on seismic Category I structures is determined by appropriate combinations of the individual effects of the tornado wind pressure, tornado wind pressure drop, and tornado-generated missiles. The applicant's procedures for transforming the tornado loading into effective loads and determining the distribution across the structures are in accordance with BC-TOP-3-A, Revision 3. The procedures for transforming the tornado wind velocity into pressure loadings in BC-TOP-3-A are similar to those used for the design wind loadings discussed in Section 3.3.1 of this report. By using BC-TOP-3-A, the applicant designed the ESBWR plant structures with sufficient margin to prevent structural damage during the most severe tornado loadings determined to be appropriate for most sites. Section 3.5.3 of this report discusses the procedure for transforming the tornado-generated missile impact into an effective or equivalent static load on structures, as described in DCD, Tier 2, Section 3.5.3. The loading combinations of the individual tornado loading components and the load factors are consistent with those of SRP Section 3.3.2.

The staff finds that the use of these procedures provides reasonable assurance that a DBT will not impair the structural integrity of the ESBWR plant structures that must be designed for tornadoes, and consequently, safety-related systems and components located within these structures will be adequately protected to enable the performance of their intended safety functions.

The applicant further stated that it will be necessary for the COL applicant to ensure that the remainder of plant SSCs not designed for tornado loads are analyzed for the site-specific loadings so that their modes of failure do not affect the ability of the seismic Category I ESBWR standard plant SSCs to perform their intended functions.

In RAI 3.3-3, the staff asked the applicant to provide the following information:

> Section 3.3.3.2 of the DCD states that the COL applicant shall ensure that the remainder of plant SSCs not designed for tornado loads are analyzed for the site-specific loadings to ensure that their modes of failure do not affect the ability of the seismic Category I ESBWR Standard Plant SSCs to perform their intended functions. Since the site specific loadings cited above exclude tornado loads, confirm that these SSCs were all assumed to fail under the tornado loadings and appropriate tornado related II/I structural interaction analyses were performed for the SSCs to ensure that their modes of failure do not affect the ability of the seismic Category I ESBWR Standard Plant SSCs to perform their intended functions.

In its response to RAI 3.3-3, the applicant stated that it will revise the DCD to show that seismic Category II structures are designed for tornado loads (wind force only and no missiles) to preclude adverse seismic Category II/I interactions. The applicant stated that the non-safety-related, non-seismic (NS) SSCs are postulated to fail under tornado loadings, and it will clarify the DCD to require that these NS structures are located at least a one-story height above grade from seismic Category I or II structures. The applicant provided proposed changes to DCD Sections 3.3 and 3.3.2.3. The applicant planned to delete DCD Section 3.3.3.2 in the next update. The staff confirmed that this section was deleted from the DCD.

The staff reviewed the applicant's response to RAI 3.3-3 and found that designing seismic Category II structures for tornado loads (wind only and no missiles) and locating NS structures postulated to fail under tornado loadings at least a one-story height above grade away from seismic Category I and II structures will preclude adverse seismic Category II/I interactions and will ensure that failure of NS structures will not adversely affect the ability of safety-related structures to perform their intended functions.

In DCD, Revision 3, Section 3.3.2.3, however, the applicant stated that any NS structure (except the radwaste (RW) building) postulated to fail under tornado loading is located at least a distance of its height above grade from seismic Category I structures. In RAI 3.3-3 S01, the staff asked the applicant to provide the following information:

> In DCD Revision 3, Section 1.2.2.16.9, the applicant stated that the Radwaste Building is a non-seismic category structure and it is designed according to the safety classification defined in RG 1.143. Note 1 for Table 2.0-1 of the DCD indicates that the Radwaste Building is classified as Class RW IIa and is designed to the corresponding parameters in Table 2 of RG 1.143. This indicates that, for tornado hazard, the Radwaste Building is designed for three-fifth of the DBT parameters used for seismic Category I structures. Given the exemption of the Radwaste Building from the location criteria and its reduced tornado design criteria, describe in details the approach and the technical bases for ensuring that the failure of the Radwaste Building under full tornado loadings either is precluded or will not adversely impact the safety-related functions of adjacent C-I and C-II SSCs.

RAI 3.3-3 was being tracked as an open item in the SER with open items. In its response, the applicant stated that the RW building is designed with a sufficient design margin such that it will not collapse under tornado winds specified in RG 1.76, Revision 1, and it will revise DCD, Tier 2, Section 3.3.2.3, to clarify this. Additionally, the applicant stated that, there is no adverse impact on the safety-related functions of the adjacent Category I buildings under tornado load winds specified in RG 1.76, Revision 1.

The staff reviewed the applicant's response to RAI 3.3-3 S01 and found it to be inadequate because the applicant did not provide the requested information to demonstrate that a potential failure of the RW building under the ESBWR tornado loads is either precluded or will not affect the ability of seismic Category I SSCs to perform their safety functions.

In supplemental RAI 3.3-3 S02, the staff requested that the applicant demonstrate that a potential failure of the RW building under the ESBWR tornado loads is either precluded or will not affect the ability of seismic Category I SSCs to perform their safety functions. The staff requested this information because ESBWR DCD Section 3.3.2.3 indicates that the RW building is not located at a sufficient distance from Category I SSCs to preclude adverse interaction. Further, according to Note 1 to DCD Table 2.0-1, the RW building is designed to a lower tornado windspeed than that for Category I SSCs. These two conditions do not provide reasonable assurance that, under tornado loading, adverse interaction between the RW building and the adjacent Category I SSCs is avoided.

In its response, the applicant stated that the RW building is designed for the tornado loads described in DCD, Tier 2, Table 2.0-1. Therefore, any adverse interaction with adjacent Category I structures caused by tornado loads is precluded. In addition, the RW building will be designed to full safe-shutdown earthquake (SSE) instead of one-half SSE as required by RG 1.143, "Design Guidance for Radioactive Waste Management Systems, Structures, and Components Installed in Light-Water-Cooled Nuclear Power Plants," Revision 2; this will preclude any adverse interaction with adjacent Category I structures due to seismic loading.

By the applicant increasing the loads to full tornado wind speeds and by using the standards referenced in RG 1.143 (American Concrete Institute (ACI) 349 and 318 or NS90/AISC LRFD "Load and resistance factor design" for capacities and load factors, a reasonable margin of safety exists in the design of the building. The limitations of the RW building design, as compared to a Category I structure, are the use of a smaller missile spectrum and load combinations that do not combine flood with tornado. Damage associated with missiles is likely to be localized and would not lead to collapse. Also, a combination of both extreme loads (flood and tornado) has a very low probability of less than 10^{-7} as recommended by RG 1.76. The objective here is to demonstrate only that under full tornado wind, the RW building will not fail and will not adversely impact adjacent Category I SSCs. Given the design loading, the standards used, and the separation between the RW building and the adjacent RB, the design gives reasonable assurance of that. This response is acceptable to the staff, and therefore, RAI 3.3-3 and associated open item are considered resolved.

3.3.2.4 *Conclusions*

Based on satisfactory resolution of the RAIs specified above, the staff concludes that the applicant has met the requirements of GDC 2 with respect to the capability of structures to withstand DBT wind effects and tornado-generated atmospheric pressure change effects so that the design of the structures reflects the following:

(1) appropriate consideration of the postulated most severe tornado with an appropriate margin;

(2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena; and,

(3) the importance of the safety function to be performed.

The applicant has designed the plant structures with sufficient margin to prevent structural damage during the postulated most severe tornado loadings so that the requirements in item (1) above are met. In addition, the design of seismic Category I structures, as required in item (2) above, has included load combinations of the most severe tornado load and the loads resulting from normal and accident conditions.

The procedures used to determine the loadings on structures induced by the DBT specified for the plant are acceptable, because these procedures have been used in the design of conventional structures and are proven to provide a conservative basis which, with other engineering design considerations, ensures that the structures can withstand such environmental forces.

The use of these procedures provides reasonable assurance that in the event of a DBT, the structural integrity of the plant structures that must be designed for tornadoes will not be impaired, and in consequence, safety-related systems and components located within these structures will be adequately protected and may be expected to perform necessary safety functions as required, thus satisfying the requirement in item (3) above.

3.4.1 Flood Protection

3.4.1.1 *Regulatory Criteria*

The staff reviewed the ESBWR design for flood protection in accordance with SRP Section 3.4.1, Revision 3. The staff's acceptance of the design is based on compliance with the following requirements:

- GDC 2 requires, in part, that SSCs important to safety shall be designed to withstand the effects of natural phenomena such as floods;

- GDC 4, "Environmental and dynamic effects design bases," requires, in part, that SSCs important to safety be designed to accommodate the effects of and be compatible with the environmental conditions associated with normal operation, maintenance, testing and postulated accidents, including loss-of-coolant accidents (LOCAs); and,

- 10 CFR 52.47(b)(1) requires that a design certification (DC) application contain the proposed inspections, tests, analyses, and acceptance criteria (ITAAC) that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, a facility that incorporates the DC is built and will operate in accordance with the DC, the provisions of the Atomic Energy Act, and the NRC's regulations.

3.4.1.2 *Summary of Technical Information*

In DCD, Tier 2, Revision 7, Section 2.0, the applicant defined the envelope of site-related parameters that the ESBWR standard plant is designed to accommodate. DCD, Tier 2, Table 2.0-1, "Envelope of ESBWR Standard Plant Site Parameters," and Table 3.4-1, "Structures, Penetrations and Access Openings Designed for Flood Protection," describe these site envelope parameters, which include the following:

- maximum ground water level;

- maximum flood (or tsunami) level;

- precipitation (for roof design);

- ambient design temperature;

- extreme wind;

- tornado (e.g., maximum speed, pressure drop, missile spectra);

- maximum settlement values for seismic Category I buildings;

- soil properties (minimum static bearing capacity, minimum shear wave velocity, liquefaction potential, angle of internal friction);

- seismology (SSE response spectra, shown in figures);

- hazards in the site vicinity;

- required stability of slopes; and,

- meteorological dispersion (values at exclusion area boundary and low-population zone at appropriate short- and long-term time intervals).

In addition, the applicant identified the following COL action items in DCD Table 1.10-1, “Summary of COL Items”:

- COL Action Item 2.0-12-A—Hydraulic Description Maximum Ground Water Level in Accordance with SRP Section 2.4.1;

- COL Action Item 2.0-13-A—Floods in Accordance with SRP Section 2.4.2;

- COL Action Item 2.0-14-A—Probable Maximum Flood on Streams and Rivers in Accordance with SRP Section 2.4.3;

- COL Action Item 2.0-15-A—Potential Dam Failures in Accordance with SRP Section 2.4.4;

- COL Action Item 2.0-16-A—Probable Maximum Surge and Seiche Flooding in Accordance with SRP Section 2.4.5;

- COL Action Item 2.0-17-A—Probable Maximum Tsunami Flooding in Accordance with SRP Section 2.4.6;

- COL Action Item 2.0-21-A—Flooding Protection Requirements in Accordance with SRP Section 2.4.10; and,

- COL Action Item 2.0-23-A—Groundwater in Accordance with SRP Section 2.4.12.

Section 2.0 of this report addresses the staff’s evaluation of the above site envelope parameters and COL action items.

In DCD, Tier 2, Revision 7, Section 3.4.1, the applicant discussed the flood protection measures provided in the ESBWR design for postulated external flooding resulting from natural phenomena, as well as for internal flooding from system and component failures. The applicant conducted flooding analyses based on the site envelope parameters with the following purposes:

- to identify the safety-related SSCs that require protection against flooding from both external and internal sources;

- to demonstrate the capabilities of structures housing safety-related systems or equipment to withstand flood considerations (i.e., the relationship between structure elevation and flood elevation, including waves and wind effects as described in DCD Table 2.0-1); and,

- to assess the adequacy of the isolation of redundant safety-related systems or equipment subject to flooding, including possible in-leakage sources such as cracks in structures not designed to withstand seismic events and exterior or access openings or penetrations in structures located at a lower elevation than the flood level and associated wave activity.

The analysis also considered flooding of safety-related SSCs from internal sources such as the failure of tanks, vessels, and piping.

The ESBWR safety-related SSCs are located in seismic Category I structures that protect against flooding from both external and internal sources, as well as ground water damage. All exterior access openings for the seismic Category I structures are above flood level. Exterior penetrations below design flood and ground water levels are appropriately sealed.

Section 3.8 of this report addresses the staff's evaluation of the seismic Category I structures that house the SSCs.

The applicant's internal flood analyses evaluated whether a single pipe failure, a firefighting event, or other flooding sources, as described in DCD, Tier 2, Revision 7, Section 3.4.1.4, could prevent a safe reactor shutdown. Appropriate means are provided to prevent flooding of compartments that house redundant system trains or divisions. Some of the mechanisms used to minimize flooding are structural barriers or compartments, curbs and elevated thresholds at least 300 millimeters (mm) (12 inches (in.)) high, and leak detection systems.

3.4.1.3 *Staff Evaluation*

The staff reviewed ESBWR DCD, Tier 2, Revision 7, Section 3.4.1, in accordance with the guidance of Section 3.4.1 of the SRP. The staff also reviewed DCD, Tier 1, Revision 7, Section 2.0 and other DCD Tier 2 sections noted below.

Compliance with GDCs 2 and 4 is based on meeting the guidance of the following RG and SECY-94-084:

- RG 1.59, "Design Basis Floods for Nuclear Power Plants," with regard to the methods for establishing the probable maximum flood (PMF) and probable maximum precipitation (PMP); and,

- RG 1.102, "Flood Protection for Nuclear Power Plants," with regard to the means for protecting safety-related SSCs from the effects of the PMF and PMP.

- SECY-94-084, "Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems in Passive Plant Designs," provides guidance as to which systems should be RTNSS and would call for enhanced design requirements.

<u>External Flooding</u>

The plant design protects safety-related systems and components from exterior sources (e.g., floods, ground water) by locating them above design flood level or enclosing them in concrete structures protected from ground water. The seismic Category I structures that may be subjected to the design-basis flood are designed to withstand the flood level and ground water level as stated in DCD, Tier 2, Table 2.0-1. This is done by locating the plant grade elevation 300 mm (1 ft) above the flood level and incorporating structural provisions into the plant design to protect the SSCs from the postulated flood and ground water conditions.

This approach includes the following:

- walls below flood level designed to withstand hydrostatic loads;
- water stops in all expansion and construction joints below flood and ground water levels;
- waterproofing of external surfaces below flood and ground water levels;
- water seals at pipe penetrations below flood and ground water levels;
- roofs designed to prevent pooling of large amounts of water in accordance with RG 1.102; and,
- no exterior access openings below grade.

These measures not only protect against external natural floods, but also guard against flooding from onsite storage tank rupture. Such tanks are designed and constructed to minimize the risk of catastrophic failure and are located to allow drainage without damage to site facilities. Because the plant grade is above the design flood level, the seismic Category I structures remain accessible during postulated flood events. The staff finds the above approach for external flood protection acceptable.

In RG 1.59, the staff discusses the design-basis floods that nuclear power plants should be designed to withstand without loss of capability to achieve and maintain a cold shutdown condition. In Position C.1 of RG 1.59, the staff states that the conditions resulting from the worst probable site-related flood at a nuclear power plant with attendant wind-generated wave activity should constitute the design-basis flood condition from which safety-related SSCs must be protected. ESBWR safety-related SSCs are designed to withstand the effects of external flooding in accordance with the above-stated criteria in Position C.1 of RG 1.59.

Based on its review, and for the reasons given above, the staff finds that the applicant has properly identified the design-basis flood assumed for the ESBWR design and also specified the site parameters, design characteristics, and any additional requirements and restrictions necessary for the COL applicant to adequately protect against the worst possible site-related flood conditions to ensure that safety-related SSCs will be adequately protected from the worst-probable site-related flood conditions. Therefore, the staff concludes that the ESBWR design conforms to the guidelines of Position C.1 of RG 1.59.

In Position C.2 of RG 1.59, the NRC provides alternate guidance for flood protection when the “hardened protection” method is not used. The hardened protection method provides that passive structural provisions be incorporated into the plant design to protect safety-related SSCs from the static and dynamic effects of floods. In the ESBWR, reinforced concrete seismic Category I structures, incorporating the waterproofing and sealing features previously described, provide hardened protection for safety-related SSCs as defined in RG 1.59. Therefore, Position C.2 of RG 1.59 is not applicable to the ESBWR design.

In RG 1.102, the NRC describes the types of flood protection acceptable to the staff for safety-related SSCs. In Position C.1 of RG 1.102, the staff defines the various types of flood protection it finds acceptable. One of the acceptable methods of flood protection incorporates a special design of walls and penetrations. The walls are reinforced concrete, designed to resist the static and dynamic forces of the design-basis flood and to incorporate water stops at construction joints to prevent in-leakage. Penetrations are sealed and also capable of withstanding the static and dynamic forces of the design-basis flood. As described above, the ESBWR flood design incorporates these protective features. Therefore, the staff concludes that the flood design conforms to the guidelines of Position C.1 of RG 1.102.

In Position C.2 of RG 1.102, the NRC discusses the technical specifications and emergency operating procedures necessary to utilize Position C.2 of RG 1.59. However, as discussed above, Position C.2 of RG 1.59 does not apply to the ESBWR flood design, which incorporates hardened protection and locates the plant grade elevation 300 mm (1 ft) above the flood level. Consequently, Position C.2 of RG 1.102 is not applicable to the ESBWR design.

Based on the evaluation of the information in DCD, Tier 2, Revision 7, and for the reasons given above, the staff concludes that the applicant adequately characterized the PMP and PMF for the ESBWR flood design and provided design features to protect safety-related equipment from external flood effects associated with the PMP, PMF, ground water seepage, and system and component failures. Therefore, the flood design meets the applicable guidelines of RG 1.59 with regard to the methods used for establishing the PMF and PMP and meets the guidelines of RG 1.102 with regard to acceptable external flood protection methods.

Internal Flooding

For the ESBWR plant design, all safety-related SSCs required to achieve safe shutdown of the plant are located in the seismic Category I RB and seismic Category I CB. Redundant systems and components are physically separated from each other, as well as from non-safety-related components. If the failure of a system causes one division to be inoperable, the redundant division is available to perform the safe shutdown of the plant. The following protective features are used to mitigate or eliminate the consequences of internal flooding:

- structural enclosures or barriers;
- curbs and sills;
- leakage detection components; and,
- drainage systems.

The applicant identified the following flooding sources considered in the internal flooding analysis:

- high-energy piping breaks and cracks;
- moderate-energy piping, through-wall cracks;
- pump mechanical seal failures;
- storage tank ruptures;
- actuation of the fire protection system (FPS); and,
- flow from upper elevations and nearby areas.

The staff did not identify any other internal flood sources. The staff concludes that the applicant has adequately identified all internal flood sources for the ESBWR design.

The internal flooding analysis, besides identifying flooding sources, equipment in each area, effects on safety-related equipment, and maximum flood levels, also considered the following criteria:

- identification of a flooding source when a flooding alarm occurs in the main control room is followed by operator action within 30 minutes;
- for firefighting events, the analysis assumed that fuel inventory for the fire is limited to a 1-hour event, during which two fire hoses with a capacity of 7.9 liters per second (125 gallons per minute are in service;
- the analysis assumed a single active failure of flood mitigating systems;
- the analysis took no credit for the drainage system or operation of the drain sump pumps for flooding mitigation, although they are expected to operate during some of the postulated flooding events; and,
- the analysis considered reduction of at least 10 percent of the free surface in each flooding zone to account for space utilization by components located in that zone.

The applicant used the criteria stated in ESBWR DCD, Tier 2, Revision 7, Section 3.6 to define break and crack configurations and locations for both high- and moderate-energy fluid piping failures. The flooding analysis considered through-wall cracks in seismically supported moderate-energy piping, as well as breaks and through-wall cracks in non-seismically supported moderate-energy piping. The analysis assumed no breaks for piping with nominal diameters of 2.54 centimeters (cm) (1 in.) or less. In the case of storage tank rupture, the flooding analysis assumed that the entire tank inventory is drained. Safety-related equipment and equipment necessary for safe shutdown are located above the maximum flood height or are qualified for flood conditions. Accordingly, flooding from moderate-energy pipe failure, firefighting, or other flooding sources does not adversely affect any safety-related equipment or the ability to safely shut down the plant.

The FPS headers from the FPS pumps are routed outside seismic Category I buildings. The analysis assumed that floors will prevent water seepage to lower levels. Spray damage is avoided by moving the required equipment or pipe or providing spray protection. Doors and penetrations rated as 3-hour fire barriers are assumed to prevent water spray from crossing divisional boundaries.

All safety-related equipment within the containment that must operate during or after a design-basis accident is qualified for LOCA environmental conditions. Flooding associated with the postulated failure of any moderate-energy pipe inside containment is within the bounds of the LOCA qualification. Consequently, no detailed evaluation of this less severe event is necessary to verify the effect of moderate-energy piping failures in the containment on safety-related equipment or safe plant shutdown capability.

Leakage from pipe breaks and cracks, fire hose discharges, and other flooding sources collects in the floor drainage system (as stated above, the analysis takes no credit for the drainage system or operation of the drain sump pumps for flooding mitigation), stair towers, and elevator shafts and discharges to appropriate sumps. The evaluation of the flood level considers the flow paths described above. The RB and CB drain collection system and sumps are designed and separated so that drainage from a flooded compartment containing equipment for a train or division does not flow to compartments containing equipment for another system train or division. Zones that are isolated by watertight doors provide physical separation. Watertight doors between flood divisions have open/close sensors with status indication and alarms in the main control room. The location of the zones prevents flooding from affecting two redundant trains at the same time.

In reviewing DCD, Tier 2, Section 3.4.1, the staff also identified significant areas in which it needed additional information to complete the evaluation of the applicant's plant design for flood protection. Therefore, the staff issued RAIs concerning each specific issue to determine whether flood protection was properly designed for the ESBWR plant. The staff's RAIs, applicant's responses, and the staff's evaluation of the applicant's responses are described below.

In RAI 3.4-9, the staff asked the applicant to provide calculations to demonstrate the resulting flood level in each of the following areas:

- The resulting flood level in the RB lower elevation is 8 in and that maximum flood level is lower than the Control Rod Drive Hydraulic Control Unit room elevation.
- The maximum water depth of 16 in. in the lowest floor of the CB is below Distributed Control and Information System room floor elevation.
- Water in the lower elevation of the CB from pipe failures in the heating, ventilation and air conditioning (HVAC) rooms is retained in the HVAC rooms by the installation of 8 in high curbs in the access doors, chases and other floor openings, as well as by normally closed isolation valves in the drain lines.

These calculations should include the physical dimensions (e.g., floor length, width and height, and calculated floor areas) of each area and the maximum volume of floodwater in each area. RAI 3.4-9 was being tracked as an open item in the SER with open items.

In its response to RAI 3.4-9, the applicant provided information extracted from its flood protection calculation reports (092-134-C-M-01401, "Flood Protection Calculation—Chilled Water System in Control Building," Revision 0, dated October 15, 2007, and 092-134-F-M-01400, "Flood Protection Analysis," Revision 2, dated October 17, 2007) to demonstrate the resulting flood level in the areas due to internal flooding.

Based on its review, the staff found the applicant's response acceptable. Also during the review of the ESBWR DCD, Revision 4, the staff conducted an audit of the above-cited applicant's flood protection analysis and calculations and found them acceptable. Therefore, the staff considers the concern described in RAI 3.4-9 and its associated open item resolved.

In RAI 3.4-12 regarding the ESBWR design against external flood, the staff stated that the COL holder should have emergency operating procedures directing plant personnel to take the appropriate actions as an external flood condition develops. RAI 3.4-12 was being tracked as an open item in the SER with open items.

In its response, the applicant stated that no emergency actions are required to ensure the safe operation of the ESBWR plant if flooding occurs. This is because the ESBWR is protected from floods from exterior sources (e.g., floods, ground water) by location of the plant grade elevation at least 300 mm (1 ft) above the flood level and by incorporation of structural provisions into the plant design which include the following:

- walls below flood level designed to withstand hydrostatic loads;
- water stops in all expansion and construction joints below flood and ground water levels;
- waterproofing of external surfaces below flood and ground water levels;
- water seals at pipe penetrations below flood and ground water levels;
- roofs designed to prevent pooling of large amounts of water in accordance with RG 1.102; and,
- no exterior access openings below grade.

The staff has reviewed the applicant's response and based on its audit of the applicant's flood protection analysis/calculations and evaluation of the information provided in DCD, Tier 2, Revision 7, the staff concurs with the applicant's rationale that, in the event of flooding, no emergency operating procedures are required to ensure the safe operation of the ESBWR plant. Therefore, the staff considers its concern described in RAI 3.4-12 and associated open item resolved.

ITAACs

The ESBWR safety-related SSCs and RTNSS are protected against flooding from both external and internal sources, as well as ground water damage. In ESBWR DCD, Tier 1, Revision 7, Section 2.0, the applicant provides the design descriptions and ITAAC that commit to verifying that the flood protection measures provided for safety-related SSCs and RTNSS are designed and perform as described in ESBWR DCD, Tier 2, Revision 7. Section 14.3 "Inspections, Tests, Analyses, and Acceptance Criteria." of this report addresses the staff's evaluation of the ITAAC.

Chapter 22, "Regulatory Treatment of Non-Safety Systems," of this report addresses the staff's evaluation regarding RTNSS in conformance with the requirements of SECY-94-084, "Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems in Passive Plant Designs," dated March 28, 1994.

3.4.1.4 *Conclusions*

Based on its review of the ESBWR DCD Tier 1 and Tier 2, Revision 7, and the evaluation discussed above, the staff finds that the ESBWR has adequate flood protection for safety-related SSCs and RTNSS against flood-related effects associated with both high- and moderate-energy fluid piping and component failures inside and outside containment and flood-related effects associated with both natural phenomena and system and component failures. The staff concludes that the ESBWR design regarding flood protection satisfies the guidelines described in SRP Section 3.4.1, Revision 3 and provides reasonable assurance that the ESBWR safety-related SSCs will maintain their structural integrity and perform their intended safety functions when subjected to design-basis flood, and therefore, satisfies the requirements of GDC 2 and GDC 4..

3.4.2 Analysis Procedures

The staff reviewed Revision 7 of the ESBWR DCD, Section 3.4.2, following the guidance in SRP Section 3.4.2, Revision 3, regarding the design of seismic Category I structures to withstand the effects of the highest flood and ground water levels specified for the ESBWR. The staff considered the applicant's responses to RAIs, open items, and confirmatory items. The following summarizes the results of the staff's technical review of DCD Section 3.4.2.

3.4.2.1 *Regulatory Criteria*

The staff accepts the design of structures that are important to safety and that must withstand the effects of the design-basis flood load if their design satisfies the relevant requirements of GDC 2 concerning natural phenomena.

GDC 2 requires that SSCs important to safety be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunamis, and seiches without loss of capability to perform their intended safety functions. GDC 2 further requires that the design bases reflect appropriate considerations of the most severe natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated. GDC2 also requires consideration of the appropriate combinations of the effects of normal and accident conditions with the effect of natural phenomena and the importance of the safety functions to be performed

To ensure compliance with the requirements of GDC 2, the staff reviewed the following areas relating to the design of structures that must withstand the effects of the design flood specified for the plant:

- the data on the highest flood and ground water and the establishment of appropriate loading to account for flood and ground water effects on seismic Category I structures;

- the analysis procedures used to transform the static and dynamic effects of the highest flood and ground water levels into effective loads applied to seismic Category I structures.

3.4.2.2 *Summary of Technical Information*

The applicant presented the flood and ground water site parameters and discussed the analysis procedures in Table 2.0-1 and Section 3.4.2, respectively, of DCD, Tier 2, Revision 6.

In DCD Table 2.0-1, the applicant indicated that the maximum ground water level is 0.61 m (2 ft) below plant grade, and the maximum flood or tsunami level is 0.3 m (1 ft) below plant grade. In Note 2 to DCD Table 2.0-1, the applicant indicated that the maximum flood level is based on the PMF " Probable maximum flood" as defined in Table 1.2-6 of Volume III of the Electric Power Research Institute's "Advanced Light Water Reactor Utility Requirements Document," Revision 6, issued 1997.

The applicant stated that the design parameters of the flood or highest ground water are considered in defining the input parameters for the structural design criteria appropriate to account for flood and ground water loadings. The applicant indicated that since the flood level is less than the finished grade level around the structures, the dynamic phenomena associated with flooding, such as currents, wind waves, and their hydrodynamic effects, are not considered. The analysis considers the hydrostatic head associated with the flood or with the highest ground water level as a structural load on the foundation mat and basement walls. The analysis accounts for uplift or floating of the structure, and the total buoyancy force is based on the flood or highest ground water head excluding wave action. The lateral, overturning, and upward hydrostatic pressures acting on the side walls and on the foundation slab, respectively, are considered in the structural design of these elements and are based on the total head.

3.4.2.3 *Staff Evaluation*

Sections 2.4.3 and 2.4.12 of this report address the staff's review of the acceptability of the site parameters related to flood and ground water, respectively, while this section of the report addresses the acceptability of the analysis procedures.

The staff reviewed the information provided in DCD, Tier 2, Revision 3, Section 3.4.2 and Table 2.0-1, and determined that it needed additional information to complete its review.

In RAI 3.4-10, the staff asked the applicant to provide a list of penetrations below design flood level that go through the reactor, fuel, and CBs (including the access opening at the CB access to the RB at tunnel) and typical sketches of the penetrations and access openings depicting how the water-leak-tight function of the seals is ensured against the hydrostatic pressure head due to the design flood or ground water. The staff also asked the applicant to indicate if bellows are used for some large diameter penetrations to accommodate the potential differential displacement effects. RAI 3.4-10 was being tracked as an open item in the SER with open items.

In its response, the applicant stated that locations of penetrations below design flood level that go through the reactor, fuel, and CBs are determined during the detailed design. The water-leak-tight function is ensured by the membrane waterproofing applied on exterior concrete surfaces and waterstops installed between two adjoining buildings. Seismic Category I piping below grade is placed in reinforced concrete trenches located near the surface. There is no plan to use bellows at piping penetrations. The staff concludes from the response that the waterproofing details provided are adequate and consistent with common practice. Therefore, RAI 3.4-10 and its associated open item are considered resolved.

In RAI 3.4-11, the staff requested that the applicant discuss the specific steps adopted in accounting for the lateral hydrostatic pressure due to the design flood level, as well as ground water and soil pressure for the embedded areas of the reactor and FB, including references to pertinent quantitative analysis results of Appendix 3G to DCD Tier 2. RAI 3.4-11 was being tracked as an open item in the SER with open items.

In its response, the applicant stated that DCD, Tier 2, Table 2.0-1 and Table 3.4-1, provide the design flood level and design ground water level. As stated in DCD, Tier 2, Section 3.4.2. Item 3, the flood level is below the finished ground level, and only the hydrostatic effects need to be considered.

DCD, Tier 2, Section 3.8.4.3 and Table 3.8-15, provide the loads and load combinations used for the design of seismic Category I concrete structures. The load, H, refers to lateral pressure caused by soil and water in the soil. DCD, Tier 2, Sections 3G.1.5.2.1.3, 3G.2.5.2.1.3,and 3G.3.5.2.1.3 and Figures 3G.1-19, and 3G.2-12, give details about the magnitude of this loading used in the structural design.

The design flood level is 3100 m m (1 ft) higher than the design ground water level. Figure 3.4-11(1) shows the static soil pressure (including hydrostatic pressures) for the design ground water level 0.6 m (2 ft) below design plant grade) during normal operation and design flood level 0.30 m (1 ft) below design plant grade) for flood conditions. The difference between the two conditions is very small. According to Article 9.2.7 of ACI 349-01, to which the design of the safety-related concrete structures conforms, the design flood is considered in No. 6 or 7 combinations in DCD, Tier 2, Table 3.8-15. In the load combinations including E "basic SSE seismic load", dynamic increments of soil pressures need to be considered, together with the static soil pressures (including design ground water hydrostatic pressures) during normal operation. Figure 3.4-11(1) also indicates the distribution of the dynamic increment of soil pressure, which has a magnitude much larger than the differences between the static soil pressures during normal operation and flood conditions.

Because soil pressures during flood conditions are enveloped by those due to the SSE, they do not govern the design.

The description for load, H, given in DCD, Tier 2, Section 3.8.4.3.1.1, was clarified. On this basis, the staff concludes that the applicant properly accounted for flood and ground water in the analysis. Therefore, RAI 3.4-11 and associated open item are considered resolved.

3.4.2.4 *Conclusions*

Based on satisfactory resolution of the RAIs specified above, the staff concludes that the design is acceptable and meets the requirements of GDC 2. The staff finds that the applicant has met the requirements of GDC 2 with respect to the structures' capability to withstand the effects of the highest flood and ground water levels so that their design reflects the following:

- appropriate consideration of the most severe flood recorded for the site with an appropriate margin;
- appropriate combination of the effects of normal and accident conditions with the effects of the natural phenomena; and,
- the importance of the safety functions to be performed.

3.5 Missile Protection

Seismic Category I SSCs in the ESBWR standard design are analyzed and designed for protection against a wide spectrum of missiles that pressurized components, rotating machinery, dropped loads, explosions, tornadoes, and transportation accidents may generate.

3.5.1 Missile Selection and Description

In ESBWR DCD, Tier 2, Revision 7, Section 3.5.1, the applicant described the criteria for identifying missiles and protecting SSCs from their effects. Once a potential missile is identified, its statistical significance is determined by the combined probability of an event that is defined as the product of the following:

- probability of missile occurrence (P_1);

- probability of impact on a significant target (P_2);
- probability of significant damage (P_3); and,
- combined probability ($P_4 = P_1 \times P_2 \times P_3$).

If the event combined probability of a potential missile is greater than 1×10^{-7} per year, the missile is considered as credible, and protection of safety-related SSCs against the credible missile will be provided in accordance with the guidance in SRP Sections 3.5.1.1, 3.5.1.2, 3.5.1.3, 3.5.1.4, and 3.5.1.5. If the event combined probability of a potential missile is less than 1×10^{-7} per year, the event is considered not statistically significant, the missile is considered noncredible, and protection of safety-related SSCs against the noncredible missile would not be provided.

The staff finds the applicant's approach to identifying potential missiles, determining the statistical significance of potential missiles, and providing measures for SSCs requiring protection against the effects of missiles to be acceptable because it follows the guidance described in SRP Sections 3.5.1.1, 3.5.1.2, 3.5.1.3, 3.5.1.4, and 3.5.1.5. The staff addresses the evaluation of this approach in more details in Subsection 3.5.1.1.3 of this report. However, during the review of DCD, Tier 2, Revision 1, the staff found that the applicant did not address protection for RTNSS against potential missiles. Therefore, the staff issued RAI 3.5-1. This RAI, the applicant's response, and the staff's evaluation of the applicant's response are described below.

In Section 3.5.1 of DCD Tier 2, the applicant described the criteria for missile protection and listed the systems requiring missile protection. However, the staff concluded that the information was not sufficient to determine its acceptability. Therefore, in RAI 3.5-1, the staff asked the applicant to (1) provide information on missile protection for the systems classified under RTNSS, such as the fuel and auxiliary pool cooling system, (2) explain why the reactor water cleanup/shutdown (RWCU/SDC) system was not listed as requiring missile protection for its reactor coolant pressure boundary and shutdown cooling functions, and (3) confirm that a single active failure concurrent with postulated internally generated missiles had been properly assumed in the selections.

In its response to items (1) and (2) of RAI 3.5-1, the applicant stated that it discussed RTNSS in DCD Section 19.6 and Appendix 1D (Section 19.6 and Appendix 1D have been replaced with Section 19A), and the RWCU/SDC system was not identified as a candidate for RTNSS. The applicant's rationale was that the probabilistic risk analyses did not rely on the RWCU/SDC system to meet the staff's safety goal (a core damage frequency less than 1×10^{-4} per year and large release frequency less than 1×10^{-6} per year), and Table 1D-1 of Appendix 1D to DCD Tier 2 did not include the system as an RTNSS candidate. Therefore, the RWCU/SDC system required no specific missile protection. Furthermore, the applicant stated that the design of the system provides effective protective measures for the type of hazard via separation of redundant components outside of containment in different rooms with strong resistance to any expected missiles.

The staff did not find the above response to items (1) and (2) of RAI 3.5-1 to be acceptable because the applicant had not identified all the non-safety-related systems that might meet one or more of the five criteria established in SECY-94-084 to determine which systems were candidates for RTNSS consideration. For this concern, the staff also issued RAI 19.1.0-2, regarding the determination of non-safety-related systems as candidates for RTNSS consideration.

The applicant responded to the staff's RAI 19.1.0-2. Chapter 22 of this report addresses the staff's evaluation of the applicant's response to this RAI, including the acceptability of its response to items (1) and (2) of RAI 3.5-1.

In its response to item (3) of RAI 3.5-1, the applicant stated that a concurrent single active failure had been assumed in the safety-related components used to respond to the consequences of the postulated missile and achieve safe shutdown. The staff finds this response to item (3) acceptable, because a concurrent single active failure had been assumed in the safety-related components used to respond to the consequences of the postulated missile and achieve safe shutdown.

Section 19.0, "Probabilistic Risk Assessment (PRA) and Severe Accident Evaluation," of this SER addresses the staff's evaluation of GEH's PRA methodology including assumptions (such as a concurrent single active failure in the safety-related components) used to assess the consequences of the postulated missile and achieve safe shutdown.

Sections 3.5.1.1 through 3.5.1.5 below describe the staff's evaluation of various types of missiles.

3.5.1.1 *Internally Generated Missiles (Outside Containment)*

3.5.1.1.1 Regulatory Criteria

The staff reviewed the ESBWR design for protecting SSCs important to safety against internally generated missiles (outside containment) in accordance with SRP Section 3.5.1.1, Revision 3. The staff's acceptance of the design is based on compliance with the requirements of the following regulations:

- GDC 4 as it relates to the design of the SSCs important to safety if the design affords protection from the internally generated missile that may result from equipment failure.

- 10 CFR 52.47(b)(1) requires that a DC application contain the proposed ITAAC that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, a facility that incorporates the DC is built and will operate in accordance with the DC, the provisions of the Atomic Energy Act, and the NRC's regulations.

3.5.1.1.2 Summary of Technical Information

The applicant evaluated potential internally generated missiles that could result from failure of plant equipment located outside containment. These potential internally generated missiles are categorized into the following two groups:

(1) Internally Generated Missiles Resulting from In-Plant Rotating Equipment Overspeed Failures. The applicant evaluated potential missiles that could result from in-plant rotating equipment overspeed failures and examined the equipment within the general categories of pumps, fans, blowers, diesel generators, compressors, and turbines for possible missile generation. In particular, it examined components in the systems normally functioning during reactor power operation for any potential source of credible missiles.

(2) Internally Generated Missiles Resulting from In-Plant High-Pressure System Ruptures. The applicant evaluated the potential missiles that could result from high-pressure system ruptures against the design criteria. The applicant stated that the pressurized components considered as possible and capable of producing missiles were valve bonnets (large and small), valve stems, pressure vessel, thermowells, retaining bolts, and blowout panels. The applicant categorized the potential missiles generated by these pressurized components as contained fluid-energy missiles or stored-energy (elastic) missiles. The applicant further classified valve bonnets as jet-propelled missiles, valve stems as piston-type missiles, and retaining bolts as examples of stored strain-energy missiles.

3.5.1.1.3 Staff Evaluation

The staff reviewed ESBWR DCD, Tier 2, Revision 7, Section 3.5.1.1, in accordance with the guidance of SRP Section 3.5.1.1. The staff also reviewed DCD, Tier 1, Revision 7, Section 2.0, and other DCD Tier 2 sections noted below.

Compliance with GDC 4 is based on meeting the guidance of the following RGs and SECY-94-084:

- RG 1.115, "Protection against Low-Trajectory Turbine Missiles," Revision 1, Regulatory Positions C.1 and C.3, as they relate to the protection of the SSCs important to safety from the effects of turbine missiles; and,

- RG 1.117, "Tornado Design Classification," Revision 1, Appendix A, which provides guidance as to which SSCs should be protected from missile impacts.

- SECY-94-084, "Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems in Passive Plant Designs," provides guidance as to which systems should be RTNSS and would call for enhanced design requirements.

The applicant evaluated potential internally generated missiles that could result from failure of the plant equipment located outside the containment. The potential missiles internally generated outside containment are the following:

- missiles resulting from in-plant rotating equipment overspeed failures;

- missiles resulting from in-plant high-pressure system ruptures such as in valves, piping, fittings, tank manways and hand holes, bolts in high-energy systems, valve bonnets and valve stems, pressure vessel, thermowells, and retaining bolts; and,

- missiles generated by onsite explosions of stored gases, including equipment that uses or generates hydrogen gas.

Once a potential missile is identified, its statistical significance is determined by the combined probability of an event that is defined as the product of the following:

- probability of missile occurrence (P_1);
- probability of impact on a significant target (P_2);

- probability of significant damage (P_3); and,
- combined probability ($P_4 = P_1 \times P_2 \times P_3$).

If the event combined probability of a potential missile is greater than 1×10^{-7} per year, the missile is considered as credible, and protection of safety-related SSCs against the credible missile will be provided. If the event combined probability of a potential missile is less than 1×10^{-7} per year, the event is considered not statistically significant, the missile is considered noncredible, and protection of safety-related SSCs against the noncredible missile would not be provided.

Once a potential credible missile is identified, protection of safety-related SSCs against the credible missile will be provided in accordance with the guidance of SRP Section 3.5.1.1 by one or more of the following methods:

- locating the system or component in a missile-proof structure;
- separating redundant systems or components of the system from the missile path or range;
- providing local shields or barriers for systems and components;
- designing the equipment to withstand the impact of the most damaging missile;
- providing design features to prevent the generation of the missile; and,
- orienting a missile source to prevent missiles from striking equipment important to safety.

Also, the effects of potential internally generated missiles are minimized by the separation and the redundancy of safety-related systems throughout the ESBWR plant. Components within one train of a system with redundant trains would not be protected from missiles originating from the same train.

Based on its review, the staff finds the applicant's approach to protecting safety-related SSCs against the effects of internally generated missiles outside containment acceptable since it is consistent with the recommendations in SRP Section 3.5.1.1.

The applicant evaluated the rotating equipment within the general categories of electrically powered rotating equipment, such as pumps, blowers, diesel generators, and compressors, for any possible source of credible missiles. The applicant determined that no credible missiles meet the significant criteria of having a probability (P_4) greater than 1×10^{-7} per year. The applicant's rationale is that the equipment design and manufacturing criteria result in a probability (P_1) less than 1×10^{-7} per year, and sufficient physical separation of safety-related and redundant equipment exists so that the combined probability ($P_1 \times P_2$) is less than 1×10^{-7} per year. In addition, since pumps, fans, and the like are powered by alternating current (ac) and the ac power supply frequency variation is limited to a narrow range, the rotating equipment is unlikely to attain an overspeed condition. As an example, the applicant analyzed the containment high-purge exhaust fan for a thrown blade at rated speed conditions and determined that the blade could penetrate but would not escape from the fan casing.

Based on its review, the staff finds the applicant's analyses of potential missiles outside containment resulting from the failures of rotating equipment (excluding turbine missiles) to be acceptable.

Section 3.5.1.3 of this report addresses the staff's evaluation of the protection of safety-related SSCs from the effects of turbine missiles, including meeting the guidance of RG 1.115.

The applicant evaluated potential missiles that could result from the failure of pressurized components. The applicant indicated that those valves of American National Standards Institute (ANSI) Pressure Class rating 900 psig and above are pressure-seal, bonnet-type valves. They are prevented from becoming missiles by limiting stress in the bolting and designing flanges in accordance with applicable American Society of Mechanical Engineers (ASME) Code requirements. Valves of ANSI Pressure Class rating 600 psig and below are the valves with bolted bonnets that are analyzed for the safety factors against any failures. All the isolation valves installed in the reactor coolant systems have stems with backseats that eliminate the possibility of these valve stems ejecting even if the stem threads fail. Nuts, bolts, nut-and-bolt combinations, and nut-and-stud combinations have only a small amount of stored energy and have no potential to become missiles. Moderate-energy vessels less than 275 psig are not credible missile sources as defined in DCD Section 3.6.2.1. The pneumatic system with pressures higher than 275 psig, such as in air bottles, the emergency breathing air system, and the standby liquid control accumulator tank, are not considered a credible source of missiles based on the following qualitative analysis:

- the bottles are fabricated from heavy-wall rolled steel;
- the bottles are topped with steel covers thick enough to preclude penetration by a missile, and operating orientation is vertical with the end facing concrete slabs;
- a permanent steel collar protects the fill connection and critical parts; and,
- the bottles are strapped in a rack to prevent them from toppling over, and the rack is seismically designed.

During the review of Section 3.5.1.1 in the earlier DCD versions regarding protection for safety-related SSCs against internally generated missiles outside containment, the staff identified areas in which it needed additional information to complete its review. Therefore, the staff issued RAIs to the applicant. The staff's RAIs, the applicant's responses, and the staff's evaluation of the applicant's responses are described below.

In DCD Section 3.5.1.1.2.2, the applicant analyzed the remaining pressurized components considered to be potentially capable of producing missiles. However, the information was not sufficient to determine their acceptability. In RAI 3.5-2, the staff requested that the applicant provide information on how the various pipe fittings were screened to determine those that could credibly become missiles.

In its response to RAI 3.5-2, the applicant provided general criteria considered in the analysis to define potential missiles. Particularly, it indicated that pressure-seal, bonnet-type valves are constructed in accordance with ASME Code, Section III. Valve bonnets are prevented from becoming missiles by limiting stresses in the bolting to those defined by the ASME Code and designing flanges in accordance with applicable code requirements. Sufficiently high safety factors were applied in calculations for those pressure-seal-type valve bonnets to prevent them from becoming potential missile sources. Valves with bolted bonnets are constructed in accordance with ASME Code, Section III, and were analyzed for the safety factors against failure. The applicant determined that these types of components are not a potential missile source, especially when coupled with the low historical incidence of complete severance failure. The bolted bonnets are prevented from becoming missiles by limiting stresses in the bonnet-to-body bolting material according to the ASME Code.

The isolation valves installed in the reactor coolant systems have stems with backseats, which eliminate the possibility of ejecting valve stems even if the stem threads fail. Since the overall probability of occurrence is less than $1x10^{-7}$ per year, the applicant did not consider valve stems to be missile sources.

The analysis did not consider thermowells and similar fittings attached to piping on pressurized equipment that are joined by welding to be credible missiles. The complete joint has greater design strength than the parent metal. Threaded connections are not used in high-energy systems.

The applicant stated that instrumentation, such as pressure, level, and flow transmitters and associated piping and tubing are not considered as credible missiles, because the quantity of high energy fluid in these components is not sufficient to generate missiles. The staff agrees with the applicant’s conclusion because the instrument lines are not large enough to contain high energy fluid.

The applicant evaluated the design of various piping fittings and their related components, screened various fittings with general criteria and applicable ASME Code sections, and concluded that they could not become missile sources. Based on its review, the staff finds the applicant’s response to RAI 3.5-2 acceptable. Therefore, the staff considers the concern described in RAI 3.5-2 resolved.

In DCD Section 3.5.1.1.2.2, the applicant stated that piping failures did not form missiles because the whipping section stays attached to the remainder of the pipe. However, a guillotine break of a high-energy line could cause piping attachments to become missile sources. In DCD Section 3.6, the applicant discussed the dynamic effects related to jet impingement forces and pipe whipping but did not consider missile generation. Therefore, in RAI 3.5-3, the staff asked the applicant to discuss a postulated guillotine break of a high-energy line outside the containment that could become a potential missile source.

In its response to RAI 3.5-3, the applicant stated that high-energy piping outside containment is designed in such a way that consideration need not be given to circumferential breaks after applying the break postulation exclusion criteria defined in accordance with Branch Technical Position (BTP) EMEB 3-1, as described in DCD Section 3.6.

Also, in DCD, Tier 2, Revision 6, Section 3.6.2.1, the applicant provided the criteria for defining potential breaks of high-energy line systems outside the containment, stating that (1) circumferential (guillotine) breaks are assumed only at all terminal ends, (2) if the maximum stress range in the longitudinal direction is greater than 1.5 times the maximum stress range in the circumferential direction, only the circumferential direction break is postulated, and (3) if the maximum stress range in the circumferential direction is greater than 1.5 times the maximum stress range in the longitudinal direction, only the longitudinal break is postulated. The staff’s review found that these criteria meet the intent of Items B.1.b and B.1.c of BTP EMEB 3-1 in

SRP Section 3.6.2, because all the terminal ends of high-energy fluid system piping are located within the containment, and BTP EMEB 3-1 requires the circumferential stress range to be at least 1.5 times the axial stress range. The staff concurs with the applicant's rationale that there is no potential for a guillotine break of a high-energy line outside the containment. Therefore, the staff considers the concern described in RAI 3.5-3 resolved.

In DCD Section 3.5.1.1.1.3, the applicant described other missile analyses. However, this section does not address gravitational missiles. The staff, therefore, requested in RAI 3.5-4 that the applicant provide an assessment of potential gravitational missiles generated outside containment and explain plant design features that could prevent the impact of a falling object on safety-related equipment necessary to achieve a safe shutdown.

In its response to RAI 3.5-4, the applicant stated that components that do not perform safety functions, but whose interaction or structural failure may impair the actuation of seismic Category I components, are categorized as seismic Category II components. Safety-related components are located on certain floors of the nuclear island, surrounded by walls and floors of seismic Category I structures that provide them with physical protection against gravitational missiles located outside these areas. The potential missile loads that could be generated by NS components located within these areas are prevented from becoming missiles by seismic anchorage of the NS components in the vicinity of safety-related components, along with physical separation to avoid any potential damage.

The staff reviewed the applicant's response and found it acceptable. Because seismic Category I components are designed and protected to meet the spatial requirements of RTNSS and separation requirements of BTP EMEB 3-1, there should be no potential gravitational missiles that could be generated outside the containment. Therefore, the staff considers the concern described in RAI 3.5-4 resolved.

In DCD Section 3.5.1.1.2.2.6, the applicant stated that blowout panels are hinged to prevent them from becoming missiles. In RAI 3.5-5, the staff asked the applicant to discuss how it provided protection from external missiles for safety-related components located near the opening of the swing-type blowout panels.

In its response to RAI 3.5-5, the applicant stated that the hinged blowout panels, which are designed to prevent them from becoming missiles, are located near the roof of the RB. No safety-related components are near this area, so there is no concern. The staff finds the applicant's response acceptable. Therefore, the staff considers the concern described in RAI 3.5-5 resolved.

Based on its review and the evaluation discussed in the preceding paragraphs, the staff finds the applicant's analyses of potential missiles resulting from high-pressure system ruptures acceptable.

DCD, Tier 2, Table 3.2-1, "Classification Summary," lists all the SSCs (safety-related and non-safety-related) in various locations of the plant (inside and outside the containment) and identifies for each SSC the associated seismic category, quality group, and equipment classifications. DCD, Tier 2, Section 7.4, lists the systems required for safe shutdown. DCD, Tier 2, Section 1.2, presents the general arrangement drawings further defining the building locations. The staff finds that the SSCs afforded missile protection meet the guidance of RG 1.115, Positions C.1 and C.3, and RG 1.117, Appendix A. Therefore, the staff finds that the applicant’s evaluation of potential internally generated missiles outside the containment resulting from equipment and component failures satisfies GDC 4.

In addition, during the review of the earlier DCD versions, the staff identified issues regarding the lack of information on missile protection for RTNSS. Therefore, the staff requested as part of RAI 22.5-5 that the applicant address its concern.

In its response to RAI 22.5-5, the applicant added a new section (19A – Regulatory Treatment of Non-Safety Systems) in DCD, Revision 5. In this new Section 19A, the applicant provided two tables, Table 19A-3, “Structure Housing RTNSS Functions,” and Table 19A-4, “Capability of RTNSS Related Structures.” In Table 19A-3, the applicant identified the RTNSS together with their associated RTNSS criteria, locations (buildings), and building category. In Table 19A-4, the applicant identified how the RTNSS in each area (building) are protected from internal flooding, external flooding, internal missiles, and extreme wind and missiles. The staff found the applicant’s response to RAI 22.5-5 inadequate. Specifically, the applicant did not provide sufficient details about the design of the protection provided for RTNSS against internal missiles and extreme wind missiles. Subsequently, as part of supplemental RAI 22.5-5 S01, the staff asked the applicant to provide a detailed description of the design and installation of each RTNSS and discuss how this design and installation would protect the RTNSS SSCs against extreme wind and missiles and internally generated missiles outside containment. Also, in supplemental RAI 22.5-5 S02, the staff asked the applicant to provide ITAAC for the RTNSS.

The staff finds the applicant’s responses to RAI 22.5-5 S01 and RAI 22.5-5 S02 acceptable and, therefore, considers the concerns described in RAI 22.5-5, RAI 22.5-5 S01, and RAI 22.5-5 S02 resolved. Chapter 22, “Regulatory Treatment of Non-Safety Systems,” of this report addresses the staff’s evaluation of the applicant’s responses to these RAIs regarding the protection provided for RTNSS against internally generated missiles outside containment.

Section 3.5.3 of this report addresses the staff’s evaluation of the design of structures, shields, and barriers required for missile protection.

Section 3.6.1 of this report addresses the staff’s evaluation of the design of structures, shields, and barriers required for missile protection against dynamic effects of high-energy line breaks.

Section 3.7.3 of this report addresses the staff’s evaluation of the impact of the fall or overturning of NS components on safety-related SSCs resulting from a seismic event.

<u>ITAAC</u>

In DCD, Tier 1, Revision 7, Section 2.0, the applicant provided the design descriptions, including the loads due to design-basis internal events, and ITAAC for the ESBWR. These ITAAC commit to the verification of the SSCs important to safety, including ensuring that RTNSS are designed and perform as described in ESBWR DCD, Tier 2, Revision 7. Therefore, the staff concludes that missile protection against internally generated missiles (outside containment) complies with the requirements of 10 CFR 52.47(b)(1).

3.5.1.1.4 Conclusions

Based on its review and the evaluation discussed above, the staff finds that the ESBWR design complies with GDC 4 as it relates to protection for SSCs important to safety against internally generated missiles outside containment. Therefore, the staff concludes that the design of the facility satisfies the guidelines described in SRP Section 3.5.1.1, Revision 3.

3.5.1.2 *Internally Generated Missiles (Inside Containment)*

3.5.1.2.1 Regulatory Criteria

The staff reviewed the ESBWR design for protecting SSCs important to safety against internally generated missiles (inside containment) in accordance with SRP Section 3.5.1.2, Revision 3. The staff based its acceptance of the design on compliance with the requirements of the following regulations:

- GDC 4 as it relates to the design of the SSCs important to safety if the design affords protection from the internally generated missile that may result from equipment failure.

- 10 CFR 52.47(b)(1) requires that a DC application contain the proposed ITAAC that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, a facility that incorporates the DC is built and will operate in accordance with the DC, the provisions of the Atomic Energy Act, and the NRC's regulations.

3.5.1.2.2 Summary of Technical Information

The applicant evaluated potential internally generated missiles that could result from failure of plant equipment located inside containment. These potential internally generated missiles are categorized into the following three groups:

(1) <u>Internally Generated Missiles Resulting from In-Containment Rotating Equipment Overspeed Failures</u>. The applicant evaluated the potential missiles that could result from in-containment rotating equipment overspeed failures and examined the equipment within the general categories of pumps, fans, and blowers for possible missile generation. The applicant stated that, from an analysis similar to that described in DCD, Tier 2, Section 3.5.1.1, it had concluded that no items of rotating equipment inside the containment are capable of becoming potential missiles.

(2) <u>Internally Generated Missiles Resulting from In-Containment High-Pressure System Ruptures</u>. The applicant stated that it had specified and discussed the identification of potential missiles resulting from high-pressure system ruptures and their consequences outside containment in DCD, Tier 2, Section 3.5.1.1. The applicant drew the same conclusions for pressurized components inside of containment. For example, the automatic depressurization system (ADS) accumulators are moderate-energy vessels and therefore are not considered a credible missile source. Additional structural missiles are the fine motion control rod drive (FMCRD) under the reactor vessel. The FMCRD mechanisms are not credible missiles, because the FMCRD housings are designed to prevent any significant nuclear transient if the drive housing breaks. Specifically, the pressure boundary containing the FMCRD mechanisms, including bolted flange connections, is designed within the ASME Code limits and meets all code requirements. To prevent control rod drop accidents, internal restraints are provided to support the FMCRD housing in the event of failure in the housing-to-nozzle weld or the housing.

(3) Gravitational Missiles. The applicant stated that seismic Category I SSCs are not considered potential gravitational missile sources. NS components and systems located inside containment are considered as follows:

- cable trays—all cable trays for both Class IE and non-Class IE circuits are seismically supported whether or not a hazard potential is evident;

- non-safety-related conduit and pipe—non-Class IE conduit is seismically supported if it is identified as a potential hazard to safety-related equipment. All non-safety-related piping that is identified as a potential hazard is seismically analyzed as specified in DCD, Tier 2, Section 3.7.3.8; and,

- equipment for maintenance—all other equipment, such as a hoist, that is required during maintenance is either removed during operation, moved to a location where it is not a potential hazard to safety-related equipment, or seismically restrained to prevent it from becoming a missile.

3.5.1.2.3 Staff Evaluation

The staff reviewed ESBWR DCD, Tier 2, Revision 7, Section 3.5.1.2, in accordance with the guidance of SRP Section 3.5.1.2. The staff also reviewed DCD, Tier 1, Revision 7, Section 2.0, and other DCD Tier 2 sections noted below.

Compliance with GDC 4 is also based on meeting the guidance of the following SECY-94-084:

- SECY-94-084, "Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems in Passive Plant Designs," provides guidance as to which systems should be RTNSS and would call for enhanced design requirements.

The applicant evaluated the potential internal missiles resulting from plant equipment and component failures within the containment structure. As described above, the potential missiles generated inside containment are the following:

- internally generated missiles resulting from in-containment rotating equipment overspeed failures;

- internally generated missiles resulting from in-containment high-pressure system ruptures; and,

- gravitational missiles.

Once a potential missile is identified, its statistical significance is determined by the combined probability of an event that is defined as the product of the following:

- probability of missile occurrence (P_1);
- probability of impact on a significant target (P_2);
- probability of significant damage (P_3); and,
- combined probability ($P_4 = P_1 \times P_2 \times P_3$).

If the event combined probability of a potential missile is greater than 1×10^{-7} per year, the missile is considered as credible and protection of safety-related SSCs against the credible missile will be provided. If the event combined probability of a potential missile is less than 1×10^{-7} per year, the event is considered not statistically significant, the missile is considered noncredible, and protection of safety-related SSCs against the noncredible missile would not be provided.

Once a potential credible missile is identified, protection of safety-related SSCs against the credible missile will be provided in accordance with the guidance of SRP Section 3.5.1.2 by one or more of the following methods:

- locating the system or component in a missile-proof structure;
- separating redundant systems or components of the system from the missile path or range;
- providing local shields or barriers for systems and components;
- designing the equipment to withstand the impact of the most damaging missile;
- providing design features to prevent the generation of missiles; and,
- orienting a missile source to prevent missiles from striking equipment important to safety.

Components within one train of a system with redundant trains would not be protected from missiles originating from the same train.

Based on its review, the staff finds the applicant's approach to protecting safety-related SSCs against the effects of missiles generated inside containment acceptable since it is consistent with the recommendations in SRP Section 3.5.1.2.

The applicant analyzed the rotating equipment and concluded that no items of rotating equipment inside the containment have the capability of becoming potential missiles. The applicant's rationale is that all the electrically powered rotating equipment, such as pumps and fans, are ac powered and their speeds are governed by an ac power supply. Since ac power supply frequency variation is limited to a narrow range, the rotating equipment is unlikely to attain an overspeed condition. Fan blade casings are designed with sufficient thickness so that even if a fan blade breaks off at rated speed, it will not penetrate the fan casing.

The applicant analyzed the pressurized components, such as valve bonnets, valve stems, bolts, nuts, nut-and-bolt combinations, and nut-and-stud combinations inside the containment and determined that they are not credible potential missiles based on their design features or insufficient stored energy. The applicant justified its decision in DCD, Tier 2, Section 3.5.1.2.2, with the following pressurized components:

- accumulators of the ADS are moderate-energy vessels that are not a credible missile source; and,
- FMCRD mechanisms under the reactor vessel are not credible missiles because the

housings are designed to prevent any significant nuclear transient in the event of a drive housing break. Specifically, the pressure boundary containing the FMCRD mechanisms, including bolted flange connections, are designed within the ASME Code limits and meet all code requirements. To prevent control rod drop accidents, internal restraints are provided to support the FMCRD housing in the event of failure in the housing-to-nozzle weld or the housing.

The applicant also analyzed the gravitational missiles inside containment and determined that seismic Category I SSCs are designed with no potential to become a gravitational missile source because of the following design features:

- all cable trays for both Class IE and non-Class IE circuits are seismically supported whether or not a hazard potential is evident;

- non-safety-related components are seismically supported to prevent their collapse during an SSE;

- components that are identified as potential hazards to safety-related equipment, including all cable trays for both Class IE and non-Class IE circuits, as well as non-Class IE conduits and non-safety-related piping, are seismically analyzed;

- non-Class IE conduit is seismically supported if it is identified as a potential hazard to safety-related equipment; and,

- non-safety-related piping identified as a potential hazard is seismically analyzed as addressed in DCD Section 3.7.3.8.

The applicant stated that other equipment, such as a hoist that is required during maintenance, will be either removed during operation to a location where it is not a potential hazard to safety-related equipment or seismically restrained to prevent it from becoming a missile. In RAI 3.5-18, the staff asked the applicant to include a COL action item that requires the COL holder to establish and provide procedures to require that this equipment be either removed or seismically restrained following maintenance to prevent it from becoming a missile. RAI 3.5-18 was being tracked as open item in the SER with open items.

In its response to RAI 3.5-18, the applicant revised Section 3.5.1.2.3 in DCD, Tier 2, Revision 5, to state that procedures established to require that equipment either be removed or seismically restrained inside containment following maintenance to prevent it from becoming a missile are ensured by the plant procedures described in Section 13.5. The applicant further stated that since a potential COL applicant would incorporate the DCD into the COL application by reference, the COL applicant is committed to establishing such plant procedures when the license is granted. The staff finds the applicant's response acceptable and considers its concern described in RAI 3.5-18 and associated open item resolved.

Based on its review, the staff finds that the applicant's evaluation of internal missiles resulting from failures of plant equipment and components and analysis of gravitational missiles are acceptable.

Section 13.5 of this report addresses the staff's evaluation of plant procedures, including the procedures to be established to require that equipment either be removed or seismically restrained inside containment following maintenance to prevent it from becoming a missile.

During the review of Section 3.5.1.2 in the earlier DCD versions regarding protection for safety-related SSCs against internally generated missiles inside the containment, the staff also identified areas in which additional information was necessary to complete its review. Therefore, the staff issued RAIs to the applicant. The staff's RAIs, the applicant's responses, and the staff's evaluation of applicant's responses are described below:

Since operating nuclear plants seldom use squib valves, the reliability of the valve is not traceable through plant operation experiences. In RAI 3.5-6, the staff asked the applicant to discuss how it evaluated the failure of explosive squib valves, both as an initiating event and at the time of actuation demand, to verify that potential missiles could not damage surrounding safety-related components in a way that would threaten a safety function. The staff also asked the applicant to provide any design information used as a basis for the evaluation to show that this type of valve will not become a credible missile source.

In its response to RAI 3.5-6, the applicant stated that boiling-water reactor (BWR) standby liquid control systems have used explosive valves in the past. Other systems also employ explosive valves in the ESBWR design, namely, the gravity-driven cooling system (GDCS) and depressurization valves. These valves have been specified to be integrally designed, manufactured, tested, and built such that no missile actuation could be generated in the event of squib actuation. The applicant also provided sketches in its response showing relevant features for the depressurization valve and explosive squib valves.

The staff reviewed the applicant's response, including the figures of the depressurization valve and the typical squib explosive valve for GDCS injection. The staff finds that these squib valves are actuated by the booster assembly that causes an explosion inside the valve assembly, and the explosive pressure is just adequate to push the piston that opens the valve outlet. The staff concurs with the applicant's rationale that the explosive booster assembly cannot generate a missile because the assembly is integrally built with the valve. Therefore, the staff considers the concern described in RAI 3.5-6 resolved.

Safety/relief valves (SRVs) used in the ESBWR design function as the safety valves; they open to prevent nuclear system overpressurization and are self-actuating by inlet steam pressure. In RAI 3.5-7, the staff asked the applicant to discuss the possibility of the SRVs becoming internally generated missiles and to provide its basis for determining that these valves will not credibly affect the safety-related equipment needed for a plant's safe shutdown.

In its response to RAI 3.5-7, the applicant stated that DCD Section 3.5.1.1.2.2 discusses the design characteristics of the SRVs that provide the basis for excluding the possibility of internally generated missiles. All operating BWRs use these valves, which are designed and manufactured so that they do not produce potential missiles upon failure. The applicant noted that the remaining components that act as guides will prevent the larger diameter components in the shaft from becoming missiles. The applicant provided a sketch showing relevant features for the SRVs.

The staff reviewed the applicant's response and the sketch showing relevant features for the SRVs. The staff finds that the SRV actuation is controlled by the piston-type pneumatic actuator to isolate the valve with setpoint spring (belleville washers). When the pressurized equipment or piping sections pressure exceeds the setpoint, the valve will automatically release the extra pressure above the setpoint. The piston and lifting mechanism of the valve are integrally designed under ASME Code, Section III. The staff concurs that the SRV has no potential to become a missile source. Therefore, the staff considers the concern described in RAI 3.5-7 resolved.

DCD, Tier 2, Table 3.2-1, lists all the SSCs (safety-related and non-safety-related) in various locations of the plant (inside and outside the containment) and identifies for each SSC the associated seismic category, quality group, and equipment classifications. DCD, Tier 2, Section 7.4, lists the systems required for safe shutdown. DCD, Tier 2, Section 1.2, presents general arrangement drawings further defining the building locations. Based on its review, the staff finds that the applicant's evaluation of potential internally generated missiles inside the containment resulting from equipment and component failures satisfies GDC 4.

In addition, during the review of the earlier DCD versions, the staff identified issues regarding the lack of information on the missile protection for RTNSS. Therefore, as part of RAI 22.5-5, the staff asked the applicant to address this concern.

In its response to RAI 22.5-5, the applicant added a new section (19A – Regulatory Treatment of Non-Safety Systems) in DCD, Revision 5. In this new Section 19A, the applicant provided Tables 19A-3 and 19A-4. In Table 19A-3, the applicant identified the RTNSS together with their associated RTNSS criteria, locations (buildings), and building category. In Table 19A-4, the applicant identified how the RTNSS in each area (building) are protected from internal flooding, external flooding, internal missiles, and extreme wind and missiles. The staff found the applicant's response to RAI 22.5-5 inadequate. Specifically, the applicant did not provide sufficient details about the design of the protection provided for RTNSS against internal missiles and extreme wind missiles. Subsequently, as part of supplemental RAI 22.5-5 S01, the staff asked the applicant to provide a detailed description of the design and installation of each RTNSS and discuss how this design and installation would protect the RTNSS SSCs against internally generated missiles inside containment. Also, in supplemental RAI 22.5-5 S02, the staff requested that the applicant provide ITAAC for the RTNSS.

The staff finds the applicant's responses to RAI 22.5-5 S01 and RAI 22.5-5 S02 acceptable and, therefore, considers the concerns described in RAI 22.5-5, RAI 22.5-5 S01, and RAI 22.5-5 S02 resolved. Chapter 22 of this report, in part, addresses the staff's evaluation of the applicant's responses to these RAIs regarding the protection provided for RTNSS against internally generated missiles inside containment.

Section 3.5.3 of this report addresses the staff's evaluation of the design of structures, shields, and barriers required for missile protection.

Section 3.6.2 of this report addresses the staff's evaluation of break and crack sizes, configurations, and locations.

Section 3.7.3 of this report addresses the staff's evaluation of the impact of the fall or overturning of NS components on safety-related SSCs resulting from a seismic event.

ITAAC

In DCD, Tier 1, Revision 7, Section 2.0, the applicant provided the design descriptions, including the loads due to design-basis internal events, and ITAAC for the ESBWR design. These ITAAC commit to verifying that the SSCs important to safety, including RTNSS, are designed and perform as described in ESBWR DCD, Tier 2, Revision 7. Therefore, the staff concludes that protection against internally generated missiles (inside containment) complies with the requirements of 10 CFR 52.47(b)(1).

3.5.1.2.4 Conclusions

Based on its review and the evaluation discussed above, the staff finds that the ESBWR design complies with GDC 4 as it relates to protection for SSCs important to safety against internally generated missiles inside containment. Therefore, the staff concludes that the design of the facility satisfies the guidelines described in SRP Section 3.5.1.2, Revision 3.

3.5.1.3 *Turbine Missiles*

3.5.1.3.1 Regulatory Criteria

The staff reviewed Section 3.5.1.1.1.2 of DCD, Tier 2, Revision 7, in accordance with the following regulations and guidance:

- GDC 4 states that SSCs important to safety shall be appropriately protected against dynamic effects, including the effects of missiles that may result from equipment failures. The steam turbine is considered to be a component important to safety because the failure of its massive rotor at a high rotating speed during normal operating conditions of a nuclear unit could generate high-energy missiles that have the potential to damage safety-related SSCs.

- RG 1.115 and SRP Sections 10.2, 10.2.3, and 3.5.1.3 guide the evaluation of the effect of turbine missiles on public health and safety. SRP Section 3.5.1.3, Revision 3, provides primary guidance on the issues related to the probability of turbine missile generation, which is the focus of the staff's evaluation in this section of this report.

As specified in SRP Section 3.5.1.3, Revision 3, the probability of unacceptable damage from turbine missiles is expressed as the product of (1) the probability of turbine missile generation resulting in the ejection of turbine disk (or internal structure) fragments through the turbine casing (P_1), (2) the probability of ejected missiles perforating intervening barriers and striking safety-related SSCs (P_2), and (3) the probability of impacted SSCs failing to perform their safety functions (P_3).

In view of the operating experience of turbines and the NRC's safety objectives, the NRC staff shifted its emphasis in the review of turbine missile issues from missile generation, strike, and damage probability, $P_1 \times P_2 \times P_3$, to the missile generation probability, P_1. The minimum reliability values (i.e., P_1) for loading the turbine and bringing the system on line were established in 1986. The minimum recommended reliability values of P_1 are less than 1×10^{-4} per reactor year for favorably oriented turbines and less than 1×10^{-5} per reactor year for unfavorably oriented turbines. These values are derived from (1) simple estimates for a variety of plant layouts which show that $P_2 \times P_3$ can be reasonably taken to fall within the range of 1×10^{-4} to 1×10^{-3} per year for favorably oriented turbines, and (2) the NRC's criterion of 1×10^{-7} per reactor year for $P_1 \times P_2 \times P_3$, as stated in RG 1.115. The P_1 calculation is related to maintenance and inspection of turbine rotors and control valves, operating experience of similar equipment, and inspection results.

3.5.1.3.2 Summary of Technical Information

Section 3.5.1.1.1.2 of DCD Tier 2 states that the main turbine has a favorable turbine generator placement and orientation relative to placement of the containment (as shown in Figure 3.5-2 of the DCD). The arrangement adheres to the guidelines of RG 1.115. Favorable turbine generator placement and orientation, combined with quality assurance (QA) in design and fabrication, inspection and testing programs as provided in Section 10.2 of the DCD, and overspeed protection systems, result in an acceptably small risk from turbine missiles.

3.5.1.3.3 Staff Evaluation

The staff used the guidelines of SRP Section 3.5.1.3, Revision 3, to review and evaluate the information submitted by the applicant to ensure a low probability of turbine rotor failure. SRP Section 3.5.1.3 states that with the use of proper turbine rotor design, materials that satisfy the acceptance criteria in SRP Section 10.2.3, Revision 2, and acceptable preservice and inservice nondestructive examination methods, the probability of turbine missile generation, P_1, is expected to be no greater than $1x10^{-5}$ per reactor year for an unfavorably oriented turbine and no greater than $1x10^{-4}$ for a favorably oriented turbine. This probability represents the general minimum reliability requirement for loading the turbine and bringing the system on line.

Table 3.5-1 of DCD Tier 2 provides probability requirements for turbine missile generation that are consistent with Table 3.5.1.3-1 of SRP Section 3.5.1.3. In addition, Figure 3.5-2 of DCD Tier 2 shows the low-trajectory turbine missile ejection zone. Figure 3.5-2 also shows that the turbine is designed in a favorably oriented location with respect to the RB. The favorably oriented turbine will minimize the potential of a turbine missile striking the safety-related systems should the turbine fail. Therefore, the ESBWR design satisfies SRP Section 3.5.1.3 guidance in terms of the probability of turbine missile generation and favorably oriented turbine placement.

SRP Section 3.5.1.3.II.4 states that the turbine manufacturers should provide applicants with tables of missile generation probabilities versus time (inservice visual, surface, and volumetric rotor inspection interval for design speed failure and inservice valve testing interval for destructive overspeed failure). These probabilities should be used to establish inservice and test schedules that meet the NRC’s safety objectives. This requires the applicant to demonstrate the capability to perform volumetric (ultrasonic) examinations suitable for inservice inspection (ISI) of turbine rotors and shafts and to provide reports describing its methods for determining turbine missile generation probabilities for the NRC’s review and approval.

The ESBWR DCD, Tier 2, Section 10.2.5, states that the COL applicant will provide a description of the plant-specific turbine maintenance program required to satisfy the original equipment manufacturer’s turbine missile generation probability calculation, including each of the criteria identified in Section II of SRP Section 3.5.1.3. Because the COL applicant will provide to the NRC a description of the plant-specific turbine maintenance program, which will include a turbine missile generation analysis, the staff concludes that the ESBWR design satisfies SRP Section 3.5.1.3 guidance for ISI and testing of the turbine components and thus meets the NRC safety objectives.

SRP Section 3.5.1.3.II.4 also states that applicants obtaining turbines from manufacturers that have prepared NRC-approved reports to describe their methods and procedures for calculating turbine missile generation probabilities are expected to satisfy the criteria in Table 3.5.1.3-1 of SRP Section 3.5.1.3.

In Revision 3 to Section 3.5.1.1.1.2 of DCD Tier 2, the applicant stated that the COL holder will provide an evaluation that concludes that the probability of turbine missile generation (P_1) is less than $1x10^{-5}$ in accordance with Section 10.2.5 of the DCD. Because SRP Section 3.5.1.3 requires the plant owner to perform certain nondestructive examinations if the probability calculation is not approved by the NRC before license issuance, in RAI 10.2-21, the staff asked the applicant to justify the use of the term “COL holder” in lieu of “COL applicant” in DCD Section 3.5.1.1.1.2. In its response, the applicant explained that the turbine missile probability analysis will not be available until after the as-built turbine material properties and final as-built rotor design details are available. This information will not be available until after the issuance of the COL and is therefore, specified as a COL holder item. The staff accepted this explanation as a reason not to have on hand an NRC-approved report and requested that the applicant include an ITAAC in its DCD Tier 1.

In Revision 5 to ESBWR DCD Tier 1, the applicant included an ITAAC in Section 2.11.4, which requires that a turbine missile probability analysis be performed to demonstrate that the turbine missile probability is less than $1x10^{-4}$ per turbine year. Based on its review of the provided information, the staff finds that it is acceptable for the COL holder to provide an evaluation of the probability of turbine missile generation to the NRC because (1) the turbine missile probability analysis will not be available until after the as-built turbine material properties and final as-built rotor design details are available, and (2) an ITAAC exists to ensure that the probability of turbine material and overspeed-related failures resulting in external turbine missiles will be less than $1x10^{-4}$ per turbine year.

Section 10.2.3 of this report provides additional discussion of the staff’s evaluation of the turbine ISI program. Section 10.2.2 of this report discusses the staff’s detailed evaluation of the turbine overspeed protection system of the ESBWR design. On the basis of the above evaluation, the staff concludes that the probability of turbine missile generation and turbine orientation as required in Section 3.5.1.1.1.2 of DCD, Tier 2, Revision 6, are consistent with the acceptance criteria in SRP Section 3.5.1.3 and RG 1.115.

3.5.1.3.4 Conclusions

The staff concludes that the applicant has imposed design requirements for the probability of turbine missile generation and favorable turbine orientation. The design requirements are consistent with the acceptance criteria in SRP Section 3.5.1.3 and RG 1.115. ESBWR DCD Tier 2 also requires that the COL holder provide an evaluation that concludes that the probability of turbine missile generation (P_1) is less than $1x10^{-4}$ in accordance with Section 10.2.5 of the DCD. Therefore, the staff concludes that the risk posed by turbine missiles for the proposed plant design is acceptable and meets the relevant requirements of GDC 4. The staff bases this conclusion on the applicant having sufficiently demonstrated to the staff, in accordance with the guidance of SRP Section 3.5.1.3 and RG 1.115, that the overall probability of turbine missile damage to SSCs important to safety is acceptably low.

The staff will review the plant-specific turbine system maintenance program and the calculation of the plant-specific probability of turbine missile generation upon their submittal by the COL holder.

3.5.1.4 ***Missiles Generated by Natural Phenomena***

3.5.1.4.1 Regulatory Criteria

The staff reviewed the ESBWR design for protecting SSCs important to safety against missiles generated by natural phenomena in accordance with SRP Section 3.5.1.4, Revision 3. The staff's acceptance of the design is based on compliance with the requirements of the following regulations:

- GDC 2 requires, in part, that SSCs important to safety shall be designed to withstand the effects of natural phenomena such as tornadoes and hurricanes without loss of capability to perform their safety functions;

- GDC 4 requires, in part, that SSCs important to safety shall be appropriately protected against the effects of missiles that may result from events and conditions outside the nuclear power unit; and,

- 10 CFR 52.47(b)(1) requires that a DC application contain the proposed ITAAC that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, a facility that incorporates the DC is built and will operate in accordance with the DC, the provisions of the Atomic Energy Act, and the NRC's regulations.

3.5.1.4.2 Summary of Technical Information

Based on a study, "Rationale for Wind-bone Missile Criteria facilities," dated September 1999, GEH determines tornado-generated missiles, to be the limiting natural phenomena hazard in the design of all structures required for the safe shutdown of the nuclear power plant,and to be used in the design basis for the ESBWR design. In DCD, Tier 2, Table 2.0-1, the applicant specified the design parameters for the DBT and tornado missile spectrum.

DCD, Tier 2, Table 3.2-1, lists all the SSCs (safety-related and non-safety-related) in various locations of the plant (inside and outside the containment) and identifies for each SSC the associated seismic category, quality group, and equipment classifications. DCD, Tier 2, Section 7.4, lists the systems required for safe shutdown. DCD, Tier 2, Section 1.2, presents general arrangement drawings further defining the building locations.

3.5.1.4.3 Staff Evaluation

The staff reviewed the ESBWR design for protecting SSCs important to safety against missiles generated by tornadoes and extreme winds in accordance with the guidance of SRP Section 3.5.1.4. The staff reviewed DCD, Tier 2, Revision 7, Section 3.5.1.4. The staff also reviewed DCD, Tier 1, Revision 7, Section 2.0, and other DCD Tier 2 sections noted below.

Compliance with GDC 2 and 4 is based on meeting the guidance of Positions C.1, "Design-Basis Tornado Parameters," and C.2, "Design-Basis Tornado-Generated Missile Spectrum," of RG 1.76, Revision 1.

Compliance with GDC 4 is also based on meeting the guidance of the following SECY-94-084:

- SECY-94-084, “Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems in Passive Plant Designs,” provides guidance as to which systems should be RTNSS and would call for enhanced design requirements.

In DCD, Tier 2, Revision 7, Table 2.0-1, the applicant listed the following parameters for the DBT:

- maximum tornado windspeed of 147.5 m/s (330 mph);
- maximum rotational speed of 116.2 m/s (260 mph);
- translational velocity of 31.3 m/s (70 mph);
- radius of maximum rotational wind from center of tornado of 45.7 m (150 ft);
- maximum atmospheric pressure differential of 16.6 kPa (2.4 psi); and,
- rate of pressure change of 11.7 kPa/s (1.7 psi/s).

The staff finds these design parameters, which are more conservative than those specified in the guidance of Position C.1 of RG 1.76, acceptable. With regard to the tornado-generated missile spectrum, in DCD, Tier 2, Revision 7, Section 3.5.1.4, the applicant stated that the tornado-generated missile spectrum meets Position C.2 of RG 1.76. Therefore, the staff finds that the DBT and tornado missile spectrum are properly selected for the ESBWR design and meet the requirements of GDC 2 and 4 with respect to protection for safety-related SSCs against the effects of natural phenomena.

During the review of Section 3.5.1.4 in the earlier DCD versions regarding protection for safety-related SSCs against missiles generated by natural phenomena, the staff identified areas in which it needed additional information to complete its review. Therefore, the staff issued RAIs to the applicant. The staff’s RAIs, the applicant’s responses, and the staff’s evaluation of the applicant’s responses are described below.

DCD Section 3.5.1.4 states that the DBT and tornado missile spectrum are defined in DCD Sections 2.3.1 and 2.3.2 and Table 2.0-1 in the discussion of the design of seismic Category I buildings. In considering tornado-generated missile threats to plant safety-related SSCs, the staff issued RAI 3.5-8, requesting that the applicant explain whether the missile threat is considered concurrent with a loss-of-offsite power (LOOP).

In its response to RAI 3.5-8, the applicant stated that the seismic Category I buildings for the ESBWR are designed to remain intact and to protect any safety-related SSCs located within them from damage resulting from the DBT missile spectrum. The ESBWR is designed to accommodate the design-basis LOCA events with a concurrent LOOP. LOCA events take credit only for safety-related SSCs located in seismic Category I structures. A DBT and tornado missile spectrum would not disable any equipment credited for use in responding to a design-basis LOCA. Therefore, the response of the ESBWR to a DBT and tornado missile spectrum concurrent with a LOOP is bounded by the LOCA analysis results contained in DCD, Tier 2, Sections 6.2.1 and 6.3.3.

In addition, the station blackout event described in DCD, Tier 2, Section 15.5.5, begins with a loss of all ac power and also takes credit only for safety-related SSCs located in seismic Category I structures. Therefore, the response to a DBT and tornado missile spectrum concurrent with a LOOP is also bounded by the station blackout event response.

The staff finds the applicant's response acceptable, because the ESBWR has been designed to accommodate the design-basis LOCA with a concurrent LOOP, and the LOCA analyses have taken credit for safety-related SSCs located in seismic Category I structures. Since all seismic Category I structures are designed to protect any safety-related SSCs located within them from damage resulting from the DBT missile spectrum, the staff considers the concern described in RAI 3.5-8 resolved.

DCD Section 3.5.1.4 states that "because tornado missiles are used in the design basis, it is not necessary to consider missiles generated from other natural phenomena." The staff was concerned that this statement may not be true. Wind-driven missiles generated by other site-specific extreme winds should be considered on a case-by-case basis if they are deemed to be credible. The staff requested in RAI 3.5-9 that the applicant address the potential for other extreme winds in more detail.

In its response to RAI 3.5-9, the applicant stated that a U.S. Department of Energy (DOE) study conducted by the University of Texas at Lubbock concluded that extreme winds are less intense than tornado winds and do not have the strong vertical component that produces airborne missiles in tornadoes. Therefore, the design does not consider wind-driven missiles. The applicant provided reference to study report: James R. McDonald's "Rationale for Wind-Borne Missile Criteria for DOE Facilities," issued September 1999 UCRL-CR-135687 S/C B 505188, to support its conclusion.

Based on its review, the staff agrees with the results of the DOE study, which demonstrates that extreme winds are less intense than tornado winds and do not have the strong vertical component that produces airborne missiles in tornadoes. Therefore, the staff finds the applicant's response to RAI 3.5-9 acceptable and considers the concern described in RAI 3.5-9 resolved.

Based on its review and the evaluation discussed above, the staff finds that the applicant's assessment of possible hazards-attributaed to missiles generated by high-speed winds, such as tornado, hurricane, and any other extreme winds, has chosen and properly characterized appropriate design-basis missiles and that the effects caused by those missiles are acceptable.

Also, during the review of the earlier DCD versions, the staff identified issues regarding the lack of information on missile protection for RTNSS. Therefore, as part of RAI 22.5-5, the staff requested that the applicant address this concern.

In its response to RAI 22.5-5, the applicant added a new section (19A – Regulatory Treatment of Non-Safety Systems) in DCD, Revision 5. In this new Section 19A, the applicant provided Tables 19A-3 and 19A-4. In Table 19A-3, the applicant identified the RTNSS together with their associated RTNSS criteria, locations (buildings), and building category. In Table 19A-4, the applicant identified how the RTNSS in each area (building) are protected from internal flooding, external flooding, internal missiles, and extreme wind and missiles. The staff found the applicant's response to RAI 22.5-5 inadequate. Specifically, the applicant did not provide sufficient details about the design of the protection provided for RTNSS against internally generated missiles and externally generated missiles resulting from natural phenomena such as tornadoes and hurricanes. Subsequently, as part of supplemental RAI 22.5-5 S01, the staff requested that the applicant provide a detailed description of the design and installation of each RTNSS and discuss how this design and installation would protect the RTNSS SSCs against missiles generated by natural phenomena. Also, in supplemental RAI 22.5-5 S02, the staff asked the applicant to provide ITAAC for the RTNSS.

The staff finds the applicant's responses to RAI 22.5-5 S01 and RAI 22.5-5 S02 acceptable and, therefore, considers the concerns described in RAI 22.5-5, RAI 22.5-5 S01, and RAI 22.5-5 S02 resolved. Chapter 22 of this report addresses the staff's evaluation of the applicant's responses to these RAIs regarding the protection provided for RTNSS against internal flooding, external flooding, extreme wind and missiles, and internally generated missiles outside and inside containment.

Section 3.5.2 of this report addresses the staff's evaluation of the adequacy of the protection provided for ESBWR plant structures and SSCs important to safety against the effects of externally generated missiles.

Section 3.5.3 of this report addresses the staff's evaluation of the adequacy of the barriers and structures designed to withstand the effects of the identified tornado missiles.

Section 3.8.4 of this report addresses the staff's evaluation of the ESBWR structural design.

ITAAC

In DCD, Tier 1, Revision 7, Section 2.0, the applicant provided the design descriptions, including the loads due to design-basis internal events, and ITAAC for the ESBWR design. These ITAAC commit to verifying that the SSCs important to safety, including RTNSS, are designed and perform as described in ESBWR DCD, Tier 2, Revision 7. Therefore, the staff concludes that protection against missiles generated by natural phenomena complies with the requirements of 10 CFR 52.47(b)(1).

3.5.1.4.4 Conclusions

Based on its review and the evaluation discussed above, the staff finds that the ESBWR design complies with GDC 2 and 4 as they relate to protection for SSCs important to safety against effects of natural phenomena such as tornadoes and hurricanes without loss of capability to perform their safety functions. Therefore, the staff concludes that the design of the facility satisfies the guidelines described in SRP Section 3.5.1.4, Revision 3.

3.5.1.5 *Site Proximity Missiles (Except Aircraft)*

3.5.1.5.1 Regulatory Criteria

The following regulatory requirements provide the basis for the acceptance criteria for the staff's review:

- 10 CFR 52.47, "Contents of Applications; Technical Information," as it relates to the contents of DCD applications;

- 10 CFR 100.20(b), which states that the nature and proximity of man-related hazards (e.g., airports, dams, transportation routes, and military or chemical facilities) must be evaluated to establish site parameters for use in determining whether a plant design can accommodate commonly occurring hazards and whether the risk of other hazards is very low;

- 10 CFR 100.20, “Factors To Be Considered When Evaluating Sites,” as it relates to the requirement that site characteristics be evaluated to determine whether the risk to individuals and society of potential plant accidents is low;

- 10 CFR 100.21(e), which states that potential hazards associated with nearby transportation routes and industrial and military facilities must be evaluated and site parameters established such that potential hazards from such routes and facilities will pose no undue risk to the type of facility proposed to be located at the site;

- GDC 4, which requires that SSCs important to safety be appropriately protected against the effects of missiles that may result from events and conditions outside the nuclear power units and that the plant meet the relevant requirements of GDC 4;

- 10 CFR 52.47(b)(1), as it relates to ITAAC sufficient to ensure that the SSCs in this area of review will operate in accordance with the certification, the provisions of the Act, and the Commission’s rules and regulations; and,

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

SRP Section 3.5.1.5, Revision 4, addresses the specific criteria acceptable to meet the relevant requirements. The criteria typically involve reviewing event probability for which the expected rate of occurrence of potential exposure in excess of the 10 CFR Part 100 guidelines is estimated to be less than an order of magnitude of 1×10^{-7} per year.

3.5.1.5.2 Summary of Technical Information

The applicant specified the envelope of ESBWR standard plant site design parameters in DCD, Tier 2, Table 2.0-1. The site is selected such that the probable occurrence of the site proximity missile (except aircraft) is less than 1×10^{-7} per year. The site proximity missile has been dismissed from further consideration, because at that likelihood of occurrence, it is not considered a statistically significant risk.

3.5.1.5.3 Staff Evaluation

Since the information regarding site proximity missiles (except aircraft) in the vicinity of the site is site specific, the applicant specified the envelope of ESBWR standard plant site design parameters in DCD, Tier 2, Table 2.0-1. The COL applicant must confirm that the probable occurrence of the site proximity missile (except aircraft) is less than 1×10^{-7} per year based on the site-specific information in accordance with SRP Section 3.5.1.5.

3.5.1.5.4 Conclusions

The applicant has not analyzed the site proximity missiles (except aircraft). As this information is site specific, the applicant has provided the appropriate information needed by the COL applicant to address each site. Therefore, the requirement that the COL applicant address these issues is acceptable.

3.5.1.6 *Aircraft Hazards*

3.5.1.6.1 Regulatory Criteria

The following regulatory requirements provide the basis for the acceptance criteria for the staff's review:

- 10 CFR 52.47, as it relates to the contents of DCD applications;

- 10 CFR 100.20(b), which states that the nature and proximity of man-related hazards (e.g., airports) must be evaluated to establish site parameters for use in determining whether a plant design can accommodate commonly occurring hazards and whether the risk of other hazards is very low;

- 10 CFR 100.20, as it relates to the requirement that site characteristics be evaluated to determine whether the risk to individuals and society of potential plant accidents is low;

- 10 CFR 100.21(e), which states that potential hazards associated with nearby transportation routes and industrial and military facilities must be evaluated and site parameters established such that potential hazards from such routes and facilities will pose no undue risk to the type of facility proposed to be located at the site;

- GDC 3, "Fire Protection," which requires that SSCs important to safety have appropriate protection against the effects of fires and explosions;

- GDC 4, which requires that SSCs important to safety have appropriate protection against the effects of missiles that may result from events and conditions outside the nuclear power units;

- 10 CFR 52.47(b)(1), as it relates to ITAAC sufficient to ensure that the SSCs in this area of review will be constructed and will operate in accordance with the certification, the provisions of the Act, and the Commission's rules and regulations.

SRP Section 3.5.1.6, Revision 4, addresses specific criteria acceptable to meet the relevant requirements, which typically involve reviewing event probability for which the expected rate of occurrence of potential exposure in excess of the 10 CFR Part 100 guidelines is estimated to be less than an order of magnitude of $1\text{x}10^{-7}$ per year.

3.5.1.6.2 Summary of Technical Information

The applicant specified the envelope of ESBWR standard plant site design parameters in DCD, Tier 2, Table 2.0-1. The applicant stated that the probability of aircraft hazards impacting the ESBWR standard plant and causing consequences greater than the 10 CFR Part 100 (and 10 CFR 50.34(a)) exposure guidelines is less than $1\text{x}10^{-7}$ per year.

3.5.1.6.3 Staff Evaluation

Since the information regarding potential aircraft hazards in the vicinity of the site is site specific, the COL applicant will demonstrate that the probability of aircraft hazards impacting the ESBWR standard plant and causing consequences greater than the 10 CFR Part 100 (and

10 CFR 50.34(a)) exposure guidelines is less than $1x10^{-7}$ per year based on the COL applicant's use of site-specific information in accordance with SRP Section 3.5.1.6.

3.5.1.6.4 Conclusions

The applicant has not analyzed the aircraft hazards. As this information is site specific, the applicant has provided appropriate information that the COL applicant needs to address for each site. The requirement that the COL applicant address these issues is acceptable.

3.5.2 Structures, Systems, and Components To Be Protected From Externally Generated Missiles

3.5.2.1 *Regulatory Criteria*

The staff reviewed the ESBWR design for protecting SSCs important to safety against externally generated missiles in accordance with SRP Section 3.5.2, Revision 3. The staff's acceptance of the design is based on compliance with the following requirements:

- GDC 2 requires, in part, that SSCs important to safety shall be designed to withstand the effects of natural phenomena such as tornadoes and hurricanes without loss of capability to perform their safety functions;

- GDC 4 requires, in part, that SSCs important to safety shall be appropriately protected against the effects of missiles that may result from events and conditions outside the nuclear power unit; and,

- 10 CFR 52.47(b)(1) requires that a DC application contain the proposed ITAAC that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, a facility that incorporates the DC is built and will operate in accordance with the DC, the provisions of the Atomic Energy Act, and the NRC's regulations.

3.5.2.2 *Summary of Technical Information*

This section discusses the SSCs to be protected from externally generated missiles, including all safety-related SSCs on a plant site that support the reactor facility. DCD, Tier 2, Revision 7, Section 3.5.1, identifies the sources of external missiles. The applicant considers tornado-generated missiles as the limiting externally generated missile on a plant site. DCD, Tier 2, Revision 7, Table 3 2-1, lists all the SSCs (safety-related and non-safety-related) in various locations of the plant (including inside and outside the containment) and identifies for each SSC the associated seismic category, quality group, and equipment classifications. All of the safety-related systems listed are located in buildings that are designed to be tornado resistant. Provisions are made to protect the offgas charcoal bed absorbers, seismic Category I portions of the FPS, and components of the fuel auxiliary pools cooling system that transport makeup water to the spent fuel pool and isolation condenser and passive containment cooling pools from the FPS against tornado missiles.

3.5.2.3 *Staff Evaluation*

The staff reviewed the ESBWR design for protecting SSCs important to safety against externally generated missiles in accordance with the guidance of SRP Section 3.5.2. The staff reviewed DCD, Tier 2, Revision 7, Section 3.5.2. The staff also reviewed DCD, Tier 1, Revision 7, Section 2.0, and other DCD Tier 2 sections noted below.

Compliance with GDC 2 and 4 is based on meeting the guidance of the following RGs and SECY-94-084:

- RG 1.13, "Spent Fuel Storage Facility Design Basis," Revision 2, issued March 2007, as it relates to the capacity of the spent fuel pool cooling systems and structures to withstand the effects of externally generated missiles and to prevent missiles from contacting the stored fuel assemblies

- RG 1.27, "Ultimate Heat Sink for Nuclear Plants," Revision 2, issued January 1976, as it relates to the capability of the ultimate heat sink and connecting conduits to withstand the effects of externally generated missiles

- RG 1.115, Revision 1, as it relates to the protection of the SSCs important to safety from the effects of turbine missiles

- RG 1.117, Revision 1, as it relates to the protection of the SSCs important to safety from the effects of tornado missiles

- SECY-94-084, "Policy and Technical Issues Associated with the Reulatory Treatment of Non-Safety Systems in Passive Plant Designs," provides guidance as to which systems should be RTNSS and would call for enhanced design requirements.

In the ESBWR design, the new fuel and spent fuel are stored on the racks of the refueling area located in the RB buffer pool, and the spent fuel assemblies (with channels) or bundles (without channels) are located in the FB spent fuel storage pool. The reinforced concrete walls and roofs of these buildings protect the buffer pool and the spent fuel pool from externally generated missiles. Therefore, the staff concludes that the spent fuel pool meets the guidelines of RG 1.13.

The ESBWR design does not use an ultimate heat sink as addressed in RG 1.27 for cooling the reactor facilities for operating plants. In case of a LOCA in an ESBWR plant, the GDCS in conjunction with the ADS will provide the emergency core cooling. The isolation condenser system removes decay heat after any reactor isolation during power operations. Both the GDCS pool and the isolation condenser pool are located inside the containment with heavy concrete walls that protect the pools from external missiles. The ESBWR design requires no safety-related auxiliary systems to achieve a safe shutdown of the reactor or to maintain it in a safe condition. Other auxiliary systems, such as service water, cooling water, fire protection, and heating and ventilating, are designed to function as needed during normal conditions. They can also operate during accident conditions but are not required to do so. On the basis of this review, the staff finds that the ESBWR design meets the intent of RG 1.27, as it relates to the capability of the ultimate heat sink to withstand the effects of externally generated missiles.

As stated in DCD, Tier 2, Revision 7, Section 3.5.1.1.1.2 and shown in DCD Figure 3.5-2, "ESBWR Standard Plant Low-Trajectory Missile Strike Zone," the ESBWR is designed with a favorable turbine generator placement and orientation such that no safety-related equipment is located within the low-trajectory turbine missile strike zones. Based on this information, the staff finds that the ESBWR design meets the guidelines of RG 1.115.

Section 3.5.1.3 of this report addresses the staff's evaluation of turbine-generated missiles.

In SRP Section 3.5.2, the staff states that the SSCs required for safe shutdown of the reactor should be identified. RG 1.115, Position C.1, and RG 1.117, Appendix A, provide guidance as to which SSCs should be protected from missile impacts.

In DCD, Tier 2, Table 3.2-1, the applicant lists all the SSCs (safety-related and non-safety-related) in various locations of the plant (inside and outside the containment) and identifies for each SSC the associated seismic category, quality group, and equipment classifications. In DCD, Tier 2, Section 7.4, the applicant lists the systems required for safe shutdown. Also, DCD, Tier 2, Section 1.2 provides general arrangement drawings defining the building locations. Based on its review, the staff finds that the missile protection provided for SSCs in the ESBWR plant complies with Positions C.1 and C.3 of RG 1.115 and the guidance of RG 1.117, Appendix A.

During the review of the earlier DCD versions, the staff identified issues regarding the lack of information on missile protection for RTNSS. Therefore, the staff requested that the applicant address this concern as part of RAI 22.5-5.

In its response to RAI 22.5-5, the applicant added a new section (19A – Regulatory Treatment of Non-Safety Systems) in DCD Revision 5. In this new Section 19A, the applicant provided Tables 19A-3 and 19A-4. In Table 19A-3, the applicant identified the RTNSS together with their associated RTNSS criteria, locations (buildings), and building category. In Table 19A-4, the applicant identified how the RTNSS in each area (building) are protected from internal and external flooding and internally and externally generated missiles. The staff found the applicant's response to RAI 22.5-5 inadequate. Specifically, the applicant did not provide sufficient details about the design of the protection provided for RTNSS against internally generated missiles and externally generated missiles resulting from equipment and pipe failures and effects of natural phenomena such as tornadoes and hurricanes. Subsequently, in supplemental RAI 22.5-5 S01, the staff asked the applicant to provide a detailed description of the design and installation of each RTNSS and discuss how this design and installation would protect the RTNSS SSCs against internally and externally generated missiles. Also, in supplemental RAI 22.5-5 S02, the staff requested that the applicant provide ITAAC for the RTNSS.

The staff finds the applicant's responses to RAI 22.5-5 S01 and RAI 22.5-5 S02 acceptable and, therefore, considers the concerns described in RAI 22.5-5, RAI 22.5-5 S01, and RAI 22.5-5 S02 resolved. Chapter 22 of this report addresses the staff's evaluation of the applicant's responses to these RAIs regarding the protection provided for RTNSS against internal and external flooding and internally and externally generated missiles, including missiles generated outside and inside containment.

Section 3.5.3 of this report addresses the staff's evaluation of the adequacy of the barriers and structures designed to withstand the effects of the identified tornado missiles.

Section 3.8.4 of this report addresses the staff's evaluation of the ESBWR structural design.

ITAAC

In DCD, Tier 1, Revision 7, Section 2.0, the applicant provided the design descriptions, including the loads due to design-basis internal events, and ITAAC for the ESBWR design. These ITAAC commit to verifying that the SSCs important to safety, including RTNSS, are designed and perform as described in ESBWR DCD, Tier 2, Revision 7. Therefore, the staff concludes that missile protection against externally generated missiles complies with the requirements of 10 CFR 52.47(b)(1).

3.5.2.4 *Conclusions*

Based on its review of the information provided in DCD Tier 1 and Tier 2 and the evaluation discussed above, the staff concludes that the ESBWR design for protecting SSCs against externally generated missiles is in accordance with the guidelines of RGs 1.13, 1.27, 1.115, and 1.117, with respect to protecting the SSCs important to safety from the effects of tornado missiles, including all safety-related SSCs on a plant site, stored spent fuel, and the ultimate heat sink. Therefore, the staff concludes that the ESBWR design complies with the requirements of GDC 2 and 4 with respect to environmental effects and missiles and that it meets the guidelines described in SRP Section 3.5.2, Revision 3.

3.5.3 Barrier Design Procedures

The staff reviewed Revision 7 of the ESBWR DCD, Section 3.5.3, following the guidance in SRP Section 3.5.3, Revision 3, regarding the procedures used in the design of seismic Category I structures, shields, and barriers to withstand the effects of missile impact and considered the applicant's responses to RAIs, open items, and confirmatory items. The following summarizes the results of the staff's technical review of DCD Section 3.5.3.

3.5.3.1 *Regulatory Criteria*

The design of structures that are important to safety and must withstand and absorb missile impact loads to prevent damage to safety-related SSCs must comply with the relevant requirements of GDC 2 and 4 with respect to the capability of structures to withstand the effects of missile impacts and to protect against their dynamic effects.

GDC 2 requires that SSCs important to safety be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their intended safety functions. GDC 2 further requires that the design bases reflect appropriate consideration of the most severe natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated. GDC2 also requires consideration of the appropriate combinations of the effects of normal and accident conditions with the effect of natural phenomena and the importance of the safety functions to be performed. GDC 4 requires that SSCs important to safety be designed to accommodate the effects of, and to be compatible with, the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including LOCAs. These SSCs shall be appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids, that may result from equipment failures and from events and conditions outside the nuclear power unit.

The staff reviewed the following areas related to procedures used in the design of seismic Category I structures, shields, and barriers to withstand the effects of missile impact:

- procedures for predicting local damage in the impacted area, including estimation of the depth of penetration and, in the case of concrete barriers, the potential for generation of secondary missiles by spalling or scabbing effects; and,

- procedures for predicting the overall response of the barrier or portions of the barrier to missile impacts, including assumptions on acceptable ductility ratios where elasto-plastic behavior is relied on, and procedures for estimating forces, moments, and shears induced in the barrier by the impact force of the missile.

3.5.3.2 *Summary of Technical Information*

The applicant discussed the barrier design procedures used for the ESBWR design in DCD, Tier 2, Section 3.5.3. For the prediction of local damage from missiles, the applicant provided information on the procedures used in the design of concrete and steel structures. The applicant applied the modified National Defense Research Council analytical formula for missile protection in concrete. To prevent missile perforation, the applicant relied on the procedures in Section C.7 of Appendix C to ACI 349. The applicant also stated that the resulting thickness of the concrete required to prevent perforation, spalling, or scabbing should in no case be less than that for Region I listed in Table 1 of SRP Section 3.5.3. For missile penetration in steel, the applicant used the Stanford equation. The ESBWR design does not use composite barriers, and therefore the applicant did not discuss them.

Regarding the overall damage predicted for a structure or barrier from missile impact, the applicant stated that it depends on the location of impact, dynamic properties of the structure/barrier and missile, and the kinetic energy of the missile. The applicant assumed that (1) the momentum of the missile is transferred to the structure or barrier, and (2) only a portion of the kinetic energy is absorbed as strain energy within the structure or barrier. The applicant stated that it determined an equivalent static load concentrated at the impact area after demonstrating that the missile does not perforate the structure or barrier. The applicant evaluated the static load on the impacted area using an analysis for rigid missiles similar to the Williamson and Alvy analysis in "Impact Effect of Fragments Striking Structural Elements," Holmes and Narver, Inc., issued November 1973.

3.5.3.3 *Staff Evaluation*

The staff reviewed the information provided by the applicant in Section 3.5.3 of DCD Tier 2 to determine if the barrier design procedures used in the ESBWR design meet the guidelines of SRP Section 3.5.3, Revision 1, issued July 1981, as well as GDC 2 and 4, with respect to the capabilities of the structures, shields, and barriers to provide sufficient protection to the safety-related SSCs.

In RAI 3.5-15, the staff made the following request:

> DCD, Tier 2, Section 3.5.3.1.1 states that ACI-349, Appendix C, Section C.7, "Special Provisions for Impulsive and Impactive Effects," was used to prevent perforation in the event of missile impact. RG 1.142 provides guidance to licensees and applicants on methods acceptable to the NRC staff for complying with the NRC's regulations in the design, evaluation, and QA of safety-related

> nuclear concrete structures, excluding concrete reactor vessels and concrete containments. This RG contains some exceptions to ACI-349 to reflect the existing review practices of the NRC staff. For example, part C.3.7.a of ACI-349 states that a ductility ratio of 1.3 is acceptable for shear carried by concrete alone. In contrast, RG 1.142, Regulatory Position C 10.4.1 states that a ductility ratio of 1.0 is acceptable for the same case. Confirm that all applicable provisions of RG 1.142, "Safety-Related Concrete Structures for Nuclear Power Plants (Other than Reactor Vessels and Containments)," including the permissible ductility ratio, are complied with in the ESBWR design. Otherwise, discuss the bases for exceptions taken with respect to RG 1.142.

In its response to RAI 3.5-15, the applicant stated that the ESBWR complies with the requirements of RG 1.142, including the permissible ductility ratio, and referred the staff to Table 1.9-21 of DCD Tier 2. The staff verified that the applicant had listed RG 1.142 as one of the NRC's RGs applicable to the ESBWR; therefore, the staff finds the response acceptable, and RAI 3.5-15 is resolved.

The applicant proposed to delete COL action items in DCD Revision 2, Sections 3.5.4.1 and 3.5.4.3, and to incorporate the discussion of these topics into a new Section 3.5.3.3. Section 3.5.3.3 clarifies that non-safety-related structures are either seismic Category II or NS. seismic Category II structures are designed not to collapse under tornado wind loads. The discussion of tornado design criteria for seismic Category II and NS SSCs is acceptable to the staff.

The staff noted an inconsistency between the tornado design parameters listed in DCD Table 2.0-1 and the minimum concrete barrier thickness referenced by the applicant in DCD Section 3.5.3.1.1. The applicant committed to satisfy the minimum concrete barrier thickness for Region II listed in Table 1 of SRP Section 3.5.3, Revision 1, which is compatible with a maximum tornado wind speed of 483 km/h (300 mph) in accordance with RG 1.76, Revision 0, issued April 1974. Since the maximum tornado wind speed for the ESBWR certified design is 531 km/h (330 mph), the staff considers the Region II minimum barrier thickness to be not conservative. The applicant revised DCD, Tier 2, Revision 4, Section 3.5.3.1.1, by committing to satisfy the minimum concrete barrier thickness of Region I listed in Table 1 of SRP Section 3.5.3. These values are acceptable to the staff because they are compatible with a maximum tornado wind speed of 579 km/h (360 mph), which exceeds the ESBWR design parameters.

In its response to RAI 3.8-64 S02, the applicant indicated that it had estimated the effects of impact loads generated by an automobile missile using the methods described in Bechtel topical report BC-TOP-9A, "Design of Structures for Missile Impact," Revision 2, issued 1974. The applicant also committed to changing DCD Section 3.5.3.2 in Revision 4 to include reference to the Bechtel topical report. The NRC staff confirmed that the applicant included reference to BC-TOP-9A in section 3.5.7 of the DCD. SRP Section 3.5.3.II.2 stipulates that missile impact analysis procedures other than those following the Williamson and Alvy analysis must be shown to produce results comparable to those reached by the Williamson and Alvy methods. The staff has accepted the missile impact evaluation methods delineated in BC-TOP-9A, which the staff considers adequate to meet SRP Section 3.5.3.II.2 requirements.

The staff finds that the procedures used by the applicant for determining the effects and loadings on seismic Category I structures, as well as on missile shields and barriers, induced by design-basis tornado missiles selected for the plant provide reasonable assurance that if a design-basis tornado missile should strike a seismic Category I structure or other missile shields and barriers, the structures, shields, and barriers will not be impaired or degraded to an extent that will result in a loss of required protection. Seismic Category I systems and components protected by these structures will, therefore, be adequately protected against the effects of missiles and will be capable of performing their intended safety functions. Conformance with these procedures is an acceptable basis for satisfying the requirements of GDC 2 and 4 as they relate to the capabilities of the structures, shields, and barriers to provide sufficient protection to equipment that must withstand the effects of natural phenomena (tornado missiles) and environmental effects, including the effects of missiles, pipe whipping, and discharging fluids.

3.5.3.4 *Conclusions*

Based on the above evaluation, the staff finds that the procedures used for determining the effects and loadings on seismic Category I structures, as well as on missile shields and barriers, induced by design-basis tornado missiles selected for the plant are acceptable because they provide a conservative basis for engineering design to ensure that the structures or barriers will adequately withstand the effects of such forces. This staff conclusion constitutes an acceptable basis for satisfying the requirements of 10 CFR Part 50, Appendix A, GDC 2 and 4.

3.6 Protection against the Dynamic Effects Associated with the Postulated Rupture of Piping

Section 6.2 of this report discusses plant design for protection against postulated piping failures in fluid systems inside of containment.

3.6.1 Plant Design for Protection against Postulated Piping Failures in Fluid Systems Outside of Containment

3.6.1.1 *Regulatory Criteria*

The staff reviewed the ESBWR design for protecting SSCs important to safety against piping failures in fluid systems outside containment in accordance with SRP Section 3.6.1, Revision 3. The staff's acceptance of the design is based on compliance with the following requirements:

- GDC 2 requires, in part, that SSCs important to safety be designed to withstand the effects of natural phenomena, such as seismically induced failures of NS piping.

- GDC 4 requires, in part, that SSCs important to safety be designed to accommodate the dynamic effects of postulated pipe rupture, including the effects of pipe whipping and discharging fluids.

- 10 CFR 52.47(b)(1) requires that a DC application contain the proposed ITAAC that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, a plant that incorporates the DC is built and will operate in accordance with the DC, the provisions of the Atomic Energy Act, and the NRC's regulations.

3.6.1.2 *Summary of Technical Information*

The ESBWR plant is designed in accordance with the guidance in SRP Section 3.6.1 for protection against piping failures outside containment to ensure that such failures do not cause the loss of needed functions of safety-related systems and to ensure that the plant can be safely shut down. The design considers failures of high-energy and moderate-energy fluid system piping located outside of containment. Where such a system penetrates containment, consideration starts with the first isolation valve outside of containment.

In DCD, Tier 2, Revision 7, Section 3.6.1, the applicant provided the design basis and criteria for the analysis needed to demonstrate that safety-related systems are protected from pipe ruptures. This DCD section identifies the high- and moderate-energy systems that are potential sources of the dynamic effects associated with pipe ruptures. It also defines criteria for separation and isolation by plant arrangement for the protection of safety-related SSCs. The applicant conducted an analysis to identify those safety-related SSCs required to mitigate to acceptable limits the consequences of the pipe break events postulated outside the containment. DCD Table 3.6-2, "Safety-Related Systems, Components, and Equipment for Postulated Pipe Failures Outside Containment," identifies the safety-related SSCs, and DCD Table 3.6-4, "High and Moderate Energy Piping Outside Containment," identifies the high- and moderate-energy fluid systems.

3.6.1.3 *Staff Evaluation*

The staff reviewed the ESBWR design for protecting SSCs important to safety against piping failures in fluid systems outside containment in accordance with the guidance of SRP Section 3.6.1. The staff reviewed DCD, Tier 2, Revision 7, Section 3.6.1. The staff also reviewed DCD, Tier 1, Revision 7, Sections 2.0 and Section 3.0, and other DCD Tier 2 sections noted below.

Compliance with GDC 2 and GDC 4 is based on meeting the guidance of Positions B.1, "Plant Arrangement," B.2, "Design Features," and B.3, "Analyses and Effects of Postulated Piping Features," in Branch Technical Position (BTP) 3-3, "Protection against Postulated Piping Failures in Fluid Systems Outside Containment," Revision 3.

Compliance with GDC 2 and GDC 4 is also based on meeting the guidance of the following SECY-94-084:

- SECY-94-084, "Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems (RTNSS) in Passive Plant Designs," provides guidance as to which systems should be RTNSS and would call for enhanced design requirements.

In DCD, Tier 2, Revision 7, Section 3.6.1.3, the applicant stated that an analysis of pipe break events involving high-energy fluid systems is being performed to evaluate the effects of pipe whip, jet impingement, flooding, room pressurization, and other environmental effects such as temperature. Pipe break events involving moderate-energy fluid systems are evaluated for wetting from spray, flooding, and other environmental effects. The following assumptions are made to determine the operability of systems and components and the protection requirements:

- Pipe break events may occur during normal plant conditions (i.e., reactor startup, operation at power, normal hot standby or reactor cooldown to cold shutdown conditions but excluding test mode).

- A pipe break event may occur simultaneously with a seismic event; however, a seismic event does not initiate a pipe break event. This applies to seismic Category I and NS Category I piping (seismically analyzed).

- A single active component failure (SACF) is assumed in systems used to mitigate consequences of the postulated piping failure and to shut down the reactor.

- Where the postulated piping failure is assumed to occur in one of two or more redundant trains of a dual-purpose, moderate-energy safety-related system (i.e., one required to operate during normal plant conditions as well as to shut down the reactor and mitigate the consequences of the piping failure), only a single active failure of components in the other train or trains of that system is assumed, provided that the system is designed to seismic Category I standards; is powered from both offsite and onsite sources; and is constructed, operated, and inspected according to QA testing and ISI standards appropriate for nuclear safety-related systems.

- If a pipe break event involves a failure of NS Category I piping, the pipe break event must not result in failure of safety-related systems, components, and equipment to shut down the reactor and mitigate the consequences of the pipe break event in the case of an SACF.

- If loss of preferred power (LOPP) is a direct consequence of the pipe break event (e.g., a trip of the turbine generator produces a power surge that, in turn, trips the main breaker), then a LOPP occurs in a mechanistic time sequence with an SACF. Otherwise, preferred power is assumed available with an SACF.

- A whipping pipe was not capable of rupturing impacted pipes of equal or greater nominal pipe diameters, but might develop through-wall cracks in equal or larger nominal pipe sizes with thinner wall thickness.

- All available systems, including those actuated by operator actions, are able to mitigate the consequences of a failure. In judging the availability of systems, account is taken of the postulated failure and its direct consequences, such as unit trip and LOPP, and the assumed SACF and its direct consequences. The feasibility of carrying out operator actions is based on the availability of ample time and adequate access to equipment for the proposed actions.

- Although a pipe break event outside the containment may require a cold shutdown, the evaluation allows up to 8 hours in hot standby for plant personnel to assess the situation and make repairs.

- Pipe whip with rapid motion of pipe resulting from a postulated pipe break occurs in the plane determined by the piping geometry and causes movement in the direction of the jet reaction. If unrestrained, a whipping pipe with a constant energy source forms a plastic hinge and rotates about the nearest rigid restraint, anchor, or wall penetration. If unrestrained, a whipping pipe without a constant energy source (i.e., a break at a closed valve with only one side subject to pressure) is not capable of forming a plastic hinge and rotating about the hinge, provided that its movement can be defined and evaluated.

- The fluid internal energy associated with the pipe break reaction can be affected by any line restrictions (e.g., flow limiters) between the pressure source and break location and absence of energy reservoirs, as applicable.

- All structural divisional separation walls are designed to maintain their structural integrity after a postulated failure outside containment and within the RB. Divisional separation doors, penetration, and floors are not required to maintain their structural integrity.

Based on its review, the staff finds the above assumptions used in the applicant's evaluation of piping failure events acceptable because they are consistent with the guidance of Position B.3 in BTP 3-3.

Also, in DCD, Tier 2, Revision 7, Section 3.6.1.3, the applicant stated that the direct effects associated with a particular postulated break or crack are mechanistically consistent with the failure. Thus, actual pipe dimensions, piping layouts, material properties, and equipment arrangements are considered in defining the specific measure for protection against actual pipe movement and other associated consequences of postulated failures. Safety-related SSCs will be protected against piping failure, in accordance with the guidance of SRP Section 3.6.1, by one or more of the methods described below.

<u>Protection Methods by Separation</u>

The plant arrangement provides physical separation, to the extent practicable, to maintain the independence of redundant safety-related systems (including their auxiliaries) and thereby prevent the loss of safety function caused by any single postulated event. Redundant trains (e.g., A and B trains) and divisions are located in separate compartments to the extent possible. Physical separation between redundant safety-related systems with their related auxiliary supporting features is thus the basic protective measure incorporated in the design to protect against the dynamic effects of postulated pipe failures. If spatial separation requirements (distance and/or arrangement to prevent damage) cannot be met based on the postulation of specific breaks, then barriers, enclosures, shields, or restraints are provided.

<u>Barriers, Shields, and Enclosures</u>

In many cases, protection requirements are met through the protection afforded by the walls, floors, columns, abutments, and foundations. Where spatial separation or existing plant features do not already provide adequate protection, additional barriers, deflectors, or shields are identified as necessary to meet the functional protection requirements. Barriers or shields that are identified as necessary by the use of specific break locations are designed for the specific loads associated with the particular break location. The main steam isolation valves and the feedwater isolation and check valves located inside the tunnel will be designed for the effects of a line break. Barriers or shields identified as necessary by the high-energy line separation analysis (i.e., based on no specific break locations) are designed for worst-case loads. The closest high-energy pipe location and resultant loads are used to size the barriers.

<u>Pipe Whip Restraints</u>

Pipe whip restraints are used where pipe break protection requirements cannot be satisfied using spatial separation, barriers, shields, or enclosures alone. Restraints are located based on the specific break locations determined in accordance with DCD, Tier 2, Revision 6, Section 3.6.2.1. After the restraints are located, the piping and safety-related systems are evaluated for jet impingement and pipe whip. For those cases where jet impingement damage could still occur, the applicant used barriers, shields, or enclosures. DCD, Tier 2, Revision 6, Section 3.6.2.3, gives the design criteria for restraints.

Based on its review, the staff finds the above approach to protecting safety-related SSCs against the effects of pipe break events acceptable, because it is consistent with the guidance of Positions B.1 and B.2 in BTP 3-3 regarding plant arrangement and design features, respectively.

Section 3.6.2 of this report addresses the staff's evaluation of break and crack sizes, configurations, and locations, including the review of the ITAAC items listed in Table 3.1-1 of DCD, Tier 1, Revision 7, Section 3.1.

During the review of the earlier DCD versions, the staff identified issues regarding the lack of information on missile protection for RTNSS SSCs resulting from piping failures. Therefore, as part of RAI 22.5-5, the staff requested that the applicant address this concern.

In its response to RAI 22.5-5, the applicant added a new section (19A – Regulatory Treatment of Non-Safety Systems) in DCD, Revision 5 In this new Section 19A, the applicant provided Tables 19A-3 and 19A-4. In Table 19A-3, the applicant identified the RTNSS SSCs, together with their associated RTNSS criteria, locations (buildings), and building category. In Table 19A-4, the applicant identified how the RTNSS in each area (building) are protected from internal flooding, external flooding, internal missiles, and extreme wind and missiles resulting from events such as piping failures, extreme wind, and tornadoes. The staff found the applicant's response to RAI 22.5-5 inadequate. Specifically, the applicant did not provide sufficient details about the design of the protection provided for RTNSS against internal missiles and extreme wind missiles. Subsequently, as part of supplemental RAI 22.5-5 S01, the staff asked the applicant to provide a detailed description of the design and installation of each RTNSS and discuss how this design and installation would protect the RTNSS SSCs against the effects of internal and/or external flooding.

In its response to RAI 22.5-5 S01, the applicant stated that:

- RTNSS components are located and installed above the maximum analyzed flood levels in each of the buildings referenced. This requirement is incorporated in the Design Specifications and implemented during the detailed design to ensure protection of the RTNSS components against internal flooding.

- The maximum flood level for the ESBWR is 1 ft below the finished grade per DCD, Tier 2, Revision 5 Table 2.0-1. The maximum groundwater level is 2 ft below the finished grade. The plant service water system located outdoors is designed with protection from water intrusion if installed below the maximum flood and groundwater levels. This includes designing for hydrostatic loading and provision of cell enclosures. These requirements are incorporated in the Design Specifications and implemented during detailed design.

The staff found applicant's responses to RAI 22.5-5 and RAI 22.5-5 S01 acceptable providing that DCD Tier 1, would have design descriptions and ITAACs to ensure that RTNSS systems would be protected against the dynamic effects including flooding and missiles associated with the postulated rupture of piping. Therefore, in supplemental RAI 22.5-5 S02 the staff requested the applicant to provide ITAACs in DCD, Tier 1, Section 2.0, "Design Descriptions and ITAAC," to ensure that RTNSS systems will be protected against the dynamic effects including flooding and missiles associated with the postulated rupture of piping.

In its response to RAI 22.5-5 S02, the applicant stated that ESBWR DCD, Revision 5, will be revised to include ITAACs as marked in the response for RTNSS to ensure that the RTNSS systems will be protected against dynamic effects including flooding and missiles associated with both high and moderate-energy fluid piping and component failures inside and outside containment. The staff found the applicant's response to RAI 22.5-5 S02 acceptable and complies with the requirements of 10 CFR 52.47(b)(1). Therefore, the staff considers its concerns as described in RAI 22.5-5, RAI 22.5-5 S01 and RAI 22.5-5 S02 resolved. The staff has confirmed that DCD Tier I and Tier 2, Revision 6, were revised as committed in the RAI responses.

3.6.1.4 *Conclusions*

Based on its review of the information provided in DCD Tier 1 and Tier 2 and the evaluation discussed above, the staff finds that the ESBWR design for protecting SSCs important to safety and RTNSS against the effects associated with postulated piping failures in fluid systems outside containment is in accordance with the guidelines of Positions B.1, B.2, and B.3 of BTP 3-3. Therefore, the staff concludes that the ESBWR design complies with the requirements of GDC 2 and 4 with respect to protecting SSCs important to safety and RTNSS against the effects associated with postulated piping failures in fluid systems outside containment and that it meets the guidelines described in SRP Section 3.6.1, Revision 3.

3.6.2 Determination of Pipe Break Locations and Dynamic Effects Associated with the Postulated Rupture of Piping

3.6.2.1 *Regulatory Criteria*

The staff reviewed DCD, Tier 2, Section 3.6.2, "Determination of Break Locations and Dynamic Effects Associated with the Postulated Rupture of Piping," in accordance with SRP Section 3.6.2, Revision 2, "Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping." In addition, this review included DCD, Tier 2, Section 3.6.4, "As-Built Inspection of High-Energy Pipe Break Mitigation Features"; Section 3.6.5, "COL Information"; Appendix 3D, "Computer Programs Used in the Design of Components, Equipment and Structures"; and Appendix 3J, "Evaluation of Postulated Ruptures in High Energy Pipes." The applicant's pipe break location criteria and method of analysis used to evaluate the dynamic effects associated with postulated pipe breaks and cracks in high- and moderate-energy fluid system piping inside and outside the primary containment are acceptable if they meet codes, standards, and regulatory guidance documents recommended by the staff. This will ensure that the relevant requirements of GDC 4, "Environmental and Dynamic Effects Design Bases," are met.

GDC 4 requires that nuclear power plant SSCs important to safety be designed to accommodate the effects of, and be compatible with, environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including loss-of-coolant accidents (LOCAs). These SSCs are to be protected against the effects of pipe whip and discharging fluids.

The NRC has established requirements in BTP 3-4, Postulated Rupture Locations in Fluid System Piping Inside and Outside Containment, March 2007, which contains the criteria for defining postulated rupture locations in fluid system piping inside and outside the containment. The staff based its evaluation of DCD, Tier 2, Section 3.6.2.1, on the criteria provided in this BTP.

3.6.2.2 *Summary of Technical Information*

To address the GDC 4 requirements, the applicant described the following items in DCD, Tier 2, Section 3.6.2:

- design bases for locating postulated breaks and cracks in high- and moderate-energy piping systems inside and outside the containment

- procedures used to define the jet thrust reaction of the fluid at the break location, the pipe whipping of the ruptured pipe, and the jet impingement loading on adjacent essential SSCs

- design criteria for pipe whip restraints, jet impingement barriers and shields, and guard pipes

The applicant listed the safety-related SSCs in DCD, Tier 2, Table 3.6-1, for inside containment, and Table 3.6-2, for outside containment. The applicant also listed all high-energy systems in an ESBWR plant that are subject to a postulated pipe break in DCD, Tier 2, Table 3.6-3, for high-energy piping inside containment, and Table 3.6-4, for high-energy piping outside containment.

In DCD, Tier 2, Section 3.6.2.1, the applicant defined the postulated pipe break as a sudden gross failure of the pressure boundary either in the form of a complete circumferential severance (i.e., guillotine break) or a sudden longitudinal split without pipe severance. Such pipe breaks are postulated for high-energy fluid systems only. The effects of such a pipe break include pipe whip, jet impingement, flooding, room pressurization, and other environmental effects such as temperature and humidity. On the other hand, postulated through-wall pipe leakage cracks in piping and branch runs, applicable to moderate-energy fluid systems, affect the surrounding environmental conditions and do not result in whipping of the cracked pipe. The effects of such a pipe crack in moderate-energy systems include water spray, flooding, and other environmental effects.

3.6.2.2.1 Criteria Used To Define Pipe Break and Crack Locations and Configurations

In DCD, Tier 2, Section 3.6.2.1, the applicant provided the criteria for defining the location and configuration of postulated pipe breaks and leakage cracks. Section 3.6.2.1.1 provides criteria for the postulated pipe break locations for piping meeting spatial separation requirements, piping in containment penetration areas, and piping that is not designed in accordance with the American Society of Mechanical Engineers Boiler and Pressure Vessel (BPV) Code (referred to as the ASME Code). For a structure separating a high-energy line from a safety-related component, the applicant stated that the separating structure will be designed to withstand the consequences of the pipe break in the high-energy line at locations postulated on the basis of these criteria. However, some structures that are identified as necessary by the high-energy line separation analysis (HELSA), which is based on no specific pipe break locations, are designed for worst-case loads. Section 3.6.2.1.2 provides criteria for postulated pipe crack locations for piping meeting separation requirements, high-energy piping, moderate-energy piping in containment penetration and other areas, and moderate-energy piping in proximity to high-energy piping. Finally, Section 3.6.2.1.3 provides criteria for defining the types of pipe breaks (i.e., break configuration) postulated in high-energy fluid system piping and the postulated through-wall leakage crack configurations in both high- and moderate-energy fluid systems or portions of systems.

3.6.2.2.2 Analysis Methods To Define Blowdown Forcing Functions and Response Models

In DCD, Tier 2, Section 3.6.2.2, the applicant discussed criteria for the analytical methods to be used to calculate the blowdown forcing function. The blowdown force is characterized as a function of time and space, and it depends on fluid state within the pipe before rupture, break flow area, frictional losses, plant system characteristics, piping system, and other factors. The applicant originally stated that these forcing functions are determined for the ESBWR by the method specified in Appendix B to American National Standards Institute/American Nuclear Society (ANSI/ANS) 58.2-1988 (ANS 58.2), “Design Basis for Protection of Light Water Nuclear Power Plants Against the Effects of Postulated Pipe Rupture.” Paragraph 6 of ANS 58.2 provides the mathematical equations for evaluating pipe whip and pipe internal load effects on the ruptured piping system. In addition, DCD Section 3.6.2.1.3 provides other requirements for configuring the breaks and cracks, consistent with BTP 3-4, Item B.3, to calculate the blowdown force acting on the ruptured pipe. In addition, in its response to the staff RAIs concerning jet expansion modeling, the applicant submitted Technical Report 0000-0105-2955-R6,ESBWR MSLB CFD Modeling: Jet Impingement During High Energy Line Breaks, dated March 25, 2010, as Appendix B in GEH Licensing Topical Report NEDE-33440P which is referenced in DCD, Tier 2, Section 3.6.2.3.1. The summary of the information provided in the Technical Report 0000-0105-2955-R6 is addressed in Section 3.6.2.2.3.1 of this report.

In DCD, Tier 2, Section 3.6.2.2, the applicant also discussed the criteria for dynamic response analyses of the ruptured piping system to evaluate the potential for pipe whip and to establish the pipe whip restraint and associated structural loads. The piping response when subject to the pipe blowdown thrust force occurring after a pipe break is analyzed using the piping dynamic analysis (PDA) computer code and a pipe break modeling program using the commercially available computer code ANSYS. Appendix 3D to DCD Tier 2 discusses these computer codes. The PDA computer program predicts the response of a pipe subjected to the thrust force occurring after a pipe break, while the ANSYS computer program is used to perform nonlinear stress analysis of a piping system for time-varying displacements and forces resulting from the postulated pipe break.

In addition, in Appendix 3J to DCD Tier 2, the applicant provided a procedure for evaluating postulated ruptures in high-energy pipes based on the use of analytical methodology, computer programs, and pipe whip restraints. This appendix presents a step-by-step procedure to evaluate a pipe rupture event at an ESBWR plant. The procedure provides guidance for (1) identification of rupture location and rupture geometry, (2) design and selection of pipe whip restraints, (3) pipe rupture evaluation, and (4) jet impingement on safety-related SSCs. The procedure includes only U-bar-type whip restraints and simplified computer models of the piping and pipe whip restraints. Using the pipe thrust load and the pipe’s physical and material characteristics, the PDA computer program calculates the displacements of the pipe and pipe whip restraint, pipe whip U-bar strains, pipe forces and moments at fixed end, time at peak load, and lapsed time to achieve steady state. The two approaches presented are dynamic time-history analysis with a simplified model and dynamic time-history analysis with a detailed piping model.

3.6.2.2.3 Dynamic Analysis Methods To Verify Integrity and Operability

In DCD, Tier 2, Section 3.6.2.3, the applicant provided the methods to perform dynamic analyses of a ruptured pipe and its jet impingement and whipping effects on safety-related SSCs.

3.6.2.2.3.1 Jet Impingement Analyses and Effects on Safety-Related Structures, Systems, and Components

A circumferential or longitudinal break in a high-energy line could result in a jet of fluid emanating from the breakpoint. In many cases, the dominant jet loads are quasi-static after an initial ramp-up and slowly decrease during blowdown of the source liquid. In some cases, however, when the distance between the ruptured pipe and target is less than 10 diameters of the source pipe, instabilities and feedback mechanisms lead to strong oscillating loads. These dynamic loads typically occur at a nondimensional frequency (frequency*diameter/jet velocity) between 0.3 and 0.5 and can be two or three times the amplitude of the static load component. Blast loads also occur immediately following a pipe rupture, and should also be accounted for. Safety-related SSCs should be protected or designed to withstand the static and dynamic loads induced by the impingement of jets, as well as the blast loads emanated from the pipe rupture.

In DCD, Tier 2, Section 3.6.2.3.1, the applicant discussed methods for evaluating the fluid jet impingement loads on safety-related SSCs, including jet shape, direction, and pressure distribution within the jet plume resulting from the postulated breaks in high-energy piping. For a pipe break where the absence of an energy reservoir upstream or downstream of the break does not result in a continuous jet blowdown, the methods are commensurate with those given in Appendices C and D to ANS 58.2, which describe simplified models for defining the geometry and direction of a jet discharging from a pipe break, along with simplified methods of defining the jet impingement force, including impingement load, temperature, and moisture content with the following two exceptions. The applicant included additional simplifications in its analytical methods for determining impingement loads, assuming that the pressure distribution throughout a jet plume cross-section is uniform. In DCD, Tier 2, Section 3.6.2.2, the applicant stated that all jet loads are assumed to be time and distance invariant and are equal in magnitude to the steady-state blowdown force. In addition, in Appendix 3J to DCD Tier 2, the applicant explained that when multiple jet loads impinge on a single structure, each load is considered independently, and the load generating the largest bending moments at each piping joint is used for evaluation. Appendix 3J also explains that static and dynamic components of jet loads are considered separately, and that when the effects of dynamic loads are analyzed using static methods, a factor of 2 is applied to the static analysis results.

Furthermore, the applicant stated that, on a case-by-case basis, a quantitative analysis approach to determine the dynamic jet force is necessary where jet characteristics, such as jet nonlinearity, turbulence, feedback amplification, and jet reflection, are deemed significant in the jet modeling. For this purpose, other dynamic analysis methods are appropriate such as computational fluid dynamic (CFD) analysis. This method of analysis is capable of defining parameters associated with the jet flow properties, ambient conditions, and surface profile of the interacting targets. The resulting force time history and jet pressures on the target surface are obtained from such CFD analysis.

The applicant describes its detailed jet analysis evaluation method in this DCD subsection, citing GEH Licensing Topical Report NEDE-33440P and Technical Report 0000-0105-2955-R6. The applicant will use a thermal-hydraulic code, such as RELAP5 or TRACG to compute the fluid conditions at the sources of postulated jets. These conditions will be applied to FLUENT compressible CFD calculations of the time histories of the static and dynamic jet loads. The calculations include the possibility of load amplification caused by feedback between acoustic waves reflected from the target and vortices shed from the pipe break. The applicant has conducted two-dimensional benchmark calculations of (a) a jet load amplification case, based on the measurements of Ho and Nosseir (Journal of Fluid Mechanics, Vol. 105, pp. 119-142, 1981) and (b) a prototypic ESBWR Main Steam Line break in GEH Technical Report 0000-0105-2955. Based on its calculations, the applicant concluded that their calculation procedure is conservative, based on the Ho and Nosseir benchmark, and also provides three-dimensional modeling and analysis procedures in their ESBWR MSL break benchmark that they plan to apply to future ESBWR design calculations. The applicant stated that, the procedures will ensure that worst-case jet loadings will be applied to impinged-upon structures based on uncertainties in modeling and boundary conditions. Finally, the applicant provides in DCD, Tier 2, Tables 3.6-5, 3.6-6, and 3.6-7 that explain which postulated pipe breaks will be analyzed using the applicant's CFD approach. Several breaks will be evaluated using bounding calculations for geometrically similar conditions, or with scaled calculations.

The pressures induced by the initial blast waves emanated by postulated pipe ruptures will also be simulated using CFD analysis. The applicant provided a Technical Report-(0000-0102-6265-R0), which describes in detail the modeling procedure they plan to apply to ESBWR blast wave calculations. The applicant demonstrates a calculation of a blast wave induced by a high energy line break inside containment of ESBWR feedwater piping. The blast wave propagates into the annular region between the reactor pressure vessel (RPV) and the shield wall, and reflects between the boundaries of the annulus. The applicant stated that a two dimensional (2D) approximation of the annulus is conservative by comparing 2D pressure amplitudes with those computed using a three dimensional (3D) model. Since the 2D loads are significantly higher than those that would occur in a 3D analysis, the applicant plans to use 3D analysis approaches, identical to those used in the 2D analysis, for ESBWR design. The applicant stated that it will ensure that converged, worst-case loading scenarios will be applied to all SSCs and neighboring structures when using their 3D analysis approach. In addition, the analyses will be conducted early and late during the blowdowns, spanning jet discharge Mach numbers of 4 to 0.3. Also, the applicant will benchmark their 3D analysis approach prior to applying it to ESBWR designs.

Once blast and jet impingement loading time histories are computed, the applicant will apply them to finite element (FE) models of the structures and components impinged upon by the jets. To account for uncertainty in the frequencies of resonance simulated by the applicant's finite element models, the applicant will stretch and compress their loading time histories in 2.5 percent increments spanning an uncertainty range of +/-10 percent. Finally, the applicant will assess the possibility of structural resonance feedback on impinging jets and include those effects in their design assessments if applicable.

3.6.2.2.3.2 Pipe Whip Effects on Safety-Related Structures, Systems, and Components and Loading Combinations and Design Criteria for Pipe Whip Restraint

In DCD, Tier 2, Section 3.6.2.3.2, the applicant provided criteria and methods used to evaluate the effects of pipe displacement following a postulated pipe rupture resulting from pipe break whip loads on components (e.g., nozzles, valves, tees, supports) on the ruptured pipe run and on other safety-related SSCs such as building structures, other piping systems, conduits, and equipment. Components on the ruptured pipe need not be designed to meet ASME Code, Section III, design requirements for safety-related components under Service Level D (i.e., faulted) loading unless they are required for safe shutdown of the reactor or to protect the structural integrity of a safety-related component. The applicant also stated that if the components are designed in accordance with the ASME Code, meeting the ASME Code requirements for faulted conditions ensures meeting the required operability of the ruptured piping system.

In DCD, Tier 2, Section 3.6.2.3.3, the applicant provided load combinations and criteria for designing pipe whip restraints. These include the design requirements of one type of whip restraint design (U-bar type). The material characteristics of the whip restraint conform with the requirements of paragraph 6.6 of ANS 58.2.

The applicant also stated that in an ESBWR plant, the piping integrity does not depend on the pipe whip restraint and the piping will remain functional following an earthquake up to and including the SSE. The pipe whip restraints are non-ASME Code components; however, the ASME Code requirements may be used selectively in the design to ensure the components' safety-related function if ever needed. Other methods (i.e., testing) with a reliable database for design and sizing of whip restraints may also be used. For the purpose of pipe whip restraint design, the pipe break is considered to be a faulted condition, and the supporting structure to which the restraint is attached is analyzed and designed accordingly. Since these restraints serve only to control the movement of a ruptured pipe following a pipe break, they are designed for a once-in-a-lifetime loading.

In Section 3J.5 of Appendix 3J to DCD Tier 2, the applicant provided the load combination for combining the stresses produced by the jet impingement load (a faulted load) with those produced by the SSE load. Stresses produced by the dynamic part of the jet impingement load are combined by the square root of the sum of squares method with the stresses caused by the SSE. However, stresses produced by the static part of the load are combined with SSE stresses by absolute sum. The applicant also noted that snubbers in the piping system are considered activated during the analysis of the dynamic part, while they remain not activated during the analysis of the static part.

3.6.2.2.4 Guard Pipe Assembly Design

In DCD, Tier 2, Section 3.6.2.4, the applicant stated that the ESBWR does not require guard pipes. However, in Section 3.6.2.1.1 for piping in containment penetration areas, the applicant used sleeves for those portions of the piping in the containment penetration areas designed in accordance with BTP3-4, Item B.1.b(6).

3.6.2.2.5 Pipe Break Analysis Results and Protection Methods

In DCD, Tier 2, Section 3.6.2.5, the applicant outlined the information to be included in a pipe break evaluation report which will be completed in conjunction with closure of inspections, tests, analyses, and acceptance criteria (ITAAC) Tier 1, Table 3.1-1, related to the pipe break analysis report.

3.6.2.2.6 Analytic Methods To Define Blast Wave Interaction to Structures, Systems, and Components

In DCD, Tier 2, Section 3.6.2.6, the applicant stated that SSCs are evaluated for the blast wave effects. The blast effects are evaluated from all break types such as for the circumferential and longitudinal breaks for high- and moderate-energy piping systems. The applicant also described the wave propagation of a blast wave resulting from a pipe rupture occurring in an open space and in an enclosed space.

3.6.2.2.7 As-Built Inspection of High-Energy Pipe Break Mitigation Features

In DCD, Tier 2, Section 3.6.4, the applicant stated that there will be an as-built inspection of the high-energy pipe break mitigation features for the ESBWR plant. The as-built inspection will confirm that SSCs that are required to be functional during and following an SSE are protected against the dynamic effects associated with high-energy pipe breaks. An as-built inspection of pipe whip restraints, jet shields, structural barriers, and physical separation distances will also be performed. In DCD Section 3.6.2.1.1, the applicant provided criteria for as-built inspections that result in significant changes in the original pipe break postulation and/or require changes in the original mitigation features (i.e., pipe whip restraint and jet shields).

3.6.2.3 *Staff Evaluation*

To meet the requirements of GDC 4, the NRC requires, in part, that SSCs important to safety be designed to be compatible with, and to accommodate, the effects of the environmental conditions resulting from postulated pipe rupture accidents, including LOCAs. The NRC also requires that such SSCs be adequately protected against dynamic effects (including the effects of pipe whipping and discharging fluids) that may result from postulated pipe rupture events.

In accordance with SRP Section 3.6.2, draft Revision 2, and BTP MEB 3-1, the staff reviewed the proposed criteria and methodology presented by the applicant in DCD, Tier 2, Section 3.6.2, and other associated sections and appendices. The COL applicant for an ESBWR plant can use these criteria and methods to analyze pipe breaks in high- and moderate-energy fluid systems and to ensure adequate protection against the dynamic effects that would occur on adjacent safety-related SSCs with regard to pipe whip and jet impingement loadings. The staff’s evaluation includes the following:

- definition of pipe break and leakage crack locations
- analysis methods to define blowdown forcing functions and pipe response models
- dynamic analysis methods to verify pipe integrity and operability, including the effects of jet impingement on neighboring SSCs including blast wave evaluation
- guard pipe assembly design
- pipe break analysis results and protection methods
- as-built inspection of high-energy pipe break mitigation features

3.6.2.3.1 Criteria Used To Define Pipe Break and Crack Locations and Configurations

In DCD, Tier 2, Section 3.6.2.1, the applicant provided the criteria for defining high- and moderate-energy piping systems applicable to an ESBWR plant. The staff noted that the criteria in the DCD for the definition of high- and moderate-energy piping systems are not consistent with the criteria in Appendix A to BTP 3-3, Protection Against Postulated Piping Failures in Fluid Systems outside Containment, March 2007. The operating temperature that separates the high-energy piping from moderate-energy piping is slightly different in Appendix A to BTP 3-3 than in the DCD. Appendix A to BTP 3-3 defines this temperature to be 95 degrees Celsius (C), while the DCD identifies it to be 93.3 degrees C. However, both have the same values when expressed in their corresponding Fahrenheit (F) values of 200 degrees F, and the DCD value in degrees C corresponds exactly to this value. The staff finds that this will have no impact on defining the high- and moderate-energy piping systems for the ESBWR design. On this basis, the staff concludes that the definitions of high- and moderate-energy systems are consistent with those of Appendix A to BTP 3-3, and the definition for the maximum operating temperature in DCD, Tier 2, Section 3.6.2.1, is acceptable.

In DCD, Tier 2, Tables 3.6-3 and 3.6-4, the applicant identified high-energy piping systems inside and outside the containment that are subject to postulated pipe breaks. However, the applicant did not identify the moderate-energy systems for both inside and outside the containment applicable to an ESBWR plant. In RAI 3.6-2, the staff requested that the applicant identify moderate-energy systems that will be subject to postulated leakage cracks in accordance with SRP Section 3.6.1 and BTP3-3 and will be used by the COL applicant, or provide reasons for not including them in the DCD for design certification. In response to RAI 3.6-2, the applicant provided revised copies of DCD Section 3.6.1.2, Tables 3.6-3 and 3.6-4, which include the systems categorized as moderate-energy piping systems both inside and outside the containment. The staff verified that the applicant revised DCD, Tier 2, Revision 6, Section 3.6.1.2, and listed the moderate-energy piping systems subject to postulated leakage cracks in DCD, Tier 2, Revision 6, Tables 3.6-3 and 3.6-4. Since Tables 3.6-3 and 3.6-4 in DCD, Tier 2, Revision 6, identify both high- and moderate-energy piping systems of an ESBWR standard plant for both inside and outside the containment, subject to pipe breaks or leakage cracks in accordance with SRP Section 3.6.1, the staff finds this acceptable. Therefore, RAI 3.6-2 was resolved.

In DCD, Tier 2, Section 3.6.2.1, the applicant stated that portions of piping systems that are isolated from the source of the high-energy fluid during normal plant conditions in accordance with the separation criteria established in DCD, Tier 2, Section 3.6.1.3, are exempt from consideration of postulated pipe breaks. The applicant also stated that for other areas where physical separation is not possible, a HELSA is performed to determine which high-energy lines meet the separation requirement and which lines require further protection. In addition, portions of piping systems beyond normally closed valves and pump and valve bodies, because of their larger wall thicknesses, are also exempt from consideration of pipe breaks. This is consistent with the requirements given in BTP 3-4, Item B.1; therefore, the staff finds this acceptable.

In DCD, Tier 2, Section 3.6.2.1, the applicant provided the criteria that use maximum stresses, stress ranges, and usage factors of the piping system to define pipe break and crack locations and their configurations. In DCD, Tier 2, Section 3.7, the applicant stated that the ESBWR OBE ground motion is one-third of the SSE ground motion. and DCD Sections 3.7.3 and 3.7.4 address the effects of low-level earthquakes (of lesser magnitude than the SSE) on fatigue evaluation and plant shutdown criteria, respectively. The ESBWR design does not include the OBE load in the piping design. The applicant further stated that this is consistent with 10 CFR Part 50, Appendix S, the design requirements associated with the OBE when the level of OBE ground motion is chosen to be one-third of the SSE ground motion are satisfied without the performance of explicit response or design analyses.

In Appendix S to 10 CFR Part 50, the staff approves the elimination of the OBE in the design process of a plant on the basis that its elimination would not significantly decrease the overall plant safety margin. Furthermore, the staff concluded that no replacement earthquake loading should be used to establish the locations of the postulated pipe ruptures and leakage cracks once the OBE is eliminated from the design. The staff also concluded that the criteria for postulating pipe ruptures and leakage cracks in high- and moderate-energy piping systems should be based on factors attributed only to normal and operational transients. However, for establishing pipe breaks and leakage cracks from fatigue effects, the staff concluded that calculation of the CUF should continue to include seismic cyclic effects. As described above, the ESBWR is not explicitly designed for OBE loads. In RAI 3.6-1, the staff asked the applicant to clarify whether criteria used in determining postulated high- and moderate-energy pipe break and leakage crack locations for the ESBWR design are consistent with the above staff position. In response to RAI 3.6-1, the applicant stated that DCD Section 3.7.3.2 will be used to define the seismic cycle requirements for fatigue analysis. Also, Equations 9, 10, and 11 in the ASME Code Class 1 criteria for piping design will not consider OBE since SSE is the only design earthquake considered for the ESBWR standard plant. All the cumulative fatigue usage factors should be less than 0.4 to meet the no-postulated-pipe-break criteria. This is consistent with the guidelines given in BTP 3-4, Item B.1.b(1)(b). The staff finds this acceptable; therefore, RAI 3.6-1 was resolved.

Item B.1.c(5) in BTP 3-4 states that safety-related equipment must be environmentally qualified in accordance with SRP Section 3.11. Required pipe breaks and leakage cracks must be part of the design bases for defining the qualifying environment for these components both inside and outside the containment. In RAI 3.6-3, the staff requested that the applicant clarify whether the design bases for environmental qualification of safety-related equipment include consideration of the environment resulting from pipe breaks or leakage cracks. In response to RAI 3.6-3, the applicant stated that the design bases for environmental qualification of safety-related equipment in an ESBWR plant include the consideration of the environment resulting from pipe breaks or leakage cracks. The applicant also suggested a revision of DCD Section 3.11.2.1 to state that no chemical sprays are applicable to the ESBWR. The staff verified that the applicant revised Section 3.11.2.1 in DCD, Tier 2, Revision 2, to include the accident environment profiles (i.e., pressure, temperature, radiation) and operating service conditions for environmental qualification of safety-related equipment. The staff noted that in Revision 5 of the DCD, the applicant completely revised Section 3.11, “Environmental Qualification of Mechanical and Electrical Equipment,” to address some of the staff’s other concerns in this subject area. In defining the environmental conditions in Revision 5 of DCD Section 3.11.3, the applicant appropriately identified the conditions to which the equipment is exposed, including the worst-case design-basis accidents (DBAs), such as pipe breaks. Since this would ensure that the environmental conditions resulting from pipe breaks or leakage cracks will be considered for the environmental qualification of safety-related equipment, the staff finds this change acceptable. Therefore, RAI 3.6-3 was resolved.

Item B.1.d in BTP 3-4 states that in complex systems, such as those containing arrangements of headers and parallel piping running between headers, the designer should identify and include all such piping within the designated run so as to postulate the number of breaks required by the criteria in Item B.1.c. In RAI 3.6-4, the staff asked the applicant to clarify whether this criterion is applicable to the ESBWR for identifying pipe break locations. The applicant responded to RAI 3.6-4 that the criterion in BTP 3-4, Item B.1.c, applies to the ESBWR for identification of pipe breaks, as summarized in DCD Section 3.6.2.1.1. However, the RAI was related to BTP MEB 3-1, Item B.1.d, and the applicant has not provided the information requested (specifically, whether DCD Section 3.6.2.1.1 applies to the complex piping system defined in BTP MEB 3-1, Item B.1.d). The staff was tracking RAI 3.6-4 as an open item in the SER with open items. In a letter dated February 17, 2008, the applicant added this criterion to DCD Section 3.6.2.1.1 for postulating pipe breaks for complex piping systems, such as those containing arrangements of headers and parallel piping running between headers, consistent with the staff position in BTP 3-4, Item B.1.d. The staff verified this in Revision 5 of the DCD and finds it acceptable; RAI 3.6-4 and its associated open item were therefore resolved.

In DCD, Tier 2, Section 3.6.2.1.3, the applicant discussed the reasons that the 1.25-in. HCU fast scram lines do not require protection against pipe breaks. The second reason is that the total amount of energy contained in the 1.25-in. piping between the normally closed scram insert valve on the HCU module and the ball-check valve in the control rod housing is small. In RAI 3.6-5, the staff requested that the applicant indicate the actual amount of energy contained in this line and demonstrate how its small amount of energy prevents any pipe ruptures in HCU fast scram lines. The applicant responded to RAI 3.6-5 by providing the result of the calculation of energy level for the 1.25-in. HCU fast scram lines at ambient temperature and operating pressure shown to be approximately 5.67 kilojoules per meter (kJ/m). The applicant also stated that this is small enough not to cause any whipping during a pipe break and does not require protection against any pipe breaks. The applicant provided a markup of changes in DCD Section 3.6.2.1.3. The staff verified that the applicant revised DCD, Tier 2, Revision 2, Section 3.6.2.1.3, to include the energy level of 6 kJ/m in the 1.25-in. HCU fast scram lines. The staff also concurs with the applicant that an energy level of 6 kJ/m in 1.25-in. HCU fast scram lines is not large enough to cause any whipping during a pipe break. Based on this, the staff finds this response acceptable; therefore, RAI 3.6-5 was resolved.

In BTP 3-4, Item B.1.b, the staff states that breaks need not be postulated in portions of high-energy fluid system piping located in the containment penetration area both inside and outside the containment, provided that they are designed to meet ASME Code, Section III, Subsection NE-1120, and the additional conditions specified in BTP 3-4. The staff evaluated the information in DCD, Tier 2, Section 3.6.2, to determine if the applicant had provided acceptable commitments to these guidelines for the ESBWR design. In DCD, Tier 2, Section 3.6.2.1.1, for piping in containment penetration areas, the applicant identified those portions of the ESBWR piping systems that qualify for break exclusion. The applicant also provided additional design bases for these break exclusion areas which meet the guidelines in BTP 3-4, and the staff finds them acceptable.

One important guideline of SRP Section 3.6.2 states that a 100-percent volumetric inservice examination of all pipe welds should be conducted during each inspection interval as defined in Subsection IWA-2400 of the ASME Code, Section XI, for those portions of piping within the break exclusion zone. In DCD, Tier 2, Section 3.6.2.1.1, the applicant included a requirement for such a program for all piping in the break exclusion zone. This commitment meets the applicable SRP Section 3.6.2 guidelines and is, therefore, acceptable.

In RAI 3.6-23, the staff asked the applicant to identify the criteria for locating and configuring pipe breaks and leakage cracks in high- and moderate-energy piping systems as Tier 2*. The staff verified that the applicant had identified the information related to criteria for locating and configuring pipe breaks and leakage cracks in high- and moderate-energy piping systems as Tier 2* in Revision 6 of the DCD; RAI 3.6-23 was therefore resolved.

On the basis of its review, the staff concludes that the ESBWR design, as it relates to the criteria for locating and configuring pipe breaks and leakage cracks in high- and moderate-energy piping systems to protect the safety-related SSCs from the effects of pipe ruptures, meets the pertinent guidelines of SRP Section 3.6.2.

3.6.2.3.2 Analysis Methods To Define Blowdown Forcing Functions and Response Models

In DCD, Tier 2, Revision 1, Section 3.6.2.2, the applicant stated that blowdown forcing functions are determined by the method specified in Appendix B to ANS 58.2. The staff reviewed the methods presented in Section 6.2 and Appendices A and B of ANS 58.2 for calculation of fluid forces acting on a postulated ruptured pipe. The staff noted that in the method presented in the standard to solve the mathematical equations for the reaction thrust force, computer programs are used to predict the transient thermodynamic state properties of the fluid in a piping system following pipe rupture. The programs require inputs related to break area characteristics and pipe fluid transient conditions. In addition, ANS 58.2 suggests simplified methods that may be used when demonstrated to be conservative. However, the applicant did not provide any details of the method for calculating the blowdown forces for the ESBWR design, and it also did not provide any sample calculations to illustrate the adequacy of any analytical method. There did not appear to be any consideration of potential feedback between the jet and any nearby reflecting surface(s), which can substantially increase the dynamic jet forces impinging on the nearby target component and the dynamic thrust blowdown forces on the ruptured pipe through resonance. In RAI 3.6-6, the staff asked the applicant to provide details (including the methods and computer programs, if any), with examples, for calculating the blowdown forcing functions at break locations that the COL applicant will use. The staff also requested a description of how the calculation will consider feedback amplification of dynamic blowdown forces.

In response to RAI 3.6-6, the applicant provided a sample calculation for a typical ABWR plant for the pipe break forcing functions for main steamline (MSL) pipe break at terminal ends, reactor pressure vessel (RPV) nozzle, and turbine stop valve (TSV). The sample calculation is a representative method to be used for the ESBWR plant. This sample calculation refers to the applicant document, “Thermal-Hydraulics of a Boiling Water Nuclear Reactor, Equation 9.122,” by F.J. Moody and Lahey, which is not available for review by the staff. In addition, the sample calculations use the method given in Appendix B to ANS 58.2. However, it should be noted that the use of ANS 58.2 for the jet load evaluation is not universally acceptable. In RAIs 3.6-11 through 3.6-19, the staff requested that the applicant provide technical justification for the assumptions used in the ANS 58.2 method of calculating fluid thrust force that may lead to nonconservative assessments (including neglect of feedback amplification of dynamic jet loads) of the jet loading effects on neighboring SSCs. In addition, in its response to RAI 3.6-6, the applicant did not address the staff’s concern relating to how feedback amplification of dynamic blowdown forces will be considered in its calculation. In RAI 3.6-6 S01, the staff requested the applicant to address this staff’s concern.

In its response to RAI 3.6.6 S01, the applicant provided conflicting answers, explaining first that feedback amplification of dynamic blowdown forces is calculated using a nonlinear time-accurate analysis, but then stating that an equivalent static analysis with a dynamic load factor of 2 may be used instead. The staff found that the response was incomplete and unclear. The staff was tracking RAI 3.6-6 S01as an open item in the SER with open items. Therefore, the staff issued followup RAI 3.6-6 S02, which consist of three questions:

(a) Which analysis approach will GEH use—the time domain calculations or the equivalent static calculations with a dynamic load factor of 2?

(b) If the time domain calculations will be used, what tools are employed? How have they been validated and certified? What are the bias errors and uncertainties associated with the tools? Also, how are the time-varying jet impingement loads simulated?

(c) If the static analysis approach is used, how has GEH established that it is conservative in light of the questions raised in followup RAI 3.6-14 S01?

In its response to Part (a) of RAI 3.6-6 S01, the applicant provided detailed tables and figures showing postulated pipe break locations and conditions. For each postulated pipe break, the applicant described one of two analysis approaches to be used for computing reaction loads on the piping and jet loads on neighboring barriers or structures:

(1) For high-energy lines near barriers, such as the reactor shield wall (RSW) or the pool walls of the gravity-driven cooling system (GDCS), GEH will perform unsteady CFD analysis using the ANSYS CFX software. The analyses will include the effects of turbulence, jet unsteadiness, reflections from nearby surfaces, feedback effects and amplification, and compressibility. GEH also plans to use the RELAP5 computer program to determine thrust force and jet flow time histories. Once the loads on the neighboring structures are determined, they are applied to ANSYS dynamic finite element models of the structures to confirm structural integrity. In some cases, GEH may take advantage of geometric similarity between pipes to reduce the number of analyses to be performed.

(2) For smaller lines that contain limited amounts of fluid and are not near safety-related components (such as the 8-in.-diameter isolation condenser (IC) return nozzles, the 6-in.-diameter GDCS nozzles, the 2-in.-diameter standby liquid control pipes, the 2-in.-diameter reactor water cleanup (RWCU) drain piping nozzles, the 2-in.-diameter nozzles of the reactor vessel level instrument system, and the 8-in.- and 12-in.-diameter RWCU pump outlet nozzles), an equivalent static analysis is performed which does not consider blast waves or jet unsteadiness effects.

The staff found that the applicant's response to Part (a) was thorough and acceptable, with one exception: it was not clear to the staff when and how RELAP5 and CFX would be used. Therefore, the staff issued followup RAI 3.6-6 S03 to request the applicant to clarify when the respective codes are used and to explain in detail how they are exercised, and how time histories of impingement pressure and blowdown force are determined and applied to finite element models of the ruptured pipe and neighboring structures.

Moreover, in its response to Part (b) of RAI 3.6-6 S02, the applicant described the CFD methodology that will be used to compute the nonlinear unsteady time histories of dynamic forces and pressures induced by jets. The applicant cited test cases used to validate CFX, including an analysis of the effects of a pipe break on ABWR steam dryers (ICONE 16-48410 by Jin Yan, et al.).

Based on its evaluation, the staff found that while the CFX benchmarks and the example calculations are necessary, they are not sufficient to establish that the procedures are conservative for high-energy line break events in an ESBWR design. In particular, the ICONE paper does not describe jet loads, only shock waves. Also, the applicant did not respond fully to the RAI, in that it did not provide the bias errors and uncertainties associated with its methodologies. Therefore, the staff requested in followup RAI 3.6-6 S03 that the applicant provide relevant benchmark(s) and accompanying bias errors and uncertainties.

Furthermore, in its response to Part (c) of RAI 3.6-6 S02, the applicant stated that it plans to use an equivalent static analysis method for break locations where the blowdown and jet forces are expected to be small compared to those from larger high-energy breaks. The applicant listed these locations in its response. The staff finds this approach acceptable, since low-energy pipe breaks are highly unlikely to damage nearby structures and SSCs. However, it was not clear to the staff how the applicant would determine the maximum value of the jet impingement force, so the staff issued followup RAI 3.6-6 S03 requesting that the applicant clarify this issue. Finally, although the applicant provided significant detail in this RAI response, it declined to include this detail in a revision of the DCD. The staff therefore issued followup RAI 3.6-6 S03, which requested that the applicant include analysis methodologies, along with tables and figures explaining postulated break locations, in a revision of the DCD.

(a) The applicant states in its response to RAI 3.6-6 S02 (a) that the RELAP5 computer code will be used to determine thrust force and jet flow time history. The applicant also states that CFX will be used to model jet flow pressure and force time history. It is unclear to the staff if both codes are used for all applications, or if the applicant chooses a specific code for a particular application. The applicant is requested to clarify when the respective codes are used, and explain in detail how they are exercised, and how time histories of impingement pressure and blowdown force are determined and applied to finite element models of the ruptured pipe and neighboring structures.

(b) The applicant is requested to provide benchmark(s) which establish that their methodologies for computing jet and thrust loads are conservative. The staff does not find the citation of CFX benchmarks, nor the ICONE paper submitted previously by the applicant to be sufficient. The benchmark(s) should be representative of the worst-case conditions in an ESBWR plant, and establish any bias errors and uncertainties in the procedures (if any). The benchmark(s) should include a jet impinging on a nearby surface. The applicant should note that the staff defines a procedure as not only the use of specific software, but also as the application of that software. Therefore, the applicant is requested to should provide a complete description of their approach, beginning with a basic statement of the problem and the governing physics, including the governing equations. It is acceptable to reference existing manuals and literature, provided that the applicant submits relevant sections of those references as part of their response. The applicant is also requested to supply the spatial and temporal discretizations used, the boundary conditions applied, and some figures pictorially showing the grids (vertices, volumes, etc.) applied in a critical region. Since jet loads are unsteady, the applicant is requested to provide a time step convergence study, or established guidelines based on the grids used and instantaneous solution wave speeds. The applicant is also requested to provide a spatial grid convergence study. A relevant parameter for establishing convergence and accuracy must be chosen, such as the integrated maximum force, or a peak pressure, on a critical structure during the transient calculation. The staff offers the attached guidance from the *Journal of Fluids Engineering* for the applicant's consideration.

(c) The applicant is requested to explain how $F_{imp\ max}$ (maximum value of the jet impingement force) is determined for their equivalent static analyses.

(d) The applicant is requested to include most of the material in their response to RAI 3.6-6 S02 in a revised DCD, including the analysis methodologies, and tables and figures explaining the break locations.

Subsequently, the applicant responded to RAI 3.6-6 S03 by clarifying its analysis procedure. For high-energy line breaks, the applicant stated that it would take several actions. First, it will conduct a thermal-hydraulic analysis using the RELAP5 code to compute the mass flow rate and pipe reaction force time history through the break, along with the fluid conditions at the break. RELAP5 solves one-dimensional mass, momentum, and energy equations for homogenous fluid volumes. However, these computed quantities do not include any of the effects that may be caused by unsteadiness and feedback phenomena in the jet. Using the mass flow rate and fluid conditions computed with RELAP5, and considering a worst-case displaced pipe configuration (aligned to maximize jet impact on the target structure), the applicant will conduct CFD analyses using CFX or FLUENT to compute the time history of the jet loads on the target. The CFD analysis will consider fluid compressibility, and capture the flow effects associated with the jet unsteadiness, nonlinearity, feedback amplification, and jet reflections. Finally, the applicant will use ANSYS finite element software to model the target structure and use the jet load time history computed from RELAP5 thermal – hydraulic analysis and CFD analysis as input to the ANSYS analysis. If the target has any resonances near the dominant frequencies of the jet loading, the analysis will capture the resonant amplification and increased structural stresses.

The staff found aspects of the clarified applicant's approach acceptable (subject to the resolution of questions regarding the conservativeness of the applicant's CFD analysis approach in followup RAI 3.6-6 S03(b)), but requested the following clarifications in followup RAI 3.6-6 S04(a):

(1) The staff finds GEH's clarified approach for modeling jet impingement loads from high-energy line breaks acceptable, but requests that the applicant explain how it will account for uncertainty in the resonance frequencies of the target finite element structural model. As an example, in other dynamic structural modeling approaches used by GEH for ESBWR design (such as those associated with the steam dryer), the loading time histories are stretched or compressed in 2.5-percent increments spanning a ±10-percent uncertainty before they are applied to the structural finite element model, which ensures that the worst-case structural response is computed and used to assess structural integrity.

(2) The applicant stated that RELAP5 will be used to compute mass flow rates and pipe reaction forces at break locations, along with fluid conditions at the break, for use as inputs to unsteady CFD analyses. However, in GEH Technical Report 0000-0105-2955-R3, GEH used TRACG to perform these calculations for the example problem of an MSL break. The applicant was requested to clarify or amend its approach to allow for using either RELAP5 or TRACG or some other suitable code that has been previously accepted by the staff.

In its response to this RAI, the applicant revised Section 3.6.2.3.1 of the DCD to state the loading time histories shifted in 2.5 percent increments spanning a +/-10 percent uncertainty will be applied to structural FE models. Also, the applicant clarified that either RELAP5 or TRACG will be used for thermal hydraulic analyses which provide the boundary conditions for subsequent jet analyses. Section 3.6.2.3.1 of the DCD has been modified accordingly. Since the applicant now accounts for uncertainty in structural resonance frequencies by shifting their loading time histories, and has clarified their use of thermal-hydraulic software, RAI 3.6-6 S04(a) is resolved.

In its response to RAI 3.6-6 S03(b), the applicant provided Technical Report 0000-0105-2955-R3, which describes the modeling procedure it plans to apply to ESBWR LOCA unsteady jet calculations. The report includes (1) the applicant's general calculation procedure as applied to an unsteady jet configuration measured by Ho and Nosseir (in "Dynamics of an Impinging Jet. Part 1. The Feedback Phenomenon," in Journal of Fluid Mechanics, Volume 105, pages 119-142, 1981) and (2) a demonstration of how it plans to use the procedure to model unsteady jets from postulated high-energy line breaks in ESBWR design calculations. The applicant's methodology for evaluating the dynamic blowdown forces caused by impinging jets emanating from high-energy line breaks is to use two-dimensional CFD modeling using the commercial finite volume software FLUENT, marketed by ANSYS. The solver assumes ideal gas laws for compressible air, is pressure-based, and is capable of modeling steady and unsteady behavior. The applicant applies a shear stress transport (SST) k-omega turbulence model and treats all walls as hydrodynamically smooth.

In item (1) in the paragraph above, the applicant analyzes jet impingement on a flat surface for a ratio of jet-target separation distance/jet nozzle with a diameter of 4 at two conditions measured by Ho and Nosseir (Mach numbers of 0.5 and 0.9). While the measurements, unfortunately, do not include specific amplitudes, they do provide relative differences between conditions without strong feedback and instabilities (M = 0.5) and with strong feedback (M = 0.9). The applicant's analyses, however, showed trends opposite those observed in the measurements, with unsteady pressure amplitudes decreasing significantly from M = 0.5 and M = 0.9. The applicant suggested applying a bias factor of 3.0 to future ESBWR simulations to account for this discrepancy. The applicant also showed a plot of instantaneous pressure gradient, apparently highlighting vortices emanating from the jet nozzle. This suggests that the general physics of the unsteady jet flows are indeed modeled.

In item (2) above, the applicant applies its analysis procedure to a simulated break of an MSL outside the shield wall, with the jet impinging on the GDCS pool wall. The applicant points out that, by performing the calculations in two dimensions (rather than three), the jet impinges normally to the wall, rather than at the actual angle of 18 degrees, leading to a conservative calculation. The applicant uses the TRACG software to compute the jet inlet temperature and pressure blowdown history, which is applied as a boundary condition to the FLUENT CFD analysis. The applicant shows sample results of instantaneous pressures throughout the jet region, along with a time history of the pressure loading on the GDCS wall. Although the example does not lead to a resonant jet, it does demonstrate the applicant's general procedure applied to a relevant ESBWR example.

The staff reviewed the information included in this technical report and found that, while the applicant's procedures are a significant improvement over the previous approach using ANS 58.2, they still have not been sufficiently proven to be conservative methods for computing unsteady resonant jet loads. In particular, the Ho and Nosseir benchmark did not demonstrate credible results, with pressures decreasing near the resonant condition. The applicant had also not established how it will conduct sensitivity analyses to confirm that it has captured the worst-case jet condition(s). In its ESBWR example, the applicant has not established that it has achieved a converged solution and also appears to have used TRACG to compute the jet boundary conditions applied to the CFD model, rather than RELAP5. Finally, while the applicant had presented the elements of its CFD approach in the report, it has not formally committed to applying this procedure to ESBWR design work in the future. Therefore, in followup RAI 3.6-6 S04(B), to the staff requested that the applicant address the following:

(1) The current Ho and Nosseir simulations do not demonstrate the key behavior of unsteady jets with strong feedback phenomena. Specifically, the GEH simulations showed that the unsteady loads decrease when feedback occurs (Mach number of 0.9) instead of increasing. The staff asks that the applicant further analyze the Ho and Nosseir problem to establish CFD solutions that demonstrate realistic physical behavior, such as increasing unsteady pressures when jet instabilities occur (such as near a Mach Number of 0.9). The staff also requests that GEH demonstrate the sensitivity of the CFD solution with respect to critical parameters, such as distance between the jet and impingement surface, jet source boundary conditions (pressure and temperature), external conditions, and any other parameters that strongly influence the unsteady jet behavior. In summary, the staff requests that GEH demonstrate that its procedure is a conservative means of bounding the worst-case unsteady jet loads that may occur in an ESBWR high-energy line break event.

(2) The staff requests that GEH establish that the solution from the ESBWR MSL B jet flow demonstration is converged with respect to grid/mesh and time step resolution. A mesh convergence study showing that the strong degree of anisotropy in the existing grid does not influence the results would be useful.

(3) The staff asks that GEH modify the short formal description in the DCD (referencing GEH Technical Report 0000-0105-2955-R3 for further details) of the general procedure that GEH will use to assess dynamic blowdown forces caused by impinging jets emanating from high-energy line breaks (the current description is on pages 3.6-21 through 3.6-22 of Revision 6 of the DCD). In particular, the staff requests that GEH include information such as the bullets on page 4 of GEH Technical Report 0000-0105-2955-R3, and some of the information in Tables 2-7 of that report. The staff asks that GEH include guidelines and rules of thumb that it will apply to generating meshes and grids and for running FLUENT. Also, the staff requests that GEH include a description of the procedure it will apply for assessing the convergence of its solutions (such as grid resolution studies), and for assessing the sensitivity of its solutions to uncertainties in problem parameters, such as physical distances between jets and impingement surfaces, jet boundary conditions, and external conditions. Finally, the staff requests that GEH formally list any bias errors and uncertainties that it plans to apply to unsteady loads computed using its procedure.

In its response to RAI 3.6-6 S04 (B) Part (1) above, the applicant references Section 3.4.2 of Technical Report 0000-0105-2955. This report provides updated analysis results for a benchmark by Ho and Nosseir. The results show that the applicant's analysis approach successfully reproduces the feedback mechanism between a jet and waves reflected backward from the impingement region. The applicant's computed oscillating pressures are an order of magnitude higher than those measured by Ho and Nosseir. Part (1) of RAI 3.6-6 S04 (B) is therefore, resolved.

In its response to Part (2) of this RAI, the applicant provided a mesh convergence study. The results of the study, however, were not consistent with the calculations shown previously in the report. Specifically, the Mesh 100 percent time histories shown in Figures 3.27 - 3.29 do not match those shown in Figures 3.10 and 3.13; the levels and character of the curves are different, and the applicant had not subtracted the mean pressures from the data in Figures 3.27 - 3.29. The time histories in Figures 3.27 - 3.29 are more than an order of magnitude shorter than those in Figures 3.10 and Figure 3.13. Also, the solutions shown in Figures 3.27 - 3.29 did not appear to have reached steady state. The applicant's argument that the differences in pressure are small with respect to the mean are irrelevant, since the oscillating pressure amplitude is of interest, not the mean. Finally, the applicant had not conducted a time step convergence study, nor had they provided a rationale for how their time step size was chosen. The applicant was therefore requested to resolve these concerns in follow-up RAI 3.6-6 S05 (B2).

Moreover, in its response to Part (3) of RAI 3.6-6 S04 (B), the applicant included Technical Report 000-0105-2955 as an Appendix to NEDE-33440P, which is referenced by DCD, Tier 2, Section 3.6.2.3.1. The applicant also included a very brief description of their dynamic jet impingement analysis capability in the DCD. However, the applicant had not provided a general description of the procedure they will commit to applying during the ESBWR design process. This description, along with accompanying guidelines for exercising it, including any bias errors and uncertainties, is required to address this portion of the RAI. The applicant also stated that 3D analyses may be used for ESBWR design calculations, even though they rely on the conservatism of the benchmark 2D analyses to address some of our RAIs regarding modeling uncertainty. 3D analysis approaches cannot be accepted without proper benchmarking, however. The applicant was therefore requested to expound on this information in follow-up RAI 3.6-6 S05 (B3).

In RAI 3.6-6 S05, Part B, the staff requested the applicant to address the following

(1) This portion of the RAI is now closed under the review of RAI 3.6-6 S04(B), Part 1.

(2) In its response to Part (2) to RAI 3.6-6 S04 (B), the applicant provides a mesh convergence study. The results of the study, however, are not consistent with the calculations shown previously in the report. The applicant is requested to explain why the results of the mesh convergence study for the Ho and Nossier benchmark are inconsistent with other calculations in Technical Report 0000-0105-2955. Specifically, the Mesh 100 percent/Base Mesh time histories shown in Figures 3.27 - 3.29 do not match those shown in Figures 3.10 and 3.13; the levels and character of the curves are different, and the applicant has not subtracted the mean pressures from the data in Figures 3.27 - 3.29. The time histories in Figures 3.27-3.29 are more than an order of magnitude shorter than those in Figures 3.10 and Figure 3.13, and do not appear to have achieved mesh convergence. Once these issues are resolved, the applicant should reassess the conclusions of their mesh convergence study, keeping in mind that errors computed based on mean pressure are irrelevant to a discussion of the errors in oscillating pressures. The applicant should assess errors in oscillating pressure amplitudes after subtracting mean pressure from their time histories. Also, the applicant has declined to produce a time step resolution convergence study; this decision is not consistent with standard numerical practices and must be explained. The applicant must provide a physically meaningful, well substantiated rationale for the time step size(s) they have chosen.

(3) In its response to Part (3) to RAI 3.6-6 S04 (B), the applicant included Technical Report 000-0105-2955. The applicant also included a very brief description of their

dynamic jet impingement analysis capability in the DCD. While GEH Technical Report 0000-0105-2955 provides reasonably rigorous details of the applicant's jet impingement modeling procedure as applied to two benchmarks, it does not commit formally to using those procedures for ESBWR design support.

As requested in version S04 of this RAI, the applicant should provide a formal description of the general procedure that they will commit to using to assess dynamic blowdown forces caused by impinging jets emanating from high energy line breaks in ESBWR plants. This description, which must include guidelines and rules of thumb for generating CFD meshes and grids, procedures for assessing solution convergence (grid distribution and resolution and time series resolution, including time step length and overall solution length), means of assessing sensitivity of loading solutions to uncertainties, and bias errors and uncertainties (if any) the applicant may apply, may reference existing sections in GEH Technical Report 0000-0105-2955.

Finally, the applicant should clarify whether they plan to run conservative 2D analyses for ESBWR design calculations, or less conservative (but possibly more accurate) 3D analyses. The applicant argues in Section 4.7 of the report that the most significant geometric uncertainties in their solution approach are subsumed by using conservative 2D modeling. While the staff concurs with this argument, the applicant then states that 3D modeling may be used for ESBWR design calculations at the end of Section 4.7.1 and at the end of Section 4.7.3. Since the applicant's 3D modeling approach has not been benchmarked and proven to be conservative, the applicant must provide suitable benchmarking prior to the staff's acceptance of a 3D approach. This requested formal methodology description and commitment may be included as a new section in the Technical Report, or in the DCD.

In its response to Part 2 of follow-up RAI 3.6-6 S05(B), the applicant submitted revised analysis results, along with Appendices A and B to their CFD Modeling Report (000-0105-2955-R6), which established the convergence of the CFD grid (or mesh) and time step size used to analyze the Ho and Nosseir impinging jet benchmark case. Calculations for the baseline and a refined mesh (25 percent higher spatial resolution) were performed for the 0.9 Mach Number case, which corresponds to a resonance condition, where the acoustic waves reflected from the surface impinged upon amplify the jet oscillations. The applicant's simulations were run for sufficient times to eliminate any startup transients, and have reached steady state, where jet oscillations are repeatable over time. The mesh convergence study is described in Appendix A, where the oscillation amplitudes, computed by subtracting the mean static pressure from the pressure solutions, are higher in the baseline mesh than in the refined mesh, indicating the baseline mesh is conservative. The oscillating pressures significantly exceed those measured by Ho and Nosseir, further establishing the conservatism of the applicant's methodology. The applicant also established that the dominant oscillation frequency is within 10 percent of that measured by Ho and Nosseir. Since the applicant will shift their forcing functions within a band of +/-10 percent to account for uncertainty in frequency, this agreement is acceptable.

The time step convergence study is described in Appendix B, where the applicant computes a minimum time step based on multiple modeling criteria. The smallest time step was used in the applicant's baseline study, and leads to converged results. Using larger time steps leads to increased dynamic loading, which is conservative. The staff found that using larger time steps also leads to reduced peak oscillation frequencies. In addition, the applicant stated that this shift, should it occur during ESBWR design calculations, will be accounted for when the applicant time-shifts their loading histories by +/-10 percent. Therefore, the staff determines that the applicant's time step convergence study is acceptable and Part 2 of RAI 3.6-6 S05(B) is closed.

In its response to Part 3 of follow-up RAI 3.6-6 S05(B), the applicant updated Chapter 7 of their CFD Modeling report (000-0105-2955-R6), which includes a detailed description of their jet impingement loading modeling plan for 3D analyses. The report will be included as Appendix B of NEDE-33440P and DCD, Tier 2, Section 3.6.2.3.1 is revised to reference the report and briefly summarize its contents. The applicant's 3D modeling procedure is nearly identical to that used in their 2D benchmark studies. The applicant explains how they define the computational domain, develop a convergence computational mesh, determine solver setup and boundary conditions, determine converged time step sizes and solutions, confirm solution convergence, and design for worst-case loading conditions. To ensure that worst-case loading conditions are used, the applicant will perform sensitivity studies for the domain geometry and boundary and initial conditions in support of ITAAC closure. The most critical parameters will then be adjusted to maximize loading. The applicant will also consider the possibility of additional lock-in between resonances of the impinged upon structures and the oscillations in the fluid flow.

Furthermore, for their 3D approach, the applicant will use the same procedures that established converged solutions for their 2D benchmarks. The applicant will consider jet loads throughout the blowdown event, until the nozzle discharge Mach number reduces to 0.3. This is well below the strongest jet loading time regions, and allows the jet to progress to a narrow, full-steam jet which extends over long distances (up to 25 diameters from the nozzle). This allows many lock-in conditions to be assessed throughout the blow-down process, as the jet will move in and out of the lock-in state as the blowdown progresses. Finally, the applicant will benchmark their 3D approach against experimental data which captures the key physics of the ESBWR high energy line break phenomenon and are representative of ESBWR pipe break conditions. Since the applicant has committed to a rigorous procedure to ensure converged 3D solutions which are adjusted to simulate worst-case conditions, and the procedure will be benchmarked, Part 3 of RAI 3.6-6 S05(B) is therefore, resolved.

The applicant responded to Part (c) of RAI 3.6-6 S03 by explaining that the maximum value of jet impingement force that will be used for quasi-static analysis of low-energy line breaks will be computed based on Section 7.3 of the ANS 58.2 standard. This clarification is acceptable because the use of equivalent static analysis method of NS 58.2 standard is appropriate for break locations where the blowdown and jet forces are expected to be small compared to those from larger high-energy breaks. Therefore, RAI 3.6-6 S03(c) was closed.

The applicant responded to Part (d) of RAI 3.6-6 S03 by agreeing to include tables pertaining to pipe break locations in the DCD, including pipe break data. However, the applicant stated that it will not include all the technical data that it had previously provided in the responses to RAI 3.6-6 S02 (Tables 1 and 2), RAI 3.6-13 S01 (Tables 1 and 2), and RAI 3.6-16 S01 (Tables 1 and 2) since these tables contain the applicant's proprietary information. The staff also noted that in the response to RAI 3.6 16 S02, the applicant stated that it will make no DCD changes in response to this RAI, other than those described in the responses to RAIs 3.6-6 S03 and 3.6-13 S02.

Based on its review of the information included in the applicant's responses to RAIs 3.6-6, -13 and -16 and their associated tables as well as information provided in ESBWR DCD Revision 6, the staff determined that the information pertaining to consideration of jet reflections and analysis procedure that the applicant's plans to use for each postulated break should be included in Tables 3.6-5 through 3.6-7 of the DCD. Therefore, the applicant was requested in

RAI 3.6-6 S04(d) to include the following in additional columns and/or notes in Tables 3.6-5 through 3.6-7 of the DCD: (a) whether jet reflections will be considered in the jet impingement analyses and (b) the analysis procedure the applicant's plans to use for each potential pipe break (i.e., CFD and FE as described in the applicant's response to RAI 3.6-6 S03(a) or ANS 58.2).

In its response, the applicant refered to this RAI as Part (c) rather than Part (d). The applicant updated Tables 3.6-5 through 3.6-7 in the DCD to indicate which calculation approach will be used for each postulated break. In some cases, the applicant will use conservative assessments from other bounding postulated breaks, sometimes scaling results from geometrically similar conditions. The applicant also explains that jet reflections will be considered for all postulated breaks. This will be completed later as a part of as-designed pipe break analysis report. The as-designed pipe break analysis is an ITAAC Item. Since the applicant has updated the tables as requested in DCD Revision 7, and the analysis approaches are appropriate for the respective system conditions and the jet type included in Tables 3.6-5 through 3.6-7 of the DCD. Therefore, RAI 3.6-6 S04 (d) is resolved.

SRP Section 3.6.2.III.2.a provides dynamic analysis criteria and discusses material capacity limitations for a crushable material type of whip restraint, while SRP Section 3.6.2.III.2.b discusses various methods of dynamic analyses for postulated pipe ruptures and pipe whip restraint. In addition, paragraph 6.3 of ANS 58.2 presents several different types of piping dynamic analysis methods. In DCD Section 3.6.2.2 and Appendix 3J, the applicant provided details regarding assumptions in the piping dynamic analysis. In RAI 3.6-7(a) through (e), the staff requested that the applicant provide additional information. The following discusses the specific issues associated with this RAI, the applicant's responses, and the staff's evaluation findings:

(a) SRP Section 3.6.2.III.2.a states that for piping pressurized during normal operation at power, the initial condition should be the greater of the contained energy at hot standby or at 102-percent power. In RAI 3.6-7(a), the staff requested that the applicant clarify whether this is applicable to all approaches used for the ESBWR. If it is not, then the applicant should provide technical justification for the alternate initial conditions assumed in the analyses. In its response to RAI 3.6-7(a), the applicant provided an updated DCD Section 3.6.2.3.1, showing the criterion of energy at hot standby or 102-percent power given in SRP Section 3.6.2.III.2.a as applicable to the ESBWR. The staff verified that the applicant revised Section 3.6.2.3.1 in DCD, Tier 2, Revision 2, to include this initial condition of 102-percent power operation of the plant for postulating breaks in high-energy lines resulting in jet impingement loads. The staff finds this acceptable because it meets the pertinent guidelines of SRP Section 3.6.2; therefore, RAI 3.6-7(a) was resolved.

(b) Acceptable dynamic models suggested in the SRP include lumped parameter analysis models, energy balance analysis models, and static analysis models. In addition, paragraphs 6.3.1 through 6.3.5 of ANS 58.2 give alternate analytical approaches. Appendix 3J to the DCD presents only two specific approaches, dynamic time-history analysis with simplified models and dynamic time-history analysis with detailed piping models. In RAI 3.6-7(b), the staff requested that the applicant clarify whether any other analytical (nonlinear) methods and modeling techniques (discussed in the SRP and ANS 58.2) will be used for ESBWR plants. In its response to RAI 3.6-7(b), the applicant referred to Enclosure 4, which should be Enclosure 3. Enclosure 3 provides a sample calculation prepared for a typical ABWR plant for a pipe break nonlinear method and modeling technique for an MSL pipe break at terminal-end RPV nozzles, which claims to be the representative method to be used. The staff was tracking RAI 3.6-7(b) as an open item in the SER with open items. The staff requested that the applicant clarify whether any other methods discussed in the SRP and ANS 58.2 will be used for the ESBWR. In a letter dated December 14, 2007, the applicant confirmed that the ESBWR is committed to using the only two specific methods presented in DCD Appendix 3J. The staff verified that the two specific approaches, dynamic time-history analysis with simplified models and dynamic time-history analysis with detailed piping models, are the only methods that will be used for the design of ESBWR plants. Since these two methods utilize acceptable dynamic models and are typically used by the industry, the staff finds this acceptable. Therefore, RAI 3.6-7(b) and its associated open item were resolved.

(c) This part of the RAI relates to the question raised in paragraph (b) above. Specifically, the staff asked the applicant to discuss procedures and computer programs that will be used to calculate the pipe whip dynamic responses for all methods not discussed in DCD Appendix 3J, if any. In its response, the applicant stated that the computer programs PDA and ANSYS will be used to calculate the pipe whip dynamic responses. The staff was tracking RAI 3.6-7(c) as an open item in the SER with open items. In a letter dated December 14, 2007, the applicant stated that PDA and ANSYS computer codes perform the pipe rupture evaluations as illustrated in DCD Appendix 3J. Subsequently, in a letter dated August 4, 2008, the applicant stated that the computer file “REDEP” identified in DCD Appendix 3J is a data file to store information for selecting force/deflection data for the design of pipe whip restraints. The applicant also stated that REDEP is maintained in the applicant’s design record file in accordance with all appropriate quality assurance (QA) requirements for the ESBWR project. The staff finds that these methods and procedures are typically used industrywide and are acceptable. However, the applicant did not include in DCD Revision 6 the information related to maintaining the REDEP data file with applicable applicant’s QA requirements. Therefore, in followup RAI 3.6-7 S03(c), the staff asked the applicant to include the applicable its QA requirement for the REDEP data file in a revised DCD. Subsequently, the applicant includes this information in DCD Revision 7 as requested by staff. The staff finds this acceptable and, therefore, RAI 3.6-7 S03(c) is closed.

(d) In RAI 3.6-7(d), the staff requested that the applicant provide examples to illustrate the nonlinear and simplified methods of analysis that will be used in the ESBWR design and to demonstrate compliance with the SRP Section 3.6.2 stress limit requirements. The staff also requested that the applicant describe the computer programs for selecting the size and different types of whip restraints (i.e., crushable or rigid, if any). In its response, the applicant provided in Enclosure 3 an example of a nonlinear and simplified method of analysis to be used in the ESBWR design. The example refers to a U-bar type restraint. In addition, the applicant stated that only the U-bar type of pipe whip restraint is applicable to the ESBWR. The staff finds that the sample calculation demonstrates compliance with the SRP Section 3.6.2 stress limit requirements for the U-bar type of pipe whip restraint. The staff finds this acceptable. Therefore, RAI 3.6-7(d) was resolved.

(e) In RAI 3.6-7(e), the staff requested that the applicant discuss the validation of the computer programs for which the NRC staff has not yet given its approval. This part of the RAI relates to the quality control of the computer programs and the computed results, as required by SRP Section 3.9.1. The applicant’s response includes the analytical approach used for the two types of analyses presented in DCD Appendix 3J. However, the applicant did not address the quality control of the computer codes ANSYS and PDA, which these analyses used. The staff was tracking RAI 3.6-7(e) as an open item in the SER with open items. In addition, the pipe break analysis in Enclosure 3 of the applicant's response includes the ANSYS, PDA, and REDEP computer programs. The staff notes that ANSYS is a commercial code typically used for structural analysis and is acceptable for its specified use. In a letter dated December 14, 2007, the applicant confirmed that ANSYS and PDA are identified as "Level 2" status, which follows the QA and quality control requirements for maintenance in a computer library; such programs maintain the users' manual and other quality control requirements. The staff finds this acceptable in accordance with SRP Section 3.9.1; therefore, RAI 3.6-7(e) and its associated open item were resolved.

3.6.2.3.3 Dynamic Analysis Methods To Verify Integrity and Operability

3.6.2.3.3.1 Jet Impingement Analyses and Effects on Safety-Related Structures, Systems, and Components

SRP Section 3.6.2, Revision 2, describes currently acceptable procedures for assessing the forces induced by jets emanating from postulated piping breaks on neighboring SSCs, along with acceptable means of modeling jet expansion (which determine the spatial zones of influence of the loads within expanding jets). SRP Section 3.6.2.III.3f states that expansion models may be used for jet shapes when substantiated by test or analysis, but only for steam and water/steam mixtures, and jet expansion should not be applied to cases of saturated water or subcooled water blowdown. The nuclear industry commonly uses ANS 58.2 (Appendices C and D) for estimating jet plume geometries and loads based on the fluid conditions internal and external to the piping, and to date, the NRC's reviewers have accepted ANS 58.2.

The original DCD Section 3.6.2.3.1 refers to the use of Appendices C and D to ANS 58.2 to assess which SSCs might be loaded by jets emanating from postulated pipe breaks and to assess resulting jet impingement loads on the impacted SSCs. The applicant included additional information regarding jet impingement loading in DCD, Tier 2, Section 3.6.2, that appears to conflict with the contents of ANS 58.2. The staff reviewed ANS 58.2 and its appendices and DCD, Tier 2, Section 3.6.2 and Appendix J. The staff also considered the recent scrutiny of ANS 58.2 expanding jet models by the Advisory Committee on Reactor Safeguards (ACRS) (G. Wallis, "The ANSI/ANS Standard 58.2-1988: Two-Phase Jet Model," Agencywide Documents Access and Management System (ADAMS) Accession No. ML050830344, dated September 15, 2004; V. Ransom, "Comments on GSI-191 Models for Debris Generation," ADAMS Accession No. ML050830341, dated September 14, 2004). The ACRS scrutiny of ANS 58.2 expanding jet models has revealed several inaccuracies that may lead to nonconservative assessments of the strength, zone of influence, and space- and time-varying nature of the loading effects of supersonic expanding jets on neighboring structures.

The motivation for the ACRS review of ANS 58.2 jet models was Generic Safety Issue 191, "Assessment of Debris Accumulation on PWR Sump Performance," which addresses the blockage of strainers upstream of emergency sump pumps by particulate. The particulate is formed by fibrous ceramic insulation, which can be broken loose by blast waves and/or jets emanating from nearby pipe ruptures. ACRS safety evaluation letters to the NRC's chairman (ACRSR-2097, ADAMS Accession No. ML042920334, October 18, 2004; ACRSR-2110, ADAMS Accession No. ML043450346, December 10, 2004) cited the Wallis and Ransom critiques. Although the focus of the ACRS was on debris generation and sump blockage, its comments directly impact the assessments of jet impingement loading from postulated pipe breaks on neighboring SSCs. RAIs 3.6-11 through 3.6-14 summarize the ACRS criticisms that relate specifically to possible nonconservatisms in ANS 58.2, along with inconsistencies between the applicant's approach and ANS 58.2. These RAIs request that the applicant address the inaccuracies and omissions in ANS 58.2 discovered by ACRS, along with inconsistencies between ANS 58.2 and the applicant's approach. It should be noted that RAI 3.6-6 related to jet impingement loading was issued under Section 3.6.2.3.2, since it also addressed blowdown forcing functions. Much of the applicant's response to that RAI is relevant to Section 3.6.2.3.3.

<u>Neglect of the Effects of Blast Waves</u>

In the event of a high-pressure pipe rupture, the first significant fluid load on surrounding structures would be induced by a blast wave. A spherically expanding blast wave is reasonably approximated to be a short-duration transient and is analyzed independently of any subsequent jet formation. Since blast waves are not considered in ANS 58.2 or in the original ESBWR DCD Section 3.6.2 for evaluating the dynamic effects associated with the postulated pipe rupture, their omission was clearly nonconservative. In RAI 3.6-11, the staff asked the applicant to explain how it will account for the effects of blast loads on neighboring SSCs. The staff was tracking RAI 3.6-11 as an open item in the SER with open items.

In its response to RAI 3.6-11, the applicant argued that the blast loads will be negligible compared to loads caused by jets, citing a lower density of the fluid outside the high-energy pipe compared to the jet fluid, and the decay in load amplitude with increasing distance from the break. Practical experience cited by the international nuclear community, however, clearly shows the strength and damage caused by blast waves ("Knowledge Base for Emergency Core Cooling System Recirculation Reliability," issued by the Nuclear Energy Agency/Committee on the Safety of Nuclear Installations (NEA/CSNI) in February 1996. The document recommends that all high-pressure and high-temperature pipes should be considered as sources of blast waves, with initial energy and mass roughly equal to the exposed volume from a hypothesized break. The subsequent damage from such waves has been well documented and is not properly accounted for by the isolated analysis of a pure spherically expanding wave.

In followup RAI 3.6-11 S01, the staff asked the applicant to provide a rigorous and thorough explanation of its procedures for estimating the effects of blast waves on nearby SSCs. In its response to RAI 3.6-11 S01, the applicant agreed to consider the effects of blast waves on neighboring structures and SSCs. If the blast emanates into an open space, spherical decay is assumed. If the blast occurs in an enclosed space, then a compressible CFD analysis of the time history of the blast wave is performed. The applicant included an example for the annulus between the RPV and the RSW, which shows that high pressures occur throughout the annulus and do not obey spherical decay laws. The applicant will use the higher annulus pressures in its evaluation of the integrity of other RPV nozzles and attached piping. The applicant included a detailed description of its annulus analysis. However, the applicant did not include a convergence study to establish the conservatism of its analysis. Therefore, the staff issued followup RAI 3.6-11 S02, requesting that the applicant provide this convergence study.

In its response to RAI 3.6-11 S02, the applicant referenced GEH Technical Report 0000-0102-6265-R0, CFD Modeling of Blast Wave Propagation During an ESBWR Feedwater Line Break dated March 25, 2010, which describes in detail the modeling procedure it plans to apply to ESBWR blast wave calculations. The applicant demonstrated a calculation of a blast wave induced by a high-energy line break inside containment of ESBWR feedwater piping. The blast wave propagates into the annular region between the RPV and the RSW and reflects between the boundaries of the annulus. The applicant established that a two-dimensional (2D) approximation of the annulus is conservative by comparing 2D pressure amplitudes with those computed using a three-dimensional (3D) model. The applicant will use 2D models where applicable in ESBWR calculations. The applicant also established that the mesh discretization used in its example is conservative by comparing pressures and velocities to those from a model generated with a coarser mesh. While the staff accepts the technical approach described in the report, the applicant did not reference the report in a revised version of the DCD. In the followup RAI 3.6-11 S03, the staff asked the applicant to include this reference in a revised DCD. In response to RAI 3.6-11 S03 the applicant included GEH Technical Report 0000-0102-6265-R0 as Appendix A in a revision to NEDE-33440P, and references the report in DCD, Tier 2, Section 3.6.2.6, which also now includes a brief description of the blast wave modeling procedure. RAI 3.6-11 S03 is therefore, resolved.

Nonphysical Spatial Expanding Jet Model

In the characterization of supersonic jets given by ANS 58.2, some physically incorrect assumptions underlie the approximating methodology. The model of the supersonic jet itself is given in Figures C-1 and C-2 of the standard and contains references to supposedly universal jet characteristics that are not reasonable. A fundamental problem is the assumption that a jet issuing from a high-pressure pipe break will always spread with a fixed 45-degree angle up to an asymptotic plane and subsequently spread at a constant 10-degree angle. Each of these characteristics is generally inapplicable and far from universal. The initial jet spreading rate is highly dependent on the ratio of the total conditions of the source flow to the ambient conditions. In reality, subsequent spreading rates depend, at a given axial position, on the ratio of the static pressure in the outermost jet flow region to the ambient static pressure. The standard describes the asymptotic plane as the point at which the jet begins to interact with the surrounding environment. In his critique, Dr. Wallis takes this to mean that the jet is subsonic downstream of the asymptotic plane. In fact, as shown by Wallis and Ransom, supersonic or not, the jet is highly dependent on the conditions in the surrounding medium and, at a given distance from the issuing break, will spread or contract at a rate depending on the local jet conditions relative to the surrounding fluid pressure. Supersonic jet behavior can persist over distances from the break far longer than those estimated by the standard, extending the zone of influence of the jet and the number of SSCs that could be impacted by a supersonic jet. For example, tests in the Siemens/Kraftwerk Union Aktiengesellschaft (KWU) facility in Karlstein, Germany, showed that significant damage from steam jets can occur as far as 25 pipe diameters from a rupture (NEA/CSNI).

In RAI 3.6-12, the staff requested that the applicant perform the following:

(a) Explain what analysis and/or testing has been used to substantiate the use of the ANS-58.2 Standard, Appendices C and D for defining conservatively which SSCs are in jet paths and the subsequent loading areas on the SSCs.

(b) Provide the maximum piping and postulated break size dimensions to confirm that 9.1 meters is larger than 25 diameters for all postulated breaks. It is noted that in DCD, Tier 2, Section 3.6.1.3, the applicant states that impingement force becomes negligible beyond 9.1 meters.

The staff was tracking RAI 3.6-12 as an open item in the SER with open items. In its response to RAI 3.6-12 part (a), the applicant did not explain what analysis and/or testing has been used. Instead, the applicant maintained that the analysis and testing were compliant with ANS 58.2. Therefore, the staff issued followup RAI 3.6-12 S01(a), advising the applicant that ANS 58.2 was no longer universally acceptable for modeling jet expansion in nuclear power plants and requesting that the applicant respond to the original RAI. In its response to part (b), the applicant provided a table of maximum piping and postulated break dimensions and compared 25 diameters to its maximum impingement distance of 9.1 meters. Except for the MSLs, 25-diameter distances from all piping are less than 9.1 meters. However, 25 diameters from the MSLs is 19.1 meters, 10 meters more than the applicant's maximum jet impingement distance of 9.1 meters. The applicant stated that "analytical justifications to determine if safety-related features require protection against an interacting jet from a pipe break will be provided for targets intercepted by jet outside 25D." However, the applicant did not add this commitment to the DCD. Therefore, the staff issued followup RAI 3.6-12 S01(b), asking the applicant to revise the DCD to state that the loads on any SSCs within 19.1 meters of postulated ruptures of the MSLs will be assessed, along with the structural integrity of the SSCs.

The applicant responded to both followup RAIs 3.6-12 S01(a) and 3.6-12 S01(b) and referred to its response to RAI 3.6-6 S02 to address followup RAI 3.6-12 S01(a). The applicant also stated that it is sometimes acceptable to use detailed jet loading analysis (described in the applicant's response to RAI 3.6-6 S02) from pipes that are geometrically and hydrodynamically similar to other pipes in order to reduce the number of computations that must be performed. The staff finds this response acceptable since similar configurations will behave in similar ways. Followup RAI 3.6-12 S01(a) was therefore resolved. The applicant also acknowledged in its response to part (b) that its evaluation zone will be extended to 25 diameters (19.1 meters) for MSL breaks. The staff verified that this exception is included in the applicant's revised DCD and finds it acceptable because the applicant adequately addressed the staff's concern related to potential jet impingement distance as identified in the staff's RAI. RAI 3.6-12 S01(b) was therefore resolved. RAI 3.6-12 and its associated open item are therefore considered resolved.

<u>Nonphysical Pressure Distribution within Expanding Jet Model</u>

The ANS 58.2 formulas for the spatial distribution of pressure through a jet cross-section are incorrect, as pointed out by Wallis and Ransom. In some cases, the ANS 58.2 assumption that the pressure within a jet cross-section is maximum at the jet centerline is correct (near the break, for instance), but far from the break, the pressure variation is quite different, often peaking near the outer edges of the jet. Applying the standard's formulas could lead to nonconservative pressures away from the jet centerline.

In DCD, Tier 2, Section 3.6.2.3.1, the applicant stated that the jet impingement force is uniformly distributed across the cross-sectional area of the jet, and only the portion intercepted by the target is considered. The applicant also stated that the analysis uses Appendix D to ANS 58.2 is used, which defines variable (not uniform) pressures over the cross-section of an expanding jet. (ANS 58.2 does specify a uniform pressure over the cross-section of a nonexpanding jet, so it appears that the applicant is mixing the methods of the standard, combining the shape of an expanding jet with the uniform pressure distribution of a nonexpanding jet. In RAI 3.6-13, the staff requested the following:

(a) Clarify which approach (variable pressure over an expanding jet cross-section as defined in Appendix D of ANS-58.2 Standard, or a uniform pressure distribution assumed in DCD) will be used to specify pressure distribution over an expanding jet cross section. In either case, the applicant should explain what analysis and/or testing has been used to substantiate use of Appendix D of the ANS-58.2 Standard and/or the formulas in DCD Tier 2 for defining conservatively the net jet impingement loading on SSCs in light of the information presented by Ransom and Wallis (ADAMS ML050830344, ADAMS ML050830341), which challenges the accuracy of the pressure distribution models presented in ANS-58.2 Standard.

(b) Submit a table of all postulated break types, along with the properties of the fluid internal and external to the ruptured pipe. The table should specify what type of jet the applicant assumes will emanate from each pipe break (i.e., incompressible nonexpanding jet or compressible supersonic expanding jet) along with how impingement forces will be calculated for each jet. Specific examples of jet impingement loading calculations made using the ANS-58.2 Standard and/or the methods in DCD Tier 2 for the postulated piping breaks in an ESBWR should be given, along with proof that the calculations lead to conservative impingement loads in spite of the cited inaccuracies and omissions in the ANS-58.2 Standard models pointed out by Ransom and Wallis.

The staff was tracking RAI 3.6-13 as an open item in the SER with open items. In its response to RAI 3.6-13 part (a), the applicant stated that it would use Appendix D of ANS 58.2 methods to compute pressure distributions over SSTs, and that it would modify DCD, Tier 2, Section 3.6.2.3, accordingly. However, the applicant did not address the second question in part (a), which is to explain what analysis and/or testing has been used to substantiate the use of Appendix D to ANS 58.2 in light of ACRS criticisms. Instead, the applicant stated that it was compliant with ANS 58.2. Therefore, the staff issued followup RAI 3.6-13 S01(a), which referred the applicant to the staff's original concerns regarding the inadequacy of ANS 58.2. The staff asked the applicant to address the original RAI. In its response to Part (b), the applicant stated that the ESBWR pipes have been designed such that breaks may occur only at terminal ends. The remainder of the applicant's response, however, is vague and incomplete. Therefore, in followup RAI 3.6-13 S01(b), the staff requested that the applicant provide a more detailed and thorough response to the original RAI.

The applicant responded to the followup RAIs, and agreed to use more appropriate analysis methodologies (CFD) to address the staff's concerns. The applicant referred the staff to its response to followup RAI 3.6-6 S02. Since followup RAI 3.6-6 S02 addresses the same issues as RAI 3.6-13 S01(a), RAI 3.6-13 S01(a) was resolved. In its response to RAI 3.6-13 S01(b), the applicant provided detailed tables of pipe break locations, environmental conditions, and break conditions. However, the applicant did not include this information in a revised DCD. Therefore, the staff issued followup RAI 3.6-13 S02(b), requesting that the tables be included in the DCD. The applicant responded to followup RAI 3.6-13 S02(b), dated May 12, 2009. The applicant has included tables (3.6-5 through 3.6-7) in the DCD which include terminal-end breaks inside containment, outside containment, and at the containment penetration for all high-energy piping inside and outside the containment boundary, along with Figure 3.6-3 which clarifies the break locations. The applicant has also revised the DCD to state that piping will be designed such that intermediate breaks are avoided.

However, the applicant did not include in the tables how impingement forces will be calculated for each postulated jet. The staff also noted that in its response to RAI 3.6-6 S03, the applicant agreed to include tables pertaining to pipe break locations in the DCD, including pipe break data. However, the applicant stated that it will not include all the technical data that it had previously provided in the responses to RAI 3.6-6 S02 (Tables 1 and 2), RAI 3.6-13 S01 (Tables 1 and 2), and RAI 3.6-16 S01 (Tables 1 and 2) since these tables contain proprietary information. Based on its review of the information included in the applicant's responses to RAIs 3.6-6, 3.6-13, and 3.6-16 and their associated tables, as well as information provided in ESBWR DCD Revision 6, the staff has determined that the information pertaining to the analysis procedure that the applicant's plans to use for each postulated break should be included in Tables 3.6-5 through 3.6-7 of the DCD. In followup RAI 3.6-6 S04(d), the staff requested that the applicant include its calculation approaches in Tables 3.6-5 through 3.6-7 of the DCD. RAI 3.6-13 S02(b) is therefore, closed in favor of RAI 3.6-6 S04(d). RAI 3.6-13 and its associated open item are considered resolved.

Neglect of Jet Dynamic Loading and Structural Dynamic Response and Neglect of Feedback Amplification of Dynamic Jet Loads

In DCD, Tier 2, Section 3.6.2.3.1, the applicant stated that the total impingement force acting on any cross-sectional area of the jet is time and distance invariant, with a total magnitude equivalent to the steady-state fluid blowdown force given in Section 3.6.2.2 and with jet characteristics shown in Figure 3.6-1. While this may be true for some subsonic nonexpanding jets, it is certainly not true for supersonic expanding jets, particularly those impinging on nearby structures. The staff asked the applicant to examine NEA/CSNI, "Knowledge Base for Emergency Core Cooling System Recirculation Reliability," which states that tests in Germany's Heissdampfreaktor showed high dynamic (oscillating) loads in the immediate vicinity of breaks. The applicant provided additional criteria and procedures for jet loading evaluations in Appendix 3J.5 to the DCD. The applicant explained that the dynamic component of jet loading is considered independently from the static component, and that when static analysis methods are used to assess dynamic jet loads, the results are to be multiplied by a factor of 2. However, in Section 3.6.2 of DCD Tier 2, the applicant assumed that all jet loads are time invariant.

Free jets are notoriously unsteady, and in the case of supersonic jets, such strong unsteadiness will tend to propagate in the shear layer and induce unsteady (time-varying oscillatory) loads on obstacles in the flow path. Pressures and densities vary nonmonotonically with distance along the axis of a typical supersonic jet, and this in turn feeds and interacts with shear layer unsteadiness. In addition, for a typical supersonic jet, interaction with obstructions will lead to backward-propagating transient shock and expansion waves that will cause further unsteadiness in downstream shear layers.

In some cases, synchronization of the transient waves with the shear layer vortices emanating from the jet break can lead to significant amplification of the jet pressures and forces (a form of resonance) that is not considered in ANS 58.2 or DCD, Tier 2, Section 3.6.2. Should the dynamic response of the neighboring structure also synchronize with the jet loading time scales, further amplification of the loading can occur, including that at the source of the jet. These feedback phenomena are well known to those in the aerospace industry who work with aircraft that use jets to lift off and land vertically (see, for example, the 1981 article by C.M. Ho and N.S. Nosseir). Past investigators have observed generally that strong discrete frequency loads are seen when the impingement surface is within 10 diameters of the jet opening, and that when resonance within the jet occurs, significant amplification of impingement loads can result (Ho and Nosseir show a factor of 2 to 3 increase in pressure fluctuations at the frequency of the resonance). In RAI 3.6-14, the staff requested that the applicant perform the following:

(a) Provide information that establishes that the applicant's interpretation of the jet impingement force as static is conservative.

(b) Explain whether any postulated pipe break locations are within 10 diameters of a neighboring SSC (or barrier/shield), and if so, how jet feedback/resonance and resulting dynamic load amplification are accounted for.

(c) Clarify whether dynamic jet loads are to be considered, and, if so, using what methods. Also, should the dynamic loading include strong excitation at discrete frequencies corresponding to resonance frequencies of the SSC impinged upon, provide the basis for assuming a static analysis with a dynamic load factor (DLF) of two is conservative.

The staff was tracking RAI 3.6-14 as an open item in the SER with open items. In its response to RAI 3.6-14 Part (a), the applicant described an approach for obtaining the load resulting from jet impingement. In its approach, the applicant assumed that there is a thrust coefficient that may be used to obtain a conservative, but static, load applied by the jet. Thus, an unsteady, nonuniform load is replaced, for analysis, with a uniform, constant load. It is unclear that this is consistent with a compressible flow analysis. It has been documented, in the aforementioned comments of Wallis and Ransom and the NEA/CSNI "Knowledge Base for Emergency Core Cooling System Recirculation Reliability" that such high-energy free expanding jets will generally contain a complex of oblique shock and expansion waves and an unsteady shear layer. There will be significant unsteadiness and nonuniformity. Therefore, the staff issued followup RAI 3.6-14 S01(a), which requested that the applicant provide a response that clearly demonstrates a conservative approach for modeling what is properly considered as a compressible, turbulent, unsteady flow.

In its response to RAI 3.6-14 Part (b), the applicant stated that time-accurate simulations of the jet blowdown and structural response would account for dynamic amplification. However, the applicant did not provide any details of its analysis approach. Also, as in its response to RAI 3.6-6, the applicant provided a conflicting static analysis approach using a DLF of 2.0. It was unclear from its response which approach the applicant planned to use. Therefore, the staff issued followup RAI 3.6-14 S01(b), which requested that the applicant further clarify its planned approach. In addition, the staff asked the applicant to explain how its time-accurate analysis addresses feedback and resonance, including all validation exercises, and bias errors/uncertainties associated with its analysis approach.

In its response to RAI 3.6-14 Part (c), the applicant ignored dynamic jet loads, relying on the assumed 0.001-second rise time in the ANS 58.2 standard as the only time-dependent component of the jet loads. Therefore, the staff issued followup RAI 3.6-14 S01(c), referring the applicant to the original RAI and the multiple references to literature that clearly substantiates the presence of dynamic effects in actual jets, and requesting that the applicant respond again to the original RAI.

The applicant responded to followup RAIs 3.6-14 S01(a), (b), and (c) and agreed to use more appropriate analysis methodologies (CFD) to address the staff's concerns. The applicant referred the staff to its response to followup RAI 3.6-6 S02. Since followup RAI 3.6-6 S02 addresses the same issues as RAI 3.6-14, RAIs 3.6-14 S01(a), (b), and (c) and the associated open item were therefore resolved.

The applicant defined the limiting temperature (93.3 degrees C) and pressure (1.9 megapascals gauge) or 275 pounds per square inch gauge that separate the definitions of high-energy and moderate-energy fluid systems. However, the staff could not readily locate the maximum temperature and pressure in the high-energy systems. Many of the staff's RAIs are related to potential errors in modeling the many types of jets that could emanate from different piping breaks; however, some of the RAIs may refer to jet types that are not applicable to the ESBWR design. So that the staff can better understand the types of jets and blast waves that might emanate from the postulated breaks in the ESBWR, the staff requested in RAI 3.6-15 that the applicant clarify the maximum expected high-energy line temperature, pressure, and pipe diameter. The staff was tracking RAI 3.6-15 as an open item in the SER with open items. In its response to RAI 3.6-15, the applicant provided the table requested. However, the applicant did not include the conditions outside the high-energy lines. Therefore, the staff issued followup RAI 3.6-15 S01, requesting that the applicant provide the temperature and pressure of the external fluid regions in a revised table. The applicant responded to RAI 3.6-15 S01 and provided the requested tables in its response to followup RAI 3.6-13 S01. The staff verified that this table was included in a revised DCD. Therefore, RAI 3.6-15 and its associated open item were resolved.

In DCD, Tier 2, Section 3.6.2.3.1, the applicant stated that reflected jets are considered only when there is an obvious reflecting surface (such as a flat plate). In RAI 3.6-16, the staff asked the applicant to explain quantitatively how the reflections will be considered. The staff was tracking RAI 3.6-16 as an open item in the SER with open items. In its response to RAI 3.6-16, the applicant stated that the reflective force of the jet may be conservatively addressed using a shape factor and the assumed momentum of the jet. The applicant did not explain how it would determine the shape factor and how it would address the unsteadiness, compressibility, and coupled structural interaction with the jet. The staff therefore issued followup RAI 3.6-16 S01, which asked the applicant to modify its DCD to clearly delineate how candidate reflecting surfaces are chosen and how this analysis addresses the unsteadiness, compressibility, and coupled, potentially resonant, structural interaction with the jet. The applicant responded to RAI 3.6-16 S01 and provided tables showing configurations with potential reflection interactions between jets and targets. The applicant stated that it will perform detailed unsteady CFD analyses for those configurations according to the methods outlined in its response to RAI 3.6-6 S02. The applicant also summarized its approach for modeling reflections in a revised DCD. However, the applicant did not include the tables provided in its RAI response in the DCD revision. Therefore, the staff issued followup RAI 3.6-16 S02, requesting that the applicant include those tables in a revised version of the DCD. In response to RAI 3.6-16 S02, the applicant agreed to include the requested pipe break data in table format in DCD, Tier 2, Section 3.6.

However, the applicant also stated that it would make no DCD changes in response to this RAI, other than those described in the responses to RAIs 3.6-6 S03 and 3.6-13 S02. Based on its review of the information included in the applicant's responses to RAIs 3.6-6, 3.6-13, and 3.6-16 and their associated tables, as well as the information provided in ESBWR DCD Revision 6, the staff has determined that the information pertaining to consideration of jet reflections and analysis procedure that the applicant plans to use for each postulated break should be included in Tables 3.6-5 through 3.6-7 of the DCD. Therefore, in followup RAI 3.6-6 S04(d), the staff asked GEH to indicate in Tables 3.6-5 through 3.6-7 of the DCD whether jet reflections will be considered in the analyses. RAI 3.6-16 and its associated open item were therefore closed in favor of RAI 3.6-6 S04(d).

In DCD, Tier 2, Section 3.6.1.3, the applicant stated that in some cases, barriers, shields, and enclosures around high-energy lines will be specified. These nearby surfaces can induce feedback and resonance within jets, potentially destroying the barrier, shield, or enclosure. In RAI 3.6-17, the staff asked the applicant to explain how the barriers, shields, and enclosures will be designed so that they will not be damaged or destroyed by dynamic jet resonant loading. The staff was tracking RAI 3.6-17 as an open item in the SER with open items. In its response, the applicant explained that it planned to use ANS 58.2 to design barriers, shields, and enclosures around high-energy lines. An equivalent static analysis with a DLF of 2 would be used to account for the initial ramp-up of jet loading. The applicant, however, did not address the possibility of dynamic jet resonant loading in its response, which the staff considered unacceptable. The staff therefore issued RAI 3.6-17 S01, stating that ANS 58.2 was no longer universally acceptable for specifying jet loads over barriers, shields, and enclosures in nuclear power plants and that dynamic effects beyond those resulting from the initial transient assumed in ANS 58.2 must now be considered in the DCD. The staff requested that the applicant consider realistic jet loads, which include dynamic effects and possible resonant amplification, in its response to this followup RAI.

The applicant responded to RAI 3.6-17 S01 by stating that it no longer planned to use ANS 58.2 to design barriers, shields, and enclosures around high-energy lines. Instead, it will now use the methods outlined in its response to RAI 3.6-6 S02. The staff has verified that the applicant included this change in its methodology in a revised DCD and finds it acceptable, because the applicant's methodology appropriately considers the jet loads including dynamic effects and possible resonant amplification for the design of barriers, shields and enclosures around high-energy lines. Therefore, RAI 3.6-17 and its associated open item were resolved.

In DCD, Tier 2, Section 3.6.2.3.1, the applicant stated that potential targets in the jet path are considered at the calculated final position of the broken end of the ruptured pipe. However, Section 7.2 of ANS 58.2 states that "those targets which are close enough to the jet boundary of the model assumed such that with reasonable variations in the jet geometry or pipe movement parameters they could be impinged upon, shall be assumed to be impinged upon." In RAI 3.6-18, the staff requested that the applicant justify this departure from ANS 58.2. The staff was tracking RAI 3.6-18 as an open item in the SER with open items. The applicant responded to RAI 3.6-18 by stating that it will now use ANS 58.2, Section 7.2, in selected potential targets interacting with a jet from a ruptured pipe. The staff finds this acceptable because the applicant's criteria will ensure that all the potential targets within the jet path will be appropriately considered. Therefore, RAI 3.6-18 and its associated open item were resolved.

DCD Section 3.6.2, which describes how target loads are computed, provides an equation for calculating the jet pressure at the target based on the target area and the jet force (which is assumed to be equal to the blowdown force), and it also states that target shape factors are included in accordance with ANS 58.2. The standard uses shape factors for various geometries to adjust the net force on an object, not the pressure distribution over the object. In RAI 3.6-19, the staff requested that the applicant clarify how its jet load calculations will use target shape factors. The staff was tracking RAI 3.6-19 as an open item in the SER with open items. In its response to RAI 3.6-19, the applicant explained that target shape factors are indeed applied to target loads, and not to pressures. This addressed the staff's concern, and therefore, RAI 3.6-19 and its associated open item were resolved.

Finally, in RAI 3.6-24, the applicant was requested to provide a description of how jet impingement loading calculations will be performed to capture the range of worst-case conditions throughout a blowdown process. For example, jets expand far more rapidly at the beginning of blowdown than at the end of blowdown, when the jets become long and narrow and can propagate over longer distances. In addition, the applicant was requested to provide a detailed description of the capabilities of the applicant's analysis tool (Fluent) for modeling supersonic jets at conditions representative of those in postulated HELB events in an ESBWR reactor. The description should include citations to articles in the open literature as well as reports that confirm the tool's capabilities, preferably against analytic and/or measured data. The description should also explain and substantiate (with citations to articles and/or reports) the applicant's choice of turbulence model for jet impingement modeling.

The applicant responded to this RAI in Enclosure 1 of MFN 09-787, dated December 15, 2009. The applicant provided a detailed description of the Fluent analysis tool, citing articles in the open literature relevant to the analyses that will be conducted during the ESBWR design process. The applicant also explained and substantiated their choice of turbulence modeling. However, the applicant did not address how their calculation approach will capture the range of worst-case conditions throughout a blowdown event, instead stating that analyzing only the initial portion of the blowdown is conservative. While this is true of jet impingement on systems and structures that are close to a jet source, this is not necessarily true for systems and structures that are far (but less than 25 pipe diameters) from a source. For systems and structures that are far from a source, the jet shape during initial blowdown is severely underexpanded, and loads diminish significantly far from the source. Later, however, the jet expansion angle reduces, and strong jet loads are sustained even up to 25 diameters from a source. The applicant was once again requested, in follow-up RAI 3.6-24 S01, to provide a description of how jet impingement loading calculations will be performed to capture the range of worst-case conditions throughout a blowdown process. This explanation should be part of the overall procedure description requested in follow-up RAI 3.6-6 S05(B).

In its response to RAI 3.6-24 S01 the applicant provided a detailed description of how worst-case loading conditions would be assessed using their analysis approach in a revised Chapter 7 of Technical Report 0000-0105-2955 R6, which is included in NEDE-33440P. The applicant agreed to compute jet loads throughout the blowdown process, encompassing jet discharge Mach numbers between 4 and 0.3, which will capture loads from short jets (at high Mach numbers at the beginning of blowdown) and long steam jets (at low Mach numbers) toward the end of blowdown. The staff verified that this explanation was provided as part of the applicant's response to RAI 3.6-6 S05 (B) and incorporated in NEDE-33440P. Since the applicant will assess worst-case loading conditions throughout jet blowdown, RAI 3.6-24 S01 is resolved.

3.6.2.3.3.2 Pipe Whip Effects on Safety-Related Structures, Systems, and Components and Loading Combinations and Design Criteria for Pipe Whip Restraint

In DCD, Tier 2, Section 3.6.2.3.2, the applicant stated that components of the ruptured piping required for safe shutdown or that serve to protect the structural integrity of a safety-related component meet the limits to satisfy the ASME Code requirements for faulted conditions and to ensure required operability. The staff needs more clarification of the meaning of this particular criterion. If it means that satisfying the ASME Code requirements for faulted conditions ensures meeting the required operability of the safety-related components, the applicant did not provide the technical justification for this criterion. In RAI 3.6-8, the staff requested that the applicant provide the technical justification for operability criteria in DCD Section 3.6.2.3.2 for components of the ruptured piping required for safe shutdown or that serve the structural integrity of a safety-related component. The DCD states that these components will meet the limits to satisfy the ASME Code requirements for faulted conditions and to ensure required operability.

In a letter dated August 28, 2006, the applicant did not entirely address this RAI. For a ruptured pipe, the applicant claimed that the pipe stresses for an MSL within the containment penetration region are required to be less than 2.25 S_m in accordance with BTP 3-4 criteria. As the technical justification for this claim, the applicant referred to the statement in DCD, Tier 2, Section 3.6.2.2, under "Pipe Whip Dynamic Response Analysis," which states, "Piping systems are designed so that plastic instability does not occur in the pipe at the design dynamic and static loads unless damage studies are performed which show the consequences do not result in direct damage to any safety-related system or component." The applicant further stated that this criterion meets the ASME Code requirement for faulted condition. However, the applicant did not address the technical justification concerning the limits used to ensure the required operability of the safety-related components. In its response, the applicant stated that Appendix 3J contains further clarifications; this statement is not sufficiently specific. In addition, in the last paragraph on main steam isolation valve (MSIV) operability, the applicant stated that satisfying the 2.25-S_m requirement in accordance with BTP 3-4 criteria is of itself sufficient to ensure the operability of the MSIV installed within the containment penetration. However, the staff determined that merely satisfying the code limit does not ensure the component's operability; it must also meet the operability assurance program specified in SRP Section 3.10. The staff was tracking RAI 3.6-8 as an open item in the SER with open items. In a letter dated December 14, 2007, the applicant stated that pipe-mounted components will also have to satisfy SRP Section 3.9.3 for component environmental qualification. Further, in a letter dated April 25, 2008, the applicant provided markup copies of DCD Section 3.6.2.3.2 indicating that the operability qualification of active pipe-mounted components will be subject to SRP Section 3.9.3 requirements. The staff verified this change in Revision 6 of the DCD and finds it acceptable. Therefore, RAI 3.6-8 and the associated open item were resolved.

Nuclear power plants typically use several other types of whip restraint design. They include crushable materials (e.g., crushable ring, honeycomb, and frame with series of rings) and rigid restraints (e.g., elastic ring, ring with strut, and other structural designs) in addition to the U-bar type discussed in the DCD and shown in DCD Figure 3.6-2. In DCD, Tier 2, Section 3.6.2.3.3, the applicant provided design criteria for one type of whip restraint design (i.e., U-bar type). Therefore, in RAI 3.6-9, the staff asked the applicant to provide design criteria for other types of whip restraints if they will be used in the design of the ESBWR piping system. In its response to RAI 3.6-9, the applicant stated that no other types of whip restraints will be used in the ESBWR plant. The staff finds this acceptable; therefore, RAI 3.6-9 was resolved.

SRP Section 3.6.2 states that if a structure separates high-energy piping from a safety-related component, the separating structure should be designed to withstand the consequences of the pipe break in the high-energy line that could produce the greatest effect on the structure. This is irrespective of the fact that the pipe rupture criteria in SRP Section 3.6.2 might not require such a break location to be postulated. In DCD, Tier 2, Section 3.6.2.1.1, describing a separating structure with high-energy lines, the applicant met this requirement; therefore, the staff finds this acceptable.

For the ESBWR, the structures are designed to withstand the dynamic effects of postulated pipe breaks where the pipe rupture criteria require the specification of break locations. In addition, for areas where physical separation of redundant trains is not practical, performance of the HELSA evaluation determines which high-energy lines meet the spatial separation requirement and which lines require further protection. For the HELSA evaluation, discussed in DCD Section 3.6.1.3, no particular breakpoints are evaluated. Breaks are postulated at any point in all of the high-energy piping systems listed in DCD Tables 3.6-3 and 3.6-4, and any structure identified as necessary by the HELSA evaluation is designed for worst-case loads.

Using the above HELSA evaluation, the applicant claimed that an adequate level of protection is provided to ensure that a postulated break in any ESBWR high-energy piping system will not adversely affect the intended function of safety-related SSCs. Plant arrangement provides physical separation to the extent practical, and the HELSA evaluation ensures that no more than one redundant train can be damaged. If damage could occur to more than one division of a redundant safety-related system within 9.14 m (30 ft) of any high-energy piping, the design uses other protection devices such as barriers, shields, enclosures, deflectors, or pipe whip restraints. the applicant also claimed that when necessary, the protection requirements are met through the use of walls, floors, columns, abutments, and foundations.

In RAI 3.6-12(b), the staff noted that recent German tests show that significant damage from supersonic steam jets occurred to SSCs as far as 25 pipe diameters from the ruptured pipe location. Therefore, the 9.14-m (30-ft) separation criterion may not be adequate to satisfy the intent of the SRP Section 3.6.2 guideline by ensuring that structures are adequately designed to withstand the consequences of a worst-case pipe break with no adverse impact on the intended function of safety-related SSCs. In its response to RAI 3.6-12(b), the applicant stated that its evaluation zone will be extended to 25 diameters (19.1 m) for postulated MSL breaks. The staff finds this response acceptable; therefore, RAI 3.6-12(b) was resolved.

3.6.2.3.4 Guard Pipe Assembly Design

BTP 3-4, Item B.1.b(6), contains design, testing, and examination guidelines for guard pipes in the containment penetration areas. DCD, Tier 2, Section 3.6.2.4, states that the ESBWR primary containment does not require guard pipes. This may be because the ESBWR design does not contain guard pipes as defined in Section 3.6.2.4 of RG 1.70, Revision 3, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants (LWR Edition)," issued November 1978, which states that "a guard pipe is a device to limit pressurization of the space between dual barriers of certain containments to acceptable levels." The staff notes that SRP Section 3.6.2 uses the term "guard pipe" in a broader context than that in RG 1.70 to include all applicable sleeves in the containment penetration area. However, the applicant identified these guard pipes as sleeves in DCD, Tier 2, Section 3.6.2.1.1, and the design, testing, and examination requirements for these sleeves are consistent with the SRP Section 3.6.2 guidelines for guard pipes. In RAI 3.6-10, the staff asked the applicant to clarify this discrepancy between the guard pipe in SRP Section 3.6.2 and the sleeve in the DCD.

In its response to RAI 3.6-10, the applicant stated that the ESBWR plant design does not use guard pipes, as defined in RG 1.70. The staff recognizes that SRP Section 3.6.2 uses the term "guard pipe" in a broader context than that in RG 1.70 to include all applicable sleeves in the containment penetration area. The applicant has used the guidelines in SRP Section 3.6.2 for the design, testing, and examination requirements of guard pipes for such sleeves. The staff finds this acceptable; therefore, RAI 3.6-10 was resolved.

3.6.2.3.5 Pipe Break Analysis Results and Protection Methods

In DCD, Tier 2, Section 3.6.2.5, the applicant outlined the following information to be included in a pipe break evaluation report which will be completed in conjunction with closure of ITAAC Tier 1, Table 3.1-1, which is related to the pipe break analysis report:

- a summary of the dynamic analyses applicable to high-energy piping systems in accordance with Section 3.6.2.5 of RG 1.70, which should include the following:

– sketches of applicable piping systems showing the location, size, and orientation of postulated pipe breaks and the location of pipe whip restraints and jet impingement barriers

– a summary of the data developed to select postulated break locations, including calculated stress intensities, CUFs, and stress ranges as delineated in BTP 3-4

- for failure in the moderate-energy piping systems, descriptions showing how safety-related systems are protected from the resulting jets, flooding, and other adverse environmental effects

- identification of protective measures provided against the effects of postulated pipe failures for protection of each of the systems listed in Tables 3.6-1 and 3.6-2 of ESBWR DCD Tier 2

- details of how the MSIV functional capability is protected against the effects of postulated pipe failures

- typical examples, if any, where protection for safety-related systems and components against the dynamic effects of pipe failures includes their enclosure in suitably designed structures or compartments (including any additional drainage system or equipment environmental qualification needs)

- details of how the feedwater line check and feedwater isolation valves' functional capabilities are protected against the effects of postulated pipe failures

It should be noted that in DCD Revision 4, the applicant revised Sections 3.6.2.5 and 3.6.5-1-A. Specifically, DCD Section 3.6.5-1-A states that the COL applicant shall provide the information identified in Section 3.6.2.5, while Section 3.6.2.5 includes a list of the information that will be included in the pipe break evaluation report. The applicant also stated that the pipe break evaluation report will be completed in conjunction with closure of ITAAC Table 3.1-1, Item 3. Furthermore, in its letter dated November 29, 2007, the applicant proposed to delete Section 3.6.5-1-A regarding the COL information item that requires the COL applicant to provide details of pipe break analysis results and protection methods. Since the information discussed above is associated with the deleted COL information item, the staff requested that the ITAAC require the same design information as previously discussed in the deleted COL information item.

In RAI 14.3-131 S03, the staff asked the applicant to modify the ITAAC table to address the concern described above. In its letter of December 1, 2008, the applicant provided its RAI response to address the staff's concerns. In its response, the applicant provided two marked-up pages of the DCD, Tier 1, ITAAC Table 3.1-1. Specifically, the applicant changed the wording "as-designed pipe analysis report" of Items 3 and 6 of the ITAAC table to "as-designed pipe break analysis results report." The applicant further stated that DCD, Tier 2, Section 14.3A, states that the content of the pipe break analysis results report referred to in the ITAAC Table 3.1-1 is discussed in DCD, Tier 2, Section 3.6.2.5, which provides the details of the information required in the report on the results of the pipe break analysis. Based on its review of the information provided by the applicant, the staff determined that the applicant's proposed changes to ITAAC Table 3.1-1 adequately address the staff's concerns relating to the pipe break analysis results report and are therefore, acceptable. The staff concluded that RAI 14.3-131 S03 was resolved, pending the formal revision of ITAAC Table 3.1-1. The staff has verified that DCD Revision 6 includes all the changes discussed above; therefore, the staff concludes that the information to be included in a pipe break evaluation report, which will be completed in conjunction with closure of the Tier 1 ITAAC Table 3.1-1 related to the pipe break analysis report, is acceptable. In addition, the staff has verified that the applicant identified the information to be included in a pipe break evaluation report as Tier 2* in Revision 6 of the DCD, as requested by the staff in RAI 3.6-23, and finds this change acceptable. Therefore, RAIs 3.6-23 and 14.3-131 S03 were both resolved.

3.6.2.3.6 Analytic Methods To Define Blast Wave Interaction with Structures, Systems, and Components

In DCD, Tier 2, Section 3.6.2.6, the applicant stated that SSCs are evaluated for the blast wave effects. The blast effects are evaluated from all break types, such as for the circumferential and longitudinal breaks for high- and moderate-energy piping systems. The applicant also described the wave propagation of blast wave caused by a pipe rupture occurring in an open space and in an enclosed space. The staff's evaluation of the applicant's analytic methods to define blast wave interaction with SSCs is included in Section 3.6.2.3.3.1 of this SER.

3.6.2.3.7 As-Built Inspection of High-Energy Pipe Break Mitigation Features

In DCD, Tier 2, Section 3.6.2.1.1, the applicant stated that as a result of piping reanalysis caused by differences between the design configuration and the as-built configuration, the highest stress or CUF locations may be shifted; however, the initially determined intermediate-break locations need not be changed unless the dynamic effects from the new (as-built) break locations are not mitigated by the original pipe whip restraints and jet shields or a change is required in pipe parameters, such as major differences in pipe size, wall thickness, and routing. In addition, in DCD, Tier 2, Section 3.6.4, the applicant stated that an as-built inspection of the high-energy pipe break mitigation features will be performed for the ESBWR plant. The as-built inspection will confirm that SSCs that are required to be functional during and following an SSE are protected against the dynamic effects associated with high-energy pipe breaks. An as-built inspection of pipe whip restraints, jet shields, structural barriers, and physical separation distances will be performed. Performance of this as-built pipe break analysis reconciliation and inspection of the high-energy break mitigation/protection devices will occur as a part of ITAAC Tier 1, Table 3.1-1. This is consistent with the guidelines described in SRP Section 3.6.2; therefore, the staff finds this acceptable.

3.6.2.3.8 Generic Issues

Issue 119.1: Piping Rupture Requirements and Decoupling of Seismic and LOCA Loads

As discussed in NUREG-0933, Issue 119.1 concerns the pipe rupture requirements and decoupling of seismic and LOCA loads. The first part of the task involved rulemaking changes to GDC-4 in Appendix A of 10 CFR Part 50 to redefine the need to consider the dynamic effects of pipe breaks. A proposed rule to modify GDC-4 was published in July 1985 and codified leak-before-break (LBB) technology, but was limited only to the primary loop piping of PWRs; the final rule was published in April 1986. A proposed broad scope rule dealing with all high energy piping in light water reactors was published in July 1986; the final rule was published in October 1987. With the issuance of these revised rules, SRP Sections 3.6.1 and 3.6.2 were revised to eliminate the postulation of arbitrary intermediate breaks. In addition, Generic Letter (GL) 87-11 was issued to licensees on the relaxation of arbitrary intermediate pipe rupture requirements. Specifically, a 1987 revision to Branch Technical Position MEB 3-1 of SRP Section 3.6.2 eliminated all dynamic effects and all environmental effects resulting from arbitrary intermediate pipe ruptures. In DCD Section 3.6.2.1, the applicant described the criteria used to define the location of the postulated pipe ruptures for ESBWR. In Section 3.6.2 of this report, the staff has reviewed these criteria and found them to be consistent with the SRP concerning the elimination of arbitrary intermediate breaks. Furthermore, by a letter dated May 14, 2007, GE stated that LBB will not be used in ESBWR design. Subsequently, the applicant removed all the content pertaining to LBB from Section 3.6.3 and Appendix 3E of DCD Revision 3. Therefore, the first part of Issue 119.1 concerning the pipe rupture requirements is considered resolved for the ESBWR design.

The second part of Issue 119.1 involved relaxation of the requirement to consider LOCA and seismic loads simultaneously. A revision to SRP Section 3.9.3 was to be pursued to decouple seismic and pipe rupture loads in the mechanical design of components and their supports. However, in 1986 the staff terminated all work on a proposed revision to SRP Section 3.9.3. In DCD Section 3.9.3, the applicant provided the criteria for selection and definition of design limits and loading combinations for the mechanical design of components and their supports. In Section 3.9.3 of this report, the staff reviewed these criteria and found them to be consistent with the SRP concerning the load combination of LOCA and seismic loads. Therefore, this issue is considered resolved for the ESBWR design.

On the basis of its review as described above, the staff concludes that Issue 119.1 is resolved for the ESBWR design.

Issue 156.6.1: Pipe Break Effects on Systems and Components

As discussed in NUREG-0933, Issue 156.6.1 required that pipe break effects on systems and components be considered. This issue was derived from the Systematic Evaluation Program (SEP) lessons-learned, since then the concerns in Generic Issue 156.6.1 had been incorporated in the appropriate Subsections 3.6.1 and 3.6.2 of the SRP.

The staff reviewed the information included In ESBWR DCD Section 3.6.2 related to the determination of pipe rupture locations and their associated dynamic effects and found that the applicant has properly considered the pipe break effects on systems and components within the scope of SRP Section 3.6.2. In addition, as described in Section 3.9.3 of this SER, the staff's review of DCD Section 3.9.3 concluded that the applicant's load combination requirements for design basis pipe breaks related loads as included in DCD, Table 3.9-2 are acceptable. Therefore, the staff concludes that Issue 156.6.1 is resolved for the ESBWR design because that the applicant has properly considered the pipe break effects on systems and components as described above.

3.6.2.4 *Conclusions*

Based on its evaluation of the information pertaining to postulated pipe rupture evaluation included in the ESBWR DCD Revision 7 and the Appendix B (Technical Report 0000-0105-2955-R6) and Appendix A (Technical Report 0000-0102-6250-R0) included in the GEH Licensing Topical Report NEDE-33440P Revision 2, March 2010), the staff concludes that the criteria for postulating pipe rupture and crack locations, and the methodology for evaluating the subsequent dynamic effects on safety-related SSCs resulting from these ruptures, are generally consistent with the guidelines described in SRP Section 3.6.2 and meet the pertinent requirements of GDC 4.

3.7 Seismic Design

Using SRP Sections 3.7.1 through 3.7.3, Revision 3, as its basis, the staff reviewed DCD Sections 3.7, 3.7.1, 3.7.2, and 3.7.3 through Revision 6, regarding the seismic design adequacy of the ESBWR standard plant (seismic Category I SSCs), and considered the applicant's responses to RAIs, open items, and confirmatory items. In addition, the staff conducted two design calculation audits at the applicant's office in San Jose, CA. The purpose of these two audits was (1) to discuss resolution of the staff RAIs, open items, and confirmatory items, (2) to review detailed analysis reports and design calculations performed by the applicant, (3) to obtain additional information from the applicant, (4) to obtain RB and CB structural models and input ground motion time history (three components) from the applicant for the staff's independent soil-structure interaction (SSI) confirmatory analyses, and (5) to compare the staff's confirmatory analysis results with those generated by the applicant. The results of the staff's technical review of DCD Sections 3.7, 3.7.1, 3.7.2, and 3.7.3 are summarized below.

In DCD Section 3.7, the applicant described seismic classification of plant SSCs and the analysis criteria and methodology used to demonstrate seismic adequacy. In accordance with their function and the requirements to withstand the effects of the SSE, the applicant placed each of the plant SSCs into one of three seismic categories—seismic Category I, seismic Category II, and non-seismic, as defined in DCD Section 3.2.

The applicant stated that for seismic Category I and seismic Category II SSCs in the RB complex, the design also considers the effects of other dynamic loads resulting from reactor building vibration (RBV) caused by suppression pool dynamics. Although this section addresses seismic aspects of design and analysis in accordance with RG 1.70, the applicant stated that the methods of this section are also applicable to RBV dynamic loadings, unless noted otherwise.

The applicant stated that the site-specific SSE is based on an evaluation of the maximum earthquake potential, considering the regional and local geology, seismology, and specific characteristics of local subsurface material. Seismic Category I SSCs are designed to remain functional and within applicable stress, strain, and deformation limits when subjected to the SSE. Seismic Category I SSCs ensure the following:

- the integrity of the reactor coolant pressure boundary (RCPB)

- the capability to shut down the reactor and maintain it in a safe condition, or the capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures comparable to the applicable guideline exposures set forth in 10 CFR Part 100, "Reactor Site Criteria" (10 CFR 50.34(a))

The applicant stated that seismic Category II includes all plant SSCs that perform no safety-related function and whose continued function is not required, but whose structural failure or interaction could degrade the functioning of a seismic Category I SSC to an unacceptable safety level or could result in incapacitating injury to occupants of the control room. Thus, this category includes the SSCs whose structural integrity, not their operational performance, is required. The methods of seismic analysis and design acceptance criteria for seismic Category II SSCs are the same as those for seismic Category I; however, the procurement, fabrication, and construction requirements for seismic Category II SSCs are in accordance with industry practices. Seismic Category II items are those corresponding to position C.2 of RG 1.29, "Quality Assurance Requirements for the Installation, Inspection, and Testing of Instrumentation and Electric Equipment" (Safety Guide 30).

The applicant further stated that the OBE is a design requirement. However, for the ESBWR, the OBE ground motion was chosen to be one-third of the SSE ground motion; consequently, no explicit response or design analysis is required to show that OBE design requirements are met. This is consistent with Appendix S to 10 CFR Part 50. DCD Sections 3.7.3.2 and 3.7.4.4 address the effects of low-level earthquakes (of lesser magnitude than the SSE) on fatigue evaluation and plant shutdown criteria, respectively.

The staff concluded that the above information, presented in the introduction to DCD Section 3.7, is consistent with NRC regulations and guidance.

After completing its evaluation, the staff submitted RAIs 3.7-74 through 3.7-78 to the applicant, identifying information in DCD Section 3.7 and DCD Appendix 3A that should be designated as Tier 2*. (Information designated "Tier 2*" requires NRC staff review and approval before it can be changed.) In its responses to RAIs 3.7-74 through 3.7-78, the applicant agreed to designate in DCD Revision 6 all of the information identified by the staff as Tier 2*. The staff reviewed Revision 6 of the DCD and confirmed that it correctly incorporates the designation of Tier 2* information. Therefore, RAIs 3.7-74 through 3.7-78 were resolved.

In addition to its review in accordance with SRP Section 3.7, the staff also evaluated compliance with NUREG-0933, "Resolution of Generic Safety Issues", Issue A-40 "Seismic Design Criteria". Revision 3 to SRP Sections 2.5.2, 3.7.1, 3.7.2, and 3.7.3 incorporates the latest staff positions on review of seismic design parameters and seismic design analyses. These revised SRP sections address areas related to vibratory ground motions; design time-history criteria; development of floor response criteria, damping values, and SSI uncertainties; the combination of modal responses; and seismic analysis of the aboveground tanks and Category 1 buried piping. The revised SRP sections provide specific guidance for addressing these issues.

The review criteria for the resolution of Issue A-40 is conformance with the seismic design acceptance criteria of SRP Sections 2.5.2, 3.7.1, 3.7.2, and 3.7.3. In DCD, Tier 2, Revision 6, Section 1.11, the applicant specifies compliance of the ESBWR standard plant design with SRP Sections 2.5.2, 3.7.1, 3.7.2, and 3.7.3 as the basis for resolving Issue A-40. Sections 2.5.2, 3.7.1, 3.7.2, and 3.7.3 of this report discuss the staff's review of the corresponding DCD, Tier 2, Sections. Based on the staff's evaluations, the staff concludes that the ESBWR design is consistent with the guidelines in Revision 3 to SRP Sections 2.5.2, 3.7.1, 3.7.2, and 3.7.3. Therefore, Issue A-40 was resolved for the ESBWR design.

3.7.1 Seismic Design Parameters

3.7.1.1 *Regulatory Criteria*

The staff accepts the seismic design basis for structures that are important to safety and that must withstand the effects of the earthquakes according to GDC 2, "Design Bases for Protection Against Natural Phenomena," and Appendix S, "Earthquake Engineering Criteria for Nuclear Power Plants," to 10 CFR Part 50.

- GDC 2, as it relates to seismic design basis to reflect appropriate consideration of the most severe earthquakes that have been historically reported for the site and surrounding area with sufficient margin for the limited accuracy, quantity, and period of time in which historical data have been accumulated, and SSCs important to safety be designed to withstand the effects of earthquakes without loss of capability to perform their intended safety functions.

- 10 CFR Part 50, Appendix S, as it relates to the SSE ground motion in the free-field at the foundation level of the structures to be an appropriate response spectrum with a peak ground acceleration of at least 0.1g, and if the OBE is chosen to be less than or equal to one-third of the SSE ground motion, it is not necessary to conduct explicit response or design analyses in accordance with Section IV.(2)(i)(A) of 10 CFR Part 50, Appendix S.

The staff used SRP guidance Section 3.7.1 to review seismic design parameters to ensure that they are appropriate and contain sufficient margin such that seismic analyses (reviewed under other SRP sections) accurately and/or conservatively represent the behavior of SSCs during postulated seismic events. In addition, the staff used RG 1.60, “Design Response Spectra for Seismic Design of Nuclear Power Plants,” and RG 1.61, “Damping Values for Seismic Design of Nuclear Power Plants,” to determine the acceptability of design response spectra for input into the seismic design analysis of nuclear power plants and damping values used in the dynamic seismic analyses of seismic Category I SSCs.

3.7.1.2 *Summary of Technical Information*

In DCD Section 3.7.1, the applicant stated that safety-related structures that must withstand the effects of earthquakes are designed to the relevant requirements of GDC 2 and comply with Appendix S to 10 CFR Part 50 concerning natural phenomena, consistent with SRP Section 3.7.1. The applicant further indicated that standardized plant design needs to consider an envelope of the most severe earthquakes that may affect a large number of possible sites, with sufficient margin to account for the limited historical data that have been accumulated. The seismic design basis for the ESBWR is intended to envelop the seismic design parameters applicable to generic sites (i.e., RG 1.60, peak ground acceleration (PGA) = 0.3g (acceleration of gravity)) and to three early site permit (ESP) sites (North Anna, Clinton, and Grand Gulf). A review of the conditions at the three sites reveals that Clinton and Grand Gulf are bounded by the envelope of generic site and North Anna conditions. Therefore, The North Anna ESP site was selected for further consideration in conjunction with generic sites for the site-enveloping seismic design of the ESBWR standard plant.

3.7.1.2.1 Design Ground Motion

In DCD Section 3.7.1.1, the applicant stated that the ESBWR standard plant SSE design ground motion is rich in both low and high frequencies. The low-frequency ground motion follows RG 1.60 ground spectra anchored to 0.3g. The high-frequency ground motion matches the North Anna ESP site-specific spectra as representative of most severe rock sites in the Eastern US. These two ground motions are considered separately in the basic design. To verify the basic design, the two separate inputs are further enveloped to form a single ground motion as the design-basis ground motion for the ESBWR. The single-envelope design ground response spectra, also termed “certified seismic design response spectra” (CSDRS), are shown in DCD, Tier 2, Figures 2.0-1 and 2.0-2, for horizontal and vertical direction, respectively.

The applicant stated that these spectra are defined as free-field outcrop spectra at the foundation level (bottom of the base slab) of the RB FB and CB and that application of design ground motion at the foundation level is a conservative approach for deeply embedded foundations, as compared to the compatible free-field motion deconvoluted from the free ground surface motion at the finished grade. The ESBWR RB and CB foundations are embedded at a depth of 20 m (66 ft) and 14.9 m (49 ft), respectively. The FB shares a common foundation mat with the RB. For the firewater service complex (FWSC), the CSDRS are 1.35 times the values shown in DCD, Tier 2, Figures 2.0-1 and 2.0-2. The ESBWR CSDRS are higher than RG 1.60 spectra anchored to 0.1g PGA at the foundation level, which meets the regulations in Appendix S to 10 CFR Part 50 for 0.1g minimum PGA for the horizontal component of the SSE at the foundation level in the free-field.

In DCD Section 3.7.1.1.1, the applicant stated that the ground response spectra for low-frequency ground motion are developed in accordance with RG 1.60 anchored to 0.3g and specified at the foundation level in the free-field for generic sites. Figures 3.7-1 and 3.7-2 show the 0.3g SSE design response spectra for various damping ratios for the horizontal and vertical motions, respectively. The horizontal response spectra are equally applicable to two orthogonal horizontal directions.

The applicant stated that synthetic time histories are generated to envelop the design response spectra. DCD Figures 3.7-3 through 3.7-5 show the generic site 0.3g SSE acceleration time histories for two horizontal components (H1 and H2) and vertical (VT) component, respectively, together with corresponding velocity and displacement time histories. Each time history has a total duration of 22 seconds.

The applicant stated that these time histories satisfy the spectrum-enveloping requirement stipulated in SRP Section 3.7.1. The response spectra are computed at frequency intervals suggested in Table 3.7.1-1 of SRP Section 3.7.1, plus three additional frequencies at 40, 50, and 100 hertz (Hz). The time histories of the two horizontal components also satisfy the power spectra density (PSD) requirement stipulated in Appendix A to SRP Section 3.7.1. Because Appendix A to SRP Section 3.7.1 does not address the target PSD compatible with the RG 1.60 vertical spectrum, the applicant used the same methodology specified in Appendix A to SRP Section 3.7.1 for the RG 1.60 horizontal spectrum to develop the vertical target PSD compatible with the RG 1.60 vertical spectrum. The applicant described its methodology in detail. DCD Figure 3.7-23 indicates that the PSD of the vertical time history envelops the target PSD.

The applicant stated that the time histories of three spatial components are checked for statistical independency. The cross-correlation coefficient at zero time lag is 0.0135 between H1 and H2, 0.0704 between H1 and VT, and 0.0737 between H2 and VT. The cross-correlation coefficients are less than 0.16, which is specified as the acceptance criterion in the technical paper referenced d in RG 1.92, Revision 1, “Combining Modal Responses and Spatial Components in Seismic Response Analysis.” Thus, H1, H2, and VT acceleration time histories are mutually statistically independent.

In DCD Section 3.7.1.1.2, the applicant stated that the high-frequency ground motion is specific to the North Anna site as developed in the ESP application. Since the 0.3g RG 1.60 generic site spectra envelop the low-frequency parts of North Anna SSE ground spectra with large margins, the applicant stated that only the high-frequency part is explicitly considered. DCD Figures 3.7-24 to 3.7-35 show the high-frequency SSE ground spectra for 5-percent damping and the compatible time histories at elevations of the CB, RB, and FB foundation level. The PGA values, corresponding to the spectral acceleration at 100 Hz of the target spectra, are

0.492g at the CB base and 0.469g at the RB, FB base in both horizontal and vertical directions. The time histories are generated under the spectral matching criteria given in NUREG/CR-6728, “Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk-Consistent Ground Motion Spectra Guidelines,” issued October 2001, and the cross-correlations between the three individual components are all less than the 0.16 requirement. The applicant stated that since the more stringent matching criterion of NUREG/CR-6728 is used, a separate PSD check as described in SRP Section 3.7.1.II.1 is not required.

In DCD Section 3.7.1.1.3, the applicant stated that the single-envelope ground response spectra are constructed to envelop the low-frequency 0.3g RG 1.60 spectra (DCD Section 3.7.1.1.1) and the high-frequency North Anna site-specific spectra (DCD Section 3.7.1.1.2). DCD Table 3.7-2 and Figures 2.0-1 and 2.0-2 show the smoothed target spectra for 5-percent damping.

The spectral values up to and including 9 Hz and 10 Hz in the horizontal and vertical directions, respectively, are based on 0.3g RG 1.60 spectra. At higher frequencies, the spectral values closely match those of the envelope of North Anna ESP spectra at the ESBWR RB, FB and CB foundations as a representative ground motion for sites founded on rock in the Eastern US. The applicant noted that no recorded seismic event has ever simultaneously contained very high excitation levels both at low frequencies and at high frequencies. Therefore, the applicant considered this envelope to be very conservative in terms of energy content and used it to verify the basic design previously discussed.

A single set of three orthogonal, statistically independent time histories is generated to match the target spectra in accordance with NUREG/CR-6728 criteria. The computed response spectra are compared with the corresponding target spectra in DCD Figures 3.7-38 through 3.7-40 for H1, H2, and VT components, respectively. Spectral matching for 5-percent damping is consistent with the recommendations of NUREG/CR-6728. Because the more stringent spectral matching criterion from NUREG/CR-6728 is used, a separate PSD check as described in SRP Section 3.7.1.II.1 is not required. DCD Figures 3.7-41 through 3.7-43 show the acceleration time histories, together with corresponding velocity and displacement time histories. Each time history has a total duration of 40 seconds with time steps of 0.005 seconds. The strong motion duration is 7.8 seconds for H1, 12 seconds for H2, and 8.9 seconds for VT. The cross-correlations between the three individual components are all less than the 0.16 requirement.

The single-envelope ground motion is considered in the design-basis seismic analysis for all generic uniform and layered sites, using the DAC3N and SASSI2000 computer codes, respectively.

3.7.1.2.2 Percentage of Critical Damping Values

In DCD Section 3.7.1.2, the applicant stated that DCD Table 3.7-1 shows damping values for various structures and components for use in SSE dynamic analysis. These damping values are consistent with RG 1.61 SSE damping, except for the damping value of cable trays and conduits. The damping values shown in DCD Table 3.7-1 for cable trays and conduits are based on the results of over 2,000 individual dynamic tests conducted for a variety of raceway configurations.

The damping value for conduit systems (including supports) is 7-percent constant. For heating, ventilation, and air conditioning ducts and supports the damping value is 7 percent for companion angle construction, 10 percent for pocket lock construction, and 4 percent for welded construction.

For ASME Code, Section III, Division 1, Class 1, 2, and 3, and ASME Power Piping Code B31.1 piping systems, the damping values of Table 3.7-1 or alternative damping values specified in Figure 3.7-37 are used. The damping values shown in Table 3.7-1 are applicable to all modes of a structure or component constructed of the same material. Damping values for systems composed of subsystems with different damping properties are obtained using the procedures described in DCD Section 3.7.2.13.

3.7.1.2.3 Supporting Media for Category I Structures

In DCD Section 3.7.1.3, the applicant indicated that the seismic Category I structures have concrete mat foundations supported on soil, rock, or compacted backfill. DCD Section 3.8.5.1 gives the embedment depth, dimensions of the structural foundation, and total structural height for each structure. DCD Appendix 3A describes the soil conditions considered for SSI analysis.

3.7.1.3 *Staff Evaluation*

In DCD Revision 5, Section 3.7.1, the applicant stated that structures that are safety-related and must withstand the effects of earthquakes are designed to the relevant requirements of GDC 2 and comply with Appendix S to 10 CFR Part 50 concerning natural phenomena, consistent with SRP Section 3.7.1. The applicant further indicated that the standard plant design needs to consider an envelope of the most severe earthquakes that may affect a large number of possible sites, with sufficient margin to account for the limited historical data that have been accumulated. The seismic design basis for the ESBWR is intended to envelop the seismic design parameters applicable to generic sites (i.e., RG 1.60, PGA = 0.3g) and to three ESP sites. For the ESP, the applicant's review of the conditions at the three sites concluded that Clinton and Grand Gulf are bounded by the envelope of generic site and North Anna conditions. Therefore, the North Anna ESP site was selected for further consideration, in conjunction with generic sites, in the development of the seismic design envelope for the ESBWR standard plant.

In reviewing DCD Revision 1, the staff was unclear as to how the applicant had defined the design-basis SSE for evaluation of seismic Category I and II SSCs. The staff issued RAI 3.7-5, requesting that the applicant clarify this definition. The applicant resolved RAI 3.7-5 by redefining the design ground response spectra, also termed the CSDRS, to be the envelope of the RG 1.60 spectrum and the North Anna spectrum. The applicant substantially revised DCD Section 3.7.1 in Revision 2 to reflect this new definition of the design ground response spectra. The staff finds this approach technically acceptable, because the seismic Category I and II SSCs are subjected to a more conservative seismic loading using the envelope approach. Any site-specific SSE falling below the ESBWR design envelope spectra is acceptable without further evaluation.

Based on DCD Revision 1, the staff also issued RAI 3.7-6, requesting that the applicant describe how the two sets of seismic design parameters are applied to perform seismic analyses and perform detailed design. This RAI was no longer applicable when the applicant redefined the CSDRS to be the envelope of the RG 1.60 spectrum and the North Anna spectrum.

The applicant indicated that the North Anna ESP site was selected for further consideration in conjunction with generic sites for the site-enveloping seismic design of the ESBWR standard plant. In RAI 3.7-7, the staff asked the applicant to provide a detailed description of the North Anna site conditions (e.g., geotechnical properties), including response spectra at various depths through the profile, consistent with design spectra. During the staff audit on June 5-8, 2006, the staff compared the applicant's response spectra used at the foundation depths of the CB and RB models with the surface response spectra from the North Anna ESP application. The staff's review found that the applicant's response spectra are similar to, although about 10 to 20 percent lower than, the North Anna ESP response spectrum. The applicant justified its response spectra on the basis that they are determined at the specific building foundation depths, which are lower in the North Anna site column. In its formal RAI response dated June 30, 2006, the applicant submitted a detailed description of the North Anna site and explained the technical basis for the differences between the ESBWR spectra at the foundation depths of the CB and RB and the North Anna ESP spectra. The staff found the response to be acceptable, on the basis that the reduction in the spectra is consistent with the embedded foundation depths of the RB, FB and CB. Therefore, RAI 3.7-7 was resolved.

3.7.1.3.1 Design Ground Motion

In DCD Section 3.7.1.1, the applicant stated that the ESBWR standard plant design ground motion is rich in both low and high frequencies. The low-frequency ground motion follows RG 1.60 ground spectra anchored to 0.3g. The high-frequency ground motion matches the North Anna ESP site-specific spectra as representative of most severe rock sites in the Eastern US. These two ground motions are considered separately in the basic design. To verify the basic design, the two separate inputs are further enveloped to form a single ground motion as the design-basis ground motion for the ESBWR. In DCD, Tier 2, Figures 2.0-1 and 2.0-2 show the single-envelope design ground response spectra for the horizontal and vertical direction, respectively.

The applicant stated that these spectra are defined as free-field outcrop spectra at the foundation level (bottom of the base slab). Application of design ground motion at the foundation level is a conservative approach for deeply embedded foundations as compared to the compatible free-field motion deconvoluted from the free ground surface motion at the finished grade. The ESBWR RB and CB foundations are embedded at depths of 20 m (66 ft) and 14.9 m (49 ft), respectively. The FB shares a common foundation mat with the RB.

In RAI 3.7-8, the staff asked the applicant to provide its technical basis to justify the application of the RG 1.60 ground response spectra at two different foundation elevations. In its response to RAI 3.7-8, the applicant stated that the use of the same 0.3g RG 1.60 spectra at different foundation elevations is a conservative approach for developing enveloping seismic loads for the ESBWR standard plant design. At the COL stage, a site-specific SSE probabilistic site response analysis will be performed, and the resulting free-field outcrop spectrum at the foundation level of each seismic Category I building will be compared to the ESBWR standard plant design spectrum, as stated in the response to RAI 3.7-5. During the staff audit on October 31–November 2, 2006, the staff requested that the applicant demonstrate the conservatism in the approach for developing enveloping seismic loads. In its supplemental response to RAI 3.7-8, the applicant removed the reference to conservatism.

Per 10 CFR 52.79, to take credit for the generic certified seismic design-basis, a COL applicant must demonstrate in its FSAR that its site is enveloped by the assumptions used by applicant in the design-basis calculations. If this is not the case, a COL applicant has to identify a departure from the certified design basis, and provide the technical basis for the acceptability of the departure. The staff found the applicant's application of the RG 1.60 ground response spectra at two different foundation elevations to be acceptable on the basis that COL applicants will need to conduct site-specific comparisons of free-field outcrop motion at each foundation level to the ESBWR standard plant design spectrum at each foundation level. Therefore, RAI 3.7-8 was resolved.

In DCD Section 3.7.1.1.1, the applicant discussed the ground response spectra for low-frequency ground motion developed in accordance with RG 1.60 anchored to 0.3g and specified at the foundation level in the free-field for generic sites. With one exception, the staff found the applicant's methods to be acceptable, because they are consistent with the acceptance criteria in SRP Section 3.7.1. The exception, addressed above in RAI 3.7-8, has been resolved.

In DCD Section 3.7.1.1.2, the applicant discussed the high-frequency ground motion based on North Anna site-specific spectra developed in the ESP application. With one exception, which is addressed above in RAI 3.7-7 and has been resolved, the staff found the applicant's methods to be acceptable, because they are consistent with the staff position for addressing high-frequency ground motion issues in seismic analysis and design of seismic Category I and II structures.

In DCD Section 3.7.1.1.3, the applicant discussed the single-envelope ground response spectra constructed to envelop the low-frequency 0.3g RG 1.60 spectra (Section 3.7.1.1.1) and the high-frequency North Anna site-specific spectra (Section 3.7.1.1.2). The staff found the applicant's methods to be acceptable, because the seismic Category I and II SSCs are subjected to a more conservative seismic loading using the envelope approach.

The staff noted that the content of DCD Section 3.7.1.1, Revisions 2 through 5, is substantially different from the content of Revision 1, which the staff initially reviewed and used as the basis for its RAIs. The staff issued RAIs 3.7-9 through 3.7-12 based on Revision 1. All of these RAIs have been resolved. As applicable, Revisions 2 through 5 reflect the resolution of these RAIs. The following discusses the specific technical issues and their resolution.

In Revision 1, the applicant stated that the synthetic time histories developed to envelop the RG 1.60 spectra satisfy the spectrum-enveloping requirement in SRP Section 3.7.1 and that the response spectra are computed at frequency intervals suggested in Table 3.7.1-1 of SRP Section 3.7.1, plus three additional frequencies at 40, 50, and 100 Hz. The staff did not consider this sparse frequency set above 33 Hz to be adequate for judging the appropriateness of the time-history fit between 33 and 100 Hz. In RAI 3.7-9, the staff requested that the applicant provide additional information, including (a) the corresponding strong motion durations for the synthetic time-history records and (b) a detailed comparison of the fits to the RG 1.60 spectra, up to 100 Hz. In its response, the applicant provided the requested information, primarily in the form of figures and tables. The staff reviewed these figures and tables and concluded that the applicant's synthetic time histories used to envelop the RG 1.60 spectra are adequate up to 100 Hz. Therefore, RAI 3.7-9 was resolved.

In Revision 1, the applicant indicated that a target PSD appropriate for the vertical RG 1.60 response spectrum was developed using the same process (Appendix A to SRP Section 3.7.2) that was used to develop the horizontal target PSD. In RAI 3.7-10, the staff asked the applicant to include the details of its implementation of this process in the DCD, to facilitate staff evaluation. In its response, the applicant indicated that Appendix B to NUREG/CR-5347, "Recommendations for Resolution of Public Comments on USI A-40," issued June 1989, was used to develop the target PSD for the vertical RG 1.60 response spectrum. The applicant delineated the specific steps and committed to including this information in a future revision to the DCD. The staff reviewed the applicant's response and found that it constituted an acceptable method to develop a target PSD appropriate for the vertical RG 1.60 response spectrum. The applicant included this information in Revision 2 to the DCD. Therefore, RAI 3.7-10 was resolved.

In Revision 1, the applicant stated that the low-frequency part of North Anna SSE ground spectra is enveloped by the 0.3g RG 1.60 generic site spectra with large margins, and only the high-frequency part needs to be explicitly considered. In RAI 3.7-11, the staff asked the applicant to justify this conclusion in the DCD and to include a comparison plot of these two sets of ground response spectra in DCD Section 3.7.1. In its response, the applicant provided a comparison plot, showing that the RG 1.60 response spectrum envelops by a factor of over 5 the low-frequency part of the site-specific ground motion response spectra for all evaluated North Anna ESP cases (including the CB and RB, FB base cases). The staff noted that when the applicant redefined the design-basis SSE to be the envelope of the two spectra, this issue was automatically resolved. Therefore, RAI 3.7-11 was resolved.

Based on its review of Revision 1, the staff concluded that the description of the North Anna ESP design ground motion (5-percent damping design ground response spectra at different foundation levels, comparisons of response spectra calculated from the modified ground motion time histories with the ESP ground response spectra, and other conditions) provided in the DCD was insufficient for the staff to reach a safety conclusion regarding the design adequacy of the RB, FB and CB fore the North Anna spectra. In RAI 3.7-12, the staff requested that the applicant provide the following information in the DCD:

1. Identify which ESP ground response spectra (target spectra or spectra/1.10 or spectra x 1.30) is used for the seismic analysis and design.

2. The ESP response spectra for 2 percent, 3 percent, 4 percent, and 7 percent damping ratios;

3. Definition of the "modified" ground motion time histories;

4. Demonstrate that the response spectra calculated from the modified ground motion time histories envelope the design ESP ground response spectra for all damping ratios to be used in the analyses;

5. Demonstrate that the modified ground motion time histories satisfy the PSD requirements (including how the target PSD was calculated);

6. Basis for the statement in the second paragraph of Page 3.7-4, "the cross-correlations between the three individual components are all less than the 0.3 requirement." (The staff's position for the cross-correlations between the three individual components is 0.16. This staff's position had been applied for other design certification review, such as AP600, AP1000, etc.)

In its response to RAI 3.7-12, the applicant stated the following:

(1) The horizontal and vertical target spectra (shown as solid light gray lines in DCD Figures 3.7-24, 3.7-26, 3.7-28, 3.7-30, 3.7-32, and 3.7-34) are used for seismic analysis and design. Spectral matching of time histories associated with the target spectra was performed to satisfy criteria given in NUREG/CR-6728. These criteria provide a sound and more easily implemented method than the current version of the USNRC Standard Review Plan (NUREG-0800) to generate time histories whose response spectra match design spectra. The applicant also referred to its response to RAI 3.7-34.

(2) The applicant referred to (4) below.

(3) NUREG/CR-6728 criteria are devised to avoid any significant discrepancy between design and generated time history spectra at any frequency of interest. This requires a target spectrum digitized at 100 frequency points (equally spaced in log units) per frequency decade. Thus, for a frequency range of 0.1 Hz to 100 Hz, the target spectra are defined at 300 frequency points.

To achieve this aim, NUREG/CR-6728 recommends that the computed 5 percent damped response spectrum of the accelerogram should not fall more than 10 percent below the target spectrum at any one frequency point (a factor of 1/1.1) and that the computed 5 percent damped response spectrum of the artificial ground motion should not exceed the target spectrum at any frequency by more than 30 percent (a factor of 1.3). In addition, to prevent large frequency ranges falling below the target, no more than nine adjacent spectral points may be allowed to fall below the target spectrum at any frequency.

These criteria have been used to develop the time histories associated with, and matching, the target spectra of DCD Section 3.7.1.1.3. To satisfy the 1/1.1 factor, 1.3 factor, and nine-adjacent-points criteria, a final scalar multiplication of the near-final time history was often necessary. This “scale factor” is shown above the top left border of each target response spectrum plot. The factor is never less than 1.0 and never greater than 1.01. Multiplication of the penultimate time history by this scale factor results in the “modified” time history of the figures referenced in DCD Section 3.7.1.1.3.

To demonstrate graphically that these 1/1.1 and 1.3 factor criteria have been met, target spectra divided by 1.1 and multiplied by 1.3 are plotted on each of the figures so that it may be easily seen that the thin red line representing the response spectrum of the associated “modified” time history falls within these bounds for all frequencies.

(4) Spectral matching of time histories associated with the target spectra was performed to satisfy criteria given in NUREG/CR-6728, which only address 5 percent critically damped response spectra. Ground response spectra for additional damping ratio values were not developed as part of the ESP. The requested demonstration, therefore, is not available.

(5) The ground motion time histories generated for the North Anna ground response spectra have not been tested against any PSD enveloping guidelines, nor have target PSD spectra been developed for the high frequency target response spectrum. The applicant also referred to its response to RAI 3.7-34.

(6) The cross-correlations have been calculated for the separate components of the time histories generated under the spectral matching criteria given in NUREG/CR-6728 and have been found to all be less than 0.16.

The applicant indicated that it would revise the DCD to include the information provided in the response.

During the staff audit on June 5–8, 2006, the staff independently computed comparisons of the spectra developed from the applicant's time histories to the spectral targets being used (RG 1.60 and North Anna spectra) at the CB and RB foundation elevations. In addition, the staff independently checked cross-correlations. The staff used the CARES code in performing both of these checks. Both spectral matching and cross-correlation SRP criteria were found to be satisfied. The staff's independent evaluation conducted during the audit confirmed the accuracy of the applicant's response.

The applicant appropriately incorporated the requested information in Revision 2 to the DCD. Therefore, RAI 3.7-12 was resolved.

3.7.1.3.2 Percentage of Critical Damping Values

In DCD Section 3.7.1.2, the applicant indicated that DCD Table 3.7-1 shows the damping values for various structures and components for use in SSE dynamic analysis and that these damping values are consistent with RG 1.61 SSE damping, except for cable trays and conduits.

In RAI 3.7-13, the staff requested that the applicant discuss its compliance with RG 1.61, Revision 1, issued March 2007. In its response to RAI 3.7-13, the applicant proposed several changes to DCD Table 3.7-1 to make it consistent with RG 1.61, Revision 1. The applicant incorporated these changes in DCD Revision 1. The staff noted that, with the exception of several footnotes related to cable tray and conduit damping, DCD, Revision 1, Table 3.7-1, is either more conservative than or consistent with RG 1.61, Revision 1. Therefore, with the one exception noted, the proposed damping values are acceptable to the staff.

The staff requested supplemental information for RAI 3.7-13 to resolve this remaining issue.

The staff observed that Note 1 to Table 4 of RG 1.61, Revision 1, states, "Maximum cable loadings, in accordance with the plant design specification, are to be utilized in conjunction with these damping values," and Note 4 to Table 4 states, "When cable loadings of less-than maximum are specified for design calculations, the applicant or licensee is expected to justify the selected damping values and obtain NRC review for acceptance on a case-by-case basis." However, DCD Table 3.7-1, Footnote 2c, implies that a cable tray need be only one-third full. Also, DCD Table 3.7-1 does not address cable fill for conduits. The staff requested that the applicant concur with Note 1 to Table 4 of RG 1.61, Revision 1, or provide its technical basis for using the criterion of a one-third fill level for cable trays and no fill level criterion for conduits.

The applicant formally submitted a revision to DCD Table 3.7-1, in DCD Revision 5, in which it concurred with Note 1 to Table 4 of RG 1.61, Revision 1. Therefore, RAI 3.7-13 was resolved.

However, the staff subsequently noted an inconsistency in DCD Revision 5, between the text of DCD Section 3.7.1.2 and the information in DCD Table 3.7-1. In RAI 3.7-66, the staff asked the applicant to correct this inconsistency in the DCD. In its response to RAI 3.7-66, the applicant identified a proposed DCD change to correct the inconsistency. The staff found the proposed DCD change to be acceptable. Revision 6 of the DCD incorporated the applicable change to correct the inconsistency. Therefore, RAI 3.7-66 was resolved.

With respect to alternative piping damping, the applicant created new DCD Figure 3.7-37, with accompanying footnotes, in lieu of referencing annulled ASME Code Case N-411, in response to staff RAIs 3.7-14 and 3.12-19 on DCD Revision 1. The applicant incorporated the new figure in DCD Revision 2. Because this new figure includes all the technical information requested by the staff, these RAIs were resolved. Therefore, the applicant's proposed alternative piping damping is acceptable to the staff.

The applicant addressed composite modal damping in DCD Section 3.7.2.13. The staff's evaluation of composite modal damping appears in Section 3.7.2.3.13 of this report.

3.7.1.3.3 Supporting Media for Category I Structures

In DCD Section 3.7.1.3, the applicant indicated that the seismic Category I structures have concrete mat foundations supported on soil, rock, or compacted backfill; that DCD Section 3.8.5.1 gives the embedment depth, dimensions of the structural foundation, and total structural height for each structure; and that DCD Appendix 3A describes the soil conditions considered for SSI analysis.

Section 3.7.2.3.4 of this report presents the staff's assessment of the soil conditions considered for the SSI analysis, as described in DCD Appendix 3A.

3.7.1.4 *Conclusions*

The staff finds that the applicant has adequately addressed seismic design parameters, in accordance with the acceptance criteria delineated in SRP Section 3.7.1. On this basis, the staff concludes that the regulatory criteria delineated in Section 3.7.1.1 of this report are satisfied.

3.7.2   Seismic System Analysis

3.7.2.1 *Regulatory Criteria*

The staff accepts the seismic design basis for SSCs that are important to safety and that must withstand the effects of earthquakes according to GDC 2, "Design Bases for Protection Against Natural Phenomena," and Appendix S to 10 CFR Part 50, "Earthquake Engineering Criteria for Nuclear Power Plants."

- GDC 2, as it relates to the seismic design basis to reflect appropriate consideration of the most severe earthquakes that have been historically reported for the site and surrounding area with sufficient margin for the limited accuracy, quantity, and period of time in which historical data have been accumulated, and SSCs important to safety be designed to withstand the effects of earthquakes without loss of capability to perform their intended safety functions.

- 10 CFR Part 50, Appendix S, as it relates to the SSE ground motion in the free-field at the foundation level of the structures to be an appropriate response spectrum with a peak ground acceleration of at least 0.1g, and if the OBE is chosen to be less than or equal to one-third of the SSE ground motion, it is not necessary to conduct explicit response or design analyses in accordance with Section IV.(2)(i)(A) of 10 CFR Part 50, Appendix S.

The staff used SRP Section 3.7.2 guidance to review methods for seismic analysis and modeling of structures and major plant systems to ensure that they accurately and/or conservatively represent the behavior of SSCs during postulated seismic events. The staff also used RG 1.92 and RG 1.122, "Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components," which provide an appropriate guidance for implementing and achieving compliance with the requirements of GDC 2. RG 1.92 provides various procedures acceptable to the staff for combining the three-dimensional modal responses for both the response spectrum analysis approach and the time-history analysis approach of nuclear power plant structures. RG 1.122 describes methods acceptable to the NRC staff for use in developing two horizontal and one vertical floor design response spectra at various floors or other equipment support locations of interest from the time-history motions, resulting from the dynamic analysis of the supporting structure. Thus, RG 1.122 provides the appropriate guidance for mathematical treatment of floor response spectra (FRS) when dealing with in-structure seismic response analysis. Meeting the requirements of GDC 2, in conjunction with the guidelines provided in RG 1.92 and RG 1.122, ensures that safety-related SSCs will continue to function following a seismic event, such that the plant can be brought to, and maintained in, a safe-shutdown condition.

3.7.2.2 *Summary of Technical Information*

In DCD Revision 6, Section 3.7.2, the applicant stated that this section applies to building structures that constitute primary structural systems (RB, FB, and CB). The RPV is not a primary structural component but, because of its dynamic interaction with the supporting structure, it is considered as another part of the primary system of the RB for the purpose of dynamic analysis. DCD Table 3.7-3 summarizes the methods of seismic analysis for primary building structures.

3.7.2.2.1 Seismic Analysis Methods

In DCD Section 3.7.2.1, the applicant indicated that the analysis can be performed using any of the following methods:

- time-history method
- response spectrum method
    - singly supported or multisupported system with uniform support motion (USM)
    - multisupported system with independent support motion (ISM)
- static coefficient method

3.7.2.2.1.1 Time-History Method

In DCD, Revision 6, Section 3.7.2.1.1, the applicant presented the basic equations of motion for dynamic analysis of multi-degree-of-freedom linear systems subjected to external forces and/or uniform support excitations and indicated that these equations can be solved by modal superposition or direct integration in the time domain, or by the complex frequency response method in the frequency domain.

The applicant stated that for the time domain solution, the numerical integration time step is sufficiently small to accurately define the dynamic excitation and to render stability and convergency of the solution up to the highest frequency (or shortest period) of significance. For most commonly used numerical integration methods (such as Newmark β-method and Wilson θ-method), the maximum time step is limited to one-tenth of the shortest period of significance. The adequacy of the selected time step (Δt) is checked by ensuring that use of ½ of Δt does not change the response by more than 10 percent. For the frequency domain solution, the dynamic excitation time history is digitized with time steps no larger than the inverse of 2 times the highest frequency of significance, and the frequency interval is selected to accurately define the transfer functions at structural frequencies within the range of significance.

The applicant further stated that the modal superposition method is used when the equations of motion can be decoupled by transformation to generalized modal coordinates and presented as a single-degree-of freedom, simplified mathematical formulation. Following solution in terms of the generalized modal coordinates, the final solution for each mode is obtained by the transformation from the generalized coordinates back to the physical coordinates. The total response is the superposition of the modal responses.

The applicant indicated that all modes with frequencies up to the zero period acceleration (ZPA) frequency are included in the modal superposition and the residual rigid response resulting from the missing mass is accounted for in accordance with the methods described in DCD Section 3.7.2.7.

At the end of DCD Section 3.7.2.1.1, the applicant briefly discussed the direct integration method and the complex frequency response method and also noted that multisupported systems subjected to ISM can be analyzed using the time-history method. The applicant stated that the frequency domain solution is not used in the piping system response analysis.

3.7.2.2.1.2 Response Spectrum Method

In DCD, Revision 3, Section 3.7.2.1.2, the applicant stated that the response spectrum method, applicable to singly supported systems or multisupported systems with USM, is the same as the modal superposition method described in Section 3.7.2.1.1, except that only the peak values of the solutions of the decoupled modal equations are obtained. The maximum modal displacements are calculated and then used to determine other modal response quantities, such as forces. The applicant indicated that DCD Section 3.7.2.7 defines the applicable methods of modal response combination.

The applicant stated that the multisupported system with ISM is applicable to linear dynamic systems that are supported at two or more locations and have different excitations applied at each support. The applicant presented the basic mathematical formulation of the ISM method, and stated that (1) the time domain solution can be obtained by using the standard normal mode solution technique, (2) analysis can be performed using either the time-history method or the response spectrum method, and (3) DCD Section 3.7.3.9 describes additional considerations associated with the ISM response spectrum method of analysis.

The applicant stated that the response spectrum method is not used for seismic response analysis of primary building structures.

3.7.2.2.1.3 Static Coefficient Method

In DCD, Revision 6, Section 3.7.2.1.3, the applicant identified that the static coefficient method is an alternative simplified method of seismic analysis that incorporates additional conservatism to compensate for the mathematical simplifications. This method does not require determination of natural frequencies. The response loads are determined statically by multiplying the mass value by a static coefficient equal to 1.5 times the maximum spectral acceleration at the appropriate damping value of the input response spectrum. A static coefficient of 1.5 is intended to account for the effect of both multifrequency excitation and multimode response for linear frame-type structures, such as members physically similar to beams and columns, which can be represented by a simple model similar to those shown to produce conservative results. A factor of less than 1.5 may be used if justified. If the fundamental frequency of the structure is known, then the highest spectral acceleration value at or beyond the fundamental frequency can be multiplied by a factor of 1.5 to determine the response. A factor of 1.0 instead of 1.5 can be used if the component is simple enough that it behaves essentially as a single-degree-of-freedom system.

When the component is rigid, it is analyzed statically using the ZPA as input. SSCs are considered rigid when the fundamental frequency is equal to or greater than the frequency at which the input response spectrum returns to approximately the ZPA. Relative displacements between points of support are also considered, and the resulting response is combined with the response calculated using the equivalent static method.

The applicant stated that the static coefficient method is not used for primary building structures.

3.7.2.2.2 Natural Frequencies and Responses

In DCD, Revision 3, Section 3.7.2.2, the applicant stated that Appendix 3A presents natural frequencies and SSE responses of Category I buildings.

The staff presents its evaluation of the natural frequencies and SSE responses of Category I buildings in Sections 3.7.2.3.3 and 3.7.2.3.4 of this report.

3.7.2.2.3 Procedures Used for Analytical Modeling

In DCD Section 3.7.2.3, the applicant stated that the mathematical model of the structural system is generally constructed as a stick model or a finite element model. The details of the model are determined by the complexity of the actual systems and the information required from the analysis.

The applicant stated that, in constructing the primary structural system model, the following subsystem decoupling criteria are applicable:

- If $R_m < 0.01$, decoupling can be done for any R_f,
- If $0.01 \le R_m \le 0.1$, decoupling can be done if $R_f \le 0.8$ or $R_f \ge 1.25$,

- If Rm > 0.1, a subsystem model should be included in the primary system model,

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

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

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

The applicant further stated that, if the subsystem is comparatively rigid in relation to the supporting system, and also is rigidly connected to the supporting system, it is sufficient to include only the mass of the subsystem at the support point in the primary system model. On the other hand, in the case of a subsystem supported by very flexible connections (e.g., pipe supported by hangers), the subsystem need not be included in the primary model. In most cases, the equipment and components, which come under the definition of subsystems, are analyzed (or tested) as a decoupled system from the primary structure and the dynamic input for the former is obtained by the analysis of the latter. The applicant stated that one important exception to this procedure is the RPV, which is considered as a subsystem but is analyzed using a coupled model of the RPV and primary structure.

The applicant stated that, in general, three-dimensional models are used with six degrees of freedom (DOFs) assigned to each mass (node) point (i.e., three translational and three rotational). Some dynamic DOFs, such as rotary inertia, may be neglected, since their contribution to the total kinetic energy of the system is small compared to the contribution from translational inertia. A two- or one-dimensional model is used if the directional coupling effect is negligible. Coupling between two horizontal motions occurs when the center of mass, the centroid, and the centroid of rigidity do not coincide. The degree of coupling depends on the amount of eccentricity and the ratio of uncoupled torsional frequency to the uncoupled lateral frequency. Structures are generally designed to keep eccentricities as small as practical to minimize lateral/torsional coupling and torsional response.

With respect to modeling of mass, the applicant stated that nodal points are generally selected (1) to coincide with the locations of large masses, such as floors or at heavy equipment supports, (2) at all points where significant changes in physical geometry occur, and (3) at locations where the responses are of interest. The mass properties in the model include all contributions expected to be present at the time of dynamic excitation, such as dead weight, fluid weight, attached piping and equipment weight, and appropriate part of the live load. The hydrodynamic effects of any significant fluid mass interacting with the structure are considered in modeling of the mass properties. Masses are lumped to node points. Alternatively, the consistent mass formulation may be used. The applicant further stated that the number of masses or dynamic DOFs is considered adequate when additional DOFs do not result in more than a 10-percent increase in response. Alternatively, the number of dynamic DOFs is no less than twice the number of modes below the cutoff frequency as stated in DCD Section 3.7.2.1.1. For the stick models of the primary building structures, the number of dynamic DOFs is no less than twice the number of modes below 50 Hz.

In DCD Section 3.7.2.3, the applicant also described qualitatively the modeling procedures used for the RPV. The applicant stated that the presence of fluid and other structural components introduces a dynamic coupling effect. The hydrodynamic coupling effects caused by horizontal excitation are considered by including coupling fluid masses lumped to appropriate structural nodes at the same elevations. In the vertical excitation, the hydrodynamic coupling effects are assumed to be negligible and the fluid masses are combined for appropriate structural locations.

3.7.2.2.4 Soil-Structure Interaction

In DCD Section 3.7.2.4, the applicant stated that DCD Appendix 3A presents the seismic SSI analyses of the Category I buildings performed for a range of soil conditions.

DCD Appendix 3A presents SSI analyses performed for two site conditions, the generic site and the specific North Anna ESP site, adopted to establish seismic design loads for the RB, FB, CB, and FWSC of the ESBWR standard plant under SSE excitation. The RB and FB (frequently referred to as the "RB/FB") are integrated and founded on a common basemat. The FWSC comprises two firewater storage tanks and a fire pump enclosure, which are founded on a common basemat. Section 3.7.1 of the DCD describes the SSE design ground motion at the foundation level for both site conditions. The SSI analysis results are presented in the form of site-enveloped seismic responses at key locations in the RB/FB, CB, and FWSC. Appendix 3G of the DCD shows the structural adequacy calculations for the RB, FB, CB, and FWSC.

The applicant stated in DCD Appendix 3A that for a standard plant design, the analysis must be performed over a range of site parameters. The site parameters considered and their ranges together form the generic site conditions. The generic site conditions are selected to provide an adequate seismic design margin for the standard plant located at any site with site parameters within the range of parameters considered in this study. In addition, this study considers the North Anna ESP site-specific condition. When actual sites for these facilities are selected, site-specific geotechnical data are developed and submitted to the NRC to demonstrate their compatibility with the site-enveloping parameters considered in the standard design.

DCD Appendix 3A details the basis for selecting the site conditions and analysis cases and the method of the seismic SSI analysis. The appendix includes descriptions of the input motion and damping values, the structural model, and the soil model, in addition to the parametric study SSI results and the enveloping seismic responses. To demonstrate the seismic adequacy of the standard ESBWR design, 31 RB/FB cases, 11 CB cases, and 4 FWSC cases were analyzed for the uniform site cases using the DAC3N sway-rocking stick model for the SSE condition. In addition, six RB, FB cases, six CB cases, and four FWSC cases were analyzed for the layered site cases using the SASSI2000 SSI model. The enveloped results reported in DCD Appendix 3A form the design SSE loads.

3.7.2.2.5 Development of Floor Response Spectra

In DCD Section 3.7.2.5, the applicant stated that FRS are developed from the primary structural dynamic analysis using the time-history method. The applicant further stated that direct spectra generation, without resorting to time history, is an acceptable alternative method. Seismic FRS for various damping values are generated in three orthogonal directions (two horizontal and one vertical) at various elevations and locations of interest to the design of equipment and piping. When the dynamic analyses are performed separately for each of the three components of the input motion, the resulting codirectional response spectra are combined according to the square root of the sum of the squares (SRSS) method to obtain the combined spectrum in that direction. An alternative approach to obtain codirectional FRS is to perform dynamic analysis with simultaneous input of the three excitation components if those components are statistically independent of each other. Furthermore, when the three components are mutually statistically independent, response analysis can be performed individually, and the resulting acceleration response time histories in the same direction are added algebraically for FRS generation.

In the generation of FRS, the spectrum ordinates are computed at frequency intervals suggested in Table 3.7.1-1 of SRP Section 3.7.1 and at additional frequencies corresponding to the natural frequencies of the supporting structures. The applicant also stated that another acceptable method is to choose a set of frequencies such that each frequency is within 10 percent of the previous one, and add the natural frequencies of the supporting structures to the set. Alternatively, a set of frequencies such that each frequency is within 5 percent of the previous one may be used.

3.7.2.2.6 Three Components of Earthquake Motion

In DCD Section 3.7.2.6, the applicant presented methods for combining the three directional components of earthquake motion. The applicant stated that when the response spectrum method or static coefficient method of analysis is used, the maximum responses caused by each of the three components are combined by taking the SRSS of the maximum codirectional responses caused by each of the three earthquake components at a particular point of the structure or of the mathematical model.

The applicant stated that when the time-history method of analysis is used and separate analyses are performed for each earthquake component, the total combined response for all three components is obtained using the SRSS method to combine the maximum codirectional responses from each earthquake component. Alternatively, the total response may be obtained, if the three component motions are mutually statistically independent, by algebraically adding the codirectional responses calculated separately for each component at each time step.

When the time-history analysis is performed by applying the three component motions simultaneously, the combined response is obtained directly by solution of the equations of motion. This method of combination is applicable only if the three component motions are mutually statistically independent. The applicant stated that this method is used for seismic response analysis of primary building structures.

3.7.2.2.7 Combination of Modal Responses

In DCD Section 3.7.2.7, the applicant addressed the applicable methods for the combination of modal responses when the response spectrum method is used for response analysis. The applicant stated that the analysis methods meet the requirements in RG 1.92, Revision 2, issued July 2006, for combining the modal responses and the missing masses and presented the applicable equations from the RG for treating closely spaced modes and high-frequency modes ($f \geq f_{ZPA}$).

3.7.2.2.8 Interaction of Non-Category I Structures with seismic Category I Structures

In DCD Section 3.7.2.8, the applicant stated that the interfaces between seismic Category I and non-seismic Category I SSCs are designed for the dynamic loads and displacements produced by both the Category I and non-Category I SSCs. All non-Category I SSCs meet at least one of the following requirements:

- The collapse of any non-Category I SSC does not cause the non-Category I SSC to strike a seismic Category I SSC. SSCs in this category are classified as non-seismic.

Any non-seismic structure postulated to fail under the SSE is located at least a distance of its height above grade from seismic Category I structures.

- The collapse of any non-Category I SSC does not impair the integrity of seismic Category I SSCs. This is demonstrated by showing that the impact loads on the Category I SSC resulting from collapse of an adjacent non-Category I structure, because of its size and mass, are either negligible or smaller than those considered in the design (e.g., loads associated with tornado, including missiles). SSCs in this category are classified as non-seismic.

- The non-Category I SSCs are analyzed and designed to prevent their failure under SSE conditions in a manner such that the margin of safety of these SSCs is equivalent to that of seismic Category I SSCs. SSCs in this category are classified as seismic Category II, except the radwaste building and the turbine building (TB).

The applicant stated that the TB is a non-seismic structure that is designed using the ―IBC 2003 Edition, to maintain structural integrity with a margin of safety that is equivalent to a seismic Category I structure under SSE conditions. The TB is seismically designed using the dynamic analysis method with the SSE ground input motion equal to two-thirds of the certified seismic design spectra taken from DCD, Tier 2, Figures 2.0-1 and 2.0-2, adjusted as required to their bases. Occupancy Importance Factor of 1.5, Response Modification Factor of 2, and Seismic Design Category D/Seismic Use Group III apply to the TB. The TB is designed such that the maximum combined seismic displacement of the TB and an adjacent seismic Category I structure is less than their separation distance.

3.7.2.2.9 Effects of Parameter Variations on Floor Response Spectra

In DCD Section 3.7.2.9, the applicant stated that FRS calculated according to the procedures described in DCD Section 3.7.2.5 are peak broadened by ±15 percent to account for uncertainties in the structural frequencies owing to uncertainties in the material properties of the structure and soil and to approximations in the modeling techniques used in the analysis. When the calculated floor acceleration time history is used in the time-history analysis for piping and equipment, the uncertainties in the time history are accounted for by expanding and shrinking the time history within 1/(1±0.15) so as to change the frequency content of the time history within ±15 percent. In this case, multiple time-history analyses are performed. Alternatively, a single synthetic time history that matches the broadened FRS may be used.

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

3.7.2.2.10 Use of Equivalent Vertical Static Factors

In DCD Section 3.7.2.10, the applicant stated that equivalent vertical static factors are used when the requirements for the static coefficient method in DCD Section 3.7.2.1.3 are satisfied. The applicant further stated that all seismic Category I structures are dynamically analyzed in the vertical direction; no constant static factors are used.

3.7.2.2.11 Method Used To Account for Torsional Effects

In DCD Section 3.7.2.11, the applicant stated that one method of treating the torsional effects in the dynamic analysis is to carry out a dynamic analysis that incorporates the torsional DOFs.

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

The applicant stated that the seismic analysis for primary building structure is performed using a three-dimensional model including the torsional DOFs.

3.7.2.2.12 Comparison of Responses

In DCD Section 3.7.2.12, the applicant stated that, since only the time-history method is used for the dynamic analysis of seismic Category I structures, a comparison of responses with the response spectrum method is not necessary.

3.7.2.2.13 Analysis Procedure for Damping

In DCD Section 3.7.2.13, the applicant presented several approaches to model damping for models that consist of structural elements with different damping properties. The applicant stated that for use in mode superposition (time-history or response spectrum) analyses, the composite modal damping ratio can be obtained based on either stiffness-weighting or mass-weighting. The composite modal damping calculated by either method is limited to 20 percent. For models that take SSI into account by the lumped soil-spring approach, stiffness-weighting is acceptable. For a fixed-base model, either stiffness-weighting or mass-weighting may be used. Additional approaches applicable to frequency domain analysis and direct integration time-history analysis are also presented.

3.7.2.2.14 Determination of Seismic Category I Structure Overturning Moments

In DCD Section 3.7.2.14, the applicant described the method used to evaluate the stability of structures against seismically induced overturning moments. According to this method, when the amplitude of the rocking motion becomes so large that the center of structural mass reaches a position right above either edge of the base, the structure becomes unstable and may tip over. In this analysis method, the kinetic energy imparted to the structure from the earthquake ground motion is calculated and compared to the potential energy needed to overturn the structure. The structure is defined as stable against overturning when the ratio of the potential energy needed for overturning and the kinetic energy of the structure during the SSE is no less than 1.1.

3.7.2.3 *Staff Evaluation*

In DCD, Revision 1, Section 3.7.2, the applicant stated that this section applies to building structures that constitute primary structural systems. The applicant explained that the RPV is not a primary structural component, but because of its dynamic interaction with the supporting structure, it is considered as another part of the primary system of the RB, for the purpose of dynamic analysis.

In RAI 3.7-15, the staff requested that the applicant specifically identify and describe the building structures covered by DCD Section 3.7.2, identify the seismic classification of each building structure, confirm that design-basis seismic analyses have been completed for these building structures, and identify where the details and results of the design-basis seismic analyses are presented in the DCD. In its response, the applicant stated that the building structures covered by DCD Section 3.7.2 are the RB, FB, CB, and emergency breathing air system (EBAS) building. DCD Table 3.2-1 describes the seismic classification of building structures. The design-basis seismic analyses have been completed for the RB, FB, and CB. DCD Section 3A presents the details and results of the design-basis seismic analyses. The staff found that the applicant's response adequately identified and described the structures in the scope of DCD Section 3.7.2, as requested by RAI 3.7-15. The applicant included additional descripitive information in Revision 2 of DCD Section 3.7.2. On this basis, RAI 3.7-15 was resolved. Subsequent to resolution of RAI 3.7-15, the applicant eliminated the EBAS building from the ESBWR design and removed all references to it in DCD Revision 3.

3.7.2.3.1 Seismic Analysis Methods

In DCD Section 3.7.2.1, the applicant indicated that analysis can be performed using any of the following methods:

- time-history method
- response spectrum method
  - singly supported or multisupported system with USM)
  - multisupported system with ISM
- static coefficient method.

3.7.2.3.1.1 Time-History Method

In DCD Section 3.7.2.1.1, the applicant presented the basic equations of motion for dynamic analysis of multi-DOF linear systems subjected to external forces and/or uniform support excitations and indicated that these equations can be solved by modal superposition or direct integration in the time domain, or by the complex frequency response method in the frequency domain. In general, the staff finds the methods described by the applicant to be acceptable because they are consistent with SRP Section 3.7.2.

The applicant's presentation of the equations of motion is in terms of undamped eigenvalues and mode shapes, with solutions obtained by integration in the time domain. In RAI 3.7-16, the staff asked the applicant to address the limitations of this formulation, particularly for the case of frequency-dependent SSI stiffness and damping coefficients.

In its response, the applicant stated that in DCD Section 3A.5, the base spring is evaluated based on three-dimensional wave propagation theory, for uniform half-space soil. Though the spring values consist of frequency-dependent real and imaginary parts, they are simplified and replaced with frequency-independent soil spring K_c and damping coefficient C_c, respectively, for the time-history analysis solved in the time domain. The sites considered in the seismic analysis of the ESBWR standard plant cover a wide range of uniform soil/rock sites. For uniform sites, the applicant also stated that the use of frequency-independent soil properties in the formulation is an acceptable approach in accordance with the guidance of American Society of Civil Engineers (ASCE) 4-98, “Seismic Analysis of Safety-Related Nuclear Structures and Commentary,” Section 3.3.4.2.2. The applicant further stated that the effects of frequency-dependent SSI stiffness and damping coefficients were evaluated for four additional layered sites and referred to its response to RAI 3.7-30 for details.

After reviewing the applicant’s response to RAI 3.7-30, the staff deferred further review until it could compare the results from the staff’s independent confirmatory analyses to the applicant’s analysis results for layered sites during the second audit, scheduled for the week of October 31, 2006. During the audit, the staff discussed its preliminary confirmatory analysis results with the applicant and compared these results to the applicant’s corresponding results, including (1) comparison of the staff’s response spectra at the top of the CB and the top of basemat from its confirmatory analysis against the applicant’s design response spectra at the top of the CB and at the top of basemat, and (2) for the RB, FB, comparison of transfer functions at the top of the building, at the top of the basemat, and at the top of the four corners of the embedded walls. As a result, the staff noted an apparent problem in the transfer functions for the applicant’s RB, FB SASSI analysis, in which numerical instabilities (sharp spikes) at some frequencies were identified. The applicant agreed to verify the adequacy of connections between stick models and foundation mat and to increase frequency points around the locations of numerical instabilities.

In its supplementary response to RAI 3.7-16, the applicant provided the SASSI transfer functions for the RB, FB. By adding more frequency points near the spikes, all the spikes were eliminated except for the peak at 7.8 Hz in the Y direction. Adding frequencies near the peak at 7.8 Hz in the Y direction increased the peak amplitude. The applicant stated that a careful examination of the model did not reveal any problems associated with connectivities and concluded that the cause of the spike anomaly in the transfer function is related to differences in the calculation of the deconvolution and amplification of ground motion by the SASSI code, in which the deconvolution process of the free-field is performed by a methodology that differs slightly from the finite element methodology used to develop the structural response. This difference shows up as a discontinuity in the transfer functions and has little impact on the response spectra. The applicant calculated response spectra at the top of the RB, FB and at the top of the RB, FB basemat for X, Y, and Z directions, for both the original and the refined transfer functions, and compared them with the design-basis FRS. The applicant stated that the differences in FRS between the original and refined transfer functions are not significant, and both are bounded by the design-basis FRS. The staff reviewed the comparison and confirmed the applicant’s conclusion. Since the transfer function spike at 7.8 Hz in the Y direction does not affect the design-basis FRS, the staff found the applicant’s response for the RB, FB to be acceptable.

Several issues still needed to be addressed to resolve the differences between the applicant’s results and the staff’s confirmatory analysis results for the CB.

GE’s analyses and the staff’s confirmatory analyses both use the same single-stick, beam-mass model of the CB. GE conducted analyses for a number of uniform site conditions using DAC3N and four assumed layered site conditions using SASSI. To assess whether GE had considered an adequate number of layered site conditions, the staff conducted SASSI confirmatory analyses for nine assumed layered site conditions. The staff presented its confirmatory analysis results for the CB to GE at the October 30–November 2, 2006, audit. As stated in the applicant’s response to RAI 3.7-16 S01, “GE design spectra at the top of the CB and at the top of basemat were provided to NRC/BNL at the November 2, 2006 audit by GE." The staff based its assessment on comparison of the confirmatory analysis results to GE's design spectra (FRS) at the top of the CB and at the CB basemat, which are the broadened envelope of responses from all the uniform site and layered site cases analyzed by GE. The FRS generated by the staff at the CB basemat exceed the GE design spectra provided at the audit in the range of 15 to 20 Hz. In RAI 3.7-16 S02, the staff requested that GE address the following:

(1A) The staff noted that, in comparing the GE design spectrum at the basemat to the GE design spectrum at the top of stick, there appears to be a significant inconsistency in the amplification from the basemat to the top of stick. The FRS at the basemat shows a depression around 10 Hz, but the FRS at the top of stick shows a very significant peak around 10 Hz. The FRS is amplified in the vicinity of 10 Hz by a factor of about 6, while the remainder of the FRS is amplified by a factor of about 2. This includes what appears to be a fundamental mode response at about 3 Hz. Please explain.

(1B) Submit the individual FRS results at both the basemat and at top of stick, for all cases analyzed (DAC-3N and SASSI), and to confirm that the design spectra provided to the staff at the October 30–November 2, 2006 audit are correct.

(1C) The staff could not correlate the design spectrum at top of the CB stick, provided to the staff at the October 30–November 2, 2006 audit, with the comparable design spectrum in DCD, Revision 3, Appendix 3A. Explain this apparent discrepancy.

(1D) The design spectrum for the CB basemat, provided to the staff at the October 30–November 2, 2006 audit, was not included in DCD, Revision 3, Appendix 3A. The staff requested the applicant to include the design spectrum for the CB basemat in the next revision of DCD Appendix 3A, and to provide a technical explanation why the amplification factor is 6 between the basemat and the top of stick, in the 10 Hz range is 6.

In the second part of RAI 3.7-16 S02, the staff noted that the applicant added the following statement to DCD, Revision 3, Appendix 3A.4.1, "Input Motion": "For the layered site cases, the input ground motion is defined as an outcrop motion at the RB, FB foundation level for all the buildings. The corresponding surface motion is generated for use as input to the SASSI calculation for each site." The staff asked GE to address whether its approach to developing the surface motion is consistent with the latest update to SRP Section 3.7.1 (March 2007) and, if differences exist, to provide the technical basis for the acceptability of each difference. The staff also requested that GE submit an example of the implementation of its approach, to include (1) a description of the methodology employed to develop the surface motion, (2) the soil column data used to transfer the input ground motion to the surface, and (3) the resulting surface motion time history.

The staff identified the resolution of RAI 3.7-16 as an open item in the SER with open items.

In its response to RAI 3.7-16 S02, the applicant stated the following:

(1A) The fundamental frequency of the fixed base model is about 10 Hz. Due to the lack of beneficial SSI effects, the fixed base amplification factor is relatively large. For other soil cases with SSI effect included, the fundamental frequencies are lower and their amplification factors are smaller.

(1B) It is confirmed that the design spectra provided to the staff at the October 30–November 2, 2006 audit are correct.

(1C) The design spectra in Figures 3A.9-1g, 3A.9-2g, and 3A.9-3g of DCD, Tier 2, Revision 3, Appendix 3A have been corrected. Note that the CB seismic analysis has been updated to reflect the changes associated with reclassification to Seismic C-I for the entire building. Appendices 3A and 3G have been updated in DCD, Tier 2, Revision 4.

(1D) Please see the response to (1A) above. The design spectra for the CB basemat have been included in DCD, Tier 2, Revision 4.

(2) This issue is addressed by performing SHAKE analyses for two problems considered in the staff's confirmatory analysis and received from the NRC on August 13, 2007. Two approaches are used in the SHAKE analysis for Problem 6. One approach, termed NRC Method herein, involves two separate SHAKE runs. In the first run (Step 6a) the soil layer above the foundation level is not included and the foundation input motion is applied as outcrop motion to the soil column below the foundation. The resulting bedrock motion is then applied in the second SHAKE run (Step 6b) for the entire soil column up to the ground surface. The other approach, termed DCD Method herein, includes the entire soil column up to ground surface in a single SHAKE run with outcrop motion input at the foundation level. For Problem 4 only one-step SHAKE analysis is performed because the bedrock is at the foundation level for which the NRC and DCD Methods are the same.

The SHAKE-calculated ground surface response spectra of the two methods are compared for problem 4 and for problem 6. The enveloping surface spectra of DCD SASSI layered site cases CL-1 to CL-4 are also included in these figures for reference. For problem 6 the surface motion using the DCD Method is different from that using the NRC Method. To address the effect on SSI response, SASSI analyses are performed using the surface input motion calculated by the NRC Method and the resulting response spectra at the upper level (EL. 9.06m) and at the top of basemat (EL. -7.4m) are compared with the DCD design spectra. The FRS for problems 4 and 6 are enveloped by the design spectra.

The staff reviewed the applicant's response to RAI 3.7-16 S02 and several subsequent clarifications. As a result, the staff prepared RAI 3.7-16 S03 and asked the applicant to address the following:

(1) The staff requests the applicant to amend its Supplement 1 response, part (b), third paragraph, which begins "Adding frequencies…." The staff agrees with the applicant's conclusion that there is little impact on the

response spectra; however, the applicant's explanation for the behavior of the transfer function at 7.8 Hz is considered to be conjecture and cannot be confirmed. Please clarify or remove the statement.

(2) The staff requests the applicant to clarify whether the results for the CL-1 to CL-4 envelope (dotted curve) include a soil profile equivalent to the sketch shown to the right of the plot (NRC Problem 4). If it does, explain why the solid curve is not enveloped by the dotted curve.

(3) The staff requests the applicant to explain why the "DCD method" results for NRC Problem 4 are apparently equivalent to the "DCD method" results for NRC Problem 6.

(4) The staff requests the applicant to confirm that the analysis model used to develop the "PROB-4" and "PROB-6" results is the SASSI model, and also to clearly indicate the analysis model used.

The applicant's formal response to RAI 3.7-16 S03 is summarized below:

(1) The applicant amended the response to RAI 3.7-16 S01, part (b), third paragraph, to read: "Adding frequencies near the peak at 7.8 Hz in Y direction actually increases the peak amplitude…. A careful examination of the model did not reveal any problems associated with connectivities. This peak shows up in this case as a discontinuity in the transfer functions and has little impact on the response spectra."

(2) The results for the CL-1 to CL-4 envelope do not include a soil profile equivalent to NRC Problem 4.

(3) The surface spectra calculated by the DCD method for Problem 4 and Problem 6 were overlaid for a better visual comparison. A comparison of the corresponding transfer functions of the surface motion relative to the outcrop motion at the CB basemat bottom level shows that the surface spectra and the transfer functions have the same peaks at resonant frequencies.

The soil column models for Problem 4 and Problem 6 have identical properties for the surface layer (Layer 1). This is the reason why both surface spectra have a similar shape. The slight differences in amplitudes are attributed to the different properties of the underlying layers. The peak value of the transfer function is affected by the impedance ratio of the surface layer to the second layer, based on one-dimensional wave propagation theory. The peak value increases as the impedance ratio, α, decreases.

The shear wave velocity of the second layer is larger in Problem 6 than in Problem 4, although the surface layer is identical and other properties for the second layer are the same. This is the reason that the peak values of the transfer function are higher in Problem 6 than in Problem 4. As a result, the peak value of the surface spectrum for Problem 6 is higher.

The applicant concluded that the surface spectra calculated by the DCD method for Problem 4 and Problem 6 are similar because the surface layer in both problems is identical and the peak value of the surface spectrum is higher in Problem 6 than in

Problem 4 (since the shear wave velocity of the second layer is larger in Problem 6 than in Problem 4).

(4) The SASSI analysis model was used to develop the “PROB-4” and “PROB-6” results. The applicant will clearly indicate the analysis model used.

The staff finds the clarifications provided in the response to RAI 3.7-16 S03, parts (1), (2), and (4) to be acceptable and considers these items to be resolved.

For RAI 3.7-16 S03, part (3), the staff needed to determine why the surface spectra for NRC Problem 4 and NRC Problem 6 are almost identical when using the applicant’s DCD method to calculate the spectra at the ground surface from the spectra applied at the RB, FB foundation. After review, the staff concurs that very little difference would be expected when using the applicant’s DCD method. This is in contrast to the method used for the staff’s confirmatory analyses (designated as the “NRC method” by the applicant), for which there is considerable difference between the NRC Problem 4 surface spectra and the NRC Problem 6 surface spectra.

The applicant had previously described the differences between the “DCD method” and the “NRC method” in its response to RAI 3.7-16 S02. This difference in methodology for calculating the surface motion input for SASSI helps explain the differences between the staff’s confirmatory analysis results and the applicant’s results. Depending on the layered soil profile, the NRC method can produce higher surface input motion than the DCD method. The method used in the staff’s confirmatory analyses is consistent with the latest revision to SRP Section 3.7.1 (March 2007); the method used by the applicant is not. The staff noted, however, that the applicant conducted its SASSI SSI analyses before March 2007.

Review of the detailed results presented by the applicant led the staff to conclude that, although the staff’s confirmatory analysis predicts higher ground surface motion than does the applicant for NRC Problem 6, the CB design-basis FRS, which are based on the DAC3N analyses of uniform site cases, envelop both the applicant’s and the staff’s SASSI analysis results by a substantial margin.

The staff also reviewed DCD, Revision 4, Appendix 3A, Figures 3A.8.6-1a through 3A.8.6-3l, and determined that the FRS derived from the DAC3N uniform site cases envelop the applicant’s SASSI layered soil case results at all locations in both the CB and the RB, FB. Over most of the frequency range of interest, the DAC3N FRS exceed the SASSI results by a factor of 2 or more. Therefore, the staff concluded that any variability in seismic response introduced in the applicant’s SASSI analyses of the CB and the RB, FB, due to use of the DCD method to develop the SASSI ground motion input, would have negligible effect on (1) the seismic design of the CB and the RB, FB and (2) the FRS used to seismically qualify systems and components supported by the CB and the RB, FB. On this basis, the staff considers RAI 3.7-16 S03, part (3), to be resolved. Therefore, RAI 3.7-16 and its associated open item are considered closed.

The staff noted that the above conclusions are not applicable to the FWSC. Review of DCD Revision 4, Appendix 3A, Figures 3A.8.6-1a through 3A.8.6-3l, indicates that the DAC3N results do not always envelop the SASSI results for the FWSC. The staff addressed this issue separately under RAI 3.7-63.

The staff noted that in DCD Revision 3, the applicant added the underlined sentence to the second paragraph of Section 3.7.2.1.1, in response to RAI 3.12-4:

> For the time domain solution, the numerical integration time step is sufficiently small to accurately define the dynamic excitation and to render stability and convergency of the solution up to the highest frequency (or shortest period) of significance. <u>The approach for selecting the time step, Δt, is that the Δt used shall be small enough such that the use of ½ of Δt does not change the response by more than 10 percent.</u> For most of commonly used numerical integration methods (such as Newmark β-method and Wilson θ-method), the maximum time step is limited to one-tenth of the shortest period of significance.

The staff reviewers of DCD Section 3.7 found that the added sentence was misplaced. It should be at the end of the existing text, and it should emphasize that this is a check on the selected time step. In RAI 3.7-61, part (2), the staff requested that the applicant revise the wording accordingly**.** The applicant revised the wording as follows:

> For the time domain solution, the numerical integration time step is sufficiently small to accurately define the dynamic excitation and to render stability and convergency of the solution up to the highest frequency (or shortest period) of significance. For most of commonly used numerical integration methods (such as Newmark β-method and Wilson θ-method), the maximum time step is limited to one-tenth of the shortest period of significance. The adequacy of the selected time step (Δt) is checked by ensuring that use of ½ of Δt does not change the response by more than 10%.

The staff confirmed that the revised wording was incorporated in DCD Revision 5. On this basis, RAI 3.7-61, part (2), was resolved.

From the information provided in DCD Revision 1, Section 3.7.2.1.1, the staff could not determine which of the time-history methods described were actually used for the design-basis seismic analyses of the building structures, or how they were implemented. Therefore, in RAI 3.7-17, the staff asked the applicant to clarify this and also to describe the method used to account for missing mass when using the mode superposition time-history method:

(1) For each building structure covered by DCD Section 3.7.2, identify the specific time-history analysis method employed; describe the implementation of the method, including determination of the highest structural frequency of interest and determination/verification of an adequate integration time-step; and discuss how the analysis results were used.

(2) If modal superposition time-history analysis was employed, identify whether the alternative to the missing mass method documented in Appendix A to SRP Section 3.7.2 was used to account for the contribution of modes with frequencies above f_{ZPA}. If so, explain why it was used instead of the more accurate missing mass method; define the cutoff frequency; and explain how it was determined.

In the RAI, the staff noted that RG 1.92, Revision 2 (designated DG-1127 at the time the RAI was originally written) does not accept the alternative to the missing mass method.

In its response, the applicant stated the following:

(1) The direct integration method of analysis in the time domain as described in DCD Section 3.7.2.1.1 is employed in the seismic analysis for the RB, FB complex and the CB. The highest structural frequency of interest is 33 Hz for generic site and 50 Hz for North Anna site in view of the frequency contents and peak spectra accelerations of the respective ground response spectrum. The integration time step, Δt, is 0.002 sec for the generic site and 0.001 sec for the North Anna site in order to meet the general criteria described in DCD Section 3.7.2.1 for the maximum integration time step allowed. The adequacy of the selected Δt is confirmed for solution convergence by using ½ Δt to show no more than 10% change in response for the representative hard site. For the usage of analysis results, please see the response to RAI 3.7-6.

(2) Modal superposition time-history analysis was not employed in the building seismic analyses. However, as a general criterion for the treatment of missing mass effect using the modal superposition method, the second to last paragraph in DCD Section 3.7.2.7 will be deleted.

The applicant provided markups of the affected DCD pages as part of its RAI response.

The staff found the applicant's response concerning selected integration time steps to be acceptable, because it is consistent with common engineering practice. The staff also concurred with deletion of the discussion in the second to last paragraph in DCD Section 3.7.2.7, related to missing mass effects. During the June 5–8, 2006, audit, the staff asked the applicant to develop a roadmap table, identifying the analysis methods employed, the models utilized, the computer codes used, and the use of the analysis output. In its supplemental response, the applicant stated that it developed DCD Table 3.7-3 to identify the requested information and that it would revise DCD Section 3.7.2 to include a reference to this new DCD table. The staff reviewed the new DCD Table 3.7-3 and found that it adequately addressed the staff's request. The applicant formally included this change in DCD Revision 2.

However, in reviewing DCD, Revision 3, Section 3.7.2.7, the staff identified an inconsistency with current staff guidance for addressing the "missing mass" contribution of high-frequency modes. The current staff guidance eliminates the 10-percent threshold previously included in former Appendix A to SRP Section 3.7.2 (1989 version). Specifically, the staff no longer finds acceptable the statement in DCD, Revision 3, Section 3.7.2.7, that "If, for any DOF_i, the absolute value of this fraction e_i exceeds 0.1, one should include the response from higher modes with those included in Step 1." The contribution from 100 percent of the missing mass should be included in the total response calculation. In light of this, the staff requested that the applicant provide a supplemental response to RAI 3.7-17, deleting the sentence quoted above and citing RG 1.92, Revision 2, as a reference for the treatment of missing mass in DCD Section 3.7.2.7.

The applicant formally submitted this change in DCD Revision 5. On this basis, RAI 3.7-17 was resolved.

To ensure that the computer codes used by the applicant for performing analyses will result in reasonable seismic responses, the staff raised concerns regarding the adequacy of computer codes used for design and analysis of the ESBWR seismic Category I structures. In RAI 3.7-55, the staff requested that the applicant submit validation packages, translated into English, for the following computer codes listed in DCD Appendix 3C: SSDP-2D—concrete element cracking analysis, TEMCOM2—heat transfer analysis, and DAC3N—SSI analysis. In its response, the applicant stated that the following validation packages, prepared according to the Shimizu QA program, will be ready for the staff's audit: S/VTR-SD2, Validation Test Report for SSDP-2D, Revision C; S/VTR-D3N, Validation Test Report for DAC3N, Revision C; S/VTR-TEM, Validation Test Report for TEMCOM2, Revision C.

During the October 31–November 2, 2006, audit, the staff reviewed S/VTR-DAC3N, Revision C, and concluded that the test cases for the DAC3N computer code validation were too simple to test for any possible limitation in problem size. The applicant agreed to provide a supplemental response to include a more realistic benchmark problem. The staff further requested that the applicant update DCD Appendix 3C to include validation information for computer codes that were not used originally, but were subsequently employed to address issues related to SSI (such as the computer codes SASSI and SHAKE).

The staff determined that the SSDP-2D and TEMCOM2 validations should be reviewed as part of the staff review of DCD Section 3.8, because these codes are used for detailed design calculations, not for the seismic analysis.

In its supplemental response, the applicant stated that the revised validation report S/VTR-D3N, Validation Test Report for DAC3N, Revision D, includes a large-size problem for comparison of results obtained from NASTRAN, which is a commercially available program. For the commercial programs used (SASSI and SHAKE), the computer code vendor, University of California at Berkeley, performed the code validation. Appendix 3C to the DCD provides the validation status of other commercial programs used.

The staff found the revised validation package to be acceptable. The additional benchmark problem included 174 DOFs and compared well to NASTRAN results. The staff concluded that DAC3N accurately analyzes beam element stick models with linear soil springs, subject to dynamic seismic excitation. The staff drew no conclusions about the validity of this analytical approach to accurately address SSI. The applicant's reanalysis of SSI using SASSI provides a more recognized, state-of-the-art approach. The staff's confirmatory analyses were compared to the applicant's SASSI results.

DCD Revision 3 contains the necessary changes to Appendix 3C. Therefore, RAI 3.7-55 was resolved.

3.7.2.3.1.2 Response Spectrum Method

In DCD Section 3.7.2.1.2, the applicant stated that the response spectrum method can be used if only peak dynamic responses are required and referenced DCD Section 3.7.2.7 for applicable methods of modal response combination to obtain peak dynamic responses. In general, the applicant's description of the response spectrum method is consistent with SRP Section 3.7.2 and is acceptable to the staff.

However, from the information provided in DCD Section 3.7.2.1.2, the staff could not determine whether response spectrum methods were actually used for the design-basis seismic analyses of the building structures. In RAI 3.7-18, the staff requested that the applicant identify, for each seismic Category I building structure, whether the response spectrum analysis method was employed. If the method was used, the applicant should describe the implementation of the method, including the method used to account for the contribution of modes with frequencies above f_{ZPA}, and discuss how it used the analysis results. In its response, the applicant stated that response spectrum methods were not used for the design-basis seismic analyses of the building structures documented in DCD Appendix 3A. During the June 5–8, 2006, audit, the staff requested that the applicant revise the DCD to state that response spectrum methods were not used for the design-basis seismic analyses of the building structures documented in DCD Appendix 3A. In Revision 2 of DCD Section 3.7.2.1.2, the applicant incorporated this additional information. Therefore, RAI 3.7-18 was resolved.

3.7.2.3.1.3 Static Coefficient Method

In DCD Section 3.7.2.1.3, the applicant described the static coefficient method. The applicant identified that the static coefficient method is an alternative simplified method of seismic analysis that incorporates additional conservatism to compensate for the mathematical simplifications. The applicant’s description of the method and its range of applicability follows standard practice in the nuclear industry andis consistent with SRP Section 3.7.2, and is therefore, acceptable to the staff.

However, from the information provided in DCD Section 3.7.2.1.3, the staff could not determine whether the static coefficient method was actually used for the design-basis seismic analyses of the building structures. In RAI 3.7-19, the staff requested that the applicant identify, for each seismic Category I building structure, whether the static coefficient method was employed. If the method was used, the applicant should describe the implementation of the method and the technical basis for its use and discuss how the results were used. In its response, the applicant stated that the static coefficient method was not used for the design-basis seismic analyses of the building structures documented in DCD Section 3.A. During the June 5–8, 2006, audit, the staff asked that the applicant revise the DCD to state that the static coefficient method was not used for the design-basis seismic analyses of the building structures documented in DCD Section 3.A. In Revision 2 of DCD Section 3.7.2.1.3, the applicant stated that the static coefficient method is not used for primary building structures. Therefore, RAI 3.7-19 was resolved.

3.7.2.3.2 Natural Frequencies and Responses

In DCD Section 3.7.2.2, the applicant stated that Appendix 3A to the DCD presents natural frequencies and SSE responses of Category I buildings. In Section 3.7.2.3.4 of this report, the staff discusses its evaluation of the natural frequencies and SSE responses of Category I buildings.

3.7.2.3.3 Procedures Used for Analytical Modeling

In DCD Section 3.7.2.3, the applicant stated that the mathematical model of the structural system is generally constructed as a stick model or a finite element model. The details of the model are determined by the complexity of the actual systems and the information required from the analysis.

In RAI 3.7-20, the staff requested that the applicant describe in detail in the DCD the development of the stick models and finite element models for the structural systems covered by DCD Section 3.7.2, including whether the stick model was developed to match the overall dynamic characteristics of a detailed finite element model, the computer code that was used for modeling and analysis, and the information that was required from the analysis. In its response, the applicant stated that the seismic models used for seismic Category I buildings are stick models. DCD Section 3A.7 provides details of the development of these models. In Revision 2 of DCD Section 3.7.2.3, the applicant added, "The mathematical model of the structural system is constructed as a stick model for seismic response analysis of primary building structures." The staff found this clarification to be acceptable. Therefore, RAI 3.7-20 was resolved.

The applicant described the subsystem decoupling criteria. The staff found that the criteria are consistent with SRP Section 3.7.2(II)(3)(b) and therefore are acceptable.

The applicant also discussed general criteria for neglecting certain dynamic DOFs and uncoupling directions of input motion. In RAI 3.7-21, the staff asked the applicant to describe in detail in the DCD how it has implemented the general criteria contained in the third paragraph of DCD Section 3.7.2.3 (i.e., rotary inertia may be neglected since its contribution to the total kinetic energy of the system is small; two- or one-dimensional models may be used if the directional coupling effect is negligible; structures are generally designed to keep eccentricities as small as practical to minimize lateral/torsional coupling and torsional response) in the seismic design/analysis of the primary structural systems covered by DCD Section 3.7.2.

In its response, the applicant stated that, as described in DCD Section 3A.7, the three-dimensional stick model of the primary building structures explicitly covers rotary inertia, torsional DOFs, and eccentricities. Rotary inertia of the RPV and internals are neglected because the contribution to both the total plant response and the RPV and internals response is small. The contributions to the response are small because the physical geometry of the RPV and internals is axisymmetric and is modeled as an axisymmetric, mathematical, centerline, beam-element model. Furthermore, the RPV direct support (the RPV pedestal) is also an axisymmetric structure and keeps the eccentricities about the vertical, centerline axis as small as practical to minimize lateral/torsional coupling and torsional response. In addition, both the seismic, free-field excitation and the non-seismic suppression pool hydrodynamic loads are characterized by essentially zero rotational components about the model vertical, centerline axis. Consequently, the RPV and internals torsional DOFs are not excited by the seismic and the non-seismic suppression pool hydrodynamic loads. Therefore, analytical models can neglect the RPV and internals torsional rotary inertia.

The applicant further stated that the analytical models also neglect the RPV and internals rotary inertia about each of two horizontal, orthogonal axes. Sensitivity studies completed during the initial development of the GE boiling-water reactor (BWR) RPV and internals analytical models illustrated that the model responses were essentially the same regardless of whether the analysis included the horizontal rotary inertia components. This is because the natural frequencies of the pure rotational modes tended to be well above the ZPA frequencies of both the seismic and non-seismic excitations. Consequently, the pure rotational modes contributed essentially zero to the overall response of both the RPV and internals, as well as to those of the primary structure.

During the June 5–8, 2006, audit, the staff reviewed the method for modeling rotary inertia, described in GE Report 26A6647, Revision 1, "Seismic Analysis of RB/FB Complex," and also reviewed the technical basis for the RPV method employed. The staff noted that DCD Figure 3A.7-4 does not show eccentricities of individual sticks. The applicant agreed to revise this figure to refer to DCD Figures 3A.7-1 through 3A.7-3 for eccentricities. The applicant updated these figures in Revision 2 of DCD Appendix 3A. Therefore, RAI 3.7-21 was resolved.

The second sentence in the second paragraph on page 3.7-10 of DCD Section 3.7.2.3 states that the mass properties in the model include all contributions expected to be present at the time of dynamic excitation, such as dead weight, fluid weight, attached piping and equipment weight, and appropriate part of the live load. With respect to modeling of live load, in RAI 3.7-22, the staff requested that the applicant describe in the DCD the live loads and snow loads that are included in the seismic models. The staff's position,, as described in SRP Section 3.7.2, is that 25 percent of the floor live load or 75 percent of the roof snow load**,** whichever is applicable, should be included as mass in the global seismic models. In its response, the applicant stated that masses in the seismic model included 25 percent of the live load and 100 percent of the roof snow load and that it would revise DCD Section 3.7.2.3, fourth paragraph, and Section 3A.7.1, fifth paragraph, to clarify the amount of live and snow loads included in the seismic models. The applicant formally updated Section 3.7.2.3 and Section 3A.7.1 in DCD Revision 2 to include the requested clarification. Therefore, RAI 3.7-22 was resolved.

DCD Section 3.7.2.3 states that the hydrodynamic effects of any significant fluid mass interacting with the structure are considered in modeling of the mass properties. For the ESBWR, significant amounts of water mass are located at various elevations in the RB: Passive Containment Cooling (PCC) pool and Isolation Condenser (IC) pool at elevation 88.58 ft, GDCS pool at elevation 15.26 ft, and suppression pool at elevation -3.28 ft). In its review experience, the staff has found that the dynamic mass effect and the fluid-structure interaction effect on the overall seismic response of the RB are extremely significant. In RAI 3.7-23, the staff asked the applicant to describe in detail in the DCD the pool geometry, total height of water, location of free board, modeling procedure of water mass (sloshing effect and impulsive mass), and how the water was modeled with the main structure. In its response, the applicant identified the location of the requested information in the DCD. The applicant also stated that, as described in Appendix 3A.7.1, the water masses in the pools are included in the stick model, in which the entire water mass is conservatively considered as impulsive mass rigidly attached to the wall/slab nodes for the purpose of calculating the overall response of the building structure. During the June 5–8, 2006, audit, the staff reviewed the pool geometries with the applicant and found the approach used for modeling pool water to be appropriate and acceptable. Therefore, RAI 3.7-23 was resolved.

DCD Section 3.7.2.3 states that the number of masses or dynamic DOFs is considered adequate when additional DOFs do not result in more than a 10-percent increase in response. Alternatively, the number of dynamic DOFs is no less than twice the number of modes below the cutoff frequency. The staff generally agrees with these criteria, but it was not clear how the criteria have been implemented in the development of the seismic structural models. In RAI 3.7-24, the staff requested that the applicant include in the DCD specific information on how these criteria were satisfied for each seismic structural model. In its response, the applicant stated that, since the SSI analyses were performed by the direct integration method in the time domain, the cutoff frequency was not applied. However, as mentioned in the response to RAI 3.7-17, the highest structural frequency of interest is 33 Hz for the generic site and 50 Hz for the North Anna site. Therefore, the number of dynamic DOFs was checked to ensure that it is at least twice the number of modes below 50 Hz. The original RB/FB model in the DCD has enough dynamic DOFs. However, the original CB model in the DCD does not have enough dynamic DOFs. The applicant modified the CB model to increase the number of masses and confirmed that, for the revised model, the number of dynamic DOFs is no less than twice the number of modes below 50 Hz.

The applicant also revised the original RB/FB model in the DCD to add vertical shear springs to consider the vertical coupling of walls through the floor slabs/pool girders. The applicant made this revision in response to a staff audit comment during the review of RAI 3.7-36. The applicant confirmed that the number of dynamic DOFs is at least twice the number of modes below 50 Hz.

The applicant also stated that it would revise DCD Section 3.7.2.3 in the next update to confirm that the number of DOFs is no less than twice the number of modes below 50 Hz.

The staff noted that the applicant had not addressed the quality of the mode shapes obtained for all the modes below 50 Hz. The “2 times” rule is a necessary, but not always sufficient, condition. The distribution of mass DOFs, with respect to location and translational/rotational direction, is equally important in the development of an adequate dynamic model. During the October 31–November 2, 2006, staff audit, the staff reviewed the applicant’s data and documents to assess the adequacy of the stick models to predict modes up to 50 Hz. The applicant agreed to provide additional mode shape information to aid in the assessment of whether all critical modes are adequately captured.

In its supplemental response, the applicant provided mode shapes for all six components (three translations and three rotations) associated with the fixed-base model for modes up to 50 Hz, in Attachment SER-ESB-054, Revision 0, “Mode Shapes of RB/FB Seismic Stick Model.” The applicant also noted the good comparison of the stick and NASTRAN finite element models provided in its response to RAI 3.7-59 as further demonstration that the number of DOFs in the stick model is sufficient to capture critical modes. The staff reviewed the mode shape plots for the RB/FB that were submitted in the supplemental response and concluded that the mode shapes up to 50 Hz are adequate for use in the seismic stick model analysis. Therefore, RAI 3.7-24 was resolved.

For the development of the RB/FB seismic model, in RAI 3.7-25, the staff asked the applicant to specify in the DCD where the heavy crane (with trolley) is parked during plant operation. This information is needed to properly locate the mass and assess the effects of mass eccentricity in the seismic analysis. This information also needs to be identified as an interface item for the COL applicant. In its response, the applicant stated that for the development of the RB/FB seismic model, the heavy crane (with trolley) is assumed to be parked between Column-Rows R3 and R4 in the RB and between Column-Rows FB and FC in the FB. To assess the effects of crane location in the seismic analysis, the change of mass eccentricity was calculated with varied crane locations. The sensitivity analysis considered a worst location. The centers of gravity moved only 25 centimeters at maximum. Comparison of eigenvalue analysis results for the RB/FB model in the fixed-base case found that the difference of frequencies attributable to the crane location is negligibly small. Hence, there is no need to identify crane location as an interface item for the COL applicant. During the staff audit on October 31–November 2, 2006, the staff noted that the applicant’s response addressed the effect on overall seismic response, but did not address the effect of location of the cranes on the design loads for individual structural members in the two buildings. The applicant agreed to describe the effect of location of the main RB crane parking location on the design loads for individual structural members.

In its supplemental response, the applicant stated that column R3/RB (i.e., the column at the intersection of grid line R3 and grid line RB) and column R4/RB support the heaviest load from the RB crane. The columns F3/FB and F3/FC support the heaviest load from the FB crane. By using the stresses obtained from the stress analyses for these heaviest loaded columns, all the columns are designed and sized for the worst loading possible. Therefore, the crane can be parked anywhere from a structural design viewpoint. On the basis that the applicant has adequately considered the parked location of the crane in both the dynamic seismic analysis and the detailed stress analysis, the staff found the response to be acceptable. Therefore, RAI 3.7-25 was resolved.

For seismic subsystem analysis, accurate in-structure response spectra are needed at the subsystem support points. In RAI 3.7-26, the staff requested that the applicant describe in the DCD how it has considered the effects of out-of-plane vibration of floors and walls in the seismic structural models and the development of in-structure response spectra. In its response, the applicant stated that, as described in Section 3A.7 of Appendix 3A to the DCD, a finite element model was used to obtain the vertical floor frequencies at major floor locations. The obtained frequencies were included in the stick model by a series of vertical single DOF oscillators at the corresponding floor elevations. The in-structure response spectra were calculated using the oscillator responses. Compared to the floors, the out-of-plane vibration frequencies of walls that support subsystems that are designed using in-structure response spectra are very high. The calculated out-of-plane fundamental frequencies for the typical walls in the RB/FB are higher than the highest frequency of interest at 50 Hz. Therefore, the seismic structural models do not consider the effects of out-of-plane vibration of walls.

During the October 31–November 2, 2006, staff audit, while reviewing frequency and mode shape results presented by the applicant in response to RAI 3.7-59, the staff noted a significant out-of-plane vibration mode at 11 Hz for a wall in the RB/FB. This finding contradicted the applicant's initial RAI response that all walls have a fundamental frequency greater than 50 Hz. An independent hand calculation performed by the staff confirmed this result. In light of this finding, the applicant agreed to reassess the fundamental vibration modes for the walls of the RB/FB and the CB and to describe its approach to ensuring adequate seismic design of those walls with fundamental frequencies below 50 Hz, including any effect of amplified horizontal seismic acceleration on systems and components attached to the walls.

In its supplemental response, the applicant stated that the out-of-plane vibration frequencies of walls were reviewed. The calculated out-of-plane fundamental frequencies for the typical walls in the RB/FB and the CB are higher than the highest frequency of interest of 50 Hz. However, since the RB walls above the refueling floor at elevation 34.0 m and the FB walls at elevation 4.65 m have large heights to the upper floor, their frequencies are expected to be lower than 50 Hz. They are evaluated by using a finite element model, in the same manner as the slab frequencies. To obtain design loads of these walls and design FRS for the components attached to these walls, seismic analysis would be performed using wall oscillators calculated by the above analysis, in the same manner as floor oscillators. The cracked concrete effect would be addressed by reducing the oscillator's spring values by 50 percent. The applicant stated that it would revise DCD Appendix 3A to include the results of this analysis in the next update.

The staff considered the applicant's proposed approach to resolving this issue to be technically acceptable. The staff's review of DCD Revision 3, Appendix 3A, confirmed that the applicant has adequately addressed the treatment of flexible walls, in accordance with its commitment. Therefore, RAI 3.7-26 was resolved.

In DCD, Tier 1, Figures 2.17.5-1 through 2.17.5-11, and DCD, Tier 2, Figure 1.2-1, the applicant did not provide the foundation dimensions for the RB/FB and the CB, nor the distance from the center of the reactor vessel to the edge of the RB/FB foundation. Because this information is important for the structural modeling and the seismic response of seismic Category I structures, in RAI 3.7-27, the staff requested that the applicant include these dimensions in the figures cited above.

In its response, the applicant stated that Figures 3G.1-1, 3G.1-6, and 3G.1-7 of Revision 1 of the DCD provide the foundation dimensions of the RB/FB. The distance from the RPV center to the edge of the RB/FB foundation is also available from these figures. Figures 3G.2-1 and 3G.2-3 of DCD Revision 1 give the CB foundation dimensions. The applicant stated that in the next DCD revision, it would update DCD, Tier 1, Figures 2.17.5-1 through 2.17.5-11, and DCD, Tier 2, Figure 1.2-1, to provide the critical building foundation dimensions.

The staff's review of the applicant's response found that the dimensions of foundation mat provided in Figures 3G.1-1, 3G.1-6, and 3G.1-7 of DCD Revision 1 satisfy the needs for developing the model of basemat and therefore are acceptable. The staff reviewed DCD Revision 3 and confirmed that the applicant included the dimensions in the appropriate Tier 1 and Tier 2 figures. Therefore, RAI 3.7-27 was resolved.

The staff noted that DCD Section 3.7.2.3 does not address the method used to develop stiffness values (uncracked concrete sections versus cracked concrete sections) for concrete structural elements for the seismic analysis models. In RAI 3.7-50, the staff asked the applicant to include in the DCD a detailed description of the method applied to determine the stiffness values for both cracked concrete sections and uncracked concrete sections in the seismic analysis models. In its response, the applicant stated that, to address the effect of the cracked concrete stiffness, an additional evaluation is performed using the SASSI computer code, assuming that the cracked concrete stiffness is 50 percent of the uncracked value, in accordance with ASCE 43-05, "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities," Section 3.4.1. This evaluation shows that the FRS peaks move to lower frequencies when concrete cracking is considered. However, the FRS of both uncracked and cracked cases are bounded by the broadened envelope response of uniform site cases in the whole frequency range. Enclosure 2 of SEA-ESB-033, Revision 0, "Parametric Evaluation of Effects on SSI Response," provides details. The applicant stated that it will revise DCD Section 3A in the next update to include this information. The staff confirmed that DCD Revision 3, Appendix 3A, contains an acceptable description of the analytical approach and results for cracked versus uncracked concrete section properties. It also shows that the broadened design envelope in-structure response spectra also envelop both concrete property assumptions. Therefore, RAI 3.7-50 was resolved.

In RAI 3.7-57, the staff requested that the applicant demonstrate that the seismic stick models, developed based on the process described in DCD Appendix 3A, can transmit frequencies up to 50 Hz and be able to capture the responses resulting from the high-frequency components of North Anna input ground motions. In its response, the applicant referenced its response to RAI 3.7-24. The staff had reviewed the mode shape plots for the RB/FB that were submitted in the supplemental response to RAI 3.7-24 and had concluded that the mode shapes up to 50 Hz are adequate for use in the seismic stick model analysis. Therefore, RAI 3.7-57 was resolved.

Based on its review and audit of ESBWR DCD Sections 3.7 and 3.8, the staff determined that GE developed the seismic stick models for the RB/FB and CB and the static NASTRAN finite element models for the RB/FB and CB directly from design information, without conducting any comparison or correlation of the static and dynamic responses of these models. The staff concluded that comparison or correlation was required before the staff could complete its assessment of the adequacy of the stick models and the static NASTRAN finite element models.

In RAI 3.7-59, the staff asked the applicant to provide the following additional information:

A. Comparison/correlation between the seismic stick models and the static NASTRAN models for both the RB/FB and the CB, based on static analysis:

   (i) total reaction force/moment at the base (assume fixed base) due to a 1g static load applied separately in each horizontal direction and in the vertical direction

   (ii) deflection at the top of model in each direction

   (iii) total mass

   (iv) calculation of first mode frequency in each direction

   The static analysis comparisons should be done for the complete model, and, if feasible, for each individual stick of the seismic model. Deflections at the top of the NASTRAN model should be representative values, based on engineering judgment.

B. Comparison/correlation between the seismic stick models and the static NASTRAN models for both the RB/FB and the CB, based on dynamic analysis:

   (i) free vibration analyses (frequencies and mode shapes) for fixed base

   (ii) seismic time-history analyses or response spectrum analyses for fixed base

   The free vibration analysis (frequencies and mode shapes) results should demonstrate that the stick models reasonably include all significant frequencies and mode shapes that would affect the response to the design basis SSE.

   The time-history analysis or response spectrum analysis results should confirm the adequacy of the method currently employed by the applicant to apply the seismic loads to the static NASTRAN models.

   The time-history analysis or response spectrum analysis results should demonstrate that any differences arising from the comparisons based on static analysis and free vibration analysis have minimal effect on the response to the design basis SSE.

C. An explanation for all significant discrepancies, and the technical basis for concluding that the discrepancies are acceptable.

In its response, the applicant stated that to assess the adequacy of the stick models and the static NASTRAN finite element models, static and dynamic comparative analyses were performed for both the RB/FB and the CB. The following documents present the details of these analyses:

- Attachment SEA-ESB-043, Revision 0, “Comparative Analysis between Seismic Stick Model and Static Finite Element Model for RB/FB”

- Attachment SEA-ESB-044, Revision 0, “Comparative Analysis between Seismic Stick Model and Static Finite Element Model for CB”

The applicant stated that the stick model is consistent with the finite element model in predicting static and dynamic responses, confirming the adequacy of the stick model.

During the October 31–November 2, 2006, audit, the staff reviewed the two cited reports, and identified two areas where additional information was necessary to justify the adequacy of the modeling:

a. In the description of the stick model natural vibration modes, include both the displacement and the rotation components in the figures.

b. Address the adequacy of the design methods that apply the stick model dynamic seismic loads to the static NASTRAN model.

In its supplemental response, the applicant addressed the two issues identified above:

a. The following updated reports are being re-submitted to include stick model results for pure translational responses without contribution from rotation/torsion and to address the adequacy of design methods that apply seismic loads to the static NASTRAN models:

    - Attachment SEA-ESB-043, Comparative Analysis between Seismic Stick Model and Static Finite Element Model for RB/FB, Revision 1.

    - Attachment SEA-ESB-044, Comparative Analysis between Seismic Stick Model and Static Finite Element Model for CB, Revision 1.

b. As shown in Attachment SEA-ESB-043, it was confirmed from time history analysis that the design methods that apply the seismic loads to the static NASTRAN models are adequate.

The staff reviewed SEA-ESB-043, Revision 1, and SEA-ESB-044, Revision 1, in detail and confirmed that all technical issues raised by RAI 3.7-59 have been adequately addressed, consistent with the acceptance criteria contained in SRP Section 3.7.2. On the basis of this review, the staff concluded that the applicant has demonstrated sufficient equivalency between the dynamic seismic stick model and the static NASTRAN model. The staff further concluded, based on comparisons presented in SEA-ESB-043, Revision 1, that the method employed to define the static loads applied to the NASTRAN model from the dynamic stick model results is conservative. Therefore, RAI 3.7-59 was resolved.

3.7.2.3.4 Soil-Structure Interaction

In DCD Section 3.7.2.4, the applicant stated that DCD Appendix 3A presents the seismic SSI analyses of the Category I buildings performed for a range of soil conditions. The staff's review of DCD Appendix 3A identified a need for additional information so that the staff could complete its evaluation.

DCD Appendix 3A, Section 3A.1, states that this appendix presents SSI analysis performed for two site conditions, the generic site and the site-specific North Anna ESP, adopted to establish seismic design loads for the RB, FB, and CB of the ESBWR standard plant under SSE excitation. It was unclear to the staff whether the SSE is defined as both the 0.3g RG 1.60 ground motion response spectra and the North Anna ESP ground motion response spectra or is the combination (envelope) of these two spectra. In RAI 3.7-29, the staff asked the applicant to clarify the definition of the SSE used for the ESBWR standard plant design in the DCD. In its response, the applicant referenced its response to RAI 3.7-5. The staff confirmed that the applicant's response to RAI 3.7-5 does address this question. The applicant stated that it had defined a new SSE as the envelope of the two spectra. Since the staff found the applicant's response to RAI 3.7-5 to be acceptable, RAI 3.7-29 was resolved.

DCD Section 3A.3.1 states that three subsurface conditions (soft, medium rock, and hard rock sites) are considered to be uniform half-space, as indicated in Table 3A.3-1 for SSI analyses. According to the staff's review experience, a number of sites composed of layered materials should be considered for siting of nuclear plants. Such sites may vary significantly in shear wave velocity with depth, leading to potentially significant impedance mismatches between layers. Such profiles can have effective impedance functions that are very different from those associated with a uniform half-space (see, for example, "Handbook of Impedance Functions" by J.G. Sieffert and F. Cevaer). These sites are typically characterized by impedance functions that are highly frequency dependent. The approach of using a frequency-independent assumption for both stiffness and damping in SSI may lead to substantially different computed responses. The behavior (or response) of a massive structure (such as the RB/FB or CB) may be greatly influenced by these variations due to site conditions. For the design of a standard plant such as the ESBWR, the DCD should address the limitations on site layering that will be required to ensure the applicability of the ESBWR design, which is based on the assumption of uniformity. In RAI 3.7-30, the staff requested that the applicant include this information in the DCD and also identify it as a COL interface item.

In its response, the applicant stated that to enhance the applicability of the ESBWR design, four cases of layered sites were evaluated for the RB/FB and the CB using the SASSI computer code. These cases cover a wide range of variation of shear wave velocity with depth so that the effect of impedance mismatches between layers can be captured. Enclosure 2 of SEA-ESB-033, Revision 0, provides details. Since the results of site-envelope design loads consider layered sites, there is no limitation on site layering for COL application of the ESBWR standard plant design. The applicant noted that the input ground motion used in the layered site analysis (and also in other additional analyses performed to address other related RAIs) corresponds to the single-envelope ground spectrum described in response to RAI 3.7-5.

The applicant identified the following revisions and additions to the DCD:

> DCD Section 3.7.1 will be revised to clarify the definition of design ground motion, as shown in the attached markup;
>
> DCD Section 3A.3.1 will be revised and Table 3A.3-3 will be added in the next update as shown in the attached markups;

DCD Section 3A will also be revised in the next update to include the results of site layering evaluation.

The staff noted that the applicant proposed four layered site conditions and use of the SASSI computer code for the ESBWR SSI analyses. Including layered site conditions in the SSI analysis satisfies the staff's concern raised in this RAI. Since the staff performed a confirmatory SSI analysis (using the same structural models and ground response spectra), the staff based its assessment on a comparison of the staff's results to the applicant's results.

During the October 31–November 2, 2006, staff audit, the staff discussed with the applicant the finding that the effect of the layered site condition used in the staff's confirmatory analysis shows that the closer the hard layer is to the bottom of foundation, the higher the building response is and that frequencies shift toward the higher end. The staff and the applicant agreed that this would be addressed under RAI 3.7-16. Therefore, RAI 3.7-30 was resolved, based on the resolution of RAI 3.7-16.

The staff noted that the minimum shear wave velocity specified in DCD Appendix 3A, Table 3A.3-1, for the generic site is 1,000 feet per second (ft/s). However, the staff could not determine whether this is a best-estimate value or a lower bound value after considering potential variations (best estimate divided by the square root of 2). If the table values are best estimates, then the lower bound shear wave velocity would be 707 ft/s. The staff position is that competent material should have a lower bound shear wave velocity of 1,000 ft/s; otherwise, additional technical justification is needed to demonstrate that the soil is capable of seismically supporting a nuclear power plant. The March 2007 update to SRP Section 3.7.1 incorporates this position.

The staff also noted that the variation shown for the North Anna site in DCD Table 3A.3-2 is plus or minus the square root of 1.5, which does not meet SRP acceptance criteria. In RAI 3.7-31, the staff requested that the applicant (1) explain and justify this difference (variation in soil shear wave velocity by plus or minus the square root of 2 versus plus or minus the square root of 1.5) in criteria between the generic site and the North Anna site and (2) revise the DCD to specify the lower bound shear wave velocity for the generic site.

In its response, the applicant stated the following:

(1) SRP Section 3.7.2 provides for an exception from its recommendation for the variation in soil properties (i.e. G, 2G, and G/2) in the case of well-investigated sites. The North Anna site is considered to be a well-investigated site; therefore, the variation of shear wave velocity by ± square root of 1.5 is considered more appropriate than ± square root of 2; and

(2) DCD Section 3.7.5.1 item (3) will be revised to read: "The equivalent uniform shear wave velocity (V_{eq}) over the entire soil column is no less than 300 m/sec (1000 ft/sec) at seismic strain, which is a lower bound value after taking into account uncertainties. V_{eq} is calculated to achieve the same wave traveling time over the depth equal to the embedment depth plus 2 times the largest foundation plan dimension below the foundation.

The applicant’s response indicates that the lower bound iterated shear velocity profile at any site will be no less than 300 m/sec (1,000 ft/sec), as determined from site response analyses performed by the COL applicant. On this basis, the applicant’s response is acceptable. In DCD Revision 2, the applicant made the identified change to Section 3.7.5.1, item (3). Therefore, RAI 3.7-31 was resolved.

However, the staff reviewing DCD Section 3.7 noted that in DCD Revision 3, the applicant deleted the entire Section 3.7.5.1, which previously addressed four items related to COL information. The applicant indicated that this deletion was in response to staff RAI 3.8-95. Of the four COL information items previously identified in DCD Revision 2, Section 3.7.5.1, RAI 3.8-95 addressed only the soil-bearing pressure capacity. The staff did not evaluate the acceptability of completely deleting DCD Section 3.7.5.1. The staff concluded that the deletion of DCD Section 3.7.5.1 is not acceptable.

In RAI 3.7-61 (part 5), the staff asked the applicant to include, in the next revision of DCD Section 3.7.5, very specific references to other Tier 1 and Tier 2 sections for all four items previously addressed in DCD, Revision 2, Section 3.7.5.1, and to ensure that the exact wording previously accepted by the staff and incorporated in DCD Revision 2 has been retained. The staff identified RAI 3.7-61 (part 5) as an open item in the SER with open items.

In DCD Revision 5, the applicant revised Section 3.7.5 as follows:

(1) See Table 2.0-1 for seismology requirements of site-specific SSE ground response spectra.

(2) See Table 2.0-1 for soil properties requirements of site-specific foundation bearing capacities, minimum shear wave velocity and liquefaction potential. For sites not meeting the soil properties requirements, a site-specific analysis is required to demonstrate that site-specific conditions are enveloped by the standardized design.

The staff reviewed the revised Section 3.7.5 and the referenced Table 2.0-1 and found them sufficient to address the staff’s concern. On this basis, RAI 3.7-61 (part 5) and the associated open item were resolved.

In DCD Section 3.7.5, the applicant indicated that the COL applicant needs to confirm that the site-specific shear wave velocity is no less than 1,000 ft/s in order to verify the design adequacy of the plant. However, in following the guidance of the SRP for an individual site evaluation, the COL applicant needs to perform site-specific response calculations, reducing the low-strain shear wave velocity profile from the best estimate to a lower bound value (defined as the best estimate divided by the square root of 2). In RAI 3.7-54, the staff stated that DCD Section 3.7.5 needs to indicate that 1,000 ft/s is a lower bound velocity and not a best-estimate velocity, or, as an alternative, the minimum acceptable best-estimate velocity can be specified. In addition, since all design analyses were performed for assumed uniform velocity profiles, the site acceptance criteria need to include information on the degree of variation from the uniform velocity profile that is acceptable for the design.

In its response, the applicant referred to its response to RAI-3.7-31 for clarification of the definition of minimum shear wave velocity. To enhance site suitability for the ESBWR standard plant design, additional SSI analyses are performed for generic layered sites using the SASSI computer code. During the October 31–November 2, 2006, audit, the staff reviewed additional information provided by the applicant. The applicant has indicated that the lower bound velocity profile is no less than 1,000 ft/s or 300 m/s. Therefore, RAI 3.7-54 was resolved, based on the resolution of RAI 3.7-31.

In DCD Appendix 3A, Tables 3A.3-1 and 3A.3-2 identify material (hysteretic) damping values assumed for foundation soils for the various uniform site cases. However, the SSI description does not mention how these damping parameters are combined with the SSI radiation damping values listed in Tables 3A.5-1 and 3A.5-2. In RAI 3.7-32, the staff requested that the applicant clarify in the DCD how these properties (material damping and radiation damping) were considered in the SSI calculations.

In its response, the applicant stated that the SSI radiation damping values listed in DCD Tables 3A.5-1 and 3A.5-2 are the only damping of soil considered in the SSI calculations. Soil material damping values listed in DCD Tables 3A.3-1 and 3A.3-2 are conservatively neglected. The applicant stated that its response to RAI 3.7-49 describes the SSI analytical formulation in detail. When the SSI radiation damping is calculated by the formulation, the soil material damping values are input as zero. The applicant stated that it would revise DCD Section 3A.5 in the next update to clarify how these properties were considered in the SSI calculations.

Since neglecting soil material damping reduces energy dissipation and results in a higher seismic response, the staff found the RAI 3.7-32 response to be acceptable. The applicant's use of the SASSI computer code (frequency domain solution) to perform additional SSI analyses for layered sites resolved the staff's concern about soil damping. RAI 3.7-16 addresses the remaining issue of whether it is sufficient to investigate only four layered site conditions to cover all other potential site conditions that will be encountered at the COL stage. In DCD, Revision 2, Appendix 3A, the applicant stated that the uniform-site SSI analyses that use soil springs conservatively neglected the soil material damping. Therefore, RAI 3.7-32 was resolved.

DCD Section 3A.5 indicates that the use of lateral pressures computed from the equivalent static pressure analysis listed in ASCE 4-98 is conservative. Based on reviews of a number of facilities, it is known that actual pressures computed from detailed SSI evaluations of embedded foundations are directly influenced by the characteristics of the foundation response spectrum used to define the ground motions, as well as the relative stiffness (shear wave velocity) of the soils above the basemat level. In RAI 3.7-33, the staff requested that the applicant clearly indicate in the DCD either (1) the technical basis for the statement that these static pressures are conservative for any site or (2) any limitations that need to be incorporated into the acceptable site profile characteristics to limit the actual dynamic pressures anticipated. In its response, the applicant stated that, to confirm that the ASCE 4-98 approach is conservative, an additional evaluation was performed for the layered sites with deep embedment using the SASSI computer code, as described in the response to RAI 3.7-30. This evaluation shows that the lateral pressures calculated by the ASCE 4-98 approach are generally bounding. An envelope of these two sets of values will be used for exterior wall design. Enclosure 2 to SEA-ESB-033, Revision 0, contains details. The applicant committed to the revision of DCD Section 3A in the next update to include this information.

During the October 31–November 2, 2006, staff audit, the staff asked the applicant to clarify the RAI response by including the explanation provided at the audit, that embedded walls are designed for the worst soil pressures resulting from either SASSI analysis or ASCE 4-98 methodology. In its supplemental response, the applicant referred to the third sentence of the original response to RAI 3.7-33, which states, "An envelope of these two sets of values will be used for exterior wall design." This means that the embedded walls are designed for the worst soil pressures resulting from either the SASSI analysis or the ASCE 4-98 methodology. The staff found that the applicant's supplemental response adequately addresses the enveloping issue and is acceptable. The staff confirmed that DCD, Revision 3, Appendix 3A, includes the identified change. Therefore, RAI 3.7-33 was resolved.

In reviewing the seismic analysis of the RB/FB and CB for the North Anna site conditions (ground motion and local geotechnical properties), the staff identified the following concerns in RAI 3.7-34:

a. As indicated in DCD Figures 3.7-24 through 3.7-35, the North Anna ground motions at the base of the RB/FB are different from those at the CB base. The staff's concern is whether these ground motions are treated as design ground motions. If yes, it implies that the design ground motion is not uniquely defined (RG 1.60 ground motion and North Anna ground motions at the foundation base of the RB/FB and CB). The staff requested the applicant to (1) clarify the definition of design ground motion in the DCD, and (2) define the design site parameters (Tier 1 information) in Tier 1 Table 5.1-1.

b. Do the ground motion time histories generated for the North Anna ground response spectra satisfy the response spectrum enveloping requirements for all damping ratios to be used for the seismic design? If yes, the staff requests that the comparison plots be provided in the DCD. If not, the staff requests the applicant to provide, in the DCD, technical basis for not satisfying these SRP guidelines.

c. Do the ground motion time histories generated for the North Anna ground response spectra satisfy the PSD enveloping guidelines? If yes, the staff requests that a detailed description showing how the target PSDs were developed, and showing the comparison, be provided in the DCD. If not, the staff requests the applicant provide, in the DCD, a technical basis for not satisfying these SRP guidelines.

In its response, the applicant referenced its responses to RAIs 3.7-5 and 3.7-8 for part (a) and RAI 3.7-12 for part (b). For part (c), the applicant stated that the ground motion time histories generated for the North Anna ground response spectra have not been tested against any PSD enveloping guidelines, nor have target PSD spectra been developed for the high-frequency target response spectrum. Instead, the applicant has adopted the methodology of NUREG/CR-6728. The applicant stated that Section 5.1 of NUREG/CR-6728 explains the reasons that the report does not require spectrally matched time histories to satisfy PSD-enveloping guidelines. The applicant stated that it would revise DCD Section 3.7.1.1.3 in the next update to include the above technical basis for not satisfying the SRP PSD-enveloping guidelines, as noted in the attached markup.

The staff's confirmatory calculations demonstrated that the time histories proposed by the applicant satisfy the enveloping criteria described in NUREG/CR-6728. On this basis, the staff finds the applicant's response to be acceptable. In Revision 2 of DCD Section 3.7, the applicant made the requested DCD changes. On this basis, RAI 3.7-34 was resolved.

DCD Appendix 3A, Section 3A.7, indicates that the elastic half-space theory was used for modeling the soil foundation for both the generic site condition and the North Anna site condition. The staff identified the following issues in need of clarification: (1) what soil damping (material damping and energy loss resulting from wave propagation) was assigned for the SSI analyses, and (2) how were the embedment effects (especially at relatively soft soil sites) considered in the analysis? In RAI 3.7-35, the staff asked the applicant to clarify these issues and also describe how it applied the elastic half-space theory to the North Anna site in the DCD. The staff identified RAI 3.7-35 as an open item in the SER with open items.

In its response to part (1) of RAI 3.7-35, the applicant referenced its responses to RAIs 3.7-16 and 3.7-32. For part (2), the applicant stated that, to evaluate the embedment effects, additional evaluation is performed for the layered sites with deep embedment using the SASSI computer code, as described in the response to RAI 3.7-30. This evaluation shows that the effect of embedment works to reduce basemat reaction shear forces. Enclosure 2, SEA-ESB-033, Revision 0, contains details. The foundation properties considered in the SSI analysis for the North Anna site and shown in DCD Table 3A.3-2 are applied as uniform half-space soil. As stated in DCD Section 3A.3.2, these values are determined on the basis of the North Anna ESP site-specific conditions. The response to RAI 3.7-7 offers further details. The applicant stated that it would revise DCD Section 3A in the next update to provide the requested clarifications.

The staff determined that the acceptability of the response submitted depended on the resolution of RAI 3.7-16. RAI 3.7-35 and the associated open item were resolved based on the resolution of RAI 3.7-16.

In DCD Appendix 3A, Tables 3A.7-1 through 3A.7-14, the applicant presented the eigenvalue analysis results. The data presented indicate that the highest modal frequencies considered in the modal time-history analyses of the RB/FB are in the range of 10.83 Hz (soft soil) to 11.89 Hz (hard rock). For the CB, it appears that the highest modal frequency considered in the modal time-history analyses is 29.10 Hz. In RAI 3.7-36, the staff asked the applicant to include the following additional information in the DCD:

(a) Discuss whether only the modes listed in the cited tables were included in the modal time-history analyses. If not, then identify the additional modes included in each time-history analysis and provide the basis for their inclusion. If yes, then identify the modes excluded from each time-history analysis, up to f_{ZPA} of the spectrum, and provide the basis for their exclusion.

(b) Discuss how the missing mass (modal mass corresponding to modes with frequencies higher than the analysis cut-off frequency) was included in the seismic response analyses. The staff notes that the 10 percent criteria stated on page 3.7-10 of the DCD is no longer considered acceptable to the staff (RAI 3.7-17 provides the basis for not accepting the 10 percent criteria).

In its response, the applicant stated the following:

(a) As stated in the response to RAI 3.7-17, modal superposition time-history analysis was not employed. The direct integration method in the time domain is employed for the seismic analyses. For clarification purposes, a footnote “Modal information shown is not used in the response analysis performed by the direct integration method" will be added to Tables 3A.7-1 through 3A.7-14.

(b) The response was provided in the response to RAI 3.7-17.

The staff found that the applicant's response to RAI 3.7-17 adequately addressed part (b) of RAI 3.7-36 and that the footnote to DCD Tables 3A.7-1 through 3A.7-14, identified in part (a) of the applicant's response, clarified that the direct integration method had been implemented.

During the June 5–8, 2006, audit, the staff and the applicant discussed the required input time step needed for dynamic SSI analyses. The staff noted that 0.01 seconds is acceptable for the RG 1.60 ground response spectrum, but analyses performed with inputs enveloping the high-frequency spectrum associated with the North Anna site or with the envelope response spectrum combining both the generic and North Anna (envelope) spectra will require a time step of 0.005 seconds. The staff pointed out a potential problem in the applicant's planned use of the SASSI2000 computer code to perform SSI analyses, when using the 0.005-second time step for the artificial input motions. The version of SASSI2000 available to the applicant has a limitation of 4,096 input steps. The total input time-history duration will then be limited to 20.48 seconds. When performing analyses representing the very broad envelope spectrum, it may be difficult to develop a 20.48-second time history that properly envelops the spectrum and satisfies the enveloping criteria in NUREG/CR-6728. A total input time-history duration of 40.96 seconds (or 8,192 points at 0.005 seconds) may be needed to adequately match the broad envelope spectrum.

During the June 5–8, 2006, audit, the staff also asked the applicant to provide the frequencies and mode shapes up to 50 Hz for the RB/FB stick model. Based on its review of these data, the staff identified a possible problem concerning the lack of coupling in the vertical direction between the RB and the reinforced concrete containment vessel (RCCV). The applicant recalculated the frequencies and mode shapes with and without vertical coupling between the RB and RCCV, using a reduced model in which the three sticks representing the RPV were removed. Based on review of these new results, the staff and the applicant concluded that there is minor, but not totally negligible, vertical coupling. The applicant indicated that it would include the vertical coupling in its planned SASSI analyses.

The applicant agreed to revise its response to part (a) of RAI 3.7-36 to address the two technical issues discussed at the audit. In its supplemental response, the applicant stated that (1) the artificial time histories compatible with the single-envelope target spectrum have been developed for 40-second duration with 0.005-second time steps. The applicant increased the SASSI2000 capability to handle 8,192 input steps, and (2) the RB/FB stick model was revised to include coupling in the vertical direction between the RB and RCCV. The applicant provided the revised model to the NRC in MFN 06-278.

The staff found that the applicant's supplemental response adequately addressed the two technical issues raised by the staff during the June 5–8, 2006, audit. The applicant increased the capability of SASSI2000 to accommodate the 0.005-second time step and revised the RB/FB stick model to include coupling in the vertical direction between the RB and RCCV. Therefore, the response is acceptable. In addition, the applicant made the identified change to Tables 3A.7-1 through 3A.7-14 in Revision 2 of DCD Section 3.7. On this basis, RAI 3.7-36 was resolved.

In the third paragraph of DCD Appendix 3A, Section 3A.5, the applicant discussed how to use the frequency-independent soil spring K_c and damping coefficient C_c to represent the soil foundation in the SSI analysis of the RB/FB and CB. DCD Tables 3A.5-1 and 3A.2 provide tabulated numerical values of K_c and C_c for the RB/FB and CB. However, the applicant did not describe in the DCD how the frequency-dependent soil springs (real and imaginary parts of the soil stiffness) were calculated and how these frequency-dependent soil springs were converted to frequency-independent soil springs and damping ratios. In RAI 3.7-37, the staff requested that the applicant provide a detailed description in the DCD.

In its response, the applicant stated that the detailed description of the calculation of the frequency-dependent soil springs (real and imaginary parts of the soil impedance) is provided in the response to RAI 3.7-49, which also described the procedure used to convert these frequency-dependent soil impedances to frequency-independent soil stiffness and damping ratio. The response included an example for comparison of the calculated frequency-dependent impedance with the equivalent frequency-independent soil stiffness and damping for the soft site. The applicant stated that it would revise DCD Section 3A.5 in the next update to provide a detailed description.

Based on staff acceptance of the response to RAI 3.7-49 and review of the example provided, the staff found the response to be acceptable. The applicant made the requested DCD changes in Revision 2 of DCD Appendix 3A. Therefore, RAI 3.7-37 was resolved.

DCD Appendix 3A states that the shear wave velocities and material damping ratios are strain compatible. In RAI 3.7-38, the staff requested that the applicant provide the following information in the DCD: (1) the theory (methods or formula) for calculating all soil springs, (2) the method (or formula) for calculating damping ratios, and (3) a clear description of how the strain dependency of these values is accounted for in the soil springs used in the SSI analyses.

In its response, the applicant referenced its response to RAI 3.7-37 to address parts (1) and (2). For part (3), the applicant stated that in DCD Section 3A.3, the shear wave velocities and the material damping ratios shown in DCD Tables 3A.3-1 and 3A.3-2 are considered to be compatible with the strain level expected during the SSE. These strain-compatible values were used directly in computing soil-spring and damper properties The applicant further stated that this would be clarified in the next revision of DCD 3A.3.The staff found parts (1) and (2) of the RAI response to be acceptable, based on staff acceptance of the responses to RAIs 3.7-37 and 3.7-49. For part (3) of the RAI response, the staff determined that the use of the iterated strain-dependent shear wave velocity and material damping is an acceptable method, consistent with SRP Section 3.7.2, for incorporating the nonlinear behavior of soil. The staff confirmed that the clarification was incorporated in DCD 3A.3, Revision 2.

During the October 31–November 2, 2006, audit, the staff asked the applicant to confirm that the envelope of soil sites also includes a fixed base condition, which would resolve the staff's concern about radiation damping. In a supplemental response to RAI 3.7-38, the applicant stated that, as shown in Table 6-1 of Attachment SEA-ESB-033, Revision 0, it is confirmed that the design-basis envelope forces and FRS include the results of fixed-basis analysis, in which radiation damping is zero. The staff found the applicant's supplemental response to be acceptable, because the zero damped, fixed-base analysis included in the set of soil sites minimizes the effects of radiation damping and leads to bounding results.

The staff considered RAI 3.7-38 to be resolved, provided that the COL applicant verifies that the iterated soil properties at the site fall in the range of those considered in the generic SSI analysis. In RAI 3.7-62, the staff requested that the applicant identify a COL information item specifying that the COL applicant needs to verify this.

In its response, the applicant stated that DCD, Tier 2, Revision 4, Section 2.0.1, Item 2.0.1-A, “Site Characteristics Demonstration”, identifies that each COL applicant will demonstrate in its COL application how the site soil shear wave velocities meet or exceed the ESBWR DCD site parameter value for minimum soil shear wave velocity, as specified in DCD, Tier 2, Table 2.0-1. The staff noted that a COL applicant referencing the ESBWR DCD must demonstrate that site characteristics for a given site fall within the ESBWR DCD site parameter values, per 10 CFR 52.79.

The applicant further stated that Note 8 to this table specifies that the minimum soil shear wave velocity is at seismic strain, which by definition is an iterated soil property. The staff reviewed the referenced Revision 4 DCD sections and found that they acceptably address RAI 3.7-62. Therefore, RAI 3.7-62 was resolved.

For the SSI analyses performed, in RAI 3.7-39, the staff asked the applicant to describe in detail in the DCD how it considered the effect of structure-to-structure interaction through the soil between the RB/FB and CB. The staff considered this a potentially significant effect, especially for the response of the CB. In its response, the applicant stated that, to address the effect of structure-to-structure interaction through the soil between the RB/FB and CB, an additional analysis is performed for the layered sites using the SASSI computer code. This analysis shows that the effect of structure-to-structure interaction is the largest in the Y-direction (east-west) response of the CB. However, the FRS with and without the structure-to-structure interaction effect are bounded by the broadened envelope responses of uniform site cases in the entire frequency range. Enclosure 2 of SEA-ESB-033, Revision 0, provides details. The applicant stated that it would revise Appendix 3A to the DCD in the next update to include this information.

During the October 31–November 2, 2006, staff audit, the staff requested that the applicant clarify that the “broadened envelope response of uniform site cases in the entire frequency range” is used as the design FRS. In its supplemental response, the applicant referred to the original response to RAI 3.7-39, which stated that “both FRSs without and with structure-structure interaction effect are bounded by the broadened envelope responses of uniform site cases in the whole frequency range.” The basis of this statement is that the design FRS is determined by enveloping the results of all cases considered, as stated in Section 8 of Attachment SEA-ESB-033, Revision 0.

On the basis that the applicant confirmed that the design FRS bounds the FRS both with and without structure-to-structure interaction effects, the staff found the supplemental response to be acceptable. The applicant incorporated the change identified in the initial response into DCD Revision 3. Therefore, RAI 3.7-39 was resolved.

In addition to the evaluation of the identified issues discussed above, the staff’s review of DCD Section 3.7.2 and Appendix 3A to the DCD found that the applicant’s SSI analyses were performed based on two assumptions: (1) soil sites with uniform properties and (2) soil stiffness represented by lumped soil springs and dashpots. For calculating seismic responses of seismic Category I structures, the applicant used the Japanese computer code DAC3N to perform SSI analyses. To ensure that seismic loads generated by the applicant will result in a reasonable and acceptable design of seismic Category I SSCs, the staff used the fixed-base structural model of the RB/FB and CB developed by the applicant and the validated public domain computer code SASSI to conduct two independent SSI confirmatory analyses. In the first case, the staff chose the generic soft soil site (one of the four uniform site conditions used by the applicant) as supporting media. The purpose of these analyses was to confirm that the seismic responses (structural member forces and FRS) calculated by DAC3N are reasonable and acceptable in comparison with those calculated by SASSI. In the second case, the staff, using its engineering judgment, selected a worst layered soil site condition and used the same lumped-mass RB/FB and CB structural models to perform SASSI analyses. The purpose of these analyses was to verify the adequacy of the uniform soil site condition assumed by the applicant.

In RAI 3.7-49, the staff asked the applicant to provide the following information needed for the staff's confirmatory analyses:

1. Detailed finite element (FE) RB/FB model (including figures showing mesh plots, node numbering, etc.) used for the development of the lumped-mass stick model.

2. Detailed fixed-base (fixed at the top of the foundation mat) lumped-mass stick model used in the applicant's SSI analyses.

3. Large-size structural design drawings of the RB/FB. Specifically, drawings showing the detailed foundation mat and embedded side walls are needed.

4. Soil information used to develop soil springs and soil damping for the SSI analyses of the RB/FB supported by the soft soil condition.

5. Description of the computer code "DAC3N" used by the applicant for the SSI analyses.

6. Input ground motion time history text files in digitized form.

7. Description of the SSI analytical formulation and digitized response computation results.

In its response, the applicant provided the requested information. The applicant stated that the SSI analyses for the RB/FB and CB were performed by the direct integration method in the time domain. The response of a multi-DOF linear system subjected to external forces and/or uniform support excitations is represented by the differential equations of motion in the matrix form in DCD Equation 3.7-1. The viscous damping matrix consists of structure damping and soil radiation damping. The structure damping matrix is generated using DCD Equations 3.7-14 and 3.7-17. The soil is modeled with sway-rocking springs, as described in DCD Section 3A.5. The base spring is evaluated based on three-dimensional wave propagation theory for a uniform half-space soil. The assumptions used for the SSI analysis are as follows:

- uniform half-space soil
- rectangular shape foundation
- uniform stress distribution for horizontal and vertical spring
- triangle stress distribution for rocking and torsional spring
- evaluation by load-weighted average displacement

The staff reviewed the data provided in the response and discussed them with the applicant during the June 5–8, 2006, audit. The staff concluded that it had received all the necessary data, in electronic format, to support the confirmatory analyses of the RB/FB and found the applicant's response to be acceptable. During the audit, the staff requested that the applicant also provide the corresponding data for the CB. The applicant agreed to provide the CB model details when they were final. At the time of the audit, the applicant was in the process of refining the mass distribution in the CB model, to ensure that natural frequencies and mode shapes can be accurately calculated up to 50 Hz. The applicant formally submitted the additional information requested during the audit. Therefore, RAI 3.7-49 was resolved.

In DCD Revision 4, Section 3A.4.1, the applicant stated the following:

> For the generic sites defined in Subsection 3A.3.1, the design response spectra are conservatively applied at the level of foundation in the free field. The input motion for North Anna ESP site is also defined at the foundation level.
>
> For the layered site cases, the input ground motion is defined as an outcrop motion at the RB/FB foundation level for the RB/FB and CB. The corresponding surface motion is generated for use as input to the SASSI2000 calculation for each site.
>
> For the FWSC, which is essentially a ground surface founded structure, the input ground motion is taken to be 1.35 times the RB/FB and CB foundation input motion and is applied directly at the foundation level.

In RAI 3.7-63, the staff requested the following clarification and additional information related to the above statements:

> (Part 1) Based on the first two sentences above, it appears to the staff that the ground motion for the CB was applied at two different elevations: at the CB foundation level for the generic sites defined in Subsection 3A.3.1, and at the RB/FB foundation level for the layered site cases. Please confirm this, or clarify what was actually done. If this is the case, please describe what differences in CB response would be expected for the layered site cases if the input ground motion had been defined as an outcrop motion at the CB foundation level.
>
> (Part 2) The third sentence above defines the input ground motion used for the FWSC SSI analyses as "1.35 times the RB/FB and CB foundation input motion…applied directly at the foundation level." Please provide a detailed technical basis for the selection of the 1.35 factor, including pertinent quantitative information upon which this determination is based.

In its response, the applicant stated the following:

> (Part 1) GEH confirms that the ground motion for the CB was applied at the CB foundation level for the generic site cases and at the RB/FB foundation level for the layered site cases. Applying the outcrop motion at the RB/FB foundation level for the layered site cases is a more conservative approach than applying the outcrop motion directly at the CB foundation level. This is demonstrated by comparing the response spectra of the surface motion when the ground motion is

> applied at the RB/FB foundation level and at the CB foundation level for the typical layered site Case 2 described in DCD, Tier 2, Table 3A.3-3. The response spectrum of the surface motion is larger in the case when the ground motion is applied at the RB/FB foundation level than in the case when the ground motion is applied at the CB foundation level. Therefore, it is expected that the CB response would be smaller for the layered site cases if the input ground motion had been defined as an outcrop motion at the CB foundation level instead [of] at the RB/FB foundation level.
>
> (Part 2) The technical basis for scaling the RB/FB and CB foundation input motion for ground motions at other depths is to maintain a broad-band spectrum shape that is rich in all frequencies, regardless of site conditions, for the purpose of standard plant design. Broad-band design spectrum at any foundation depth is compatible with smooth site-specific ground motion response spectrum (GMRS) and associated foundation input response spectrum (FIRS) generated in accordance with RG 1.208 requirements for new units. The 1.35 scale factor was determined such that the resulting spectrum at the FWSC foundation level envelops the FIRS at the North Anna 3 site.

After reviewing the applicant's response to RAI 3.7-63, the staff concluded that it needed additional information to complete its assessment of the two technical issues. Therefore, the staff issued RAI 3.7-63 S01:

> Part (1) GEH needs to submit a comparison of (1) the surface spectra derived by placing the input motion at the bottom of the RB/FB foundation to (2) the surface spectra derived by placing the input motion at the bottom of the CB foundation, for each of the 4 SASSI layered soil cases. In deriving the surface spectra from the foundation motions, the method identified in the ISG on this subject (GEH referred to the method as the NRC method in its response to RAI 3.7-16) must be used.
>
> The staff noted that the surface spectra corresponding to placing the input motion at the bottom of the CB foundation (dashed line) does not appear to be correct. It resembles the spectrum of the input motion, at the foundation level. The dashed line would be expected to exhibit the same pattern of peaks and valleys as the solid line. GEH needs to confirm that the dashed line is correct, and provide an explanation for the unexpected shape.
>
> Part (2) The staff notes that GEH can define any surface spectrum it chooses to, for design certification of the FWSC. COL applicants will need to demonstrate that the site-specific surface spectrum is enveloped by the spectrum GEH has used for design certification of the FWSC. If this is not the case, then a site-specific analysis of the FWSC will be required at the COL stage. This will be in addition to the required comparisons at the RB/FB and CB foundation levels. SRP Section 3.7.1 specifies a check at the foundation level for each structure.
>
> The staff believes that the surface spectra used for seismic analysis of the FWSC should envelope the 8 surface spectral plots that the staff has asked GEH to derive under Part (1) above. This would ensure consistency between the input at the RB/FB and CB foundation levels and the input at the surface for the FWSC. GEH's proposed 1.35 factor on the input motion at the bottom of the RB/FB

foundation may or may not produce a suitable envelope; it appears to the staff that a 1.35 factor may not be sufficient over the entire frequency range.

The staff requests GEH to re-assess its methodology for selecting the surface spectra for seismic design of the FWSC; provide the technical basis for its selection; and identify the necessary COL applicant action items to ensure the seismic adequacy of the FWSC at each site.

In its response to RAI 3.7-63 S01, the applicant stated the following:

Part (1) Attached figures show comparisons of the surface spectra derived by placing the input motion at the bottom of the RB/FB foundation to the surface spectra derived by placing the input motion at the bottom of the CB foundation for each of the 4 SASSI layered soil cases by using the method identified as the NRC Method in GEH's response to NRC RAI 3.7-16 S02.

Since the fundamental frequencies of the CB in the horizontal directions are around 3 Hz, as shown in DCD, Tier 2, Table 3A.7-8, the CB responses would be smaller for all layered site cases if the input ground motion had been applied at the CB foundation level instead at the RB/FB foundation level.

GEH confirms that both the solid and dashed lines (in Figure 3.7-63(1) of the RAI response) have been correctly calculated by using the method identified as the DCD Method in GEH's response to NRC RAI 3.7-16 S02, which includes the entire soil column up to the ground surface in a single SHAKE run with outcrop motion input at the foundation level.

The reason for the dashed line resembling the foundation input spectrum is because the CB (14.9 m embedment) is shallower than the top layer (20 m thick) of the layered sites (see DCD, Tier 2, Table 3A.3-3). In other words, the soil properties above the foundation are the same as those below the foundation in the region of the top layer and, as a result, the surface motion resembles the foundation input motion. This can be further explained by the one-dimensional wave propagation theory below:

Part (2) The surface spectra computed from the input spectra defined at the RB/FB and CB foundations exhibit distinct peaks and valleys. Using these surface spectra directly as input motion could under-predict or over-predict the FWSC response depending on the SSI frequencies. The more balanced approach for the standard plant design is to maintain the broad-band characteristics in the foundation input spectra, which is rich in all frequencies, regardless of site conditions. This is the technical basis for the selection of FWSC input spectra to be 1.35 times the broad-band Certified Seismic Design Response Spectra (CSDRS) for the RB/FB and CB. As stated in the original response to this RAI, the 1.35 scale factor was chosen to envelop the FWSC Foundation Input Response Spectra (FIRS) at the North Anna 3 site. To ensure the seismic adequacy of the FWSC at each site, the COL applicant is required to compare the site-specific FIRS for the FWSC with the FWSC CSDRS, which is 1.35 times the values shown in DCD, Tier 2, Figures 2.0-1 and 2.0-2 as stipulated in footnote 9 to DCD Tier 2 Table 2.0-1.

DCD, Tier 1, Table 5.1-1, DCD, Tier 2, Table 2.0-1, DCD, Tier 2, Subsection 3.7.1.1 and DCD, Tier 2, Subsection 3A.4.1 will be revised in Revision 6 to clarify that the input ground motion for the Firewater Service Complex is applied directly at the foundation level, specifically at the bottom of the base slab.

DCD, Tier 2, Table 1.9-3, DCD, Tier 2, Table 1.9-20, DCD, Tier 2, Subsection 2.0.2 and DCD, Tier 2, Table 2.0-2 will be revised in Revision 6 to clarify that the COL applicant confirm that the site-specific Foundation Input Response Spectra is enveloped by the ESBWR design response spectra referenced at the foundation level.

The staff reviewed the Supplement 1 response and concluded that the applicant had adequately addressed the staff's questions. The staff confirmed that there is substantial conservatism in the DAC3N uniform site analysis results, which control the structure design and the design-basis FRS for the CB; consequently, the staff concluded that using the RB/FB elevation to define the CSDRS for the CB SASSI analyses did not affect the design basis of the CB.

The staff also confirmed that in the SASSI analysis of the FWSC, there is no embedment effect of the FWSC foundation. The foundation is assumed to be surface mounted. The applicant used 1.35 times the CSDRS as the surface motion input to the SASSI analysis. In this case, 1.35 times the CSDRS is the limiting FIRS for the FWSC at any specific site. A COL applicant is only covered by the generic seismic design basis for the FWSC, if the site-specific FIRS at the bottom of the FWSC foundation is enveloped by 1.35 times the CSDRS. On this basis, the applicant's use of 1.35 times the CSDRS is acceptable. The applicant formally submitted the proposed DCD changes in DCD Revision 6. On this basis, both Parts 1 and 2 of RAI 3.7-63 S01 were resolved.

~~However, during a teleconference~~ Wwith respect to ~~applicant related to~~ RAI 3.7-63 S01, the staff asked the applicant how it had addressed the potential for structure-soil-structure interaction in its evaluation of the FWSC. The applicant indicated that it had not conducted any specific analysis because of the appreciable distance between the closest building (the CB) and the FWSC. The staff stated that a quantitative evaluation of this potential effect is needed to address this issue and, in RAI 3.7-63 S02, offered the following two approaches for consideration:

1. GEH conducts a generic structure-soil-structure analysis for the FWSC.

2. The COL applicant develops its site-specific FIRS for the FWSC foundation by an analysis that considers structure-soil-structure interaction effects. As long as the site-specific FIRS for the FWSC, including any interaction effects, falls below 1.35 x CSDRS, then the FWSC is seismically qualified by reference to the ESBWR DCD.

The staff also stated that GEH may propose an alternative for staff consideration.

In its response to RAI 3.7-63 S02, GEH stated that it has conducted a generic structure-soil-structure interaction analysis for the FWSC with the CB. The analysis model comprises these two independent structures coupled through soil, using the SASSI2000 computer code. The same layered site Case 2 considered for the interaction between the RB/FB and CB is also used in the interaction between the CB and FWSC (CL-2 for CB and FL-2 for FWSC).

The input motion for the coupled CB-FWSC SSI model is the CSDRS applied at the CB foundation level. This analysis case is named Case FL-5. The analysis results of the structural response in terms of maximum vertical accelerations and maximum member forces (presented in various figures and tables included in the RAI response) indicate that the design envelope loads bound all structural response results of the structure-soil-structure interaction analysis.

Figures included in the RAI response show comparisons of FRS with the design envelope spectra at selected locations in the two structures. For comparison, the figures also show the FRS for the corresponding analysis Cases CL-2 and FL-2 without the structure-soil-structure interaction effect. The results confirm that the FRS with the structure-soil-structure interaction effect are bounded by the DCD Revision 5 design envelope spectra in all frequency ranges.

The applicant concluded that 1.35 times CSDRS is a conservative design input motion to the FWSC and can be compared with the site-specific FIRS directly without considering structure-soil-structure interaction effects in COL applications.

The applicant stated that it would update DCD, Tier 2, Appendix 3A and Appendix 3G, to include the analysis performed and the results obtained for structure-soil-structure interaction between the FWSC and CB, including revisions to DCD, Tier 2 Sections 3A.1, 3A.6, 3A.8.11, and 3G.4.5.4 ; DCD, Tier 2, Tables 3A.6-1 and 3G.4-10 through 3G.4-21; and DCD, Tier 2, Figure 3G.4-1 and Figures 3A.8.11-7 through 3A.8.11-24.

The staff reviewed the information provided by the applicant in its response to RAI 3.7-63 S02 and found that it adequately addressed the staff's question on structure-soil-structure interaction between the CB and FWSC. The effects of structure-soil-structure interaction are bounded by the design-basis analyses for both the CB and FWSC.

The applicant formally submitted the proposed DCD changes in DCD Revision 6. On this basis, RAI 3.7-63 S02 was resolved.

The staff noted a change to Table 3A.5-2 from Revision 3 to Revision 4 of DCD Appendix 3A. The change was described as "Replaced soil spring and damping coefficients due to the CB design change (making entire CB Seismic Category I)." The staff compared the Revision 3 table to the Revision 4 table and identified significant changes only for the X-X Rotation and Y-Y Rotation damping coefficients.

The staff also noted a change in Tables 3A.7-8 through 3A.7-14 from Revision 3 to Revision 4 of Appendix 3A. The change was described as "Replaced Eigenvalue analysis results to reflect the CB re-analysis (making entire CB Seismic Category I)." The staff compared the Revision 3 tables to the Revision 4 tables and identified significant changes in the natural frequencies. In RAI 3.7-64, the staff requested that the applicant provide the following:

(1) a detailed description of the "CB design change"

(2) a detailed description of the "CB re-analysis"

(3) an explanation of how the design change affects the X-X Rot and Y-Y Rot damping coefficients

(4) an explanation of why only these two parameters are affected

(5) an explanation of the significant changes in the natural frequencies obtained in the CB reanalysis

In its response, the applicant stated the following:

1. The design changes of the CB structure resulting from the CB being reclassified as entirely seismic Category I consist of the increase of the outer wall thickness above grade (EL 4650 to EL 13800), the increase of the slab thickness at roof (EL 13800), the decrease of the slab thickness (EL 4650) and the change of the room layout above grade. The applicant referred to DCD, Tier 2, Figure 3G.2-3 for details.

   The CB was reclassified as entirely seismic Category I since the CB penthouse now houses the Emergency Filter Unit (EFU). The EFU was added to the CB penthouse when the Emergency Breathing Air System (EBAS) was deleted from the ESBWR. The applicant referred to RAI 3.8-65 S01.

2. These design changes were incorporated into the seismic model and seismic analyses were repeated using the same methods of analysis as DCD, Tier 2, Revision 3.

3. As shown in DCD, Tier 2, Figure 3A.5-1, the frequency-independent damping coefficient (C) is calculated as the slope of the imaginary part of the frequency-dependent soil spring at the fundamental circular frequency ($\omega 1$). The value of C changes due to the change of $\omega 1$ even though the frequency-dependent soil spring is not changed.

4. The first attached figure (to the RAI response) shows the imaginary part of the frequency-dependent soil spring for the horizontal direction (X-dir) calculated for the soil profile of the medium site. The imaginary part for the horizontal direction is essentially linear. So, the frequency-independent damping coefficient (C), which is the slope, is not affected by the change of the fundamental circular frequency ($\omega 1$).

   The second attached figure (to the RAI response) shows the imaginary part of the frequency-dependent soil spring for the rotational direction (Y-Y Rot) calculated for the same soil profile. The imaginary part for rotational direction shows a parabolic tendency. The frequency-independent damping coefficient (C) becomes lower as the fundamental circular frequency decreases.

   This is the reason why only the frequency-independent damping coefficient (C) for the rotational directions (X-X Rot and Y-Y Rot) are affected by a change of the fundamental circular frequency ($\omega 1$) due to the design change.

5. The changes in the 1st and 2nd natural frequencies are due to the increase of the total building mass. The changes in the other natural frequencies are due to the structural changes described in Item 2 above.

The staff determined that the applicant provided sufficient technical information to address all five parts of RAI 3.7-64. The responses are considered acceptable to answer the questions posed, and no revision of the DCD was necessary in response to this RAI. On this basis, RAI 3.7-64 was resolved.

The applicant has stated in the DCD, through Revision 5, and in prior RAI responses that ignoring embedment effects is conservative. Conceptually, the staff concurred with this. Therefore, the results reported in the response to RAI 3.8-94 (in-structure response spectra generated at the top of the CB using the new SASSI analysis results for uniform sites with embedment significantly exceed the DAC3N analysis results for uniform sites without embedment) are of concern to the staff. The staff reviewed the new response spectra comparisons included in the response to RAI 3.8-94 and noted that the significant exceedances are in the two horizontal directions, at about 15 Hz, for the hard uniform site.

In RAI 3.7-72, the staff asked the applicant to provide separate one-to-one comparisons between DAC3N results and SASSI results for (1) each of the three uniform site cases (soft, medium, hard), (2) for each direction (X, Y, and Z), and (3) for the CB top and the CB basemat. This would provide a total of 18 comparisons to better characterize these results and facilitate an understanding of this behavior. The staff also requested that the applicant evaluate whether each “with embedment” exceedance can be explained on physical grounds, or if it is potentially an indication of a modeling or numerical error.

In response to RAI 3.7-72, the applicant stated that Figures 3.7-72(1) through 3.7-72(18) in the RAI response show separate one-to-one comparisons of FRS between DAC3N results and SASSI results for (1) each of the three uniform site cases (soft, medium, hard), (2) for each direction (X, Y, and Z), and (3) for the CB top and the CB basemat.

The DAC3N FRS at the CB basemat envelop the SASSI FRS because of the embedment effect. At the CB top for the hard site case, the spectral peak frequencies of the SASSI FRS in the horizontal directions (X, Y) shift from a peak frequency of approximately 8.5 Hz for the DAC3N results to a peak frequency of approximately 17 Hz for the SASSI results. At the CB top for the hard site case, the spectral peak frequency of the SASSI FRS in the vertical direction (Z) shifts from a peak frequency of approximately 21 Hz for the DAC3N results to a peak frequency of approximately 28 Hz for the SASSI results. This frequency shift is attributed to the constraining effect of the surrounding soil.

The applicant stated that the embedment effect on the CB response is pronounced because a large portion (62 percent) of the building is embedded. Thus, the entire SSI system is much more rigid when embedment is considered. The “with embedment” exceedance is attributed to local amplification of the superstructure above grade. Figure 3.7-72(19) in the RAI response shows the comparison of the FRS in the X-direction of all five floors of the CB obtained by SASSI for the hard site case. Figure 3.7-72(20) in the RAI response shows the corresponding DAC3N results. Figures 3.7-72(21) and 3.7-72(22) in the RAI response show similar comparisons in the Y-direction. The SASSI results exhibit larger variations in response amplification between floors than the DAC3N results at locations above grade (elevation 4.50).

The applicant also stated that, to further confirm that the SASSI responses above grade are caused by local amplification, the two above-grade floors are modeled as a two-mass system with a fixed base at grade level. The primary natural frequency of this system is calculated to be 21 Hz for the X-direction and 18 Hz for the Y-direction. Since the embedded portion is not perfectly rigid, the fixed-base frequencies of the two-mass superstructure system can be considered to be in good agreement with the 17-Hz peak frequency of the SASSI response spectra at floors above grade for the hard site case. Thus, it is confirmed that this “with embedment” exceedance is caused by local modes of the superstructure above grade resulting from the constraint effect of the surrounding hard soil below grade and is not caused by modeling or numerical error.

The staff reviewed the information provided in the applicant’s response to RAI 3.7-72 and concluded that it adequately addressed the staff’s questions. The applicant explained that the fundamental horizontal and vertical frequencies of the CB increase when embedment is considered in the SASSI analyses, because over one-half of the height of the building is below grade. The DAC3N analyses assume a surface-mounted structure. This shift in fundamental frequency resulted in a new peak in the horizontal FRS at the top of the CB, at 17 Hz. A moderate shift occurs in the vertical FRS, for the same reason. The staff concluded that the applicant adequately described the technical basis for the change in response when embedment is considered, as requested in RAI 3.7-72.

The applicant’s response to RAI 3.8-94 S04 identifies applicable changes to DCD Appendix 3A. The applicant formally submitted the proposed changes to DCD Appendix 3A in DCD Revision 6. On this basis, RAI 3.7-72 was resolved.

3.7.2.3.5 Development of Floor Response Spectra

In DCD Section 3.7.2.5, the applicant stated that FRS are developed from the primary structural dynamic analysis using the time-history method. The applicant also stated that direct spectra generation, without resorting to time history, is an acceptable alternative method.

The application of the direct spectra generation method requires a detailed staff review of the technical basis and sample calculations to demonstrate that the results are equivalent to using time-history analysis. In RAI 3.7-40, the staff asked the applicant to (1) identify the specific applications of the direct spectra generation method in the ESBWR design/analysis, (2) describe the methodology used to confirm equivalency to the time-history analysis method, and (3) submit the numerical results of the comparative analyses.

In its response, the applicant stated that the direct spectra generation methodology is not applied to the ESBWR primary structure models to generate in-structure FRS. However, for ESBWR application, the methodology will be applied to generate in-equipment required response spectra in subsystems such as piping systems, equipment control panels, and local racks.

The applicant-developed direct spectra generation method is an ISM response spectrum method for generation of in-structure response spectra. It is based on stochastic calculus and statistical theory. The applicant stated that the response spectra spectral accelerations are directly calculated based on the subsystem eigendata set (obtained from the subsystem eigenanalysis) and the components of the ISM response spectra, which excite the subsystem. The applicant provided numerical results, including response spectrum plots, of the comparative analyses considered in the verification of the ERSIN computer code as part of its response. In RAI 3.7-56, the staff requested the validation package for the ERSIN computer code. The staff included the resolution of RAI 3.7-56 with that of RAI 3.7-40.

During the June 5–8, 2006, audit, the staff reviewed the validation documentation for ERSIN and found the results to be conservative when compared to response spectra generated by time-history analysis. The applicant agreed to identify any previously documented staff acceptance of its use and also to identify in DCD Section 3.10, “Seismic and Dynamic Qualification of Seismic Category I Mechanical and Electrical Equipment,” that its use is for development of equipment required response spectra. After discussion with the NRC staff personnel responsible for the DCD Section 3.10 review, the staff determined that further review of the ERSIN computer code, as it applies to DCD Section 3.10, is outside the scope of the DCD Section 3.7 review. The staff considered the applicant’s response to be acceptable, as it relates to the scope of the DCD Section 3.7 review. On this basis, both RAI 3.7-40 and RAI 3.7-56 were resolved.

In DCD Section 3.7.2.5, the applicant stated that the seismic FRS for various damping values are generated in three orthogonal directions (two horizontal and one vertical) at various elevations and locations of interest to the design of equipment and piping, using three possible approaches:

(1) When the dynamic analyses are performed separately for each of the three components of the input motion, the resulting codirectional response spectra are combined according to the SRSS method to obtain the combined spectrum in that direction.

(2) An alternative approach to obtain codirectional FRS is to perform dynamic analysis with simultaneous input of the three excitation components, if those components are statistically independent of each other.

(3) When the three components are mutually statistically independent, response analysis can be performed individually and the resulting acceleration response time histories in the same direction are added algebraically for FRS generation.

The staff found these methods acceptable, on the basis that they are consistent with SRP Section 3.7.2.5 acceptance criteria.

The applicant further stated that the spectrum ordinates are computed at frequency intervals suggested in Table 3.7.1-1 of SRP Section 3.7.1, plus additional frequencies corresponding to the natural frequencies of the supporting structures, and also identified two additional methods that it considers acceptable: (1) choose a set of frequencies such that each frequency is within 10 percent of the previous one and add the natural frequencies of the supporting structures to the set, and (2) choose a set of frequencies such that each frequency is within 5 percent of the previous one.

The staff found the methods for selecting frequency intervals to be acceptable, on the basis that they are consistent with SRP Section 3.7.2.5 acceptance criteria.

3.7.2.3.6 Three Components of Earthquake Motion

In DCD Section 3.7.2.6, the applicant presented methods for combining the three directional components of earthquake motion. When the response spectrum method or static coefficient method of analysis is used, the maximum responses caused by each of the three components are combined by taking the SRSS of the maximum codirectional responses caused by each of the three earthquake components at a particular point of the structure or of the mathematical model. The staff finds this consistent with SRP Section 3.7.2.6 acceptance criteria.

The applicant also identified the 100-40-40 method of combination, as described in ASCE 4-98, as an alternative to the SRSS method. The staff accepts the 100-40-40 method of combination, as described in and subject to the limitations specified in RG 1.92, Revision 2. In RAI 3.7-41, the staff asked the applicant to confirm adherence to the staff position on use of the 100-40-40 method of combination.

In its initial response, the applicant stated that, as indicated in DCD Section 3A.5, the three component ground motion time histories are statistically independent and are input simultaneously in the response analysis using the time-history method of analysis solved by direct integration. Therefore, the 100-40-40 method of combination is not used in the building response analysis. However, the applicant planned to add a statement to the third paragraph of DCD Section 3.7.2.6, indicating that the use of the 100-40-40 method of combination shall be consistent with the requirements of RG 1.92, Revision 2. The applicant also stated that the 100-40-40 method of combination was used in the structural design of buildings, as described in DCD Sections 3.8.1.3.6, 3.8.4.3.1.2, and 3.8.4.3.1.3, and that the 100-40-40 method of combination used is consistent with the requirements of RG 1.92, Revision 2. This was acceptable to the staff.

However, during the staff’s review of DCD Section 3.8, it became apparent that the applicant had not implemented the 100-40-40 method in accordance with RG 1.92, Revision 2, Regulatory Position 2.1, Equation 13. The staff identified RAI 3.7-41 as an open item in the SER with open items. To resolve this issue, the applicant elected to implement SRSS in accordance with RG 1.92, Revision 2, instead of the 100-40-40 method, for the combination of the three components of earthquake motion. On this basis, RAI 3.7-41 and the associated open item were resolved.

In DCD Section 3.7.2.6, the applicant also stated that when the time-history method of analysis is used and separate analyses are performed for each earthquake component, the total combined response for all three components is obtained using the SRSS method to combine the maximum codirectional responses from each earthquake component. Alternatively, the total response may be obtained, if the three component motions are mutually statistically independent, by algebraically adding the codirectional responses calculated separately for each component at each time step. When the time-history analysis is performed by applying the three component motions simultaneously, the combined response is obtained directly by solution of the equations of motion. This method of combination is applicable only if the three component motions are mutually statistically independent. The staff found this acceptable because it is consistent with SRP Section 3.7.2.6 acceptance criteria.

Although the applicant described the methods for combining seismic responses resulting from the three orthogonal components of the input ground motion, the staff could not discern the scope of implementation for the methods described. In RAI 3.7-42, the staff requested that the applicant specifically identify in the DCD which spatial combination method delineated in DCD Section 3.7.2.6 was used for seismic analysis of the building structures. In its response, the applicant referred to its response to RAI 3.7-41. The staff found that the applicant’s response to RAI 3.7-41 adequately addressed the question. For seismic analysis, the three spatial directions of seismic motion are applied simultaneously; therefore, a special combination rule (e.g., SRSS, 100-40-40) is not needed. The staff found this acceptable. In Revision 2 of DCD Section 3.7.2.6, the applicant made the requested changes. On this basis, RAI 3.7-42 was resolved.

3.7.2.3.7 Combination of Modal Responses

In DCD Section 3.7.2.7, the applicant addressed the applicable methods for the combination of modal responses when the response spectrum method is used. If the modes are not closely spaced (two consecutive modes are defined as closely spaced if their frequencies differ from each other by 10 percent or less of the lower frequency), the total response is obtained by combining the peak modal responses by the SRSS method. If some or all of the modes are closely spaced, any one of the three methods (grouping method, 10-percent method, and double sum method) presented in RG 1.92, Revision 1, is applicable for the combination of modal responses. The applicant indicated that for modal combination involving high-frequency modes, the procedure of SRP Section 3.7.2, Appendix A (1989 version), applies. While both RG 1.92 and SRP Section 3.7.2 have been revised recently, the methods cited by the applicant are still acceptable to the staff.

The applicant also identified an alternative method for including high-frequency modes, in which (1) modal responses are computed for enough modes to ensure that the inclusion of additional modes does not increase the total response by more than 10 percent, (2) modes that have natural frequencies less than that at which the spectral acceleration approximately returns to the ZPA are combined in accordance with RG 1.92, (3) higher mode responses are combined algebraically (i.e., they retain sign) with each other, and (4) the absolute value of the combined higher modes is then added directly to the total response from the combined lower modes.

The staff noted that it no longer considers this alternative method acceptable, because more accurate accounting of the total contribution from high-frequency modes can be achieved by direct calculation using the missing mass approach. The staff stated its position on not accepting this alternative method in RAI 3.7-17. In RAI 3.7-43, the staff asked the applicant to identify whether the alternative method has been used, to describe all applications, and to provide a technical justification for each application. In its response, the applicant referred to the response to RAI 3.7-17, which indicates that the applicant would delete the alternative method from the DCD. Therefore, the staff found the response to be acceptable. In Revision 2 of DCD Section 3.7.2.7, the applicant made the appropriate changes. On this basis, RAI 3.7-43 was resolved.

The reviewers of DCD Section 3.7 noted that in DCD Revision 3, the applicant revised Section 3.7.2.7, paragraph 4, Step 1, in response to RAI 3.12-20, by adding the following: "The ZPA cutoff frequency is 100 Hz or f_{ZPA} as defined in Figures 1, 2 and 3 of RG 1.92. It is applicable to seismic and other building dynamic loads."

The DCD Section 3.7 reviewers considered the added sentences to be unclear. In RAI 3.7-61 (part 3), the staff asked the applicant to revise the wording.

In a teleconference between the staff and the applicant on August 10, 2007, the applicant agreed to the following revised wording:

> Step 1—Determine the modal responses only for those modes that have natural frequencies less than that at which the spectral acceleration approximately returns to the ZPA of the input response spectrum (f_{ZPA}). Examples of f_{ZPA} are shown in Figures 1, 2 and 3 of RG 1.92, Revision 2. Combine such modes in accordance with the methods described above.

> When applying these methods to building dynamic loads other than seismic, it is acceptable to use a ZPA cutoff frequency of 100 Hz if the spectral acceleration at 100 Hz has not returned to the ZPA of the response spectrum.

Because the applicant formally included this change in DCD Revision 5, RAI 3.7-61 (part 3) was resolved.

3.7.2.3.8 Interaction of Non-Category I Structures with Seismic Category I Structures

In DCD Section 3.7.2.8, the applicant stated that the interfaces between seismic Category I and non-seismic Category I SSCs are designed for the dynamic loads and displacements produced by both the Category I and non-Category I SSCs. The applicant stated that all non-Category I SSCs must meet any one of the following three requirements:

(1) The collapse of any non-Category I SSC does not cause the non-Category I SSC to strike a seismic Category I SSC.

(2) The collapse of any non-Category I SSC does not impair the integrity of seismic Category I SSCs. This may be demonstrated by showing that the impact loads on the Category I SSC resulting from collapse of an adjacent non-Category I structure, because of its size and mass, are either negligible or smaller than those considered in the design (e.g., loads associated with tornado, including missiles).

(3) The non-Category I SSCs are analyzed and designed to prevent their failure under SSE conditions in a manner such that the margin of safety of these SSCs is equivalent to that of seismic Category I SSCs.

The staff found that the criteria provided in DCD Section 3.7.2.8 are consistent with those of SRP Section 3.7.2.8 and therefore are acceptable.

In its review of DCD Revision 5, the staff noted that two changes to DCD Section 3.7.2.8, between Revision 4 and Revision 5, reference RAI 3.2-66. The changes relate to seismic classification and seismic analysis methods for the turbine and radwaste buildings. In RAI 3.7-67, the staff asked the applicant to identify the resolution status of the changes. In its response, the applicant stated the following:

> The changes in DCD, Tier 2, Revision 5, Subsection 3.7.2.8, as described by Items 7 and 8 of the DCD Revision 5 Change List, will be updated by the response to NRC RAI 3.2-66 S01 (Resolved—MFN 08-206 S01, dated December 12, 2008) and NRC RAIs 3.8-79 S03 and 3.8-80 S03 (Submitted—MFN 06-407 S12, dated February 3, 2009) to clarify the seismic design and classification of the Turbine Building (TB) and the Radwaste Building (RW).
>
> The TB will be re-classified as a seismic Category II structure by the response to NRC RAI 3.2-66 S01, and DCD, Tier 2, Subsection 3.7.2.8 will be revised in Revision 6 to reflect this change. The seismic analysis methodology and design acceptance criteria for the TB and RW will be included in DCD, Tier 2, Revision 6, Subsections 3.7.2.8.1 and 3.7.2.8.2 respectively by the response to NRC RAIs 3.8-79 S03 and 3.8-80 S03.

The staff confirmed that RAIs 3.2-66, 3.8-79, and 3.8-80 were resolved based on changes incorporated in DCD Revision 6. Therefore, RAI 3.7-67 was resolved.

3.7.2.3.9 Effects of Parameter Variations on Floor Response Spectra

In DCD Section 3.7.2.9, the applicant stated that FRS calculated according to the procedures described in Section 3.7.2.5 are peak broadened to account for uncertainties in the structural frequencies resulting from uncertainties in the material properties of the structure and soil and from approximations in the modeling techniques used in the analysis. If no parametric variation studies are performed, the spectral peaks associated with each of the structural frequencies are broadened by ±15 percent. If a detailed parametric variation study is made, the minimum peak-broadening ratio is ±10 percent. In lieu of peak broadening, the peak-shifting method of the ASME Code, Section III, Appendix N, as permitted by RG 1.84, "Design, Fabrication, and Materials Code Case Acceptability, ASME Section III," can be used. The staff found the methods identified by the applicant to be consistent with SRP Section 3.7.2.9 acceptance criteria.

To complete its review, in RAI 3.7-44, the staff requested that the applicant (1) specifically identify in the DCD which methods described in DCD Section 3.7.2.9 were actually used in the development of the design-basis in-structure response spectra to account for parameter variations, and (2) describe the specific applications of each of the three methods. In its response, the applicant stated that, as specified in Appendix 3A.9.2, the envelope spectra are peak broadened by ±15 percent and that it will revise DCD Section 3.7.2.9. The staff noted that RG 1.122 accepts the ±15-percent technique for broadening FRS peaks. In Revision 2 of DCD Section 3.7, the applicant made the identified DCD change. On this basis, RAI 3.7-44 was resolved.

However, during the June 5–8, 2006, audit, the staff noted that the applicant had used the ASCE 4-98 incoherence reduction factor to reduce the spectral peaks of the raw FRS calculated from the time-history analysis before the application of peak broadening. The staff was reviewing the use of the ASCE 4-98 incoherence reduction factor and had not found it acceptable at that time. Therefore, in RAI 3.7-58, the staff requested that the applicant submit an ESBWR-specific technical basis for using the incoherence reduction factors. In its response, the applicant stated that it would delete the third bullet ("The reduction factors due to wave incoherence according to ASCE 4-98 are applied to the site-envelope response spectra") in DCD Section 3A.9.2 and revise DCD Figures 3A.9-1a through 3A.9-3g accordingly in the next DCD update. The staff found the applicant's response to be acceptable, because the reduction factor in question is no longer used. In Revision 2 of DCD Appendix 3A, the applicant made the identified DCD changes. On this basis, RAI 3.7-58 was resolved.

The reviewers of DCD Section 3.7 noted that in DCD Revision 3, the applicant had revised Section 3.7.2.9, paragraph 1, in response to RAI 3.12-6, by adding the following:

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

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

The reviewers of DCD Section 3.7 determined that the alternate approach to addressing parameter variation, when using the time-history method for analysis of building-attached piping and equipment, is appropriate but needed additional description. In RAI 3.7-61 (part 4), the staff asked the applicant to augment the description for clarity.

In a teleconference between the staff and the applicant on August 10, 2007, the applicant agreed to the following revised wording:

> Floor response spectra calculated according to the procedures described in Subsection 3.7.2.5 are peak broadened by ±15% to account for uncertainties in the structural frequencies owing to uncertainties in the material properties of the structure and soil and to approximations in the modeling techniques used in the analysis.
>
> When, in lieu of response spectrum analysis, the calculated floor acceleration time history is used to perform a time-history analysis of piping and equipment, uncertainties are accounted for by expanding and shrinking the floor acceleration time history within 1/(1±0.15) so as to change the frequency content of the time history by ±15%. In this case, multiple time-history analyses are performed. Alternatively, a single synthetic time history, which matches the broadened FRS, may be used.
>
> The methods described above to account for the effect of parameter variation are applicable to seismic and other building dynamic loads.

On the basis that the applicant formally included this change in DCD Revision 5, RAI 3.7-61 (part 4) was resolved.

3.7.2.3.10 Use of Equivalent Vertical Static Factors

In DCD Section 3.7.2.10, the applicant stated that equivalent vertical static factors are used when the requirements for the static coefficient method in DCD Section 3.7.2.1.3 are satisfied. The applicant further stated that all seismic Category I structures are dynamically analyzed in the vertical direction, and no constant static factors are used. The staff's review of DCD Section 3.7.2.1.3 appears in Section 3.7.2.3.1.3 of this report.

3.7.2.3.11 Method Used To Account for Torsional Effects

In DCD Section 3.7.2.11, the applicant described methods of treating the torsional effects in the dynamic analysis of building structures. The staff found that the methods identified by the applicant are consistent with SRP Section 3.7.2.11 acceptance criteria and therefore are acceptable.

To complete its review, in RAI 3.7-45, the staff requested that the applicant (1) specifically identify in the DCD which of the methods described in DCD Section 3.7.2.11 were actually used to account for torsional effects in the design-basis analyses of the building structures and (2) describe the specific applications of each method. In its response, the applicant stated that, as described in DCD Appendix 3A.7.2, a dynamic analysis that incorporates the torsional DOFs was carried out to treat the torsional effects. The applicant indicated that it would revise DCD Section 3.7.2.11 to include this clarification. The staff found the applicant's response to be acceptable. In Revision 2 of DCD Section 3.7.2.11, the applicant made the identified change. On this basis, RAI 3.7-45 was resolved.

3.7.2.3.12 Comparison of Responses

In DCD Section 3.7.2.12, the applicant stated that only the time-history method is used for the dynamic analysis of seismic Category I structures, and therefore, a comparison of responses with the response spectrum method is not necessary. The staff found this acceptable.

3.7.2.3.13 Analysis Procedure for Damping

In DCD Section 3.7.2.13, the applicant presented several approaches for modeling damping when an SSC consists of structural elements with different damping properties. The applicant stated that for use in mode superposition (time-history or response spectrum) analyses, the composite modal damping ratio can be obtained based on either stiffness-weighting or mass-weighting. The composite modal damping calculated by either method is limited to 20 percent. Additional approaches applicable to frequency domain analysis and direct integration time-history analysis are also presented. The staff found the description of composite modal damping in DCD Section 3.7.2.13 to be consistent with SRP Section 3.7.2.13 acceptance criteria, with one exception.

In its review of DCD Section 3.7.2.13, the staff found that the applicant did not address the limitation that is imposed on the use of composite modal damping in SRP Section 3.7.2(II)(13), which states that for models that take SSI into account by the lumped soil-spring approach, only stiffness-weighted damping is acceptable. In RAI 3.7-46, the staff asked the applicant to describe how this limitation has been considered in the applications of composite modal damping and, if the limitation was not considered, to provide a detailed technical basis for the approach used. In its response, the applicant stated that, as described in the response to RAI 3.7-17, the SSI analyses for the RB/FB and CB were performed by the direct integration method in the time domain. DCD Section 3.7.2.13 explains the formation of the damping matrix for the analysis. The composite modal damping formulations shown in Equations 3.7-14 and 3.7-15 are not used since modal superposition was not employed. The applicant further stated that, as a general analysis procedure for damping, it would add to the DCD the following limitation described in SRP Section 3.7.2(II)(13): "For models that take SSI into account by the lumped soil-spring approach, the method defined by Equation 3.7-14 is acceptable. For fixed base model, either Equation 3.7-14 or 3.7-15 may be used." The staff found the applicant's response acceptable because it is consistent with applicable SRP acceptance criteria. In Revision 2 of DCD Section 3.7, the applicant made the identified change. On this basis, RAI 3.7-46 was resolved.

In RAI 3.7-47, the staff asked the applicant (1) to identify which of the methods described in DCD Section 3.7.2.13 were actually used in the design-basis seismic analyses of the building structures (RB/FB and CB) and (2) to describe the specific applications of each method. In its response, the applicant referred to the response to RAI 3.7-46 and committed to revising DCD Section 3.7.2.13 to identify specific applications. The staff found that the applicant's response to RAI 3.7-46 adequately addressed RAI 3.7-47. On this basis, RAI 3.7-47 was resolved.

3.7.2.3.14 Determination of Seismic Category I Structure Overturning Moments

In DCD Section 3.7.2.14, the applicant described the method used to evaluate the stability of structures against seismically induced overturning moments. According to this method, when the amplitude of the rocking motion becomes so large that the center of structural mass reaches a position right above either edge of the base, the structure becomes unstable and may tip over. In this analysis method, the kinetic energy imparted to the structure from the earthquake ground motion is calculated and compared to the potential energy needed to overturn the structure. The structure is defined as stable against overturning when the ratio of the potential energy needed for overturning and the kinetic energy of the structure during the SSE is no less than 1.1.

The staff determined that it needed additional details about the implementation of this energy-based method. In RAI 3.7-48, the staff requested that the applicant provide a more detailed description of the analysis method, including an explanation of how the energy components for the embedment (W_p) and buoyancy (W_b) are determined, and the technical justification for the two equations given for the velocity terms (V_h and V_v). In its response, the applicant stated that the analysis method to evaluate the stability of structures against seismically induced overturning moments is based on the energy method shown in the Bechtel Power Corporation report BC-TOP-4-A, Revision 3, “Seismic Analyses of Structures and Equipment for Nuclear Power Plants,” issued November 1974. The applicant provided selected sections of the referenced report as part of its response. The staff had previously accepted Revision 3 of BC-TOP-4 in 1974 (in a letter from R.W. Klecker, Atomic Energy Commission, to J.V. Morowski, Bechtel, dated October 31, 1974).

However, during the June 5–8, 2006, audit, the applicant identified two sign differences between its independently derived equation for the effects of buoyancy and Equation 4-17 of BC-TOP-4, Revision 3, for calculating the effects of buoyancy. The applicant presented numerical results to demonstrate that BC-TOP-4, Revision 3, Equation 4-17, contains an error. The staff asked the applicant to submit its results. Following the June 2006 audit, the staff conducted its own study of BC-TOP-4, Revision 3, Equation 4-17, and also concluded that there is an error in this equation.

During the June 5–8, 2006, audit, the staff asked the applicant to submit the technical basis for using the SRSS method to combine the contribution from peak values of ground velocity and relative velocity. It was not evident to the staff that these two values in a time history are sufficiently uncorrelated, which is necessary for use of the SRSS method. The applicant referred to the Bechtel topical report BC-TOP-4 as the source.

In a supplemental RAI response, the applicant provided the following:

- the corrected equation: $W_b = (zb-za)\,[B(zb\ ) - B(za\ )]/2 + B(za\ )(zb - za\ )$

- the technical basis for SRSS: The peak values of the horizontal ground velocity (Vh)g and the relative lateral velocity (Vx)i do not occur simultaneously. Similarly, the peak values of the vertical ground velocity (Vv)g and the relative vertical velocity (Vz)i do not occur simultaneously. Therefore, they are combined by the SRSS method as shown in DCD Tier 2, Equation 3.7-21.

During the October 31–November 2, 2006, staff audit, the staff informed the applicant that the basis for using SRSS combination is insufficient. The applicant agreed to submit a second supplemental response, identifying that the absolute summation would be used.

In a second supplemental RAI response, the applicant stated that it will use the absolute sum method instead of the SRSS method for combining the velocity terms V_h and V_v, that it would revise DCD Section 3.7.2.14 in the next update, and that it would also revise DCD Table 3G.1-57 to update the safety factors in the next update.

The staff found the applicant's second supplemental response to be acceptable, because the applicant will implement the more conservative absolute sum method instead of the SRSS method for combining the velocity terms V_h and V_v. The applicant formally submitted the identified revisions to DCD Section 3.7.2.14 and DCD Table 3G.1-57 in DCD Revision 3. Therefore, RAI 3.7-48 was resolved.

3.7.2.4 *Conclusions*

The staff finds that the applicant has adequately addressed seismic system analysis, in accordance with the acceptance criteria delineated in SRP Section 3.7.2. On this basis, the staff concludes that the regulatory criteria delineated in Section 3.7.2.1 of this report are satisfied.

3.7.3 Seismic Subsystem Analysis

3.7.3.1 *Regulatory Criteria*

The staff accepts the seismic design basis for subsystems that are important to safety and that must withstand the effects of earthquakes according to GDC 2 and Appendix S to 10 CFR Part 50:

- GDC 2, as it relates to the seismic design basis to reflect appropriate consideration of the most severe earthquakes reported to have affected the site and surrounding area with sufficient margin for the limited accuracy, quantity, and period of time in which historical data have been accumulated, and SSCs important to safety be designed to withstand the effects of natural phenomena such as earthquakes, without loss of capability to perform their intended safety functions.

- 10 CFR Part 50, Appendix S, as it relates to the SSE ground motion in the free-field at the foundation level of the structures to be an appropriate response spectrum with a peak grounf acceleration of at least 0.1g, and if the OBE is chosen to be less than or equal to one-third of the SSE ground motion, it is not necessary to conduct explicit response or design analyses in accordance with Section IV.(2)(i)(A) of 10 CFR Part 50, Appendix S.

The staff used SRP Section 3.7.3 guidance in the review of the seismic design basis established for the subsystems. The staff also used the guidance in the Commission approved staff recommendations in SECY-93-087 for evaluating the OBE induced fatigue analyses of piping systems.

3.7.3.2 *Summary of Technical Information*

In DCD Revision 6, Section 3.7.3, the applicant stated that this section applies to seismic Category I and seismic Category II subsystems (equipment and piping) that are qualified to satisfy the performance requirements according to their seismic Category I or Category II designation. Input motions for the qualification are usually in the form of FRS and displacements obtained from the primary system dynamic analysis. Input motions in terms of acceleration time histories are used when needed. While dynamic qualification can be performed by analysis, testing, or a combination of both, or by the use of experience data, the applicant stated that this section of the DCD addresses only the aspects related to analysis.

3.7.3.2.1 Seismic Analysis Methods

In DCD, Tier 2, Section 3.7.3.1, the applicant stated that the methods of analysis described in DCD Section 3.7.2.1 are equally applicable to equipment and piping systems. Among the various dynamic analysis methods, the response spectrum method is used most often. For multisupported systems analyzed by the response spectrum method, the input motions can be either the envelope spectrum with USM of all support points or ISM at each support. DCD Section 3.7.3.9 presents additional considerations associated with the ISM response spectrum method of analysis. The applicant also stated that for equipment analysis, the requirements of Step 1 of DCD Section 3.7.2.7 are used for ZPA cutoff frequency determination.

3.7.3.2.2 Determination of Number of Earthquake Cycles

In DCD, Tier 2, Section 3.7.3.2, the applicant stated that the SSE is the only design earthquake considered for the ESBWR standard plant. To account for the cyclic effects of the more frequent occurrences of lesser earthquakes and their aftershocks, the fatigue evaluation for ASME Code Class 1, 2, and 3 components and core support structures considers two SSE events with 10 peak stress cycles per event for a total of 20 full cycles of the peak SSE stress. This is equivalent to the cyclic load basis of one SSE and five OBE events, as currently recommended in SRP Section 3.7.3. Alternatively, a number of fractional vibratory cycles equivalent to 20 full SSE vibratory cycles is used (with an amplitude not less than one-third of the maximum SSE amplitude), when derived in accordance with Appendix D to IEEE-344.

The applicant further stated that for equipment seismic qualification performed in accordance with IEEE-344, as endorsed by RG 1.100, “Seismic Qualification of Electric and Mechanical Equipment for Nuclear Power Plants,” the equivalent seismic cyclic loads are five 0.5-SSE events, followed by one full SSE event. Alternatively, a number of fractional peak cycles equivalent to the maximum peak cycles for five 0.5-SSE events is used, in accordance with Appendix D to IEEE-344, when followed by one full SSE.

3.7.3.2.3 Procedures Used for Analytical Modeling

In DCD Section 3.7.3.3, the applicant stated that the mathematical modeling of equipment and piping is developed according to the finite element technique, following the basic modeling procedures described in DCD Section 3.7.2.3 for primary systems.

3.7.3.2.3.1 Piping Systems

In DCD Section 3.7.3.3.1, the applicant stated that mathematical models for seismic Category 1 piping systems are constructed to reflect the dynamic characteristics of the system. The continuous system is modeled as an assemblage of pipe elements (straight sections, elbows, and bends) supported by hangers and anchors and restrained by pipe guides, struts, and snubbers. The applicant identified the following rules:

Pipe and hydrodynamic fluid masses are lumped at the nodes and connected by zero-mass elastic elements, which reflect the physical properties of the corresponding piping segment.

The mass node points are selected to coincide with the locations of large masses, such as valves, pumps, and motors, and with locations of significant geometry change.

All concentrated weights on the piping systems, such as the valves, pumps, and motors, are modeled as lumped mass rigid systems if their fundamental frequencies are greater than the cutoff frequency in DCD Subsection 3.7.2.1.1.

On straight runs, mass points are located at spacing no greater than the span which would have a fundamental frequency equal to the cutoff frequency stipulated in DCD Subsection 3.7.2.1.1, when calculated as a simply supported beam with uniformly distributed mass.

The torsional effects of valve operators and other equipment with offset center of gravity with respect to the piping center line are included in the analytical model.

All pipe guides and snubbers are modeled so as to produce representative stiffness.

The equivalent linear stiffness of the snubbers is based on certified test results provided by the vendor.

Pipe supports are designed and qualified to satisfy stiffness values used in the piping analysis. For struts and snubbers, the stiffness to consider is the combined stiffness of strut, snubber, pipe clamp and piping support steel.

In general, the piping analysis considers pipe support component weights that are directly attached to a pipe such as a clamp, strut, snubber, and trapeze. Frame-type supports are designed to carry their own mass and will be subject to deflection requirements. A maximum deflection of 1.6 millimeters (mm) (1/16 in.) is used for normal operating conditions, and 3.2 mm (1/8 in.) is used for abnormal conditions. For other types of supports, it must be demonstrated either that the support is dynamically rigid, or that one-half of the support mass is less than 10 percent of the mass of the straight pipe segment of the span at the support location, to preclude amplification. Otherwise, the contribution of the support weight amplification is added into the piping analysis. Piping supports are evaluated to include the impact of self-weight excitation on support structure and anchorage in detail, along with piping analyzed loads where this effect may be significant.

The stiffness of the building steel/structure (i.e., beyond the ASME Section III, Subsection NF jurisdictional boundary) is not considered in pipe support overall stiffness. Response spectra input to the piping system include flexibility of the building structure. When attachment to a major building structure is not possible, any intermediate structures are included in the analysis of the pipe support.

3.7.3.2.3.2 Equipment

In DCD Section 3.7.3.3.2, the applicant stated that for dynamic analysis, equipment is represented by a lumped mass, which consists of discrete masses connected by zero-mass elements. The applicant presented its criteria for selecting the location and the number of lumped masses:

- The number of modes of a dynamic system is controlled by the number of masses used; therefore, the number of masses is chosen so that all significant modes are included. The number of masses or dynamic DOFs is considered adequate when additional DOFs do not result in more than a 10-percent increase in response. Alternatively, the number of dynamic DOFs is no less than twice the number of modes below the cutoff frequency of DCD Section 3.7.2.1.1.

- Mass is lumped at any point where a significant concentrated weight is located.

- Examples are the motor in the analysis of a pump stand and the impeller in the analysis of a pump shaft.

- If the equipment has a free-end overhang span with significant flexibility compared to the center span, a mass is lumped at the overhang span.

- When equipment is concentrated between two existing nodes located between two supports in a finite element model, a new node is created at that location. Alternatively, the equipment mass can be concentrated at the nearest node to either side which tends to shift the natural frequency to the higher amplification region of the input motion response spectrum. When the approximate location of the equipment mass is shifted toward the midspan between the supports, the natural frequency is lowered, and when the approximate location is shifted toward either support, the natural frequency is increased. Moving the natural frequencies of the equipment into the higher amplification region of the excitation thereby conservatively increases the equipment response levels.

Similarly, in the case of live loads (mobile) and variable support stiffness, the location of the load and the magnitude of the support stiffness are chosen to lower the system natural frequencies. Similar to the above discussion, this ensures conservative dynamic responses, because the lowered equipment frequencies tend to be shifted to the higher amplification range of the input motion spectra. If not, the model is adjusted to give more conservative responses.

3.7.3.2.3.3 Modeling of Special Engineered Pipe Supports

In DCD Section 3.7.3.3.3, the applicant stated that special engineered pipe supports are not used.

3.7.3.2.4 Basis for Selection of Frequencies

In DCD Section 3.7.3.4, the applicant indicated that equipment and components are designed and selected such that their fundamental frequencies are less than half or more than twice the dominant frequencies of the support structure, where practical, in order to avoid adverse resonance effects. The applicant further stated that equipment is analyzed and/or tested to demonstrate that it is adequately designed for the applicable loads, considering both its fundamental frequency and the forcing frequency of the applicable support structure.

3.7.3.2.5 Analysis Procedure for Damping

In DCD Section 3.7.3.5, the applicant stated that damping values for equipment and piping are shown in DCD Table 3.7-1 and are consistent with RG 1.61. For ASME Section III, Division 1, Class 1, 2, and 3, and ASME/ANSI B31.1 piping systems, alternative damping values specified in Figure 3.7-37 are used. For systems composed of subsystems with different damping properties, the analysis procedures described in DCD Section 3.7.2.13 are applicable.

3.7.3.2.6 Three Components of Earthquake Motion

In DCD Section 3.7.3.6, the applicant indicated that DCD Section 3.7.2.6 describes the applicable methods of spatial combination of responses from each of the three input motion components.

3.7.3.2.7 Combination of Modal Responses

In DCD Section 3.7.3.7, the applicant indicated that DCD Section 3.7.2.7 describes the applicable methods of modal response combination.

3.7.3.2.8 Interaction of Other Systems with Seismic Category I Systems

In DCD Section 3.7.3.8, the applicant stated that each non-Category I (i.e., Category II or non-seismic) system is designed to be isolated from any seismic Category I system by either a constraint or barrier or is remotely located from the seismic Category I system. If it is not feasible or practical to isolate the seismic Category I system, adjacent non-Category I systems are analyzed according to the same seismic criteria as applicable to the seismic Category I systems. For non-Category I systems attached to seismic Category I systems, the dynamic effects of the non-Category I systems are simulated in the modeling of the seismic Category I system. The attached non-Category I systems, up to the first anchor beyond the interface, are also designed in such a manner that during an earthquake of SSE intensity, they do not cause a failure of the seismic Category I system.

3.7.3.2.9 Multisupported Equipment and Components with Distinct Inputs

In DCD Section 3.7.3.9, the applicant stated that for multisupported systems (equipment and piping) analyzed by the response spectrum method for the determination of inertial responses, either of the following two input motions are acceptable:

(1) envelope response spectrum with USM applied at all support points for each orthogonal direction of excitation

(2) ISM response spectrum at each support for each orthogonal direction of excitation

The applicant stated that when the ISM response spectrum method of analysis (DCD Section 3.7.2.1.2) is used, a support group is defined by supports that have the same time-history input, typically all supports located on the same floor, or in a specific area of the same floor. The responses caused by motions of supports in two or more different groups are combined by the SRSS procedure.

To use the SRSS method for independent support response spectrum analysis, a 10-percent margin must be included in the design requirements for piping stress and piping support loads.

This margin is needed to address the uncertainties that may arise from the use of the SRSS method rather than the absolute sum method for the group combination method when performing an ISM analysis.

In addition to the inertial response discussed above, the effects of relative support displacements are considered. The maximum relative support displacements are obtained from the dynamic analysis of the building, or as a conservative approximation, by using the FRS. For the latter option, the maximum displacement of each support is predicted by Sd = Sa × g/ù^2, where Sa is the spectral acceleration in “g’s” at the high-frequency end of the spectrum curve (which, in turn, is equal to the maximum floor acceleration), g is the gravity constant, and ù is the fundamental frequency of the primary support structure in radians per second. The support displacements are imposed on the supported systems in a conservative manner (i.e., the most unfavorable combination), and static analysis is performed for each orthogonal direction.

The applicant stated that the resulting responses from relative support displacements are combined with the inertia effects by the SRSS method. The applicant further stated that because the OBE design is not required, the displacement-induced SSE stresses caused by seismic anchor motion are included in Service Level D load combinations.

The applicant also noted that the ISM time-history method of analysis is used for multisupported systems subjected to distinct support motions, in which case both inertial and relative displacement effects are already included.

3.7.3.2.10 Use of Equivalent Vertical Static Factors

In DCD Section 3.7.3.10, the applicant stated that equivalent vertical static factors are used when the requirements for the static coefficient method in DCD Section 3.7.2.1.3 are satisfied.

3.7.3.2.11 Torsional Effects of Eccentric Masses

In DCD Section 3.7.3.11, the applicant indicated that torsional effects of eccentric masses are included for subsystems similar to those for the piping systems discussed in DCD Section 3.7.3.3.1.

3.7.3.2.12 Effect of Differential Building Movements

In DCD Section 3.7.3.12, the applicant stated that in most cases, subsystems are anchored and restrained to floors and walls of buildings that may have differential movements during a seismic event. The movements may range from insignificant differential displacements between rigid walls of a common building at low elevations to relatively large displacements between separate buildings at a site with high seismic activity.

The applicant stated that differential endpoint or restraint deflections cause forces and moments to be induced into the system. The stress thus produced is a secondary stress. It is justifiable to place this stress, which results from restraint of free-end displacement of the system, in the secondary stress category because the stresses are self-limiting and, when the stresses exceed yield strength, minor distortions or deformations within the system satisfy the condition that caused the stress to occur.

The applicant further stated that when the piping analysis is performed using USM analysis, per SRP Section 3.9.2, the absolute sum method is used to combine the inertia results and the seismic anchor motion results for piping support design. When the piping analysis is performed by ISM, the piping stresses and pipe support loads are increased by 10 percent when using the SRSS group combination method. With the additional 10 percent added to the piping stresses and the pipe support loads, the inertia and the seismic anchor motion are combined by SRSS for piping stresses and pipe support loads.

3.7.3.2.13 Seismic Category I Buried Piping, Conduits, and Tunnels

In Revision 5 of DCD Section 3.7.3.13, the applicant provided the following expanded discussion of this topic in response to RAI 3.7-52:

> There are no seismic Category I utilities i.e. piping, conduits, or auxiliary system components that are directly buried underground.
>
> Fire Protection System yard piping with a seismic Category I classification is installed in covered reinforced concrete trenches near the ground surface with removable covers to facilitate maintenance and inspection access. There are seismic Category I conduits in four electrical duct banks from the CB to the RB. These electrical duct banks are installed in closed reinforced concrete trenches covered with backfill.
>
> There are no seismic Category I tunnels in the ESBWR design. The access tunnel, which includes walkways between and access to RB, CB, TB, and Electrical Building is classified seismic Category II. Since seismic Category II structures are designed to the same criteria as seismic Category I structures there is no impact to adjacent seismic Category I structures.
>
> The Radwaste Tunnel provides for pipes that transport radioactive waste to the Radwaste Building from RB and TB. The Radwaste Tunnel is classified non-seismic but the structural acceptance criteria are in accordance with RG 1.143—Safety Class RW-IIa.
>
> The following items are considered in the analysis and design in accordance with SRP Section 3.7.3 (Rev. 3, March 2007):
>
> - Two types of ground shaking-induced loadings are considered for design:
>   - Relative deformations imposed by seismic waves traveling through the surrounding soil or by differential deformations between the soil and anchor points.
>   - Lateral earthquake pressures and ground-water effects acting on structures.
> - When applicable, the effects caused by local soil settlements, soil arching, etc., are considered in the analysis.
> - Lateral earth pressures are determined in the same manner as for embedded walls below grade for seismic Category I structures. Effect of wave propagation is accounted in accordance with ASCE 4-98, Subsection 3.5.2 and Commentary.

- Longitudinal forces and strains are treated as secondary forces and strains (displacement-controlled).

- Longitudinal compressive strains are limited to 0.3 percent. The reinforcing steel added to the concrete addresses the effect of longitudinal tensile strains.

- Primary loadings are lateral earth pressures, hydrostatic pressures, dead loads, and live loads applied concurrently with seismic excitation. Resultant stresses due to wave propagation effects and those resulting from the dynamic anchor movement are combined by the SRSS method.

- Expansion joints are provided between the tunnel and the connecting building to provide seismic isolation.

- Expansion joints along the tunnel are located no more than 20 m (65.6 ft) apart.

3.7.3.2.14 Methods for Seismic Analysis of Seismic Category I Concrete Dams

In DCD Section 3.7.3.14, the applicant stated that the ESBWR design includes no seismic Category I concrete dams.

3.7.3.2.15 Methods for Seismic Analysis of Aboveground Tanks

In DCD Section 3.7.3.15, the applicant stated that the seismic analysis of Category I aboveground tanks considers the following items:

- At least two horizontal modes of combined fluid-tank vibration and at least one vertical mode of fluid vibration are included in the analysis. The horizontal response analysis includes at least one impulsive mode in which the response of the tank shell and roof is coupled together with the portion of the fluid contents that move in unison with the shell, and the fundamental sloshing (convective) mode.

- The fundamental natural horizontal impulsive mode of vibration of the fluid-tank system is estimated giving due consideration to the flexibility of the supporting medium and to any uplifting tendencies for the tank. The rigid tank assumption is not made unless it can be justified. The horizontal impulsive-mode spectral acceleration, Sa1, is then determined using this frequency and damping value for the impulsive mode. This is the same as that for the tank shell material in accordance with NUREG/CR-1161. Alternatively, the maximum spectral acceleration corresponding to the relevant damping is used.

- Damping values used to determine the spectral acceleration in the impulsive mode are based upon the system damping associated with the tank shell material as well as with the soil-structure interaction (SSI). The SSI system damping takes into account soil damping in the form of stiffness-weighted damping in accordance with Equation 3.7-14 or complex stiffness matrix in accordance with Equation 3.7-16.

- In determining the spectral acceleration in the horizontal convective mode, Sa2, the fluid damping ratio is 0.5 percent of critical damping unless a higher value can be substantiated by experimental results.

- The maximum overturning moment, Mo, at the base of the tank is obtained by the modal and spatial combination methods discussed in Subsections 3.7.2.7 and 3.7.2.6, respectively. The uplift tension resulting from Mo is resisted either by tying the tank to the foundation with anchor bolts, etc., or by mobilizing enough fluid weight on a thickened base skirt plate. The latter method of resisting Mo, when used, must be shown to be conservative.

- The seismically induced hydrodynamic pressures on the tank shell at any level are determined by the modal and spatial combination methods discussed in Subsections 3.7.2.7 and 3.7.2.6, respectively. The maximum hoop forces in the tank wall are evaluated with due regard for the contribution of the vertical component of ground shaking. If the effects of soil-structure interaction result in higher response then an appropriate SSI method of analysis is used. The hydrodynamic pressure at any level is added to the hydrostatic pressure at that level to determine the hoop tension in the tank shell.

- Either the tank top head is located at an elevation higher than the slosh height above the top of the fluid or else is designed for pressures resulting from fluid sloshing against this head.

- At the point of attachment, the tank shell is designed to withstand the seismic forces imposed by the attached piping. An appropriate analysis is performed to verify this design.

- The tank foundation is designed to accommodate the seismic forces imposed on it. These forces include the hydrodynamic fluid pressures imposed on the base of the tank as well as the tank shell longitudinal compressive and tensile forces resulting from Mo.

- In addition to the above, a consideration is given to prevent buckling of tank walls and roof, failure of connecting piping, and sliding of the tank.

The applicant further stated that DCD Appendix 3A describes the seismic SSI analysis of the fire water storage tanks.

3.7.3.2.16 Design of Small-Branch and Small-Bore Piping

In DCD Section 3.7.3.16, the applicant stated the following:

(1) Small branch lines are defined as those lines that can be decoupled from the analytical model used for the analysis of the main run piping to which the

branch lines attach. Branch lines can be decoupled when the ratio of run to branch pipe moment of inertia is 25 to 1, or greater. In addition to the moment of inertia criterion for acceptable decoupling, these small branch lines are designed with no concentrated masses (e.g., valves) in the first one-half span length from the main run pipe; and with sufficient flexibility to prevent restraint of movement of the main run pipe. Due to branch decoupling, the thermal displacements at the run pipe are combined with associated pressures and temperatures for the flexibility analyses of the branch pipe. All the stresses must meet the ASME Code requirements. The branch pipe analysis results insure adequate flexibility and proper design of all the restraints on the branch pipe.

(2) For small bore piping defined as piping 50 mm (2 in.) and less nominal pipe size, and small branch lines 50 mm (2 in.) and less nominal pipe size, as defined in (1) above, it is acceptable to use small bore piping handbooks in lieu of performing a system flexibility analysis, using static and dynamic mathematical models, to obtain loads on the piping elements and using these loads to calculate stresses per equations in NB, NC, and ND3600 in ASME Code Section III and ASME B31.1 Code, whenever the following are met:

   a. When the small bore piping handbook is serving the purpose of the Design Report it meets all of the ASME requirements for a piping design report. This includes the piping and its supports.

   b. Formal documentation exists showing piping designed and installed to the small bore piping handbook (1) is conservative in comparison to results from a detail stress analysis for all applied loads and load combinations using static and dynamic analysis methods defined in Subsection 3.7.3, (2) does not result in piping that is less reliable because of loss of flexibility or because of excessive number of supports, (3) satisfies required clearances around sensitive components.

The small bore piping handbook methodology is not applied when specific information is needed on (a) magnitude of pipe and fittings stresses, (b) pipe and fitting cumulative usage factors, (c) accelerations of pipe-mounted equipment, or locations of postulated breaks and leaks. The small bore piping handbook methodology is not applied to piping systems that are fully engineered and installed in accordance with the engineering drawings.

3.7.3.2.17 Interaction of Other Piping with Seismic Category I Piping

In DCD Section 3.7.3.17, the applicant stated that in certain instances, seismic Category II piping is connected to seismic Category I piping at locations other than a piece of equipment which, for purposes of analysis, could be represented as an anchor. The transition points typically occur at seismic Category I valves, which may or may not be physically anchored. The applicant identified two options:

1. Specify and design a structural anchor at the seismic Category I valve and analyze the seismic Category I subsystem.

2. Analyze the subsystem from the anchor point in the seismic Category I subsystem through the valve to either the first anchor point in the seismic Category II subsystem; or for a distance such that there are at least two seismic restraints in each of the three orthogonal directions.

The interface anchor between the seismic and non-seismic category piping is designed for the maximum load, using piping reactions from both sides. The applicant further stated that where small seismic Category II piping is directly attached to seismic Category I piping, it can be decoupled from the seismic Category I piping.

The applicant added the following considerations for dynamic and seismic anchor motion analyses:

(1) Decouple criteria is 25 to 1 in the ratio of "moment of inertia" of run pipe to branch pipe.

(2) Amplified response spectra from the seismic and dynamic analyses used in the large bore piping analysis (run pipe) are applied to the small branch piping interfaces. The seismic and dynamic displacements at the connection point use the run pipe displacements.

(3) Formal analysis methods and procedures similar to the main pipe should be used, or more conservative handbook analysis may also be used.

(4) Branch pipe decoupling using response spectrum analysis can use one of the following options.

a. Place the branch line close (4 pipe diameter, for example) to large bore pipe supports.

b. Demonstrate that the applicable pipe segment is "dynamically rigid."

c. Overlapping analysis. (1) Include the small bore pipe up to two supports in all three directions to the large bore pipe, (2) analyze the small bore pipe again.

d. The dynamic analysis obtains the accelerations at the supports on both sides of the run pipe side (Aa), and side (Ab), and at the small branch at (Ac). Envelope the adjusted amplified response spectra (ARS) from both sides of the run pipe supports, (Ac/Aa) and (Ac/Ab), in all three directions and apply to the branch pipe analysis.

e. From large bore piping analysis, obtains the ARS at the branch location to apply to the branch pipe analysis. (A referenced program is ERSIN01 user's manual.)

The applicant further stated that the decouple criterion is 25 to 1 in the ratio of "moment of inertia" of run pipe to branch pipe. If this criterion cannot be met and decoupling is needed, then the decouple method as outlined in NUREG/CR-1980, "Dynamic Analysis of Piping, Using the Structural Overlap Method," issued March 1981, is used. The specific criteria from

NUREG/CR-1980 are applied. In general, based on the current capability of modeling software, the entire system is incorporated into one model instead of using the overlap method, as described below:

(1) The overlap region has enough rigid restraints and includes enough bends in three directions to prevent the transmission of motion due to modal excitation from one end to the other and to reduce to a negligible level the sensitivity of the structure to the direction of excitation. Specifically, there are at least four rigid restraints in each of three mutually perpendicular directions in the overlap region (including the ends). For axial restraints only, this requirement may be relaxed to a single restraint in any straight segment.

(2) For cases where multiple spectra are involved at the different anchor points, the spectrum to be used for each subsystem analysis depends on the rigidity of the overlap region. If the fundamental natural frequency of the overlap is demonstrated to be at least 25 percent higher than the highest significant forcing frequency, then the envelope spectrum of the spectra associated with the boundaries of each separate subsystem is acceptable. If this rigidity of the overlap region is not demonstrated or its frequency characteristics do not meet the criterion stated above, the full system anchor-to-anchor envelope spectrum is used for all subsystems.

(3) The envelope of the support forces is increased by 10 percent for design purposes.

3.7.3.3 *Staff Evaluation Related to Seismic Subsystem Analysis*

At the beginning of DCD Revision 5, Section 3.7.3, the applicant stated that, while dynamic qualification can be performed by analysis, testing, or a combination of both, or by the use of experience data, this DCD section addresses only the aspects related to analysis.

3.7.3.3.1 Seismic Analysis Methods

In DCD Section 3.7.3.1, the applicant stated that the methods of analysis described in DCD Section 3.7.2.1 are equally applicable to equipment and piping systems and that the response spectrum method is used most often. DCD Section 3.7.3.9 describes the special considerations associated with the ISM response spectrum method of analysis.

Section 3.7.2.3.1 of this report presents the staff's review of the analysis methods described in DCD Section 3.7.2.1. Section 3.7.3.3.9 of this report contains information on the staff's review of DCD Section 3.7.3.9.

3.7.3.3.2 Determination of Number of Earthquake Cycles

In DCD Section 3.7.3.2, the applicant stated that the SSE is the only design earthquake considered for the ESBWR standard plant. To account for the cyclic effects of the more frequent occurrences of lesser earthquakes and their aftershocks, the fatigue evaluation for ASME Code Class 1, 2, and 3 components and core support structures considers two SSE events with 10 peak stress cycles per event for a total of 20 full cycles of the peak SSE stress. This is equivalent to the cyclic load basis of one SSE and five OBE events as currently recommended in SRP Section 3.9.2. Alternatively, the number of fractional vibratory cycles equivalent to 20 full SSE vibratory cycles may be used (with an amplitude not less than one-third of the maximum SSE amplitude), when derived in accordance with Appendix D to IEEE-344.

The applicant further stated that for equipment seismic qualification performed in accordance with IEEE-344, as endorsed by RG 1.100, the equivalent seismic cyclic loads are five 0.5-SSE events, followed by one full SSE event. Alternatively, the number of fractional peak cycles equivalent to the maximum peak cycles for five 0.5-SSE events may be used, in accordance with Appendix D to IEEE-344, when followed by one full SSE.

The staff finds the applicant's approach to equipment seismic qualification to be acceptable, on the basis that it is consistent with methods accepted by RG 1.100 and SRP Section 3.7.3. Specifically for piping analysis, Section 3.12.6.15 of this report contains the staff's review of DCD Section 3.7.3.2.

3.7.3.3.3 Procedures Used for Analytical Modeling

In DCD Section 3.7.3.3, the applicant stated that the mathematical modeling of equipment and piping is generally developed according to the finite element technique, following the basic modeling procedures described in DCD Section 3.7.2.3 for primary systems.

Section 3.7.2.3.3 of this report contains the staff's review of DCD Section 3.7.2.3.

3.7.3.3.3.1 Piping Systems

In DCD Section 3.7.3.3.1, the applicant stated that mathematical models for seismic Category 1 piping systems are constructed to reflect the dynamic characteristics of the system. The continuous system is modeled as an assemblage of pipe elements (straight sections, elbows, and bends) supported by hangers and anchors, and restrained by pipe guides, struts, and snubbers.

Sections 3.12.5.2 and 3.12.7.7 of this report present the staff's review of DCD Section 3.7.3.3.1.

3.7.3.3.3.2 Equipment

In DCD Section 3.7.3.3.2, the applicant stated that for dynamic analysis, equipment is represented by a lumped mass, which consists of discrete masses connected by zero-mass elements. The applicant presented its criteria for selecting the location and the number of lumped masses.

In its initial review of DCD Revision 1, the staff identified several areas where it needed additional information. In RAI 3.7-51, the staff requested that the applicant address the following:

(a) The alternate criterion in DCD Section 3.7.3.3.2 for ensuring a sufficient number of mass degrees of freedom relies on determination of the "cutoff frequency" for the analysis; DCD Section 3.7.2.1.1 is referenced. The staff's review of DCD Section 3.7.2.1.1 noted that only the missing mass method is considered acceptable for capturing the high frequency response contribution (above fzpa). Consequently, there is no acceptable basis in DCD Section 3.7.2.1.1 for determining the "cutoff frequency." The staff requests the applicant to define "cutoff frequency", as it relates to ensuring a sufficient number of mass degrees of freedom, and explain in detail how it is determined for structures, systems, and components.

(b) The staff requests the applicant to clarify its criterion in DCD Section 3.7.3.3.2 related to location of lumped masses, in order to ensure conservative dynamic loads. It appears that the goal would be to drive the natural frequency of the equipment mathematical model toward the peak of the response spectrum. However, the criterion appears to be aimed at lowering the natural frequency.

In its response, the applicant stated the following:

(a) The cutoff frequency for the modal superposition analysis of subsystems for seismic and non-seismic building dynamic loads is 100 Hz or the rigid frequency defined as f_2 in DG-1127. All modes with frequencies up to the cutoff frequency are included in the modal superposition and the residual rigid response due to the missing mass associated with the truncated higher frequency modes is accounted for in accordance with the methods described in DCD Subsection 3.7.2.7. For further clarity, DCD Subsection 3.7.2.1.1, 5th paragraph, last sentence "Alternatively, the cutoff frequency may be selected to ensure that the number of modes included is sufficient such that inclusion of all truncated modes does not result in more than a 10 percent increase in total response" will be deleted.

(b) The fourth bullet in DCD Section 3.7.3.3.2 will be revised to read as follows:

"When an equipment mass is concentrated between two supports, the concentrated mass is located at a point between the two supports where the maximum displacement of the concentrated mass will occur. This will tend to lower the natural frequencies of the equipment system model. Because the equipment fundamental frequency is typically in the higher frequency, lower amplification range of the support input motion response spectra, lowering the natural frequencies of the equipment will move them into the higher amplification region of the excitation and thereby conservatively increase the equipment response level."

The applicant added that, in the case of live loads (mobile) and variable support stiffness, the location of the load and the magnitude of the support stiffness are chosen to lower the system natural frequencies. Similar to the approach described in the above discussion, this ensures conservative dynamic responses because the lowered equipment frequencies tend to be shifted to the higher amplification range of the input motion spectra. If not, the model is adjusted to give more conservative responses.

The staff found the applicant's response to part (a) to be acceptable because it is consistent with the guidance in RG 1.92, Revision 2. During the audit of June 5–8, 2006, the staff discussed the proposed DCD revision for part (b) with the applicant. The staff noted that there may be cases where lowering the system natural frequency may not ensure conservative dynamic responses. As a result of the discussion, the applicant agreed to modify its proposed DCD revision to more clearly describe its approach to ensuring that a conservative response is obtained for equipment. In its supplemental response, the applicant stated that it would clarify DCD Section 3.7.3.3.2 as requested by the staff. The staff found this acceptable. In Revision 2 of DCD Section 3.7, the applicant incorporated the requested DCD changes. On this basis, RAI 3.7-51 was resolved.

3.7.3.3.3.3 Modeling of Special Engineered Pipe Supports

In DCD Section 3.7.3.3.3, the applicant stated that special engineered pipe supports are not used. On this basis, the staff concluded that it is not necessary to address modeling of special engineered pipe supports in the DCD.

3.7.3.3.4 Basis for Selection of Frequencies

In DCD Section 3.7.3.4, the applicant indicated that equipment and components are designed or selected such that their fundamental frequencies are less than half or more than twice the dominant frequencies of the support structure, where practical, to avoid adverse resonance effects. The applicant further stated that equipment is analyzed and/or tested to demonstrate that it is adequately designed for the applicable loads, considering both its fundamental frequency and the forcing frequency of the applicable support structure.

The staff finds the approach discussed in DCD Section 3.7.3.4 to be acceptable, on the basis that analysis and/or testing is performed to demonstrate structural adequacy. The analysis or test would automatically account for resonance effects.

3.7.3.3.5 Analysis Procedure for Damping

In DCD Section 3.7.3.5, the applicant stated that damping values for equipment and piping are shown in DCD Table 3.7-1 and are consistent with RG 1.61. For ASME Code Section III, Division 1, Class 1, 2, and 3, and ASME/ANSI B31.1 piping systems, the alternative damping values specified in DCD Figure 3.7-37 may be used. For systems composed of subsystems with different damping properties, the analysis procedures described in DCD Section 3.7.2.13 are applicable.

The staff's review of damping values appears in Sections 3.7.1.3.2 and 3.12.6.4 (for piping) of this report. Section 3.7.2.3.13 of this report presents the staff's review of analysis procedures for composite damping.

3.7.3.3.6 Three Components of Earthquake Motion

In DCD Section 3.7.3.6, the applicant indicated that DCD Section 3.7.2.6 describes the applicable methods of spatial combination of responses resulting from each of the three input motion components.

The staff's review of DCD Section 3.7.2.6 appears in Section 3.7.2.3.6 of this report.

3.7.3.3.7 Combination of Modal Responses

In DCD Section 3.7.3.7, the applicant indicated that DCD Section 3.7.2.7 describes the applicable methods of modal response combination.

The staff's review of DCD Section 3.7.2.7 appears in Sections 3.7.2.3.7 and 3.12.6.5 (for piping) of this report.

3.7.3.3.8 Interaction of Other Systems with Seismic Category I Systems

In DCD Section 3.7.3.8, the applicant addressed the issue of seismic interaction between other systems and seismic Category I systems.

The staff's review of DCD Section 3.7.3.8, specifically for interactions with piping, appears in Section 3.12.4.8 of this report. The staff determined that the review also applies to interactions between systems other than piping.

3.7.3.3.9 Multisupported Equipment and Components with Distinct Input

In DCD Section 3.7.3.9, the applicant described various methods to analyze multisupported systems and components.

The ISM method is specifically applicable to piping analysis. Therefore, the staff's review of DCD Section 3.7.3.9 appears in Sections 3.12.4.2, 3.12.4.3, and 3.12.6.13 of this report.

3.7.3.3.10 Use of Equivalent Vertical Static Factors

In DCD Section 3.7.3.10, the applicant stated that equivalent vertical static factors are used when the requirements for the static coefficient method in DCD Section 3.7.2.1.3 are satisfied.

The staff's review of DCD Section 3.7.2.1.3 appears in Section 3.7.2.3.1.3 of this report.

3.7.3.3.11 Torsional Effects of Eccentric Masses

In DCD Section 3.7.3.11, the applicant indicated that torsional effects of eccentric masses are included for subsystems similar to those for the piping systems discussed in DCD Section 3.7.3.3.1.

The staff's review of DCD Section 3.7.3.3.1, related to torsional effects of eccentric masses on piping systems, appears in Section 3.12.5.2 of this report.

3.7.3.3.12 Effect of Differential Building Movements

In DCD Section 3.7.3.12, the applicant stated that in most cases, subsystems are anchored and restrained to floors and walls of buildings that may have differential movements during a seismic event. The movements may range from insignificant differential displacements between rigid walls of a common building at low elevations to relatively large displacements between separate buildings at a site with high seismic activity.

The applicant indicated that the differential endpoint or restraint deflections produce secondary stresses, because the stresses are self-limiting, and when the stresses exceed yield strength, minor distortions or deformations within the system satisfy the condition that caused the stress.

The staff's review of DCD Section 3.7.3.12, specifically for piping, appears in Section 3.12.4.2 of this report. The staff determined that the review also applies to systems other than piping.

3.7.3.3.13 Seismic Category I Buried Piping, Conduits, and Tunnels

In DCD Section 3.7.3.13, the applicant indicated that design and analysis of seismic Category I or II buried piping, conduits, tunnels, and auxiliary systems consider the following items:

- two types of loadings induced by ground shaking—(1) relative deformations imposed by seismic waves traveling through the surrounding soil or by differential deformations between the soil and anchor points and (2) lateral earthquake pressures and ground water effects acting on structures

- when applicable, the effects caused by local soil settlements, soil arching, and other similar factors

The applicant also stated in DCD, Tier 2, Revision 3 that the ESBWR has no buried seismic Category I piping. The staff noted that the applicant was consistent with SRP Section 3.7.3.II.12 but did not provide any detail about the methods of analysis or the acceptance criteria used to determine structural adequacy. In addition, the term “auxiliary systems” was not defined. In RAI 3.7-52, the staff requested that the applicant submit additional clarifying information on the scope of buried components and the analytical methods used in the evaluation.

From its review of DCD Revision 3, Section 3.7.3.13, and the original and Supplement 1 and 2 responses to RAI 3.7-52, the staff had concluded the following:

(1) For the ESBWR, there is no buried seismic Category I piping, and it is the staff’s understanding that no buried seismic Category I piping will be added at the COL stage. Consequently, there is no need to define seismic analysis methods for buried piping. However, the staff is not clear as to how the applicant has communicated this restriction in the DCD and how it will enforce the restriction at the COL stage.

(2) No seismic Class I (same as seismic Category I) conduits are buried directly in the ground. There are seismic Class I conduits in two electrical duct banks from the CB to the RB. The electrical duct banks are buried underground utilities with a seismic Category I classification. The duct banks are located in a closed, reinforced concrete trench (or tunnel) covered with backfill. The conduits are relatively short since they are routed directly between buildings.

(3) Yard fire protection system (FPS) lines are buried underground utilities with a seismic Category I classification. The FPS lines will be located in covered, reinforced concrete trenches near the surface, with removable covers to facilitate maintenance and inspection access. These lines are relatively short since they are routed directly between buildings.

(4) The ESBWR design contains no seismic Category I tunnels. The access tunnels between seismic Category I or II buildings are considered Category II. The method of seismic analysis is the same as for the building embedded walls, taking into account the requirements described in DCD, Tier 2, Section 3.7.3.13. The effect of wave propagation is considered in accordance with ASCE 4-98, Section 3.5.2 and the applicable commentary. The staff’s understanding is that the applicant Category II designation denotes an SSC whose failure could negatively impact a safety-related SSC and which is seismically analyzed to the same criteria as a seismic Category I SSC.

(5) The applicant stated in its initial response, “See DCD Table 3.2-1 for identification of components in ‘auxiliary systems.’ See DCD Chapter 9 for identification and description

of ‘auxiliary systems.’” From this response, the staff assumed that there are other buried components associated with one or several of the approximately 50 auxiliary systems. However, the applicant did not respond to the staff’s followup request for specific details. Consequently, the staff is not sure whether the applicant has specifically identified and described all buried seismic Category I systems and components.

In RAI 3.7-52 S03, the staff asked the applicant to do the following:

(3) Confirm the staff’s understanding related to buried piping, and describe how GEH has communicated the restriction on buried piping in the DCD and how it will ensure that this restriction will be enforced at the COL stage. Include this information in DCD Section 3.7.3.13.

(2) Confirm the staff’s understanding related to buried conduit. Include this information in DCD Section 3.7.3.13.

(3) Confirm the staff’s understanding related to FPS lines. Include this information in DCD Section 3.7.3.13.

(4) Confirm the staff’s understanding related to buried tunnels. Discuss adherence to the acceptance criteria in the latest revision of SRP Section 3.7.3 (Rev. 3, issued March 2007), with respect to acceptable methods for seismic analysis and evaluation of buried SSCs. Provide a technical basis for any deviations from the SRP guidance. Include this information in DCD Section 3.7.3.13.

(5) Specifically identify and describe the buried components of seismic Category I auxiliary systems. Describe in detail the analysis methodology employed to ensure that these systems can withstand the design-basis seismic ground motion. Include this information in DCD Section 3.7.3.13.

The staff identified the resolution of RAI 3.7-52 as an open item in the SER with open items. In its response to RAI 3.7-52 S03, the applicant completely revised DCD Section 3.7.3.13, in Revision 5 of the DCD. The revised text addresses the staff’s concerns related to definition of the scope of buried structures and components and also addresses most of the staff’s concerns about the analytical methods and acceptance criteria applied to buried structures and components.

The staff asked the applicant to clarify the following statement from its response to RAI 3.7-52 S03: “Longitudinal compressive strains are limited to 0.3 percent. The reinforcing steel added to the concrete addresses the effect of longitudinal tensile strains.” Specifically, the staff asked the applicant to explain the basis for using a compressive strain limit of 0.3 percent for the design of buried trenches, duct banks, and tunnels and to identify if there is a tensile strain limit for the steel reinforcement, and to explain how the use of strain limits compares to the conventional ultimate strength design method in American Concrete Institute (ACI) 349, “Code Requirements for Nuclear Safety-Related Concrete Structures,” in which the ultimate moment, shear, and membrane capacities of a section are determined (not the strains) and compared to the moment, shear, and membrane demand from the applied loads.

In its revised response to RAI 3.7-52 S03, the applicant added the following clarification:

> Longitudinal compressive strains are limited to 0.3 percent. The reinforcing steel added to the concrete addresses the effect of longitudinal tensile strains. Member forces are calculated per ASCE 4-98 methodology and section capacities are determined per ACI 349-01. Steel section properties are determined per AISC N690-94.

The revised response also identified several editorial changes to DCD Section 3.7.3.13.

The staff finds that the applicant's revised response provides the necessary clarification and is acceptable. Revision 6 of the DCD incorporated the applicable changes to Section 3.7.3.13. Therefore, RAI 3.7-52 and the associated open item were resolved.

3.7.3.3.14 Methods for Seismic Analysis of Seismic Category I Concrete Dams

In DCD Section 3.7.3.14, the applicant stated that the ESBWR design includes no seismic Category I concrete dams. On this basis, the staff concludes that it is not necessary to address the analysis of seismic Category I dams in the DCD.

3.7.3.3.15 Methods for Seismic Analysis of Aboveground Tanks

In DCD Section 3.7.3.15, the applicant described the important elements to consider in the seismic analysis of aboveground tanks. These elements include the consideration of the impulsive mode and sloshing (convective mode), consideration of the tank flexibility, use of the appropriate damping value for each mode, use of the modal and spatial combination methods discussed in DCD Sections 3.7.2.6 and 3.7.2.7, and consideration of the hydrodynamic pressure and hydrostatic pressure at each level of the tank. In addition, the analysis considers the potential pressures resulting from fluid sloshing against the tank top head/roof, design of the tank shell to withstand the seismic forces imposed by the attached piping, tank foundation design to accommodate the seismic forces imposed on the base of the tank, buckling of tank walls and roof, failure of connecting pipe, and sliding of the tank.

All of the above items are in accordance with the guidance in SRP Section 3.7.3(II)(14) and therefore are acceptable to the staff. However, DCD Revision 1 did not clearly state several items in the analysis method for the aboveground tanks. DCD Revision 1 indicated that the beneficial effects of SSI may be considered in this evaluation but did not discuss the case where SSI effects may lead to a higher (i.e., not beneficial) response. If SSI effects are important, then they must be considered in the analysis. Also, there was no description of or reference to an appropriate SSI method of analysis, comparable to those identified in SRP Section 3.7.3(II)(14). Nor was it clear how the damping value for the impulsive mode is determined. In RAI 3.7-53, the staff requested that the applicant address the following:

> (a) DCD Section 3.7.3.15 indicates that the beneficial effects of soil-structure interaction (SSI) may be considered in this evaluation. The applicant is requested to confirm that if SSI effects are important (i.e., may lead to higher responses) then they will (not may) be considered as well. This should be included in the DCD description. In addition, provide a description or reference to an appropriate SSI method of analysis (comparable to those identified in SRP Section 3.7.3(II)(14)) that is used for the tank analysis.

(b) Describe how the damping values for the impulsive mode are determined and whether the values are in accordance with those specified in NUREG/CR-1161 and Veletsos and Tang ("The Effects of Soil-Structure Interaction on Laterally Excited Liquid-Storage Tanks," EPRI Technical Report NP-6500 (Interim Report), September 1989). If not, then provide the justification for any alternative method.

In its response, the applicant stated the following:

(a) DCD Section 3.7.3.15, 6th bullet, 3rd sentence will be revised to read: "If the effects of soil-structure interaction result in higher response then an appropriate SSI method of analysis comparable to Reference 3.7-16 is used." In DCD Section 3.7.6, the following will be added:
Reference 3.7-16 Brookhaven National Laboratory, BNL 52361, "Seismic Design and Evaluation Guidelines for the Department of Energy High-Level Waste Storage Tanks and Appurtenances." October 1995.

(b) The damping value for the impulsive mode is the same as the tank shell material in accordance with NUREG/CR-1161. DCD Section 3.7.3.15, 2nd bullet, 3rd sentence will be clarified.

The staff found the applicant's response to part (a) to be acceptable. During the audit of June 5–8, 2006, the staff asked the applicant to clarify its response to part (b) by including a discussion of how damping is determined and used if SSI effects are included in the tank analysis. The applicant agreed to revise the DCD to address damping when SSI effects are included in the tank analysis.

In its supplemental response, the applicant stated that it would revise DCD Tier 2 to clarify how the soil damping is determined and used in the analysis when SSI is included in the tank analysis. The applicant's supplemental response meets the guidelines in SRP Section 3.7.2(II)(13) and is acceptable to the staff. The applicant incorporated the requested changes in Revision 2 of DCD Section 3.7. On this basis, RAI 3.7-53 was resolved.

3.7.3.3.16 Design of Small-Branch and Small-Bore Piping

In DCD Section 3.7.3.16, the applicant defined small branch lines as those lines that can be decoupled from the analytical model used for the analysis of the main run piping to which the branch lines are attached. Branch lines can be decoupled when the ratio of run to branch pipe moment of inertia is 25 to 1, or greater. The applicant also identified additional restrictions.

Sections 3.12.4.7 and 3.12.5.4 of this report contain the staff's review of DCD Section 3.7.3.16.

3.7.3.3.17 Interaction of Other Piping with Seismic Category I Piping

In DCD Section 3.7.3.17, the applicant stated that in certain instances, seismic Category II piping may be connected to seismic Category I piping at locations other than a piece of equipment that, for purposes of analysis, could be represented as an anchor. The transition points typically occur at seismic Category I valves, which may or may not be physically anchored.

Sections 3.12.4.8 and 3.12.5.4 of this report contain the staff's review of DCD Section 3.7.3.17.

3.7.3.*4 Conclusions*

The staff finds that the applicant has adequately addressed seismic subsystem analysis, in accordance with the acceptance criteria delineated in SRP Section 3.7.3. On this basis, the staff concludes that the regulatory criteria delineated in Section 3.7.3.1 of this report are satisfied.

3.7.4 Seismic Instrumentation

3.7.4.1 *Regulatory Criteria*

The following regulatory requirements and guidance provide the basis for the acceptance criteria for the staff's review:

- GDC 2 in Appendix A to 10 CFR Part 50
- 10 CFR 100.23, "Geologic and Seismic Siting Criteria"
- RG 1.12, "Nuclear Power Plant Instrumentation for Earthquakes"
- RG 1.166, "Pre-Earthquake Planning and Immediate Nuclear Power Plant Operator Post-Earthquake Actions"
- RG 1.167, "Restart of a Nuclear Power Plant Shutdown by a Seismic Event"

3.7.4.2 *Summary of Technical Information*

ESBWR DCD, Tier 2, Section 3.7.4, Revision 7, describes the seismic instrumentation and procedures necessary to promptly evaluate the seismic response of nuclear power plant features important to safety after an earthquake and to determine if vibratory ground motion exceeding that of the OBE ground motion has occurred. Section 3.7.4 also lists the relevant regulations and RGs.

The seismic instrumentation program described in DCD, Tier 2, Section 3.7.4, specifies the location and description of instrumentation, the type of accelerograph, recording and playback equipment, control room operator notification, comparison of measured and predicted responses, and inservice surveillance.

3.7.4.3 *Staff Evaluation*

The staff reviewed the information presented in DCD, Tier 2, Section 3.7.4, in accordance with the guidance in SRP Section 3.7.4, Revision 2. The staff reviewed the list of RGs and the description provided by the applicant of the seismic instrumentation program and procedures to ensure that potential COL applicants can meet the relevant requirements of GDC 2, as well as those of Appendix S to 10 CFR Part 50 and 10 CFR 100.23. Paragraph IV(a)(4) of Appendix S requires that suitable instrumentation be provided so that the seismic response of nuclear power plant features important to safety can be evaluated promptly after an earthquake.
Paragraph IV(a)(3) of Appendix S requires shutdown of the nuclear power plant if vibratory ground motion exceeding that of the OBE occurs.

The staff review of the seismic instrumentation program described in DCD Section 3.7.4 ensured that the instrumentation program provides an adequate number of instruments in suitable locations capable of recording a suitable range of earthquake strong ground motions. The staff reviewed the dynamic range and trigger threshold specified for each instrument in addition to specifications for control room operator notification. The staff also reviewed the description of the ground motion threshold values used to determine if plant shutdown is necessary. Finally, the staff reviewed the inservice surveillance specifications to ensure continual operation of each of the seismic instruments.

3.7.4.4 *Conclusions*

Based on its review of DCD, Tier 2, Section 3.7.4, the staff concludes that the applicant has adequately described the seismic instrumentation program and procedures to ensure that potential COL applicants can meet the relevant requirements of GDC 2, as well as those of Appendix S to 10 CFR Part 50. The applicant also identified the applicable regulations and RGs.

3.8 Seismic Category I Structures

Seismic Category I structures included in the ESBWR design consist of the concrete containment, RB, CB, fuel building (FB), and firewater service complex (FWSC). In Section 3.8 of DCD, Tier 2, Revision 7, General Electric (GE) Hitachi Nuclear Energy (GEH or the applicant) described the design, analysis, testing, and ISI of these structures, following the standard final safety analysis report (FSAR) format under the sections noted below:

- Section 3.8.1
- Section 3.8.2
- Section 3.8.3
- Section 3.8.4
- Section 3.8.5

In addition, the applicant provided design details and evaluation results for seismic Category I structures in DCD, Tier 2, Appendix 3G. The applicant included other pertinent information used to analyze and design seismic Category I structures in Appendix 3B, 3C; and Appendix 3F.

The staff of the NRC reviewed the information provided by the applicant, as stated above, on the basis of the criteria in the corresponding sections (i.e., Sections 3.8.1, 3.8.2, 3.8.3, 3.8.4, and 3.8.5) of the SRP. The following sections discuss the results of the staff review.

3.8.1 Concrete Containment

The reinforced concrete containment vessel (RCCV) houses the primary nuclear system and is part of the containment system. The functional requirement of the containment system is to confine the potential release of radioactive material in the event of a LOCA. The RB totally encloses the RCCV. The concrete containment consists of the reactor pressure vessel (RPV) pedestal, containment cylindrical wall, top slab, suppression pool (SP) slab, and foundation mat. This section of this report discusses the concrete elements and steel liner of the containment structure. Section 3.8.2, “Steel Components of Concrete Containment,” of this report discusses the steel components of the containment that resist pressure and are not backed by structural concrete.

3.8.1.1 *Regulatory Criteria*

The staff reviewed DCD, Tier 2, Section 3.8.1, and DCD, Tier 2, Appendix 3G. The staff considers the applicant's design and analysis procedures, loads and load combination methods, structural acceptance criteria, material, quality control and special construction techniques, and testing and ISIs to be acceptable if they satisfy the criteria, applicable codes and standards, and regulatory guidance delineated in SRP Section 3.8.1, Revision 2. Meeting the guidance of this SRP section will ensure that the DCD meets the relevant requirements of 10 CFR 50.55a and GDC 1, "Quality Standards and Records"; GDC 2, "Design Bases for Protection Against Natural Phenomena"; GDC 4, "Environmental and Dynamic Effects Design Bases"; GDC 16, "Containment Design"; and GDC 50, "Containment Design Basis," of Appendix A to 10 CFR Part 50. The following regulatory requirements are relevant to the staff's review in Section 3.8.1:

- 10 CFR 50.55a and GDC 1 require that the concrete containment be designed, fabricated, erected, and tested to quality standards, commensurate with the importance of the safety functions to be performed.

- GDC 2 requires that the concrete containment withstand the most severe natural phenomena, such as winds, tornadoes, floods, and earthquakes, and the appropriate combination of all loads.

- GDC 4 requires that the concrete containment withstand the dynamic effects of equipment failures, including missiles and blowdown loads associated with the LOCA.

- GDC 16 requires that the concrete containment act as a leaktight membrane to prevent the uncontrolled release of radioactive effluents to the environment.

- GDC 50 requires that the concrete containment be designed with sufficient margin of safety to accommodate appropriate design loads.

- ASME Boiler and Pressure Vessel Code (hereafter referred to as the ASME Code), Section III, Division 2, Subsection CC, "Code for Concrete Reactor Vessels and Containments," contains material specifications, design criteria, fabrication and construction requirements, construction testing and examination techniques, and structural integrity testing (SIT) of the concrete containment according to 10 CFR 50.55a.

The staff evaluated the design, materials, fabrication, erection, inspection, testing, and inservice surveillance of the reinforced concrete containment, based on industry codes and standards, materials specifications, and the following RGs:

- RG 1.94, "Quality Assurance Requirements for Installation, Inspection, and Testing of Structural Concrete and Structural Steel during the Construction Phase of Nuclear Power Plants"

- RG 1.136, “Design Limits, Loading Combinations, Materials, Construction, and Testing of Concrete Containments,” Revision 3, issued March 2007

For design certification, paragraph IV(a)(2)(i)(A) of Appendix S to 10 CFR Part 50 provides an option for specification of the OBE. If it is chosen to be less than or equal to one-third of the SSE ground motion, it is not necessary to conduct explicit response or design analyses to satisfy the requirements of paragraph IV(a)(2)(i)(B)(I) of Appendix S to 10 CFR Part 50.

3.8.1.2 *Summary of Technical Information*

3.8.1.2.1 Description of the Containment

In DCD, Tier 2, Section 3.8.1.1, the applicant described the physical characteristics of the concrete containment for an ESBWR plant. The containment is designed as a reinforced concrete cylindrical shell structure with an internal welded steel plate liner made of carbon steel, except for wetted surfaces of the suppression chamber and GDCS pools, where stainless steel (SS) or carbon steel with SS cladding is used. It is divided by the diaphragm floor (DF) and the vent wall (VW) into an upper drywell (UD) chamber, a lower drywell chamber, and a suppression chamber. The containment is surrounded by, and structurally integral with, the RB through the floor slabs and the structures for the isolation condenser (IC)/passive containment cooling system (PCCS) pools and the service pools for storage of the dryer/moisture separator and other uses.

The containment wall is 2 m (6 ft 7 in.) thick with an inside radius of 18 m (59 ft) and a height of 19.95 m (65 ft 6 in.). The containment design pressure is 310.3 kPa gauge (kPag) (45 psig). The containment is designed to resist various combinations of dead loads; live loads; environmental loads, including those resulting from wind, tornadoes, and earthquakes; normal operating loads; and loads generated by a postulated LOCA.

In DCD, Tier 2, Section 3.8.1.1.3, the applicant described the jurisdictional boundary for applying Section III, Division 2, of the ASME Code to the concrete containment and referenced DCD Figure 3.8-1.

3.8.1.2.2 Applicable Codes, Standards, and Specifications

In DCD, Tier 2, Section 3.8.1.2, the applicant stated that the design, fabrication, construction, and testing of the containment are in accordance with Subsection CC of the 2004 Edition of ASME Code, Section III, Division 2. The design, construction, and testing of the concrete containment are in accordance with the guidance in RG 1.136, RG 1.142, and RG 1.199, “Anchoring Components and Structural Supports in Concrete.” In addition, the applicant used industry standards, such as the 2001 Edition of ACI 349, “Code Requirements for Nuclear Safety-Related Concrete Structures” (hereafter referred to as ACI 349-01), and standards published by the American Society for Testing and Materials (ASTM) and ANSI, as referenced by the applicable codes, standards, and regulations.

3.8.1.2.3 Loads and Load Combinations, Including Hydrodynamic Loads

In DCD, Tier 2, Sections 3.8.1.3.1 through 3.8.1.3.5, the applicant defined all credible conditions of loading, including normal loads, preoperational testing loads, loads during severe environmental conditions, loads during extreme environmental conditions, and loads during abnormal plant conditions. The containment vessel is designed for the following loads:

Normal Loads

D—Dead load of the structure and equipment, plus any other permanent loads, including vertical and lateral pressures of liquids.

L—Live loads, including any moveable equipment loads and other loads that vary in intensity and occurrence, such as forces exerted by the lateral pressure of soil. Live load for structures inside the containment is 9.6 kPa (200 pounds per square foot (psf)) during outages and laydown operations. The loads are applied to the containment interior floors, with the exception of the SP floor slab.

T_o—Thermal effects and loads during normal operating, startup, or shutdown conditions, including liner plate expansion, equipment and pipe reactions, and thermal gradients, based on the most critical transient or steady-state thermal gradient.

R_o—Pipe reactions during normal operating or shutdown conditions, based on the most critical transient or steady-state conditions.

P_o—Pressure loads resulting from the pressure difference between the interior and exterior of the containment, considering both interior pressure changes because of heating or cooling and exterior atmospheric pressure variations.

Construction loads—Loads that are applied to the containment from start to completion of construction. The definitions for D, L, and T_o given above are applicable but are based on actual construction methods or conditions, or both.

SRV loads—Oscillatory dynamic pressure loadings resulting from the discharge of SRVs into the SP.

Preoperational Testing Loads

P_t—Test loads that are applied during the SIT or integrated leak rate test (ILRT).

T_t—Thermal effects and loads during the SIT or ILRT.

Severe Environmental Loads

W—Loads indirectly transmitted by the design wind specified for the plant site, as defined in DCD, Tier 2, Section 3.3.

Extreme Environmental Loads

E′—SSE loads, as defined in DCD, Tier 2, Section 3.7, including pool-sloshing loads.

W′—Loads indirectly transmitted by the tornado specified in DCD, Tier 2, Section 3.3.

Abnormal Plant Loads

R_a—Pipe reactions (including R_o) from thermal conditions generated by a LOCA.

T_a—Thermal effects (including T_o) and loads generated by a LOCA.

P_a—Design accident pressure load within the containment generated by a LOCA, based upon the calculated peak pressure with an appropriate margin.

Y—Local effects on the containment resulting from a LOCA. The local effects include the following:

> Y_r—Load on the containment generated by the reaction of a ruptured high-energy pipe during the postulated event of the DBA. The time-dependent nature of the load and the ability of the containment to deform beyond yield shall be considered in establishing the structural capacity necessary to resist the effects of Y_r.
>
> Y_j—Load on the containment generated by the jet impingement from a ruptured high-energy pipe during the postulated DBA. The time-dependent nature of the load and the ability of the containment to deform beyond yield shall be considered in establishing the structural capacity necessary to resist the effects of Y_j.
>
> Y_m—The load on the containment resulting from the impact of a ruptured high-energy pipe during the DBA. The type of impact (e.g., plastic or elastic), together with the ability of the containment to deform beyond yield, shall be considered in establishing the structural capacity necessary to resist the impact.

CO—An oscillatory dynamic loading (condensation oscillation (CO)) on the SP boundary caused by steam condensation at the vent exits during the period of high steam mass flow through the vents following a LOCA.

CHUG—An oscillatory dynamic loading (chugging (CHUG)) in the top vent and on the SP boundary caused by steam condensation inside the top vent or at the top vent exit during the period of low steam mass flow in the top vent following a LOCA.

PS—Pool swell (PS) bubble pressure on the SP boundary resulting from a LOCA.

In DCD, Tier 2, Section 3.8.1.3.6, the applicant provided the load combination of the above loads and their load factors, in conformance with Table CC-3230-1 of ASME Code, Section III, Division 2, Subsection CC. In earlier versions of the DCD, for seismic loads, the applicant combined the maximum codirectional responses to each of the excitation components by the 100/40/40 method, in accordance with the 1998 Edition of ASCE Standard 4, "Seismic Analysis of Safety-Related Nuclear Structures" (hereafter referred to as ASCE 4-98). In DCD Revision 5, the applicant revised this method for combining the responses caused by each of the excitation components to use the square root of the sum of squares (SRSS) method.

3.8.1.2.4 Design and Analysis Procedures

In DCD, Tier 2, Section 3.8.1.4, the applicant described the analysis and design procedures used in the design of the containment. The analysis of the containment structure (as part of a coupled RB/RCCV/FB model) uses the linear elastic finite-element (FE) computer program NASTRAN, described in Appendix 3C to the DCD, and the analysis methodology described in Appendix 3G to the DCD. The foundation soil is modeled by horizontal and vertical springs, and the spring constants are calculated on the basis of soil properties. Appendix 3A, "Seismic Soil-

Structure Interaction Analysis," to the DCD describes the soil-structure interaction (SSI) analysis. The FE model (FEM) neglects the constraints by soil surrounding the RB and FB.

Both nonaxisymmetric and axisymmetric loads are imposed on the containment and its connected structures. The applicant stated that the LOCA and SRV hydrodynamic pressures in the SP boundaries are simulated as equivalent static pressure loads equal to the dynamic peak value times the dynamic load factor (DLF). The model includes such major penetrations as the drywell head, upper and lower drywell equipment and personnel hatches, suppression chamber access hatch, and main steam (MS) and feedwater (FW) pipe penetrations.

The analysis of the liner plate and its anchorage system is in accordance with the provisions of ASME Code, Section III, Division 2, Subarticle CC-3600. The strains and stresses in the liner and its anchors are within the allowable limits defined by ASME Code, Section III, Division 2, Subarticle CC-3720.

3.8.1.2.5 Structural Acceptance Criteria

In DCD, Tier 2, Section 3.8.1.5, the applicant stated that the acceptance criteria used for the concrete containment is in accordance with ASME Code, Section III, Division 2, except for the tangential shear strength provided by orthogonal reinforcement, for which the ESBWR adopts a lower allowable limit. The allowable tangential shear strength provided by orthogonal reinforcement without inclined reinforcement for concrete with 34.5 megapascals (MPa) (5,000 psi) compressive strength is 4.88 MPa (639 psi). The ESBWR containment does not use inclined reinforcement to resist tangential shear. DCD, Tier 2, Table 3.8-3, lists the major allowable stresses for concrete and reinforcing steel.

3.8.1.2.6 Material and Quality Control and Special Construction Techniques

In DCD, Tier 2, Section 3.8.1.6, the applicant provided the codes and standards for materials used in the construction of the concrete containment. The applicant used RG 1.136 and ASME Code, Section III, Division 2, Article CC-2000, for overall guidance. The applicant used ASTM standards for material characteristics in test comparisons and material specifications for reinforcing steel and ACI standards for concrete mixes.

3.8.1.2.7 Testing and Inservice Inspection Requirements

In DCD, Tier 2, Section 3.8.1.7.1, the applicant stated that it will conduct the SIT in accordance with ASME Code, Section III, Article CC-6000, and RG 1.136. Deflection and concrete crack measurements determine whether the actual structural response is within the limits predicted by the design analysis. In addition to the deflection and crack measurements, the first prototype containment structure is instrumented for the measurement of strains, in accordance with the provisions of ASME Code, Section III, Division 2, Subarticle CC-6370.

In DCD, Tier 2, Section 3.8.1.7.3.1, the applicant described the preservice and inservice inspection program requirements for ASME Code, Class CC and MC, pressure-retaining components and their integral attachments. Subsection IWE of ASME Code, Section XI, applies to the metallic shell and penetration liners of Class CC pressure-retaining components and their integral attachments. Subsection IWL of ASME Code, Section XI, applies to Class CC reinforced concrete.

The design to perform preservice inspection complies with the requirements of ASME Code, Section XI, 2001 Edition through 2003 Addenda. The preservice and inservice inspection program plans are based on the ASME Code, Section XI, edition and addenda specified, in accordance with 10 CFR 50.55a. The design of the containment structure provides access for the examinations required by ASME Section XI, Subsections IWE-2500 and IWL-2500. The actual edition of ASME Code, Section XI, to be used is based on the procurement date of the component, as discussed in 10 CFR 50.55a. The ASME Code requirements discussed in this section are provided for information and are based on the 2001 Edition of ASME Code, Section XI, with 2003 Addenda.

In DCD, Tier 2, Section 3.8.1.7.3.2, the applicant described exclusions to the preservice and inservice examination requirements of ASME Code, Section XI, Subsections IWE and IWL. The applicant stated that, during the detailed design phase, the number of inaccessible areas will be minimized to reduce the number of exclusions. Remote tooling will be used in high-radiation areas where feasible.

In DCD, Tier 2, Section 3.8.1.7.3.12, the applicant stated that, during operation, areas inaccessible for examination will be evaluated if conditions exist in accessible areas that indicate the presence of, or result in, the degradation of the inaccessible areas. For each such area identified, the ISI summary report will include the information required by ASME Section XI, Subsection IWA-6000.

3.8.1.3 *Staff Evaluation*

3.8.1.3.1 Description of the Containment

DCD, Tier 2, Section 3.8.1.1, describes the concrete containment, containment liner plate, and containment boundary. During the review of earlier versions of the DCD, the staff found the descriptive information, including figures and details of the structural elements of the containment, to be generally acceptable and in accordance with the guidance given in SRP Section 3.8.1. However, some information was lacking regarding certain structural aspects of the containment. Therefore, in RAI 3.8-3, the staff requested that the applicant provide additional information (description, plans, and sections) for the following structural elements—the reinforcement details around major RCCV piping penetrations, equipment hatches, and personnel airlocks; structural attachments to the internal wall of the containment (such as pipe restraints); containment external supports, if any, attached to the wall to support external structures and elements; RPV stabilizer (referred to in Section 3G.1.3.1.4); RB floor slabs made of composite sections (referred to in Section 3G.1.3.1.1); roof trusses and their supporting columns (referred to in Section 3G.1.3.1.1); and the basaltic concrete at the bottom of the containment. In addition, to facilitate the review, the staff noted that Figure 3.8-1 should be improved to identify a number of elements in the ESBWR containment structure that are not shown. These elements include the shield wall; RPV stabilizer, skirt, and insulation; equipment hatches; wetwell hatch; personnel airlocks; refueling seal; major equipment platforms; quenchers; representative vent pipe; and SRV downcomer pipe with sleeve (from the drywell into the SP).

In its response to RAI 3.8-3, the applicant stated that the DCD provided a sufficient level of civil-structural detail for plant certification and explained that the construction-level design details requested are not available at the current design stage. The applicant further stated that the detailed structural design is intimately connected across several disciplines, such as piping analysis results, equipment sizes, and layout and routing of commodities (e.g., cable trays, ducts), and depends on these varying disciplines for final resolution.

Among the various structural elements identified in this RAI, the applicant committed, in its response to RAI 3.8-17, to providing the NRC with the details of reinforcement around MS and FW penetrations and a representative hatch through the RCCV. This information would be representative of the detailed structural design.

The applicant further stated that it intended DCD Figure 3.8-1 to depict only the containment boundary. Various figures presented in Appendix 3G to the DCD and DCD Sections 5.3 and 6.2 provide details for the other items. The detailed design phase will include details for the RPV insulation and the major equipment platforms.

During its onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, CA, the staff discussed the initial response with the applicant, as documented in "Audit Results Summary, Prepared by BNL, 07/25/06, ESBWR DCD Section 3.8, NRC Audit at GE, San Jose, CA July 11-14," issued July 25, 2006). The staff noted that, even if the applicant does not have "construction level design details," it should provide additional information to describe and outline the major structural elements and their attachments. The first part of the RAI identified some of the important items that are lacking. The staff would find representative cases for each category to be acceptable. The staff aimed the second part of the RAI at obtaining a single figure that would show all of the various structural elements and attachments. The applicant's response also lacked some of the requested information in the RAI (e.g., attachment of the RPV stabilizer to the RCCV/RB).

During the audit, the applicant indicated that it would revise the DCD to include details for the reinforcement around a major RCCV penetration, such as a representative equipment hatch through the RCCV. The applicant also agreed to provide a revised RAI response that shows the conceptual design details for the RPV stabilizer and refueling seal. For attachments to the outside of the RCCV, the applicant would add a discussion to the DCD explaining that embedment plates will be designed in conjunction with the design of component or commodity supports at the COL stage or the COL holder will confirm them. The additional topics discussed during the audit were addressed by the applicant in response to supplemental RAI 3.8-3 S01.

In its RAI 3.8-3 S01 response, the applicant stated the following:

a. Regarding steel members such as structural steel shapes, piping supports or commodity supports inside containment, Figure 3.8-3(1) below (in the RAI response) shows a typical support plate with anchors embedded in the concrete containment. The dimensions of the plate and the number of anchors depend on the loads for each support. They are designed in accordance with ANSI/AISC N690 and Appendix B "Anchorage to Concrete," to ACI 349-01.

b. Regarding other steel members such as structural steel shapes, pipe whip restraints, piping supports, etc, outside the containment, Figure 3.8-3(2) presents a typical support plate with anchors embedded in the concrete containment. See also response to a above.

c. The top plate, bottom plate and support beam of DF are welded to thickened RCCV liner plate, therefore this end is fixed. The reference drawings are Figures 3G.1-55 and 1-56 of DCD Appendix 3G. Type of weld will be decided in detail design, however, it is expected that the full penetration weld or the partial penetration with fillet weld may be applied to ensure the required strength.

d. The same type of support shown in Figure 3.8-3(2) above is applicable in these cases. The design is based on ANSI/AISC N690 for the steel plates and ACI 349-01, Appendix B, for the embedded anchors.

In its RAI 3.8-3 S02 response, the applicant referred to its Supplement 1 response to RAI 3.7-27 for additional information related to Part (a). In response to Part (b), the applicant submitted Figure 3.8-3(3) depicting the refueling seal as additional information.

In its RAI 3.8-3 S03 response, the applicant stated that, in the next revision to DCD Tier 2, it will update the descriptions and sketch details of representative containment structural components provided in the Supplement 1 and 2 responses. The applicant further stated that a structural seal plate with an attached compressible bellows sealing mechanism between the reactor vessel and UD opening provides a leak-resistant refueling seal. The RAI response provides descriptive information and details of the refueling seal.

The applicant referred to its response to RAI 3.8-27, Supplement 1, for a description of the RPV stabilizer. The applicant indicated that it would revise DCD, Tier 2, Sections 3.8.1.1.1, 3.8.1.1.2, and 3.8.2.1.4, and add Figures 3.8-2, 3.8-3, and 3.8-4 in the next DCD update. The applicant's response included a markup of the proposed changes.

As requested by the staff, the applicant provided a typical reinforcement detail around a major penetration, details for typical supports plates for interior and exterior attachments to the containment, and information about the refueling seal. The applicant also provided descriptive information for the RPV stabilizer, which the staff evaluated under RAI 3.8-27. The staff reviewed the proposed revisions to the DCD and found them acceptable, because they provide sufficient descriptive information, in accordance with SRP Section 3.8.1, for the key structural elements. The staff confirmed that DCD Revision 3 included the proposed revisions. Therefore, RAI 3.8-3 was resolved**.**

DCD, Tier 2, Section 3.8.1.1.3, provides the jurisdictional boundary for application of Section III, Division 2, of the ASME Code. Unlike most other concrete containments, the ESBWR containment is not a free-standing structure. The ESBWR containment is integrally connected to the concrete walls, slabs, and foundation of the interior and exterior RB structure. In RAI 3.8-4, the staff requested that the applicant describe how the jurisdictional boundaries defined in DCD Section 3.8.1.1.3 and Figure 3.8-1 meet the definition of jurisdictional boundaries specified in ASME Code, Section III, Division 2, Subsection CC. This subsection states that, "When a structural concrete support is constructed as an integral part of the containment, it shall be included within the jurisdiction of these criteria." The staff noted that the RB includes a number of structural components, such as the RB concrete floor slabs, that are integrally connected to the containment structure to restrain and provide support to the containment under various loads (e.g., internal containment pressure).

In its response to RAI 3.8-4, the applicant stated that ASME Code, Section III, Division 2, Subsection CC, Section CC-1140, requires that the containment conform to the requirements of ASME Code, Section III, Article NCA-3254.2. Furthermore, Section CC-1140 states that Article NCA-3254.2 is supplemented by the following provision, "When a structural concrete support is constructed as an integral part of the containment, it shall be included within the jurisdiction of these criteria." However, the applicant noted that Interpretation No. 2 (III-2-83-01) of ASME Code, Section III, states that, when the containment mat is integral with other building foundations, only the portion of the containment foundation mat directly beneath the containment vessel, including any additional peripheral volume for anchoring the containment shell reinforcement, shall be considered within the code jurisdictional boundary and constructed in accordance with the rules of ASME Code, Section III, Division 2. The portion of the common mat subject to the rules of ASME Code, Section III, Division 2, shall be proportioned for the forces and moments resulting from consideration of the entire mat. The loads from the portion of the common mat outside the rules of ASME Code, Section III, Division 2, shall be included in the design specification and applied to the ASME Code, Section III, Division 2, mat, in combination with those specified for the ASME Code, Section III, Division 2, mat. The load combinations specified in Section CC-3000 and the design specification shall apply to all loads.

Analogous to the jurisdictional boundary definition provided in Interpretation No. 12, the RAI response stated that the design treats structural components (e.g., RB floor slabs, fuel pool girders), which are integral with the containment, the same as the containment only so far as loads and loading combinations are concerned. The applicant indicated that this is consistent with the NRC position provided in RG 1.142, on the design code (ACI 349-01) and the requirements for the DF slab in the advanced BWR (ABWR) and Mark II design, which is integral with the containment wall and participates in resisting a portion of the pressure load on the containment wall. The applicant referred to its response to RAI 3.8-101 for additional information.

During its onsite audit, conducted December 12–14, 2006, at the applicant's offices in San Jose, CA, the staff requested further clarification, as documented in "Summary of December 14, 2006, Meeting with General Electric, Regarding Audit of ESBWR Structural Design and Analysis," issued May 18, 2007). The applicant explained that it checks the loads and load combinations for the entire RB against the acceptance criteria in ASME Code, Section III, Division 2. Furthermore, the applicant has confirmed that the acceptance criteria in ASME Code, Section III, Division 2, are more conservative than the acceptance criteria in ACI 349-01. The staff asked the applicant to provide the technical basis for this conclusion in supplemental RAI 3.8-4 S01.

In its RAI 3.8-4 S01 response, the applicant stated the following:

> The entire RB is designed to both the ASME Section III, Division 2, Subsection CC code and the ACI 349-01 Code. The acceptance criteria in ASME 2004 Section III, Division 2 are more conservative than the acceptance criteria in ACI 349-01 as shown below. The current boundary shown in DCD, Tier 2 Figure 3.8-1 for the ASME jurisdictional boundary for all aspects of design, construction, fabrication, and inspection is acceptable.

In its RAI 3.8-4 S01 response, the applicant also compared the acceptance criteria in ACI 349-01 with those in the 2004 Edition of ASME Code, Section III, Division 2.

The staff reviewed the RAI 3.8-4 S01 response and found that it needed additional clarification. The applicant stated that the entire RB is designed to both ASME Code, Section III, Division 2, Subsection CC, and ACI 349-01. Therefore, the staff questioned why there was a need to demonstrate that the acceptance criteria in ASME Code, Section III, Division 2, are more conservative than the ACI 349 criteria. In addition, the response does not appear to support that conclusion. The comparison between the codes is limited to the case of a member subjected to a combination of axial loading and bending. As indicated in the response, in the high axial force (compression) region, the ASME allowable values are not more conservative. In RAI 3.8-4 S02, the staff asked the applicant to explain the purpose of the comparison and clarify how it used ASME Code, Section III, Division 2, Subsection CC, and the ACI 349-01 code to design the RB. RAI 3.8-4 was being tracked as an open item in the SER with open items.

In its RAI 3.8-4 S02 response, the applicant stated that it based the design of the entire RB on the more limiting acceptance criteria of ASME Section III, Division 2, Subsection CC, and ACI 349-01. The staff found this acceptable, since this includes enveloping the loading combinations and the allowable stresses in the concrete and steel reinforcement from both codes. Subsequently, in its RAI 3.8-4 S03 response, the applicant further explained that, for the design of the additional peripheral volume of the concrete basemat beyond the containment outside perimeter, it determined the development length of the containment reinforcement in the area in accordance with ASME Code, Section III, Division 2. The staff found the definition of the jurisdictional boundary of the containment to be technically acceptable, because it is consistent with Interpretation No. 12 (III-2-83-01) of ASME Code, Section III. The staff also verified that the applicant incorporated the proposed markup changes in the response into the appropriate sections of the DCD. Therefore, RAI 3.8-4 and its associated open item were resolved.

To understand how it made structural attachments to the ESBWR containment, the staff asked the applicant, in RAI 3.8-27, to provide the details of the locally thickened liner plate and additional anchorage at major structural attachments. In addition, the staff requested that the applicant identify how it modeled the thickened liner plate and anchorage in the NASTRAN analyses. If the NASTRAN analysis did not model these structural attachments, then the applicant should discuss the basis for not including them. Finally, the staff asked the applicant to incorporate the responses to this RAI in DCD Section 3.8.1 or Appendix 3G, or both.

In its response to RAI 3.8-27, the applicant referred to DCD Figure 3G.1-48 for thickened liner plates at the DF (38 millimeters (mm)) and pedestal (50 mm), indicated that they are modeled in NASTRAN using shell elements with the corresponding thicknesses specified, and stated that DCD Table 3G.1-35 provides the analysis results. The applicant did not model the anchorage itself; however, it evaluated the reaction forces and presented the results in DCD Tables 3G.1-38, 3G.1-40, and 3G.1-42. The thickened liner plates are modeled by shell elements, so the thicknesses are input directly as NASTRAN data. The applicant referenced its Report DC-OG-0052, Revision 1, “Structural Design Report for Containment Metal Components,” issued September 2005, which contains the evaluation method and results for the structural integrity of the containment liner and drywell head. The applicant indicated that it would revise DCD Section 3G.1.4.1 in the next update and provided a markup of the proposed change.

During its onsite audit, conducted July 11–14, 2006, at the applicant’s offices in San Jose, CA, the staff discussed the requested information in further detail. The applicant showed the staff details of the thickened portion of containment liner at the various locations and confirmed that the NASTRAN model included the thickened liner sections. The applicant included details of the major structural attachments in Figures 3G.1-48, 3G.1-49, and 3G.1-51 for the liner; Figures 3G.1-55 and 3G.1-56 for the DF; Figure 3G.1-57 for the RPV support bracket (RPVSB) and VW; and Figure 3G.1-59 for the GDCS pool. In supplemental RAI 3.8-27 S01, the staff asked the applicant to provide a sketch of the RPV stabilizer and address the design of the anchorage at the penetrations.

In its RAI 3.8-27 S01 response, the applicant described the construction of the piping penetrations and their anchorage to the containment wall. The RAI response included a typical detail for hot penetrations. The process to be used for the design of penetration anchors is to evaluate the stress state on each component by means of a local three-dimensional FEM of the penetration and to verify that the stress results are below the allowable stress limits specified by the applicable ASME subsections (e.g., NB-3220, NC-3217, NE-3220, and CC-3421.9). The RAI response also provided a detail showing the RPV stabilizer concept to be used in eight places in the ESBWR.

The staff found the applicant's response to be acceptable, because it provides sufficient descriptive information, as required by SRP Section 3.8.1, for these structural elements. However, the figure provided for the RPV stabilizer was unclear. The RPV stabilizer attachment to the reactor shield wall (RSW) did not appear to provide free radial movement, and it was not obvious how it provides lateral (i.e., tangential direction) restraint, since springs and gaps are provided for tangential movement.

The staff discussed this with the applicant during the December 2006 onsite audit. In its RAI 3.8-27 S02 response, the applicant provided a more detailed description and a revised sketch of the RPV stabilizer, which shows the tangential restraint while allowing free radial and vertical movement. The applicant also included the description and sketch of the RPV stabilizer in the DCD.

In its RAI 3.8-27 S03 response, the applicant stated that eight RPV stabilizers are equally spaced around the circumference of the RPV and attached to the RSW. The stabilizer, shown in a figure in the RAI response, allows for free thermal radial and vertical growth of the RPV through an oversized hole in an integral lug attached to the RPV. The lug, while free to move radially and vertically, is restrained tangentially by end plates welded to a bracket attached to the RSW. The seismic analysis of the RB/FB complex stick model includes a lateral directional spring stiffness for the entire stabilizer assembly between the RSW and the RPV. The applicant indicated that it would revise DCD, Tier 2, Section 3.9.1.4, in the next update and provided a markup of the proposed change.

The staff found the details of the locally thickened liner plate at the DF and the pedestal, as well as the description of the modeling and results for the thickened liner plate anchorages at these locations, to be acceptable for reasons explained below. The staff reviewed the applicant's proposed change to DCD Section 3G.1.4.1 and confirmed that the applicant incorporated it into Revision 3 of the DCD.

The staff found that the applicant provided sufficient information for the anchorage of containment and hot piping penetrations in the response to RAI 3.8-27 S01. Revision 3 of the DCD also incorporated typical details for the containment mechanical and electrical penetrations and their anchorages. The staff notes that RAI 3.8-17 addresses the analysis and design of major penetrations.

The staff found that the applicant provided sufficient information and preliminary details for the RPV stabilizer in its response to RAI 3.8-27 S03. The response demonstrated how the stabilizer would provide lateral support to the RPV while permitting free radial and vertical movement. The staff reviewed the applicant's proposed change to DCD Section 3.9.1.4 and confirmed that the applicant incorporated into Revision 4 of the DCD.

Since the applicant provided sufficient descriptive information for the key structural elements of containment, in accordance with SRP Section 3.8.1, the staff considered that the applicant adequately addressed the original questions posed by this RAI. Therefore, RAI 3.8-27 was resolved.

During its review of DCD Figures 3G.1-48 and 3G.1-49 (referenced in the response), the staff noted that the applicant reduced some liner plate thicknesses and the size of the stiffeners between DCD Revision 2 and DCD Revision 3. The applicant referenced RAI 3.8-24 as the basis for the change in the Revision 3 change summary table. The staff cannot identify any connection between the technical issue raised in RAI 3.8-24 and these design changes; however, the statement in the applicant's response to RAI 3.8-24 indicated that it revised these figures. In RAI 3.8-111, the staff requested that the applicant explain why these design changes were made and provide the technical basis for the structural adequacy of these changes. RAI 3.8-111 was being tracked as an open item in the SER with open items.

In its response to RAI 3.8-111, the applicant explained that it made the changes to the wetwell floor slab liner plate (thickness reduced from 16 mm to 6.4 mm and the anchor span reduced from 508 mm to 270 mm) to keep anchor displacements within the ASME Code limits. To simplify fabrication and construction, it also changed the 16 mm plates at the wetwell wall liner bottom portion and the pedestal liner bottom portion to a thickness of 6.4 mm. Strains in the thinner liner remain below the ASME Code limits. It changed the size of stiffeners (liner anchors) from WT 6x8 to WT 4x7.5 for consistency with the design evaluation, using load-displacement data for WT 4x7.5, and the resulting anchor loads are within the ASME Code allowables. The use of the WT 4x7.5 anchor also provides more space for placement of reinforcement. The staff found that the applicant adequately explained why it had reduced some liner plate thicknesses and the size of the stiffeners between DCD Revision 2 and DCD Revision 3. Since these changes to the liner plate design are within the ASME Code allowable limits, the staff found them acceptable. Therefore, RAI 3.8-111 and its associated open item were resolved.

3.8.1.3.2 Applicable Codes, Standards, and Specifications

DCD Section 3.8.1.2 provides the codes, standards, and regulations for design, fabrication, construction, testing, and ISI of the concrete containment. The staff found that the standards and regulations are in accordance with industry practice and SRP Section 3.8.1.II.2 criteria. The code specified for the concrete containment is the 2004 Edition of ASME Code, Section III, Division 2, Subsection CC, and ACI 349-01. The staff was concerned with the use of the 2004 Edition of the ASME Code for containment; therefore, in RAI 3.8-5, the staff requested that the applicant provide the following information:

(a) DCD Section 3.8.1.2.2 and Table 3.8-9 indicate that ASME Code, 2004 Edition, is used for the design, fabrication, construction, testing, and ISI of the concrete containment. The NRC has not yet endorsed the 2004 Edition of the ASME Code; however, it reviewed and accepted the 1989 Edition during the ABWR review process. The staff asked the applicant to describe the differences between the two editions of the ASME Code that are applicable to the design of the ESBWR containment (e.g., Subsections CC, NCA, and NE).

(b) Assuming that the staff accepts the implementation of the 2004 Edition of the ASME Code for the design of the ESBWR containment, the staff considers that any deviation from the ASME Code, 2004 Edition, for the design and construction of the containment would require NRC review and approval before implementation. The applicant should add a statement to this effect to DCD Sections 3.8.1 and 3.8.2.

(c) Since DCD Section 3.8.1.2.3 does not reference RG 1.94 (Item 29 in Table 3.8-9), the applicant should discuss how it incorporated the provisions of ANSI N45.2.5 and RG 1.94 into the referenced codes and standards.

In its response to RAI 3.8-5, the applicant stated the following:

a) The differences between 1989 edition and 2004 edition (including the addenda after 1989 Edition) of the ASME Section III Code for Subsections CC, NCA, and NE are summarized in two tables. One table presents the reduction in requirements due to the change from 1989 Edition to the editions after 1989, while the other table presents the increase in requirements due to the change. When the requirements are reduced, a column called “Comments” at the end of the table summarizes those changes accepted by the USNRC and those that have not been endorsed. When the requirements are increased, the design is more conservative and meets 1989 edition requirements. There were 13 changes identified in the table for reduction in requirements, that are not endorsed by the USNRC, and which are applicable to the ESBWR design. These will need NRC review and approval.

b) There are no deviations from ASME Code 2004 edition for the design and construction of the ESBWR containment; therefore, no revisions to the DCD are necessary in response to this item.

c) DCD Section 3.8.1.2.3 will be revised to include item 29 as well as 31 and 33 of DCD Table 3.8-9 in the next update.

The staff found the applicant’s response to Parts (b) and (c) to be acceptable. However, it noted that for Part (a), each relaxation in requirements not currently accepted by the staff will require a technical basis for concluding that an equivalent level of safety will be achieved.

The staff discussed this with the applicant during the December 2006 onsite audit. The applicant presented an update to the table included in its initial RAI response, which provided an explanation for each of the 13 items. The applicant noted that some of the 13 items do not apply to the ESBWR and indicated that it would provide additional technical information to justify the remaining items in response to supplemental RAI 3.8-5 S01.

In its RAI 3.8-5 S01 response, the applicant stated that the comparison table provided in the original response, in which the criteria in the 2004 Edition of ASME Code, Section III, are considered to be a relaxation of the 1989 Edition, is updated in Table 3.8-5(1)R1. The applicant noted that none of the changes reduce the levels of previous conservatisms in the 1989 Edition of ASME Code, Section III. No DCD change was identified.

The staff found the applicant’s responses to Parts (b) and (c) of RAI 3.8-5 to be acceptable. The staff reviewed the applicant’s proposed change to DCD Section 3.8.1.2.3 and confirmed that the applicant incorporated it into Revision 3 of the DCD. Parts (b) and (c) of RAI 3.8-5 were resolved.

The staff noted that it officially issued Revision 3 of RG 1.136 in March 2007. This RG endorses the 2001 Edition of ASME Code, Section III, Division 2, through the 2003 Addenda, subject to the exceptions cited in Section C, "Regulatory Position," of the RG. Since the staff has officially accepted the ASME Code through the 2003 Addenda, the staff informed the applicant that it should identify any applicable relaxations between the 2004 ASME Code referenced for the ESBWR design and RG 1.136, Revision 3, including its regulatory positions, and that the relaxations will require a technical justification for acceptability. Alternatively, as a means to facilitate resolution, the staff informed the applicant that it may reference RG 1.136, Revision 3, directly, thereby revising the applicable code for the ESBWR design to the 2001 Edition of the ASME Code, Section III, Division 2, through the 2003 Addenda. The DCD would have to document any revision of the applicable code edition.

In its RAI 3.8-5 S02 response, the applicant stated that RG 1.136, Revision 3, which endorses the 2001 Edition of ASME Code, Section III, Division 2, through the 2003 Addenda, did not exist 6 months before the ESBWR design certification application. Therefore, the applicant stated that RG 1.136, Revision 2, is applicable to the ESBWR. In addition, the applicant referred to the ASME Code, Section III, comparisons presented in the responses to RAIs 3.8-5 and 3.8-5 S01. These comparisons included the differences between the 2004 Edition of ASME Code, Section III, and the 2001 Edition of ASME Code, Section III, through the 2003 Addenda.

The staff reviewed the comparisons presented in the prior responses to RAI 3.8-5, which included the differences between the 2004 Edition of ASME Code, Section III, and the 2001 Edition of ASME Code, Section III, through the 2003 Addenda, which is endorsed by RG 1.136, Revision 3. The applicant provided the latest revised comparisons in its RAI 3.8-5 S01 response, submitted in a letter dated January 29, 2007. From these comparisons, the staff identified only one substantive change in the ASME Code provisions that is considered to be a relaxation in the 2004 Edition of ASME Code, Section III, related to Division 2 (Subsection CC), that is applicable to the ESBWR. The change in requirement is the addition of cold rolled formed parallel threaded splices as an acceptable form of splicing reinforcing bars. This is another type of mechanical splice that was added to those already included in ASME Code, Section CC-4330, which consists of a sleeve with ferrous filler metal splices, taper threaded splices, swaged splices, and threaded splices in thread deformed reinforcing bars. The cold rolled formed parallel threaded splices must meet the same provisions as the other mechanical splices in the ASME Code. These include the qualifications, records, and identifying stamps; splice system qualification requirements; requirements for production splicing procedures; splice qualification and performance tests; and records of test results. Since the cold rolled formed parallel threaded splices must meet the same requirements as the other mechanical splices already in the ASME Code, and they are tested to meet the tensile requirements of the splice, the staff concludes that the revisions identified in the 2004 Edition of ASME Code, Section III, Division 2, Subsection CC, for the concrete portions of the containment are acceptable. However, since the applicant used the recent 2004 Edition of ASME Code, Section III, Division 2, Subsection CC, based on a comparison to the ASME Code through the 2003 Addenda, the applicant should confirm that the regulatory positions in RG 1.136, Revision 3, which endorse the ASME Code through the 2003 Addenda, are also met. RAI 3.8-5 Part (a) was being tracked as an open item in the SER with open items.

In its RAI 3.8-5 S03 response, dated March 13, 2008, the applicant confirmed that the ESBWR design certification meets the regulatory positions stated in RG 1.136, Revision 3, which endorses ASME Section III, Division 2, Subsection CC, 2001 Edition through the 2003 Addenda. The staff verified that the applicant incorporated the proposed markup changes in the response into the appropriate sections of the DCD. RAI 3.8-5 and its associated open item were resolved.

The staff noted that some subsections in DCD Sections 3.8.1 and 3.8.2 state that the containment design meets specific subarticles and paragraphs of ASME Code, Section III, Division 2. In RAI 3.8-11, the staff requested that the applicant confirm that all applicable subarticles and paragraphs contained in the ASME Code are also satisfied. This confirmation should indicate that the DCD notes any exceptions to the ASME Code, such as the allowable tangential shear stress carried by orthogonal reinforcement.

In its response to RAI 3.8-11, the applicant stated that the containment design meets all applicable subarticles and paragraphs of ASME Code, Section III, Division 2, except that the tangential shear stress carried by orthogonal reinforcement (v_{so}) allowed by the ASME Code is replaced by a smaller value, as shown in DCD Table 3.8-3. The applicant did not identify any DCD changes. The staff reviewed the exception in DCD Table 3.8-3 and finds it acceptable, because the tangential shear strength provided by orthogonal reinforcement is consistent with the guidance given in SRP Section 3.8.1.II.5. Therefore, RAI 3.8-11 was resolved.

3.8.1.3.3 Loads and Load Combinations, Including Hydrodynamic Loads

In DCD Section 3.8.1.3, the applicant described the loads and load combinations used for the analysis and design of the concrete containment. The staff reviewed the definition of the normal loads, preoperational testing loads, severe environmental loads, extreme loads, abnormal loads, and the load combinations for the containment structure and liner plate. In general, it was evident that these definitions agreed with the acceptance criteria presented in SRP Section 3.8.1.II.3. In a few cases, however, the staff noted differences requiring additional information from the applicant; other cases required further clarification, as discussed below.

In RAI 3.8-6, the staff noted that the applicant should expand the description of live load used inside containment, given in DCD Section 3.8.1.3.1, to be similar to the description presented in Section 3.8.4.3.1.1, if applicable. The description should cover the types of loads included in live loads (e.g., floor area live loads, laydown loads, equipment handling loads), situations in which floor area live loads are omitted, and the magnitude of live load that is used for inertia effects caused by seismic and hydrodynamic loadings in the overall building model and in the design of individual local members. If a fraction of the live load is used for seismic and hydrodynamic effects, then the applicant should justify the reduced live load magnitude.

In its response to RAI 3.8-6, the applicant stated that the live load for structures inside the containment is 9.6 kPa (200 psf) during outages and laydown operations. The loads are applied to the containment interior floors, except the SP floor slab. During normal operation, the live load is not considered, since the containment is inerted and therefore inaccessible. The overall building dynamic analysis model for seismic loads reflects the normal operating conditions and hence does not include the live load inertia effects of containment internal structures. The dynamic analysis model for hydrodynamic loads included live load inertia equal to 25 percent of full live loads for containment internal structures, and the effect on structural response is negligible. The applicant based the design of individual members on the worst loading conditions, including those that contain live load. The applicant stated that it would revise DCD Section 3.8.1.3.1 in the next update and submitted a markup of the proposed change.

During its onsite audit, conducted July 11–14, 2006, at the applicant’s offices in San Jose, CA, the staff discussed the requested information in further detail. The staff asked what assurance existed that no live load would be present during normal operation and noted that it is customary to include 25 percent in the seismic analysis. The staff also asked why the applicant included 25 percent in the dynamic analysis model for hydrodynamic loads but not for seismic analysis. The applicant indicated that, during operation, no components are considered as live load, which means anything inside containment would have been included in the dead load definition. During outages, items that may be brought inside containment would be under "administrative control," which means that they would be checked for removal from inside containment before operation is resumed. The applicant reiterated that it found the effect of using the 25-percent value in the hydrodynamic loads analysis to be negligible. The applicant agreed to submit the additional information discussed during the audit in its RAI 3.8-6 S01 response.

In its RAI 3.8-6 S01 and S02 responses, the applicant provided the results of eigenvalue analyses performed for the VW, RSW, and DF, considering 25 percent of live load (9.6 kilonewton (kN)/m^2) on the DF and platforms. The applicant demonstrated that live load has a negligible effect on the frequencies of the containment internal structures.

The staff finds the applicant's response to be acceptable, because it provides a sufficient technical basis to demonstrate that the mass contribution from live loads has a negligible effect on the natural frequency of containment internal structures and, thus, would also have a very small effect on the seismic structural response. For hydrodynamic load analyses, the applicant used 25 percent of the live load, which the staff considered to be acceptable, based on past industry practice and adoption by the NRC. The staff notes that, even though the live load may be reduced for purposes of calculating the total mass for dynamic inertial loads, no reduction in live load is taken when determining the total design load corresponding to the various load combinations. Therefore, RAI 3.8-6 was resolved.

In reviewing the definition of preoperational test loads for the ESBWR, as defined in DCD Section 3.8.1.3.2, the staff could not identify leak rate test (LRT) loads. Therefore, in RAI 3.8-7, the staff asked the applicant to explain where LRT loads are included in the load definitions presented in DCD Section 3.8.1.3. ASME Code, Subsection CC-3320, places this load as part of the load P_t and T_t; however, these loads do not appear in the definition of the preoperational loads P_t and T_t described in DCD Section 3.8.1.3.2.

In its response to RAI 3.8-7, the applicant stated that the LRT loads are included in the preoperational testing loads. Because the magnitude of the LRT pressure is less than that of the SIT, the LRT loads are not explicitly included in the analysis. The LRT and SIT pressures can be readily compared in DCD Section 6.2.6.1, Table 1.3-3, and Table 3G.1-7. The applicant did not identify any DCD changes.

The staff determined that it could not identify the LRT pressures in DCD Section 6.2.6.1, Table 1.3-3, and Table 3G.1-7 for comparison with the SIT. Even though the LRT loads are less than the SIT loads, the definition of P_t and T_t in DCD Section 3.8.1.3.2 should include both test loads. In the DCD load combinations and load definitions, loads should not be eliminated from consideration because they are lower than some other load.

In its RAI 3.8-7 S01 response, the applicant stated that it would revise DCD, Tier 2, Section 3.8.1.3.2, to include the subject SIT and LRT pressure loads, and it provided a markup of the proposed change.

The staff finds the applicant's response to be acceptable, since this change makes the load definitions consistent with ASME Code, Section III, Subsection CC-3320. The staff reviewed the applicant's proposed change to DCD Section 3.8.1.3.2 and confirmed that the applicant incorporated the change into Revision 3 of the DCD. Therefore, RAI 3.8-7 was resolved.

In DCD Section 3.8.1.3.6, the applicant described the load combinations for the design of the containment structure. However, from this information, it was not evident whether the applicant considered all load combinations. Therefore, in RAI 3.8-8, the staff asked the applicant to (a) explain how it addressed the requirements contained in 10 CFR 50.34(f)(3)(v) regarding loads, loading combinations, and the design for the ESBWR containment, and (b) explain whether internal flooding of the containment, subsequent to a LOCA, is also applicable to the ESBWR containment design. If so, the applicant should also explain how it is included in the loading combinations described in DCD Section 3.8.1.3.

In its response to RAI 3.8-8, the applicant stated the following:

> (a) To satisfy 10 CFR 50.34(f)(3)(v)(A), an evaluation of the Level C pressure capability of major penetrations (Drywell Head, Equipment Hatch, Personnel Airlock and Wetwell Hatch) in the ESBWR concrete containment was performed per ASME Section III, Division 1, NE-3220. To meet concrete containment requirements of ASME Section III, Division 2, CC-3720, Factored Load Category, a nonlinear finite element analysis of the RCCV structure including liner plates was performed for over-pressurization. Level C (or Factored Load Category Level) pressure capacity of the concrete containment vessel is at least 1.468 MPa and it is higher than the 1.182 MPa (or 171 psi) controlling value of the steel components. The most critical of the piping penetrations is the one for the MSL [main steamline]. The maximum Level C pressure capability is calculated as 3.377 MPa. The discussion and results are presented in DCD Subsection 6.2.5.4.2 and DCD Table 6.2-46. As discussed in DCD Section 6.2.5, ESBWR relies on an inerted containment to control combustible gas. Post accident hydrogen control is not required for an inerted containment according to 10 CFR 50.44(c)(2). Thus, the requirements in 10 CFR 50.34(f)(3)(v)(B) do not apply.
>
> (b) Hydrostatic pressure associated with LOCA flooding during the design phase (i.e. within 72 hours after LOCA) is considered together with other LOCA loads. Internal flooding of the ESBWR containment during fuel recovery stage (i.e. beyond 72 hours after LOCA) is not controlling because the hydrostatic pressure associated with the flooding is less than the containment design pressure.

The applicant indicated that it will revise DCD Tables 3.8-2, 3.8-4, and 3.8-7 in the next update and provided markups of the proposed changes.

The staff determined that the applicant is evaluating requirements in 10 CFR 50.34(f)(3)(v)(A) under the review of DCD Section 6.2.5.4.2 and Appendix 19B. The requirements of 10 CFR 50.34(f)(3)(v)(B) do not apply to the ESBWR because the containment is inerted. Therefore, the applicant's response to Part (a) is acceptable.

DCD Appendix 19B presents the evaluation of the containment structural integrity to satisfy the pressure requirements under 10 CFR 50.44(c)(5), and the staff reviewed them in Section 19 of this report.

The applicant's response to Part (b) of the RAI did not address the postflooding load combination (which includes OBE) defined by SRP Section 3.8.1. The staff discussed the omission with the applicant during the December 2006 onsite audit. The applicant agreed to submit, in response to RAI 3.8-8 S01, additional information to demonstrate that the accident pressure + SSE + flooding during LOCA (used in design) bounds the post-LOCA flooding event with OBE; therefore, the applicant does not need to consider explicitly the post-LOCA flooding load combination with OBE.

The applicant submitted its response to RAI 3.8-8 S01. Based on its review of the supplemental information, the staff found that the applicant adequately demonstrated that the accident pressure + SSE + flooding during LOCA (used in design) bounds the post-LOCA flooding event with OBE; thus, the applicant does not need to consider explicitly the post-LOCA flooding load combination with OBE. Therefore, RAI 3.8-8 was resolved.

DCD Section 3.8.1.3 and Appendix 3B provide a limited description of the various hydrodynamic loads. Therefore, in RAI 3.8-9, the staff asked the applicant to describe the different subcategories for SRV discharge (e.g., single valve, two valve, ADS, and all valves) and for LOCAs (large, intermediate, and small), if applicable, and how they are treated in the load combinations discussed in DCD Section 3.8.1.3. The staff also requested a description and the basis for the method used to combine all the dynamic loads.

In its response to RAI 3.8-9, the applicant stated that LOCAs (large, intermediate, and small break) and SRV discharges (single valve first actuation, single valve subsequent actuation, and multiple valves) are discussed in the GEH Licensing Topical Report (LTR), NEDE-33261P, "ESBWR Containment Load Definition." The bounding pressure and temperature values are used respectively as accident pressure, P_a, and LOCA temperature, T_a, in load combinations for design. The RAI response provided a detailed description of the individual SRV and LOCA loads, explained which bounding loads the analyses considered, and described how they were treated in the load combinations in DCD Section 3.8.1.3.

The staff evaluated the applicant's response and identified the following five issues in need of further clarification:

(a) If NEDE-33261P indicates that the SRV has a range of 5 to 15 Hz, why does the analysis only consider a range of 5 to 12 Hz?

(b) Do the selected SRV frequency values of 6.06 and 8.83 Hz correspond to the fundamental natural frequencies of the structure in the vertical and horizontal direction, respectively?

(c) Provide a comparable description for selecting the appropriate forcing functions for the different LOCA loads (e.g., CHUG, CO, PS, annulus pressurization (AP), vent clearing).

(d) Since this is done to generate flood response spectra (FRS) throughout the building (not just local containment response), are there other structural natural frequencies that should be considered?

(e) The applicant provided a markup to 3.7 (first paragraph) where it states that the method for combining seismic and reactor building vibration loads for reinforced concrete structures varies the sign (+ or -), equivalent to absolute sum (ABS). This is acceptable for reinforced concrete structures. However, it also states that the method used (presumably for all other SSCs) is the SRSS method, in accordance with NUREG-0484, "Methodology for Combining Dynamic Responses," Revision 1, issued September 1978. This is acceptable for seismic plus LOCA; however, the criteria for combining other dynamic loads (e.g., SRV and individual LOCA loads (AP, PS, CO, CHUG, vent clearing) are not clearly defined. According to NUREG-0484, Revision 1, the use of SRSS for the other loads would require demonstrating that a nonexceedance probability (NEP) of 84 percent or higher is achieved. The DCD should clearly specify this criterion and address it.

The staff discussed the above items with the applicant during the December 2006 onsite audit, during which the applicant presented a draft supplemental response to this RAI. Based on the additional information, the staff concluded that Parts (a) through (d) are adequately addressed. For Part (e), the staff informed the applicant that it still needs to justify the use of the SRSS method. The applicant indicated that, in response to RAI 3.8-9 S01, additional information would be submitted to address Parts (a) through (e).

In its RAI 3.8-9 S01 response, the applicant stated the following:

(a) Frequency range of 5 to 15 Hz, as stated in the original response, was a typographical error. NEDE-33261P, page 6-5 specifies the bubble frequency range to be 5 to 12 Hz.

(b) Yes, 6.06 and 8.83 Hz are the fundamental frequencies of the structure in the vertical and horizontal directions respectively.

(c) Sixteen CHUG and five CO cases, as described in DCD, Tier 2, Subsection 3F.2.3 (4), cover the entire range of forcing functions, and there is no need to select specific structural frequencies.

(d) The dynamic analysis model includes all structures in the RB. The resulting natural frequencies of 6.06 and 8.83 Hz are the only structural frequencies within the SRV forcing frequency range of 5 to 12 Hz.

(e) ESBWR hydrodynamic loads are the same as the ABWR. The ABWR loads satisfy the 84-percentile NEP requirement of NUREG-0484, Revision 1 as shown in a GE memorandum that documents the applicability of the SRSS method for hydrodynamic loads.

The staff found that the applicant provided sufficient information to explain or justify the approach used regarding Parts (a) through (d). However, for Part (e), the staff could not confirm that the ESBWR hydrodynamic loads are the same as those of the ABWR. In addition, the memorandum attached to the response does not clearly explain that the NEP criteria were satisfied for the ABWR. Therefore, in RAI 3.8-9 S02, the staff asked the applicant to provide additional information to demonstrate that the combination of the ESBWR hydrodynamic loads (other than LOCA) satisfies the 84-percentile NEP requirement of NUREG-0484.

In its RAI 3.8-9 S02 response, the applicant stated that NEDE-33261P contains the ESBWR hydrodynamic load definitions and bases. These include the SRV loads, LOCA CO loads, and LOCA CHUG loads. The applicant developed the ESBWR load definitions based on the corresponding ABWR loads. The response explained, for each of these loads, how the specific, defined load bounds all future occurrences of the load with a confidence level that is greater than 84-percent NEP. The concern raised by the staff in the original RAI was not in demonstrating a confidence level of 84 percent when defining each individual load, but rather in the technical basis for combining multiple dynamic loads using the SRSS method. The SRSS combination method is acceptable for combining the structural responses from seismic plus LOCA; however, the criteria for combining other dynamic loads, such as SRV and individual LOCA loads (e.g., AP, PS, CO, CHUG, vent clearing) are not clearly defined. According to NUREG-0484, Revision 1, the use of SRSS (rather than the ABS method) for combining the other loads would require the applicant to demonstrate that it achieves an NEP of 84 percent or greater for the combined response as a result of multiple dynamic loadings considering the time-phase relationship. The conclusion section of NUREG-0484, Revision 1, clearly describes acceptable methods for achieving this goal. RAI 3.8-9 was being tracked as an open item in the SER with open items.

In its RAI 3.8-9 S03, S04, and S05 responses, the applicant stated that it performed a rigorous evaluation to justify ESBWR compliance with NUREG-0484, Revision 1, as the means for justifying the acceptability of using SRSS to combine the dynamic loads, other than SSE and LOCA. The applicant included the evaluation details in its report GE09-437024923-200, Revision 0, "Justification of SRSS Combination of Dynamic Responses for ESBWR," issued April 2009. The staff reviewed this report and concluded that it demonstrates that the criteria presented in NUREG-0484, Revision 1, were satisfied for the ESBWR plant design. Thus, the SRSS combination method is acceptable not only for combining the structural responses from seismic plus LOCA, as suggested in NUREG-0484, but also for combining other dynamic loads, such as SRV and individual LOCA loads (e.g., AP, PS, CO, CHUG, vent clearing). Therefore, RAI 3.8-9 and its associated open item were resolved.

DCD Section 3.8.1.3.6 describes the application of the 100/40/40 method for combining the codirectional responses caused by each of the seismic excitation components in accordance with ASCE 4-98. In RAI 3.8-10, the staff requested that the applicant confirm that its application of the 100/40/40 method for combining the directional responses is consistent with the staff-accepted method, as delineated in draft RG (DG)-1127, "Combining Modal Responses and Spatial Components in Seismic Response Analysis," issued for public comment in February 2005. If not, the applicant should provide the technical basis for the differences.

In its response to RAI 3.8-10, the applicant referred to RAI 3.7-41 for the same issue and stated that the 100/40/40 method is consistent with the DG-1127 guidance.

During the December 2006 audit, the staff noted that the applicant's implementation of the 100/40/40 method is not consistent with DG-1127 issued as RG 1.92, Revision 2, "Combining Modal Responses and Spatial Components in Seismic Response Analysis," in July 2006.

In its RAI 3.8-10 S01 response, the applicant referenced its response to RAI 3.8-107 S01, for resolution of this item. This issue will be addressed under RAI 3.8-107 in Section 3.8.5.3.4 of this report. Therefore, RAI 3.8-10 was resolved.

DCD Table 3.8-2 provides a tabulation of the load combinations, load factors, and acceptance criteria for the reinforced concrete containment. In RAI 3.8-115, the staff requested that the applicant review this table in light of the revisions to SRP Section 3.8.1, issued March 2007. Item 2 in Appendix A to SRP Section 3.8.1 takes exception to the load factors used for certain load combinations defined in ASME Code, Section III, Division 2, that include SRV loads and P_a (accident pressure loads). According to Appendix A, for the load combination that contains

1.5 P_a, a load factor of 1.25 should be applied to the SRV load. This would apply to load combination 7 in DCD Table 3.8-2. Also, for the severe environmental load combination, the load factor should be 1.3 for SRV, which is consistent with the practice of treating SRV as a live load. This would apply to load combination 4 in DCD Table 3.8-2. The staff asked the applicant to explain why it did not include these items, described in Appendix A to SRP Section 3.8.1, in DCD Table 3.8-2.

In its response to RAI 3.8-115, the applicant stated that it would revise the SRV load factor in DCD, Tier 2, Table 3.8-2, to 1.3 for load combination 4 and to 1.25 for load combination 7. The applicant provided the staff a markup of the proposed revision to DCD Table 3.8-2. The staff finds that the proposed revision to DCD Table 3.8-2 regarding the load factors for the SRV load is acceptable, on the basis that it is in accordance with the guidance presented in Appendix A to SRP Section 3.8.1. The staff verified that it incorporated the proposed markup changes in the response into the appropriate sections of the DCD. Therefore, RAI 3.8-115 was resolved.

In Appendix 3B of DCD Revision 4, the applicant deleted significant portions of information for the containment hydrodynamic load definitions that it used in the structural evaluations of the containment and its internal structures. In addition to deleting some important text information, the applicant removed all of the figures in the previous DCD Revision 3, Appendix 3B (Figures 3B-1 through 3B-11). The current text in Appendix 3B now refers to Reference 3B-1, NEDE-33261P and NEDO 33261) for the deleted information. The DCD should include descriptive information of the hydrodynamic loadings applied to the structural models, just as it includes seismic loading descriptions. This description should include some pressure distribution diagrams on the containment and its internal structures, representative pressure time histories, and the sequencing of loading events comparable to the figures deleted from DCD Revision 3. In RAI 3.8-119, the staff requested that the applicant clarify the definition of the containment's hydrodynamic loads that was deleted.

In its response to RAI 3.8-119, the applicant stated that the information contained in the text and figures in Revision 3 of DCD, Tier 2, Appendix 3B, is also contained in DCD, Tier 2, Reference 3B-1, which is LTR NEDE-33261P/NEDO-33261. To maintain consistency between DCD, Tier 2, Appendix 3B, and the LTR, the LTR includes all containment hydrodynamic load definition information. The applicant updated DCD, Tier 2, Reference 3B-1 to Revision 1 of the LTR, which it submitted to the NRC for review in MFN 07-563. The staff verified that the applicant incorporated the proposed markup changes in the response into the appropriate section of the DCD.

The staff reviewed LTR NEDE-33261P, Revision 2, to determine whether it could consider the applicant's response to RAI 3.8-119 to be acceptable. Essentially, the applicant's response to RAI 3.8-119 stated that the information about the hydrodynamic loading that was previously in DCD, Tier 2, Revision 3, Appendix 3B, was removed in DCD Revision 4, because it is contained in DCD, Tier 2, Reference 3B-1, which is LTR NEDE-33261P/NEDO-33261, dated October 2007. The staff noted that the RAI response proposed to revise Reference 3B-1 to reflect the updated Revision 1 of both reports, dated October 2007.

The staff' based its review of LTR NEDE-33261P on the most recent report—Revision 2, dated June not Revision 1, dated October 2007. The information presented in the Revision 2 report does contain the description of the various hydrodynamic loadings that it removed from DCD, Tier 2, Revision 3, Appendix 3B. The description provided in LTR Revision 2 includes pressure distribution profiles that the applicant applied to the containment and its internal structures, representative pressure time histories, and the sequencing of the hydrodynamic loading events, comparable to the information that it removed from DCD, Tier 2, Revision 3, Appendix 3B. The information provided in LTR NEDE-33261P, related to the application of the hydrodynamic loadings to structures, is consistent with the dynamic analysis methodologies and criteria presented in various sections of SRP 3.7 and 3.8, as well as industry methods. The staff therefore found this acceptable. However, the staff's requested that the applicant revise DCD, Tier 2, Reference 3B-1 to reflect the current updated Revision 2 of NEDE-33261P/NEDO-33261. The staff verified that the applicant incorporated the proposed DCD markup revisions presented in the RAI response into DCD, Tier 2, Revision 6, Appendix 3B. Therefore, RAI 3.8-119 was resolved.

In addition to its review of loads and load combinations in accordance with SRP 3.8.1, the staff also evaluated compliance with NUREG-0933, "Resolution of Generic Safety Issues," issued August 2008; in particular, Generic Issue B-6, "Loads, Load Combinations, Stress Limits," and New Generic Issue 156.6.1, "Pipe Break Effects on Systems and Components," as discussed below.

a) Generic Issue B-6 concerns the design of pressure vessels and piping systems components, which must be designed to accommodate individual and combined loads due to normal operating conditions, system transients, and postulated low probability events (accidents and natural phenomena). This issue was further amplified in recent years because postulated large LOCA and SSE loads were each increased by a factor of 2 or more to account for such phenomena as asymmetric blowdown and because better techniques for defining loading have been developed.

   The effort to investigate and establish a position on dynamic response combination methodology was completed and Appendix A to SRP Section 3.8.1, Revision 2, provides an acceptable staff position for load combination of seismic loads and LOCA and SRV loads on containment structures. Load combination requirements related to piping rupture and decoupling of seismic and LOCA loads are addressed in Generic Issue 119.1.

   For containment structures, the review criterion for the resolution of Issue B-6 is conformance with the load combination criteria of Appendix A to SRP Section 3.8.1, Revision 2. In DCD, Tier 2, Revision 7, Section 1.11, the applicant specified compliance of the ESBWR standard plant design with SRP Sections 3.8.1.3, 3.8.2.3, 3.8.3.3, 3.8.4.3, and 3.8.5.3, which reference Appendix A to SRP Section 3.8.1 for combination of dynamic loads, as the basis for resolving Issue B-6. Sections 3.8.1, 3.8.2, 3.8.3, 3.8.4, and 3.8.5 of this report discuss the staff's review of the corresponding DCD, Tier 2, Sections. Based on its evaluations, the staff concluded that the ESBWR design was consistent with the guidelines in Revision 2 to SRP Sections 3.8.1, 3.8.2, 3.8.3, 3.8.4, and 3.8.5. Therefore, Issue B-6 was resolved for the ESBWR design.

b) New Generic Issue 156.6.1 concerns the effects of pipe breaks on systems and components inside and outside of the containment structure. In particular, this includes the specific structural and environmental effects of pipe whip, jet impingement, impact, flooding, etc., on systems and components relied on for safe reactor shutdown. In DCD, Tier 2, Revision 7, Section 1.11, the applicant indicated that seismic Category I structures were designed to withstand the loads resulting from the dynamic effects of pipe breaks. It also indicated that DCD, Tier 2, Section 3.8.1.3.5 defines the specific design loads resulting from pipe breaks considered in the design of the containment and its internal structures, while DCD, Tier 2, Section 3.8.4.3.1 defines design loads affecting the RB structure. Sections 3.8.1 and 3.8.4 of this report discuss the staff's review of the corresponding DCD Tier 2, Sections.

As discussed in NUREG-0933, a technical assessment of Issue 156.6.1 was undertaken by the staff in 2007, which recommended that it could be closed with no further action. The Issue was closed in December 21, 2007. Therefore, Issue 156.6.1 was resolved for the ESBWR design.

3.8.1.3.4 Design and Analysis Procedures

DCD Sections 3.8.1.4 and 3G.1 describe the design and analysis procedures used for the concrete containment. The RCCV is included in the FEM described in DCD Sections 3.8.1.4.1.1 and 3G.1.4. The FEM includes the entire RB, the RCCV, the containment internal structures, and the FB. The model uses quadrilateral, triangular, and beam elements to represent the various structural components. It uses beam elements to represent the columns and beams and springs to represent the foundation soil. The applicant applies various loads to this model to obtain member loads for use in design. The design is based on the elastic method. The staff has determined that, in general, these procedures are acceptable, because they are consistent with the design and analysis procedures given in SRP Section 3.8.1.II.4. However, the staff noted some areas that differed and some that required further clarification. These areas are discussed below.

Appendix C to the DCD describes various computer codes used by the applicant for the analysis and design of containment and other seismic Category I structures. To ensure that all computer codes have been properly validated, the staff requested, in RAI 3.8-12, that the applicant provide the following information:

(a) Identify which codes have already been reviewed by the NRC for prior plant license applications. Include the name, version, and prior plant license application. This will minimize the review effort needed during the audit.

(b) Confirm that the following information is available for each computer program, for staff review during the audit: the author, source, and dated version; a description, and the extent and limitation of the program application; a description of how the computer program has been validated; and the user manuals. For those programs that are not widely recognized and in the public domain, more detailed information (including a summary comparison) is expected, in order to demonstrate that the computer program solutions to a series of applicable test problems are similar to solutions obtained by alternative means, such as hand calculations, analytical results published in the literature, and/or other similar computer programs.

During the onsite audit on July 11–14, 2006, the NRC team reviewed Shimizu Report S/VTR-SD2, "Validation Test Report for SSDP-2D Version 0." The SSDP-2D computer program sizes the necessary reinforcement for concrete structures. Based on this review, the audit team identified the following additional information that the applicant should provide for SSDP-2D:

1. The SSDP validation report does not explain how SSDP-2D flags stresses above the allowable. The applicant agreed to establish a post-processing procedure for SSDP-2D calculations. The applicant outlined the procedure during the audit, and indicated that it would be documented as part of the RAI response.

2. The SSDP validation report does not explain the way radial and hoop rebar spacing is calculated when the same element includes both rectangular and polar reinforcing patterns. The applicant agreed to address this issue in a revision to the SSDP-2D validation report.

Following the July 2006 audit, the staff submitted a new RAI (RAI 3.8-107) that specifically addresses its concerns regarding SSDP-2D.

In its response to RAI 3.8-12, the applicant stated the following:

a. Among all computer programs described in DCD Appendix 3C, NASTRAN, ABAQUS and ANSYS are commercially available programs. The applicant has no knowledge as to whether or not they have already been reviewed by the NRC during prior plant license applications. The ANACAP-U software, which is a concrete and steel constitutive model for ABAQUS, is written and maintained by ANATECH Corp., San Diego, California. To the best of our knowledge, ANACAP-U has never been reviewed by the NRC as part of a plant license application. However, the ABAQUS/ANACAP-U software combination has been used in many structural investigations and research projects on nuclear structures, including sponsorship by the NRC, DOE, and EPRI [Electric Power Research Institute]. It has also been used in evaluation of other critical infrastructure projects for the U.S. Army Corps of Engineers and State Departments of Transportation.

b. Validation packages for SSDP-2D, DAC3N and TEMCOM2 were provided in response to RAI 3.7-55. The SSDP-2D validation package will be revised in response to RAI 3.8-107, which is a new RAI identified after the staff's July 2006 on-site audit of DCD Section 3.8.

The staff finds the applicant's response to be acceptable for the ANSYS, ABAQUS/ANACAP-U, and NASTRAN computer programs identified in Appendix C to the DCD, on the basis that these computer codes are commercially available programs and the staff is familiar with their applications. The staff reviewed the validation package for TEMCOM2, which is a two-dimensional heat transfer analysis code, and found it to be acceptable. The staff reviewed the validation package for the DAC3N code as part of its review of DCD Section 3.7, under RAI 3.7-55. The staff's review of the SSDP-2D code is being tracked and documented under RAI 3.8-107 in Section 3.8.5.3.4 of this report. Since there are no other outstanding issues, RAI 3.8-12 was resolved.

In RAI 3.8-13, the staff requested that the applicant provide the following information for the soil springs used in the containment and RB model (DCD Section 3.8.1.4.1.1 and Appendix 3G):

(a) Explain why the foundation soil springs for rocking and translation are determined based on soil parameters corresponding to the "Soft Site" conditions for seismic and other loads. Include a discussion of the conservatism of this assumption and the basis for the conclusion.

(b) Explain how the soil springs for the non-seismic loads were determined. If the springs are modeled as having perfectly elastic stiffness, then explain why these stiffness values are so much smaller than the seismic soil springs.

In its response to RAI 3.8-13, the applicant stated the following:

(a) The deformations of buildings are greater for the case of soft soil than for hard rock. Therefore, it leads to larger section forces for member design. Hence, the soft soil condition is used. Note that the enveloped seismic loads of all soil cases, as described in DCD Section 3A.9, were conservatively applied to the soft soil condition.

(b) The pressures acting on the foundation soil in the vertical direction differ in character between horizontal earthquake loads and other loads. When horizontal earthquake loads are excluded, vertical pressures are produced according to the force in the vertical direction, and the foundation soil resists them by the vertical stiffness of the soil springs. For this reason, vertical soil springs are estimated based on the stiffness of the vertical soil spring used in the vertical seismic analysis. On the other hand, for the horizontal seismic loads, vertical pressures are produced due to overturning moments, and the foundation soil resists them by its rotational rigidity. So, the vertical soil springs (under horizontally induced seismic loads) are estimated based on the stiffness of the rotational soil spring used in seismic response analysis. The inherent rotational stiffness of the soil is larger than its vertical stiffness which explains why the soil spring stiffnesses are larger in the seismic case, compared to the nonseismic case.

During the staff's onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, CA, the staff discussed in greater detail the technical basis for calculating foundation soil springs using the soft soil conditions for seismic and other loads. During the audit, the applicant presented the results of a study that compared the basemat deformation and basemat moments for soft soil and hard rock springs, for the load combination of D + LOCA (accident pressure) + SSE. The comparison showed that the maximum moments across the mat for the soft soil springs are larger than the maximum moments for the hard rock springs. However, the audit team observed a small uplift on the south side of the mat. This raised a question about the use of soil springs having tensile forces in this region. The audit team requested that the applicant address this issue and determine whether the release of these tensile springs would cause the region of springs in tension to grow. The applicant agreed to rerun the analysis without the soil springs in the area that showed uplift to demonstrate that this effect is not significant. This additional information would be included in the response to RAI 3.8-13 S01.

The staff also raised a question about the potential variation of the soil spring constants in the horizontal direction. Since the DCD does not require the COL to meet criteria for horizontal variation in the soil properties, the applicant indicated that it would evaluate the effects of imposing a deformation on the RB/FB foundation mat caused by a horizontal variation in the soil properties. RAI 3.8-93 addresses the issue of horizontal variation of soil springs.

In its RAI 3.8-13 S01 response, the applicant formally submitted the results of the study comparing the basemat design for soft soil and hard rock conditions for dead load and seismic loads in the north-south (N-S) and vertical directions. The applicant explained that these results demonstrate that the basemat deformation for the soft soil condition is much larger than that for the hard rock condition. As for bending moments, the magnitudes for the soft soil are generally larger than for the hard rock condition. The higher bending moments at a few locations for the hard rock site have no impact on the design, since they are much less than the maximum moments of the soft soil site, which is the basis for rebar sizing. Therefore, the applicant concluded that the basemat design envelops the worst conditions.

The RAI 3.8-13 S01 response also provided the results of the followup study to address the issue of vertical soil springs in tension. The applicant used an iterative approach whereby any springs in tension were released in a subsequent iterative analysis until no soil springs remained in tension. The results of this study show that, when the tensile springs are removed, the deformations are somewhat larger than those obtained in the design-basis analysis. The applicant indicated that, in the area close to the RCCV wall, bending moments are higher than those obtained in the design-basis analysis; however, the resulting stresses in the concrete and reinforcement are still below the code allowables with large margins, as noted in the response.

In its RAI 3.8-13 S02 response, the applicant expanded the uplift study on soil springs in tension to include all three seismic-loading directions (N-S, east-west (E-W), and vertical) and other loads. The previous study only evaluated the seismic loading in the N-S direction. As reported in the earlier study, in the area close to the cylindrical wall below the RCCV wall, bending moments are higher than in the design-basis analysis; however, the resulting stresses in the concrete and reinforcement are still below the code allowables with large margins.

On the basis of its review of the applicant's responses, the staff concluded that the DCD design-basis analysis using the soft soil case and allowing a small region of the soil springs to remain in tension is acceptable. There are some locations in which the resulting stresses are higher; however, these values are still well below the allowables and, therefore, are considered acceptable. The staff also agrees that enveloping the seismic member forces for the varying soil conditions from the seismic stick model and applying them to the NASTRAN model provides some additional conservatism. Since some of the loads were higher as a result of this study, the staff indicated that the applicant should revise the DCD to describe the study and its results.

In its RAI 3.8-13 S03 response, the applicant submitted proposed changes to the DCD that describe the study and results for the soft soil versus hard rock conditions and for the potential uplift resulting from seismic loads. The staff found the proposed changes to be acceptable and confirmed that they have been incorporated into Sections 3.8.5.4 and 3G.1.5.5.1 of DCD Revision 3.

The remaining issue related to RAI 3.8-13 is the effect of horizontal variation of soil spring constants. RAI 3.8-93 in Section 3.8.5.3.4 of this report addresses this issue. Therefore, RAI 3.8-13 was resolved.

DCD Section 3G.1.5.2.1.6 describes thermal loads for normal operating conditions and abnormal loading conditions, and Table 3G.1-6 presents the equivalent linear temperature distributions at various sections. In RAI 3.8-14, the staff requested that the applicant address the following two items related to thermal loadings:

a. Even though equivalent linear temperature distributions are tabulated in DCD Table 3G.1-6, explain how nonlinear temperature gradients (e.g., SRV discharge or accident temperatures) through the containment wall are considered. This should include a description of the nonlinear temperature effects on the concrete, liner, and liner anchors.

b. Temperature values in DCD Table 3G.1-6 are presented for "Winter." Indicate whether temperature distributions are considered for other times of the year as well; if not, then explain.

In its response to RAI 3.8-14, the applicant stated the following:

a. The evaluation method of temperature effect on the concrete design is based on ACI 349-01 Commentary Figure RA.1. The equivalent linear temperature gradient is determined such that it produces the same uncracked moment about the center line of the section as does the nonlinear temperature distribution. Constant temperature distributions are considered for the thin liner and liner anchors.

b. Among all seasons of the year, winter and summer have the most extreme variation in temperatures and they are therefore selected for design conditions for environmental temperature loading. Sectional moments in concrete structures for the winter conditions are, in general, larger than those for the summer considering the temperature differences between room and exterior or inside and outside RCCV. Therefore, only the controlling "winter" case is presented in the DCD.

The applicant indicated that it would revise DCD Appendix 3G.1.5.2.1.6 in the next DCD update and provided a markup of the proposed change.

During its onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, CA, the staff discussed the requested information in further detail with the applicant. For Part (a), the applicant indicated that it evaluated the nonlinear temperature distribution through the thickness, using the approach in ACI 349-01, Commentary Figure RA-1. The temperature applied to the liner is the temperature of the containment's internal atmosphere. The temperature used to select the steel material properties is the temperature of the inside containment atmosphere, and the temperature used to select the concrete material properties is the average temperature through the thickness, based on the equivalent linear temperature distribution. For Part (b), the applicant clarified that all seasons did not have to be analyzed because winter and summer have the most extreme variation in temperatures and are therefore selected for design conditions for environmental temperature loading. Since the sectional moments in concrete structures for the winter conditions are, in general, larger than those for the summer, the DCD presents only the controlling "winter" case. Temperature distribution used in the ABAQUS/ANACAP model to evaluate LOCA thermal load effects does consider the actual nonlinear temperature distribution (see the discussion associated with RAI 3.8-19). The topics discussed during the audit were addressed by the applicant in response to RAI 3.8-14 S01.

In its RAI 3.8-14 S01 response, the applicant provided additional information on thermal loading as follows:

a. Item 31 (RG 1.142) and Item 33 (RG 1.199) of Table 3.8-9 will be added in DCD Section 3.8.1.2.3 in the next update as noted in the attached markup. ACI 349-01 will be called out in DCD Section 3.8.1.2.2 by reference to Table 3.8-9 item 1 in the next update.

b. In the global stress analysis model, walls, slabs, and liner plates are modeled using quadrilateral or triangular shell elements as described in DCD Appendix 3G.1.4.1. The RCCV liner plate is thin with relatively large heat conductivity. The surface heat transfer coefficients for the inside RCCV are set to be infinite for the LOCA conditions. Therefore, the temperatures of the liner plates are assumed to be the same as atmospheric temperatures to which the liners are exposed in the thermal analysis. In the thermal stress analyses, average temperature and temperature gradient evaluated according to the method shown in ACI 349-01 Commentary Figure RA.1 are applied to a concrete element. Reductions of material properties that are described in DCD Appendix 3G.1.5.2.3.1 are determined based on the average temperature of the concrete element.

The staff reviewed the RAI 3.8-14 S01 response and found Part (a) to be acceptable, because the approach used by the applicant is based on ACI 349-01, Commentary Figure RA.1, which is a well recognized and accepted method of determining the equivalent temperature distribution through the thickness of reinforced concrete walls. For the thermal analyses discussed in Part (b), it was not clear to the staff that using constant thermal properties (e.g., strength and E), based on the average temperature through the thickness of the concrete material, is appropriate or conservative.

In its RAI 3.8-14 S02 response, the applicant described a study that evaluated two cases consisting of material properties based on the average uniform temperature and a case that used an equivalent linear variation in material properties corresponding to the temperature distribution through the thickness of the wall. The applicant compared the axial forces and bending moments from the two cases. The results show that these forces were larger for the case of material properties, based on the average uniform temperature distribution.

The staff determined that the applicant's RAI 3.8-14 S02 response adequately addressed its questions on Part (b) and is acceptable. The staff based this conclusion on the study performed by the applicant that demonstrated that the concrete member forces for a representative section were larger when using constant material properties based on the average temperature than when using the material properties based on a linear temperature gradient across the concrete section. The applicant used the approach described in ACI 349-01 to represent the nonlinear temperature gradient as an equivalent linear temperature gradient. Therefore, RAI 3.8-14 was resolved.

DCD Section 3.8.1.4.1.1, Appendix 3B, and Appendix 3G describe the hydrodynamic loads and how they are used in the analysis of the containment structure. In RAI 3.8-15, the staff requested that the applicant provide additional information to explain how all of the pressure loads acting on the containment and internal structures are calculated and applied to the containment. This information should explain how the applicant applied axisymmetric and nonaxisymmetric loads and how it considered variations in pressure definition parameters (e.g., phasing of maximum pressure on different pool boundary locations, DLF, variation in loading function frequencies). The description should include pressures associated with normal operating and accident pressures, as well as SRV actuations. The staff asked the applicant to explain whether negative pressure loads on the containment could occur and whether upward pressure loading on the DF could develop under any conditions. Appendix 3B should be expanded to include this information. The applicant presented some information in Appendix 3B; however, it appears that much of the description is applicable to response spectra generation using a different model than the NASTRAN FEM.

In its response to RAI 3.8-15, the applicant stated that Figures 3.8-15(1), 3.8-15(2), and 3.8-15(3) show the transient pressure envelopes at DBA, the areas subject to differential pressure between the RB and containment, and areas subject to differential pressure between the drywell and wetwell. Table 3.8-15(1) shows the load combination for design pressure loads. This table shows four load phases considered critical cases for design. The DCD presents two of these cases (e.g., 6 minutes and 72 hours after LOCA). The DLF is not considered for the pressure loads.

The applicant uses the information for hydrodynamic loads presented in DCD Figures 3G.1-21 through 3G.1-23, and a DLF of 2, for SRV, CO, and CHUG to cover the variation in loading function frequencies. The use of a DLF of 2 is believed to be conservative, which will be confirmed by dynamic analysis in the detailed design phase. Only the axisymmetric loads (both positive and negative cases) are considered, since they are more severe than nonaxisymmetric loads. Figure 3.8-15(4) depicts the method of load application to the finite element.

A differential pressure of –20.7 kPa differential (kPad) (–3.0 psi differential (psid)) is generated in the RCCV as a result of steam quenching after a break caused by drywell spray actuation. The DF and vent structure are subject to this differential pressure acting from the wetwell to the drywell. It is combined with CHUG in the load combination. As presented in the containment load definition (NEDE-33261P), the DF is only subjected to downward pressure differential loading during the PS phase.

As for internal structures, the pressure loads acting on them are the same as for the RCCV. In addition, AP loads, including pressure on the inner surface of the RSW, nozzle jet, impingement jet, and pipe whip restraint loads, are applied as nonaxisymmetric loads. GEH Report DE-OG-0077, Revision 0, “AP Load Evaluation for RSW Model Input Data,” issued July 2006, describes the application of AP load. This report also discusses how the dynamic response of the RSW to AP loads is calculated. The DF slab is designed to the downward pressure of 241.5 kPad (35 psid). The DF slab is also subjected to an upward pressure of 20.7 kPad (3 psid), as shown in Figure 3.8-15(3). It does not control the design of the DF slab.

Regarding the VW structure, the pressure loads acting on its outer surface are the same as the wetwell portion of the RCCV, and those acting on the inner surface of it are the same as the drywell portion of the RCCV.

The staff discussed the response with the applicant during the December 2006 onsite audit and inquired as to whether the curve for the wetwell in Figure 3.8-15(1) should continue up to 100 hours. The staff also requested an explanation of the basis for concluding that (1) the axisymmetric loads are more severe than the nonaxisymmetric loads, and (2) the nonaxisymmetric loads did not need to be considered. The staff also inquired as to whether a COL action item exists to confirm, in the detailed design phase, that the DLF of 2 will adequately account for a variation in loading function frequencies and dynamic amplification. During the audit, the applicant presented a draft supplemental response to address the first and third items and noted that it addressed the second item under RAI 3.8-46. The topics discussed during the audit were addressed by the applicant in response to RAI 3.8-15 S01.

In its RAI 3.8-15 S01 response, the applicant stated the following:

> In Figure 3.8-15 (1), the curve for the WW coincides with the curve for the DW between 10 hours and 72 hours. For the discussion about non-axisymmetric loads, please see the response to RAI 3.8-46 S01.
>
> The DLF of 2 is the ESBWR structural design basis for hydrodynamic loads. It has been confirmed to be adequate by comparing static and dynamic results. Therefore, it is not necessary to provide a COL Action item in the DCD as suggested.

The staff determined that the applicant's RAI 3.8-15 S01 response provides the additional technical information needed to describe the hydrodynamic pressure loadings and is acceptable. The staff also reviewed the applicant's response to RAI 3.8-46 S01 and found it acceptable to justify the decision that the axisymmetric loads are controlling. Therefore, RAI 3.8-15 was resolved.

DCD Section 3G.1.5.4.2 explains how the seismic analysis considers water in the various pools. In RAI 3.8-16, the staff requested that the applicant provide additional information by describing how it considered the dynamic fluid effects (water mass, fluid-structure interaction, sloshing) associated with the SP, other pools, and water above the drywell head in the model development, analysis, and design of the containment and RB, subjected to the various dynamic loading events.

In its response to RAI 3.8-16, the applicant stated that the design of the containment and buildings considers two kinds of dynamic fluid effects. One is hydrodynamic loads of the SP water, and the other is sloshing loads resulting from earthquakes. The applicant followed the approach described in ASCE 4-98, together with the discussions given in Brookhaven National Laboratory (BNL) Report 52361. (See also the response to RAI 3.7-53.) The applicant referenced GEH Report DC-OG-0053, Revision 2, "Structural Design Report for Containment Internal Structures," issued October 2005, which contains the evaluation method and results for structural integrity of containment internal structures, and GEH Report 26A6651, Revision 1, "RB Structural Design Report," issued November 2005, which contains the structural design details of the RB.

The staff reviewed the resolution of RAI 3.7-53. The staff concluded that the technical approach described in the applicant's response to RAI 3.8-16 and the technical information presented in DCD Sections 3.7.3.15 and 3.8.1.4.1, and Appendix 3G are consistent with the guidance provided in SRP Section 3.7.3. Therefore, the staff considers the approach acceptable for the evaluation of dynamic fluid effects. However, the staff planned to evaluate the applicant's implementation by auditing GEH Report 26A6651.

During an audit at the applicant's offices in Wilmington, NC, on May 16–17, 2007, the staff reviewed GEH Report DC-OG-0053, Revision 3, dated March 30, 2007, and GEH Report 26A6651, Revision 2, dated March 27, 2007 (see audit report…). These reports describe how the analytical models included the water fluid effects. The description covers how the water mass and fluid-sloshing pressure loads were considered for the various pools. The staff concluded that the approach used is technically acceptable and consistent with the criteria presented in DCD Revision 3, Sections 3.7.3.15 and 3.8.1.4.1, and Appendix 3G. Therefore, RAI 3.8-16 was resolved**.**

DCD Section 3.8.1.4.1.1.3 states that the applicant used numerical analytical techniques to determine the state of stress and behavior of the containment around the openings at major penetrations. DCD Section 3.8.2.1.3 also states this and adds, “The analysis of the area around the penetrations consists of a three-dimensional FE analysis with boundaries extending to a region where the discontinuity effects of the opening are negligible.” In RAI 3.8-17, the staff requested that the applicant describe these analyses, including figures of the FEMs, identification of the loading conditions, the types of analyses conducted, a summary of the results of the analyses, and a comparison to ASME Code acceptance criteria. The staff requested that this information be included in DCD Section 3.8 or Appendix 3G, or both.

In its response to RAI 3.8-17, the applicant stated that Figure 3.8-17(1) is a flow chart for the design of RCCV wall penetrations. This flow chart is the same as DCD, Tier 2, Figure 3G.1-39, “Flow Chart for Structural Analysis and Design,” with the following exceptions—(1) stress analyses are performed using a local FE analysis model, which includes the local area around the opening, (2) in the local FE analysis model, displacements that are obtained from the RB/FB global model stress analyses are prescribed to the boundary nodes to consider the constraints of items not included in the model, and (3) local loads that are not considered in the analysis of the global model are considered, if necessary.

Figure 3.8-17(2) is a sketch showing reinforcements in the RCCV wall around a large opening. The area around the opening is reinforced by main hoop and vertical reinforcing bars and additional bars, which are required to resist concentrated stresses around the opening. Additional diagonal bars add reinforcement in the areas where hoop and vertical bars are terminated. The applicant referenced GEH Report SER-ESB-045, Revision 0, “Design Report for RCCV Wall around UD Personnel Airlock Opening,” which contains the calculations of the containment around an opening.

The staff determined that the applicant did not provide some of the information requested in the RAI, particularly those figures showing the FEMs, a summary of the types of analyses, a summary of results of the analyses, and a comparison to the ASME Code acceptance criteria. The applicant should have performed a representative design for one or more major penetrations; thus, this information should be available. However, Figure 3.8-17(2) has a note indicating that the amount of required reinforcements around the opening will be determined in the final design calculations. The staff asked the applicant, in RAI 3.8-17 S01, whether it considered this a COL action item, to be reviewed by the staff at a future date, since the analysis and design are not complete.

In its RAI 3.8-17 S01 response, the applicant stated that it made detailed design calculations of the containment around the UD personnel airlock opening as follows:

(1) The detail of the local FEM of the RCCV wall around the opening is shown in Figure 3.8-17(3). The model is composed of the concrete wall, the steel liner plate and the steel opening sleeve. The concrete wall and steel liner plate are modeled by SHELL elements, and the opening sleeve is modeled by ROD elements. Because the analysis model is the local FEM of the RCCV, the boundary conditions are applied at the periphery of

the model and at the connections with the surrounding slab and wall as shown Figure 3.8-17(4). The enforced displacements calculated from the RBFB global FEM analysis results are applied to the nodes shown in Figure 3.8-17(4) at the boundary conditions.

(2) Displacements for several loads at the sections illustrated in Figure 3.8-17(5) are shown in Figures 3.8-17(6) through 3.8-17(9). Figures 3.8-17(11) through 3.8-17(14) show the element forces and moments at the sections shown in Figure 3.8-17(10). Element forces and moments illustrated in the figures are defined in relation to the element coordinate system shown in Figure 3.8-17(15).

(3) Element forces and moments of individual loads were combined in accordance with the load combinations shown in Table 3.8-17(1) for section design calculations. Figures 3.8-17(16) through 3.8-17(18) show typical sections of the RCCV wall around the UD Personnel Airlock Opening. Primary reinforcements are arranged orthogonally in two directions in each section. In addition, diagonal reinforcements are arranged at four corners.

(4) Based on the rebar arrangement shown in Figures 3.8-17(16) through 3.8-17(18), stresses in the RCCV wall around the opening were evaluated. The calculated stresses are less than the allowable values specified in ASME Code, Section III, Division 2, Subsection CC-3000. A representative sketch of the reinforcement around equipment hatch/personnel airlock openings will be added to DCD Tier 2 as Figure 3.8-2 as stated in the response to RAI 3.8-3 S03.

The staff's review of the figures provided in the RAI 3.8-17 S01 response, which present the element forces and moments in the local FEM, show a sudden change in response in some cases. As an example, the plot of moment versus elevation in Section A-A, presented in Figure 3.8-17(12), shows sudden changes in magnitude from approximately -8 to -10 to +5 meganewton-meter per meter width (MNm/m) over a change in elevation from about 16.5 to 17 to 17.5 m. The applicant should explain this sudden change in element forces and determine whether it indicates a modeling error or insufficient refinement of the FE grid. In addition, as originally requested in the RAI, the DCD should be updated to include a description summarizing the analysis, a figure showing the local FEM, and figure(s) showing the reinforcement details, as provided in the applicant's RAI response. RAI 3.8-17 was being tracked as an open item in the SER with open items.

In its RAI 3.8-17 S02 response, the applicant stated that, in the analysis model shown in Figure 3.8-17(4) of the RAI 3.8-17 S01 response, the nodes at Elevation 17,200 are located on the boundary of the drywell and wetwell. Therefore, loading conditions of the regions above and below the boundary are different. In addition, the nodes at Elevation 17,200 are constrained by the surrounding floor slab and the DF slab in the RB/FB global FEM. To reproduce the constraints, enforced displacements obtained from the global model analyses are applied to the nodes in the detailed model analyses, as described in the response to RAI 3.8-17 S01. Sudden changes in element moment M_y, shown in Figure 3.8-17(12) of the applicant's response to RAI 3.8-17 S01, are the result of discontinuities in loadings and constraints by surrounding structures. The element widths in the regions of interest are around 600 mm, and the size is sufficiently small, compared with the RCCV wall thickness of 2,000 mm.

The applicant further stated that it based the calculations described in the response to RAI 3.8-17 S01 on the seismic loads developed in DCD, Tier 2, Revision 2. The applicant updated the local penetration reinforcement details with the seismic loads considered in the latest global FE analysis. The staff determined that the applicant adequately explained the sudden change in element forces in the local FEM. The staff also verified that the applicant incorporated the proposed markup changes in the response into the appropriate sections of the DCD. Therefore, RAI 3.8-17 and the associated open item were resolved.

In RAI 3.8-18, the staff requested that the applicant describe how it represented the reinforced concrete containment shell and basemat material and stiffness properties in the shell FE NASTRAN model (e.g., monolithic concrete properties with Young's modulus, thickness, Poisson's ratio, and density corresponding only concrete, neglecting the steel). For pressure, thermal, seismic, and hydrodynamic loads, the staff asked the applicant to explain how the NASTRAN overall building analysis considered the effects of concrete cracking. If the concrete stresses are very low for some loading combinations, there may still be regions where cracking in the concrete develops as a result of the containment SITs, thermal loads, and pressure loads.

In its response to RAI 3.8-18, the applicant stated that concrete properties for the containment shell and basemat material include all those stated, and they are considered to be linear elastic in the NASTRAN model, as described in DCD Section 3.8.1.4.1.2. Reinforcing steel is not explicitly modeled, and its weight is included in the overall reinforced concrete density. As allowed in ASME Code, Section III, Division 2, Section CC-3320, the NASTRAN calculations do not explicitly consider concrete cracking. However, the design of the cross section using the SSDP-2D computer program does consider cracking, as described in DCD Section 3.8.1.4.1.2, and does not allow tensile stress in the concrete. Section forces generated by NASTRAN are input to the SSDP-2D program. This procedure is used for all loads except LOCA thermal loads. The concrete-cracking effects for LOCA thermal loads are explicitly included by performing a nonlinear concrete-cracking analysis using ABAQUS/ANACAP software, as described in DCD Section 3.8.1.4.1.3.

During its onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, CA, the staff discussed the requested information in further detail. The applicant indicated that, for the seismic stick model, which provides the loads for the NASTRAN model, it assessed the effect of concrete cracking by reducing the shear stiffness. For the LOCA thermal temperature assessment, the ABAQUS/ANACAP model does consider the effect of concrete cracking. For the design of individual structural members, the cracking of concrete is considered using the computer code SSDP. The remaining concern lies with the effect of cracking on the building response analysis and the redistribution of member forces.

The applicant presented supplemental information on concrete cracking from the NASTRAN model for the SIT pressure loading. It showed that, with few exceptions, the tensile stress is less than the ACI 349-01 value of $4\sqrt{f'c}$ (= 282 psi), where f'c is the compressive strength of concrete. The staff noted that ACI 349-01 refers to this criterion as principal stress, while the tabulated SIT stresses are normal stresses (membrane + bending in the x direction and in the y direction). The applicant agreed to revise its response to calculate principal stresses for critical locations. The staff also noted that, even if the above containment principal stresses caused by SIT pressures are shown to be less than the tensile strength referenced above, the shear stiffness of concrete walls generally should consider an appropriate reduction, based on past tests and industry methods.

The staff inquired about the accuracy of the NASTRAN model compared to the seismic stick model. The applicant presented limited results from the Lungmen project (related to the ABWR), which compared the natural frequencies between the seismic stick model and the FEM. The frequency comparison table from the Lungmen project shows that the fundamental frequencies in the N-S and E-W directions for the seismic stick model are comparable to those for the FEM.

The above topics discussed during the July 11–14 2006 onsite audit were addressed by the applicant in its response to RAI 3.8-18 S01.

In its RAI 3.8-18 S01 response, the applicant referred to its response to RAI 3.7-59, where it addressed a staff request for a comparison of the seismic stick models to the static NASTRAN models.

The applicant further stated that, to justify the use of a linear elastic NASTRAN model without considering internal force and moment redistribution caused by concrete cracking, it examined the NASTRAN results for the SIT condition. The maximum concrete tensile stresses in the RCCV elements, which are listed in DCD Appendix 3G, are calculated for the SIT load combination, and calculated stresses are compared to the tensile strength of concrete. The tensile strength of concrete is evaluated using the following equation, taken from P.M. Ferguson, Reinforced Concrete Fundamentals, Third Edition, Section 1.3, John Willey & Sons:

$$f_{ct} = 0.1(f'_c),$$

where f'_c = compressive strength of concrete (34.5 MPa, except 27.6 MPa for the basemat).

The results from this evaluation show that the tensile stresses exceed the tensile strength only in a few elements. Therefore, very little cracking occurs in the concrete for the SIT condition. Since the concrete containment remains uncracked after the preservice SIT tests, the use of the elastic NASTRAN model for design analysis is justified. For seismic loads, concrete cracking is considered by overall stiffness reduction in the seismic analysis stick model. Thus, the resulting seismic design loads applied to the NASTRAN stress analysis model include the concrete-cracking effect.

The staff discussed the RAI 3.8-18 S01 response with the applicant during the December 2006 onsite audit. The staff observed that (1) only SIT was considered, and not other loads in the applicable load combinations, (2) the principal tensile stresses were calculated in the principal membrane force direction and in the principal bending moment direction, which may not give the maximum principal stresses, (3) the principal tensile stresses in Tables 3.8-18(2) and 3.8-18(3) are lower than those in Table 3.8-18(1), and (4) the maximum shear stresses from the worst loading combination would be useful to help resolve this issue. ASCE 4-98 notes that nominal shear stresses are usually shown to be below 690 kPa (100 psi) for uncracked concrete; NUREG/CR-5407, “Assessment of the Impact of Degraded Shear Wall Stiffnesses on Seismic Plant Risk and Seismic Design Loads,” issued February 1994, refers to concrete cracking under SSE with shear stresses below 1035 kPa (150 psi). As discussed in the ASCE report on the stiffness of low-rise reinforced concrete shear walls, variations in concrete properties are often used to account for potential concrete cracking. The topics discussed during the audit were addressed by the applicant in response to RAI 3.8-18 S02.

In its RAI 3.8-18 S02 response, the applicant stated that, to address the effect of redistribution of loads caused by concrete cracking, it performed an SSE dynamic analysis using the RB/FB global FEM. The analysis method is the same as that used in response to RAI 3.7-59 for comparing the stick and FEMs, except that the stiffness of RCCV elements in the FEM is reduced by 25 percent to consider concrete cracking. Figures 3.8-18(1) through 3.8-18(5) illustrate element forces at wall bottoms that were obtained by the analysis. The figures also include the results of dynamic analysis and static analysis, using uncracked concrete stiffness. Section forces in RCCV portions are slightly reduced because of concrete cracking. Section forces in RB walls were close to each other for all three cases analyzed, and the effect of RCCV concrete cracking is negligibly small. Therefore, the applicant concluded that the effect of redistribution of loads resulting from concrete cracking is insignificant.

The staff reviewed the RAI 3.8-18 S02 response and concluded that the applicant had verified the adequacy of the NASTRAN FEM against the seismic stick model in its response to RAI 3.7-59, which was resolved. To address the redistribution of loads caused by concrete cracking, the applicant performed an additional study in which it reduced the stiffness of the concrete containment by 25 percent and compared the responses at several locations with the full section properties from the global FEM and the stick model. The results show that the section forces in the concrete containment are slightly reduced, while the forces in the RB walls do not change significantly. Therefore, the applicant concluded that concrete cracking does not cause a significant redistribution of loads for the ESBWR design.

The applicant's RAI 3.8-18 S01 response also addressed the potential effect of concrete cracking. Based on the response, the staff concluded that, for the SIT, the tensile stresses in the principal membrane force and principal bending moment directions do not exceed the tensile strength of concrete, with very few localized exceptions. Therefore, RAI 3.8-18 was resolved.

DCD Section 3.8.1.4.1.3 describes how the applicant considered concrete cracking in developing the internal forces and moments in sections for LOCA thermal loads. In RAI 3.8-19, the staff requested that the applicant provide a figure showing the 3-dimensional model (including boundary conditions) used to evaluate concrete cracking under thermal loads and explain how the approach described in this section, which calculates scale factors of the individual member forces at each critical design-basis section, correctly considers the effect of redistributing the loads caused by concrete cracking in the overall containment and building model.

In its response to RAI 3.8-19, the applicant stated that Figure 3.8-19(1) illustrates the 3-dimensional model and boundary conditions used in the thermal analyses that define the temperature distributions for the thermal-stress and concrete-cracking analysis. The model is first initialized for the temperature conditions under normal operating conditions with a steady-state thermal analysis. Next, the applicant conducts a transient thermal analysis using the boundary conditions and temperature histories representing the DBA (or LOCA), as shown in the figure. Boundary conditions on exterior surfaces and interior walls exposed to air use a heat transfer coefficient and a reference air temperature. Surfaces in contact with water or the ground use a very large heat transfer coefficient to essentially set the surface temperature to the specified water or ground temperature. The applicant analyzed both winter and summer conditions. It then conducted stress analyses using the 3-dimensional ABAQUS/ANACAP model, with the temperature distributions from the transient thermal analyses associated with the specified times of 5 seconds, 6 minutes, 10 hours, and 72 hours. The stress model is initialized to be stress free at a reference temperature of 15.5 degrees C (60 degrees F). This model is used for both a linear stress analysis and a nonlinear concrete-cracking analysis for the thermal loads at each of the specified evaluation times. For the nonlinear cracking analyses, the steady-state temperature distribution for normal operating conditions is incrementally applied, and the temperature distributions corresponding to the above evaluation times are then incrementally applied, allowing concrete cracking and stress redistribution with iterations for static equilibrium.

The applicant calculated section forces and moments at the specified sections for both the linear stress analyses and the nonlinear concrete-cracking analyses at each of the specified time snapshots. It computed the thermal ratios or scale factors for each section force component by taking the ratio of the nonlinear cracking result to the linear stress result, where each has been calculated with the same continuum element model as the basis. It then used these ratios to scale the results from the overall containment and building model design-basis analyses, which use linear analyses with plate elements, for thermal stresses at corresponding section cuts. This correctly incorporates the effect of cracking and load redistribution into the design-basis model, because the physical effect is independent of the type of model used, and ratios specific to each section cut are used to scale the linear results from the plate element model.

The applicant further stated that, in the ESBWR containment thermal-stress analyses, the nonlinear cracking analyses using the 3-dimensional brick element model correctly considered the dissipation of thermal stress and redistribution of thermal load through the enforcement of concrete limit states at each integration or material point in the model. As the appropriate temperature distributions are incrementally applied, and as concrete sections develop cracking, the associated concrete thermal stress is dissipated and the section forces are reduced. This reduction in the thermal stiffness of sections can, in turn, change the restraint conditions for nearby sections for redistribution of the thermal loads. By conducting a sister analysis assuming linear response, and by calculating thermal ratios or scale factors between the nonlinear and linear results, the effect of this concrete cracking, stress dissipation, and redistribution of loads can be transferred to the design-basis model by scaling the section forces and moments obtained with the linear analysis by the appropriate thermal ratios. The applicant indicated that GEH Report 26A6625, Revision 1, issued October 2005, documents the nonlinear analyses for the thermal loads, taking into account concrete cracking and the redistribution of section forces resulting from concrete cracking.

Based on the technical approach described in the RAI response and the technical information presented in DCD Section 3.8.1.4.1.3 and Appendix 3G, the staff considered the applicant's approach capable of capturing the effects of concrete cracking and the redistribution of member forces; therefore, this approach is acceptable for the evaluation of thermal loadings.

The staff audited GEH Report 26A6625, Revision 1, at the May 16–17, 2007, audit at the applicant's offices in Wilmington, NC. Before the audit, the staff reviewed a limited set of data that used the thermal load factor approach, which the applicant submitted in response to RAI 3.8-107. Based on its limited preaudit review, the staff noted that the thermal load factors indicated very significant cracking and load redistribution, and it identified this issue for detailed discussion with the applicant at the May 2007 audit. The staff's review of GEH Report 26A6625, Revision 1, at the audit confirmed that the extent of concrete cracking and thermal load redistribution is very significant. Hence, the staff questioned the technical basis for combining mechanical load responses obtained for an uncracked condition with a thermal response scaled to reflect a very significant cracked condition.

The staff addressed this open issue under Part (c) of its supplemental information request for RAI 3.8-107, discussed in Section 3.8.5.3.4 of this report. Therefore, RAI 3.8-19 was resolved**.**

Based on the information contained in DCD Section 3G.1.5.2.1.13, the staff questioned how the applicant obtained seismic member forces for each section for use in design. In RAI 3.8-20, the staff requested the following information:

(1) If the figures provided in Appendix 3G are used (i.e., plots of shear, moment, and torsion for the entire "stick model" building versus elevation), rather than individual member forces obtained directly from the NASTRAN model, then explain how the individual member forces (for use in design) are derived.

(2) Identify the applicable detailed report/calculation (number, title, revision and date, and a brief description of the content) that will be available for audit by the staff, and reference this report/calculation in the DCD.

In its response to RAI 3.8-20, the applicant stated that it obtained seismic loads used for the structural design from seismic SSI analyses, using a lumped-mass stick model, as described in DCD Section 3A.7. Design seismic loads, which are shown in DCD Figures 3G.1-24 through 3G.1-26 and Table 3G.1-9, are established from the envelopes of all analysis results from SSI cases, as described in DCD Section 3A.9.

Seismic member forces for each section are obtained from the NASTRAN analyses for the design seismic loads mentioned above. Seismic loads consist of four components (i.e., shear, moment, torsion, and vertical acceleration) as shown in DCD Figures 3G.1-24 through 3G.1-26 and Table 3G.1-9. In the NASTRAN analyses, shear, moment, and torsion from horizontal seismic loads are applied as nodal forces to the nodes at the connections of seismic walls and floor slabs, so as to reproduce the distributions shown in Figures 3G.1-24 through 3G.1-26. For vertical seismic loads, nodal forces corresponding to the accelerations shown in Table 3G.1-9 are applied to all nodes.

The applicant referenced GEH Report 26A6651, Revision 1, which contains the structural design details of the RB. The applicant also indicated that it would revise DCD Section 3G.1.5.2.1.13 in the next DCD update and submitted a markup as part of its response.

During its onsite audit in December 2006, the staff asked about the technical basis for determining that the static analysis approach adequately represents multiple dynamic seismic responses. The applicant indicated that it would provide a comparison of NASTRAN dynamic time-history member forces to the NASTRAN static analysis results as part of its response to RAI 3.7-59 to demonstrate the acceptability of the DCD static analysis approach. The topics discussed during the audit were addressed by the applicant in response to RAI 3.8-20 S01.

In its RAI 3.8-20 S01 response, the applicant referred to its response to RAI 3.7-59 S01 for a comparison of NASTRAN dynamic and static analysis results.

The staff found that the applicant's initial response to the RAI clarified how it applied the seismic forces from the stick model to the FE NASTRAN model to obtain member forces for use in design. Therefore, this approach is acceptable. The staff also confirmed that the applicant incorporated the proposed change into DCD Revision 3. To address the adequacy of using the static analysis approach, the applicant referred to its response to RAI 3.7-59 S01, which includes a comparison of member forces obtained using the static analysis procedure presented in the DCD and the member forces obtained from a dynamic time-history analysis using the same FEM. The staff reviewed the results obtained from these two approaches and observed that they are very similar. Therefore, RAI 3.8-20 was resolved**.**

During the staff's review of the design evaluation of the containment wall, the staff noted some inconsistency in the liner strain values and also questioned the validity of one of the calculated values. Therefore, in RAI 3.8-21, the staff requested that the applicant explain why DCD Section 3G.1.5.4.1.1 indicates that the liner maximum strain is 0.0040, while DCD Table 3G.1-35 tabulates a greater value of 0.005 at the cylinder portion of containment under the abnormal loading combination. If the 0.005 strain (in tension) is correct, then it exceeds the ASME Code allowable value of 0.003.

In its response to RAI 3.8-21, the applicant stated the subject strain value is 0.0005, and it is less than the ASME Code allowable value of 0.003. DCD Table 3G.1-35 contains a typographical error. The applicant committed to revising DCD Table 3G.1-35 in the next update and provided a markup of the change.

The staff confirmed that the applicant included the correction noted in the applicant response in DCD Revision 3. Therefore, RAI 3.8-21 was resolved.

DCD Section 3.8.1.4.1.4 discusses corrosion prevention for the containment liner. In RAI 3.8-22, the staff requested that the applicant address the following items related to some of the statements made regarding corrosion prevention:

a. Explain why the amount of corrosion used for assessing the 60-year life of the suppression pool liner is based on the annual temperature profile of the pool water "for a typical plant in southern states."

b. Provide the basis for the 0.12 mm total corrosion allowance used for the Type 304L SS liner/clad material. Identify what the expected corrosion is, and how was it determined.

In its response to RAI 3.8-22, the applicant stated the following:

a. The annual temperature profile of the pool water in southern states was used for corrosion assessment since higher temperatures usually are associated with higher corrosion rates. Since the corrosion allowance is the same for temperatures up to 316 °C for Type 304L SS per DCD Section 3.8.1.4.1.4, the corrosion allowance is not affected by the average temperature profile used.

b. The 0.12 mm corrosion allowance is based on the applicant's internal design guidance for corrosion allowances for reactor system components (i.e., SS in reactor water at 550 °F). This allowance was scaled up to 60 years and conservatively applied to the pool liner. This is conservative because the expected corrosion rate for ambient temperature exposure will be substantially lower than at reactor operating conditions with flow. This design allowance has been used for the design of SS BWR components for the last 30 years. PDMA PIRT Report—Appendix A dated June 3, 2005 entitled Material Degradation Modes and their

Prediction, Page A-16, gives an actual general corrosion rate of 0.01 mils/yr of service life in a BWR reactor coolant operating environment in the 500 °F–600 °F temperature range. Applying this rate to the suppression pool environment would equate to an expected corrosion of 0.6 mils (0.01524 mm) for a plant life of 60 years. The 0.12 mm corrosion allowance provided is over 7.5 times this value and is very conservative.

The staff found that the applicant's response adequately addressed the questions, because it provided the basis for the assumed corrosion rate and described how it calculated the corrosion allowance. Therefore, RAI 3.8-22 was resolved**.**

The staff reviewed DCD, Tier 2, Chapter 1, for information of potential significance to the ESBWR containment design and identified several areas requiring additional information. In RAI 3.8-23, the staff requested that the applicant address the following:

(1) DCD, Tier 2, Section 1.2.1.2, page 1.2-3, states that the areas above the containment slab and drywell head are flooded in a pool of water during operation, and that this is effective in scrubbing any potential containment leakage through that path. Describe in greater detail this hydrostatic loading on the adjacent pool walls, the top slab, and the drywell head, including the height of the pool and the pressure gradient. Describe how this loading is included in the load combinations defined in DCD Sections 3.8.1 and 3.8.2 and describe the external pressure loading analysis of the drywell head and the results of the analysis; include the above-requested information in DCD Section 3.8.1, Section 3.8.2, and Appendix 3G, as applicable.

(2) DCD, Tier 2, Table 1.3-3, states that the design temperature of the drywell is 171 degrees C (340 degrees F). Describe how this design temperature was used in defining the concrete and steel properties in the drywell structural analyses; explain how the concrete temperature limits in ASME Code, Section III, Subsection CC (66 degrees C (150 degrees F) general, 93 degrees C (200 degrees F) local) are satisfied; and include the requested information in DCD Section 3.8.1, Section 3.8.2, and Appendix 3G, as applicable.

In its response to RAI 3.8-23, the applicant stated the following:

(1) The information of the depth of IC/PCCS pool is presented in DCD Tables 3G.1-3 and 4. The magnitude of pressure is proportional to the depth of pool water and considered as a part of dead loads in design. In the analysis model, hydrostatic loading of 6.7 m is considered as dead load for the drywell head during operation, as stated in DCD Section 3.8.1.3.1 and Tables 3G.1-3 and 4.

(2) Effects of the temperature on material properties are described in DCD Sections 3G.1.5.2.3.1 and 3G.1.5.2.3.2. ASME Code, Section III, Subsection CC-3440 specifies the temperature limits in three conditions as follows:

(a) Long term period; 150 °F general, 200 °F local
(b) Accident or short term period; 350 °F general, 650 °F local
(c) Test; may allow higher than given in (a) and (b)

> Because the Drywell temperature of 171 °C (340 °F) is for the accident condition, it satisfies the ASME Code limitations.

With regard to the local areas of concrete around high-energy penetrations, the applicant has carried out thermal analyses to demonstrate that concrete temperature limits in ASME Code, Section III, Subsection CC-3440, are satisfied. In all cases, the concrete temperature is lower than 93 degrees C (200 degrees F) for normal operation and lower than 177 degrees C (350 degrees F) for the accident condition. The sleeve length for hot penetrations is designed to meet these temperature requirements. The applicant indicated that it would revise DCD Sections 3.8.2.1.3 and 3G.1.5.2.3.1 in the next update and submitted a markup as part of the RAI response.

The staff found the applicant's response to Part (2) to be acceptable, because it demonstrated that the temperatures in the drywell meet the limits specified in ASME Code, Section III, Subsection CC. The staff confirmed that the applicant included the proposed change in DCD Revision 3.

During its onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, CA, the staff discussed the requested information for Part (1) in further detail with the applicant. The staff noted that the information provided is incomplete. It does not identify the pool above the drywell head. The IC/PCCS pool height is listed as 4.8 m in Table 3G.1-4. The reactor cavity pool height is listed as 6.7 m in Table 3G.1-4. Neither table specifically lists the height of the water above the drywell head. In addition, the response does not describe the analysis and results for external pressure loading, and there is no proposed revision to the DCD to clearly identify this loading, how it was analyzed, and the results of the analysis. The staff also asked the applicant to explain how the analysis considered water sloshing and inertia effects for seismic and hydrodynamic building loads.

During the July 2006 audit, the applicant stated that the water above the drywell head is called the reactor cavity pool. As indicated in Table 3G1-4, the depth of the water is 6.7 m. As noted in the DCD, hydrostatic loading for pool water is considered as dead load. The applicant's calculation contains analysis and results for the external pressure loading on the drywell head. The applicant indicated that it was revising this calculation to be consistent with ASME Code Case 284-1 and the NRC staff positions in RG 1.193, "ASME Code Cases Not Approved for Use." The applicant also indicated that its response to RAI 3.8-51 would explain how it considered water sloshing and inertia effects.

During the December 2006 onsite audit, the applicant indicated that GEH Design Report DE-ES-0003, Revision 0, "Buckling Evaluation for Drywell Head," issued October 2006, contained the remaining information to address this issue.

The staff reviewed the revised design report during a May 16–17, 2007, audit at the applicant's offices in Wilmington, NC. The staff found that the applicant adequately considered external pressure loading on the drywell head. The applicant's previous RAI response addressed the questions raised in Part (2) related to the temperature effects on material properties. The temperatures for the general, local, and accident conditions are less than the requirements in ASME Code, Section III, Subsection CC. The applicant included, in DCD Revision 3, the proposed changes to DCD Sections 3.8.2.1.3 and 3G.1.5.2.3.1, to clarify the temperature effects on material properties. The staff also noted that RAI 3.8-51 had been resolved. Therefore, RAI 3.8-23 was resolved.

In DCD Section 3.8.1.4.1.2, the applicant discussed procedures for the analysis and design of the liner plate and its anchorage system. In RAI 3.8-24, the staff requested that the applicant provide the following additional information:

(a) DCD Section 3.8.1.4.1.2 states that the liner plate analysis considers deviations in geometry caused by fabrication and erection tolerances. Describe the treatment of fabrication and erection tolerances in the evaluation of the liner plate. Explain whether the potential for buckling of the liner plate was considered (convex curvature caused by fabrication tolerances and concrete shrinkage), and include this information in DCD Section 3.8.1 or Appendix 3G, or both.

(b) DCD Section 3.8.1.4.1.2 also states that liner strains are within allowable limits defined by ASME Code, Subarticle CC-3720. Describe the analysis that verified this and discuss how fabrication and erection tolerances are considered in this analysis. Include this information in DCD Section 3.8.1 or Appendix 3G, or both.

In its response to RAI 3.8-24, the applicant stated the following:

> (a) Liner strains are evaluated based on the analysis results of the NASTRAN model described in DCD, Tier 2, Section 3G.1.4.1. In this model, the liner plate is modeled with nominal dimensions. The liner plate modeling method is discussed in the response to RAI 3.8-25. Strains associated with construction-related liner deformations may be excluded when calculating liner strains for the service and factored load combinations according to ASME Boiler and Pressure Vessel Code Section III, Division 2, Subarticle CC-3720.
>
> (b) The consideration of fabrication/erection tolerances for the evaluation of liner strains is described in a) above. The analysis results of the liner strains are summarized in DCD, Tier 2, Table 3G.1-35. The details of the analysis results are described in DC-OG-0052, Structural Design Report for Containment Metal Components, Revision 1, September 2005, which contains the evaluation method and results for structural integrity of the containment liner and drywell head.

The liner anchor design considers fabrication and erection tolerances. The applicant's RAI response provided the minimum, maximum, and nominal values for liner thickness, liner anchor spacing, and anchor stiffness. Considering these fabrication and erection tolerances, Tables 3.8-24(1) through 3.8-24(3) of the RAI response summarize the worst-case evaluation results. The calculated liner anchor displacements and the liner anchor pullout forces for the concrete and steel anchors were shown to be within the ASME Code limits.

The applicant also identified GEH Report DE-ES-0017, Revision 0, "Liner Anchorage Evaluation," issued October 2006, which contains the evaluation method and results for RCCV liner anchor displacement and pullout. The applicant further stated that it will revise DCD, Tier 2, Figures 3G.1-48 and 3G.1-49, in the next DCD update.

The staff evaluated the applicant's response and determined that it needed additional clarification. For Part (a), as it relates to strains associated with construction-related liner deformations, the staff noted an inconsistency between the DCD and the RAI response. At that time, the DCD stated that the liner plate analysis considers deviations in geometry resulting from fabrication and erection tolerances, while the RAI response indicated that strains associated with construction-related liner deformations may be excluded when calculating liner strains for the service and factored load combinations, according to ASME Code, Section III, Division 2, Subarticle CC-3720. For Part (b), the staff noted that DCD, Tier 2, Table 3G.1-35, does not provide the liner strains associated with construction loads, as required by Table CC-3720, which is referenced in Subarticle CC-3720 of the ASME Code.

In its RAI 3.8-24 S01 response, the applicant stated that it would revise DCD, Tier 2, Section 3.8.1.4.1.2, to state that the liner plate anchor design considers deviations in geometry resulting from fabrication and erection tolerances. In addition, the DCD would state that strains associated with construction-related liner deformations are excluded when calculating liner strains for the service and factored load combinations, according to ASME Code, Section III, Division 2, Subarticle CC-3720. The applicant will add a sentence to DCD, Tier 2, Section 3G.1.5.4.1.1, stating that the liner stresses during construction are kept within the allowable values found in Table CC-3720-1 of ASME Code, Section III, Division 2, by limiting concrete placement pressure to a maximum of 167 kPa for the top slab, 48 kPa for the UD and lower drywell wall, and 32 kPa for the wetwell wall. The applicant included the proposed DCD changes in its response.

The staff determined that the applicant’s treatment of construction-related liner deformations when calculating liner strains is in agreement with the provisions of ASME Code, Section III, Division 2, Subarticle CC-3720; thus, it is acceptable. The applicant’s proposed revision to the DCD to clarify this information is also acceptable, for the same reasons, and the staff confirmed that the applicant included this change in DCD Revision 3. The staff audited the applicant’s two design reports referenced in the RAI response at the applicant’s offices in Wilmington, NC, on May 17, 2007. The staff determined that the applicant’s evaluation documented in the two reports is consistent with the information provided in the RAI response. The staff’s acceptance of the analysis and design approach for the liner and liner anchors is evaluated separately under RAIs 3.8-25 and 3.8-26. Therefore, RAI 3.8-24 was resolved.

DCD Section 3G.1.4.1 provides a short description of the structural model developed for the RB and the RCCV. In RAI 3.8-25, the staff requested that the applicant provide additional information to describe how it analyzed a typical liner plate-to-RCCV attachment, using the NASTRAN model results. The applicant should include this information in DCD Section 3.8.1 or Appendix 3G, or both.

In its response to RAI 3.8-25, the applicant stated that rigid bar elements connect the corresponding grid points of the liner elements and concrete elements, as described in DCD Section 3G.1.4.1. Figure 3.8-25(1) shows these connections schematically. To represent the anchor, the applicant placed rigid bar elements in the radial direction for the liners of the RCCV cylinder wall and the RPV pedestal. It placed them vertically for the basemat, the SP slab, and the top slab. Using this modeling technique, the applicant obtained the design forces of liner plates directly from the analysis, and designed the anchorage in accordance with ACI 349-01, Appendix B. The applicant referenced GEH Report 26A6651, Revision 1, which contains the structural design details of the RB.

During its onsite audit, conducted July 11–14, 2006, at the applicant’s offices in San Jose, CA, the staff discussed the requested information in further detail with the applicant. The staff noted that the NASTRAN model appears to be composed of plate and shell elements to represent both the steel liner and the concrete. The rigid bar elements connect the two reference surfaces at the corresponding grid points. A study of displacements of the liner reference surface and the concrete reference surface at the middle of the plate and shell elements may show that the liner plate penetrates the concrete when the thickness of each is taken into account. If a displacement is not calculated at the middle of the plate and shell element, the presence of significant bending moments in the liner plate elements under a uniform pressure loading would indicate that the liner plate is underconstrained. The staff also inquired whether the FE grid spacing matches the actual anchor spacing.

The applicant stated that, in the NASTRAN model, the liner modulus of elasticity is reduced to 1/10,000 of its actual value to prevent any stiffness contribution to the overall model. The grid point spacing of the liner does not match the actual anchorage spacing. This could affect the calculation of the correct strains in the liner and the reaction loads calculated to evaluate the anchorage. The liner is designed using the strain at the connection of the rigid links and liner. The staff noted that the concern remains that the liner could penetrate the concrete surface in the model, and the anchorage spacing does not match the actual anchor spacing. The applicant indicated that the anchorage of the liner would meet the requirements in ACI 349-01 for anchorage. The staff noted that the applicant should include ACI 349-01 as a referenced code and standard, as well as referencing RG 1.199 and RG 1.142. The applicant also indicated that, to design the liner, it used the approach in Bechtel Topical Report BC-TOP-1, "Containment Building Liner Plate Design Report," Revision 1, issued December 1972.

Subsequent to the onsite audit, the staff also identified a concern about how the forces on the anchors are determined if 1/10,000 E is used in the model for the liner. The staff's concerns as well as the topics discussed during the audit were addressed by the applicant in response to RAI 3.8-25 S01 and RAI 3.8-25 S02.

In its RAI 3.8-25 S01 response, the applicant stated that it would revise DCD Section 3.8.1.1.2 in the next update and provided a markup of the proposed change. The applicant also referred to its response to RAI 3.8-14 S01.

In its RAI 3.8-25 S02 response, the applicant addressed the staff's concerns identified at the onsite audit in July 2006 related to the potential for the liner to penetrate the concrete surface and to the liner grid spacing versus the actual spacing. The applicant also explained how it determined the forces on the anchors if it used 1/10,000 E for the liner in the NASTRAN model.

The applicant stated that, in the NASTRAN analysis of the RB/FB global FEM, Young's modulus for the RCCV steel liners is set to a small value (i.e., 1/10,000 of the normal value for nonthermal loads) so that they do not bear any stresses. For thermal loads, the applicant used the normal Young's modulus for the liner in the model to account for the effect of differential thermal expansion between steel and concrete. The liner is modeled in the global FEM with rigid bar elements placed between the RCCV wall element and the liner element, as described in DCD Section 3G.1.4.1. The positions of these rigid bar elements do not match the layout of liner anchors.

The applicant also described a study performed for two models to justify (1) the modeling technique to correctly predict the behavior of the liner attached to the RCCV wall, and (2) the calculated strains and anchor forces used for the liner plate design. The applicant developed two simple models to predict the behavior of the nonanchored region of liner plate supported by its anchorage. The nonanchored portion of the plate is coupled to the concrete by rigid link elements in one case and contact elements in the other case. The models are subjected to pressure and thermal loads. According to the applicant, the results demonstrate that the modeling technique used in the ESBWR design correctly predicts the behavior of the liner and liner anchors.

The staff discussed this response with the applicant during the December 2006 onsite audit. On the basis of this discussion, the staff concluded that it needed to conduct a further detailed review to fully understand the analysis study and to identify specific areas of the description, figures, and tables (in the S02 response) that require further clarification. As an example, the response indicated that Case 1 simulates the DCD design technique. However, the table provided for Case 1-a and 1-b calls this model “glued.” The DCD and prior discussions with the applicant seem to indicate that the DCD model is not glued but is free to deform between attachment points (rigid links). The staff noted that the technical issues raised under this RAI are closely associated with RAI 3.8-26. The topics discussed during the audit were addressed by the applicant in response to RAI 3.8-25 S03.

In its RAI 3.8-25 S03 response, the applicant stated that the term “glued” means that all concrete and liner nodes are rigidly linked, regardless of actual liner anchor locations. This is consistent with the DCD and prior discussions indicating that the DCD model is free to deform between attachment points (nodes). To avoid confusion, the applicant changed the word “glued” to “DCD.”

Following the December 2006 onsite audit and receipt of the RAI 3.8-25 S03 response, the staff conducted a more detailed review of this technical issue. Based on the information submitted, the staff questioned whether the comparative analysis between the small “DCD model” and the “contact model” actually addresses the displacement compatibility issue. The two models basically appear to be the same, except that each rigid link was replaced by a contact element. Therefore, it is not surprising that the liner strains are the same. The applicant should also explain whether the small DCD model represents the exact concrete, liner, and rigid link modeling configuration used in the full DCD building model. This explanation should include confirmation of the horizontal and vertical spacing of the rigid links and indicate whether this model represents the most critical location (e.g., where spacings between rigid links are large). Also, from the information provided, the staff questioned whether the existing contact model had a sufficient number of contact elements and liner plate elements (with additional nodes in the plate elements between the contact elements) to properly simulate the true design configuration that will be constructed. The applicant should tabulate the comparison of responses for maximum strains (membrane and membrane plus bending) and reaction loads at key liner anchor locations. RAI 3.8-25 was being tracked as an open item in the SER with open items.

In its RAI 3.8-25 S04 response, the applicant provided some information regarding the analysis of the containment liner plate in the full DCD NASTRAN building model. The information provided in the analytical study of a small portion of the containment wall, however, did not address the major concerns raised in the RAI. The small “DCD model” was analyzed and compared to the “contact model,” which showed the same strains and reaction forces at the liner anchors. However, under pressure loads, the two models are essentially identical and so the strains and anchor loads are expected to be the same. This is similarly true for the thermal loading case. Therefore, it does not appear that the study addressed the concerns raised in the RAI. In RAI 3.8-25 S05, the staff asked the applicant to revise the analytical models or explain how the current study in the RAI response addresses the potential differences between the current liner model in the full DCD model (which does not match the actual liner anchor spacing and has a presumably coarser distribution) and the true liner configuration with actual anchor spacings.

In addition, the staff asked the applicant to explain how it determined the strains tabulated in DCD Table 3G.1-35. This explanation should indicate whether the strains were obtained directly from the individual finite elements of the full DCD NASTRAN model and whether they are the maximum membrane and maximum membrane plus bending strains acting in any direction throughout the thickness of the liner plate. Also, the staff asked the applicant to explain if the liner can buckle under the maximum calculated strains for the most critical anchor spacing configuration. If buckling can occur, then the staff asked the applicant to describe the calculation performed to obtain the strains in the buckled configuration and demonstrate that they still meet the allowable strain limits in the ASME Code.

Based on the RAI 3.8-25 S05 response, the staff concluded that the response provides the technical basis to address the remaining issues of the RAI identified above. In particular, it provides the results of a new analysis comparing the "small DCD model," which represents the full DCD FEM configuration, with the refined "contact model," which represents the actual liner anchor spacings within a refined FEM. Since the results of the two models are close to one another, the method used in the analysis of the full DCD FEM is acceptable. The RAI response also explained that the liner strains are obtained directly from the FEM. Since the membrane strains were taken directly from the results of the FEM, the bending strains were shown to be very small, and the allowable strains shown in ASME Code, Section III, Division 2, are much larger than the calculated strains, the RAI response is acceptable. Therefore, RAI 3.8-25 and its associated open item were resolved.

Originally, RAI 3.8-25 concerned how the applicant analyzed the liner plate-to-RCCV attachment using the results (strains, forces) from the global model of the RB, RCCV, and FB. Therefore, in RAI 3.8-26, the staff requested that the applicant explain whether, in the NASTRAN model, the attachment of the liner plate to the RCCV is modeled in a manner that is consistent with the physical attachment scheme. The staff asked the applicant to describe the method used to attach the liner plate to concrete in the NASTRAN model, compare it to the physical attachment scheme, discuss the adequacy of the model to predict realistic strains in the liner plate, and include this information in DCD Section 3.8.1 or Appendix 3G, or both. The staff also requested that the applicant identify the applicable detailed report or calculation (number, title, revision, and date, and a brief description of the content) that it will make available for audit by the staff.

In its response to RAI 3.8-26, the applicant stated that liner plates, as described in the response to RAI 3.8-25, are rigidly attached to the RCCV concrete in the NASTRAN model. This modeling approach is adequate to predict overall liner strains, since liners deform in conformance with the concrete, even though liner plates are physically anchored at discrete locations only. Relative movement between liner and concrete will be considered for liner anchor evaluation in the detailed design phase in accordance with the procedures outlined below:

(a) Displacement Evaluation of Liner Anchor—

The displacement of the liner anchor is evaluated for the case that one section of the liner plate, between the liner anchor and adjacent one, buckles. Once the buckling occurs, the balance of the liner plate forces due to strains on both sides of the liner anchor is disrupted. The liner anchor would strain to balance forces from both sides. The liner plate strains from the integral NASTRAN model, and liner anchor load-displacement relationships, based on the available test results for similar anchors, are used to evaluate the displacement. The evaluation is performed to meet the acceptance criteria in ASME Code, Section III, Division 2, Table CC-3730-1, using the same methodology as Bechtel Topical Report BC-TOP-1, Containment Building Liner Plate Design Report, Revision 1, December 1972.

(b) Embedment Evaluation of Liner Anchor—

A negative pressure acts on the liner plate in the wetwell portion when hydrodynamic load, such as SRV, CO, CHUG and combinations of them, occurs in the suppression pool. Such negative pressure produces a reaction force on the liner anchors embedded in the concrete of the RCCV wall. Concrete and the embedded portion of the liner anchors are evaluated based on ACI 349-01. The embedded portion is evaluated for concrete cone shear resistance and bearing on the anchor. For the liner anchor, flange bending stress and web tension stress are evaluated, and compared with ASME Code, Sec. III, Division 2, Table CC-3730-1.

During its onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, CA, the staff and the applicant discussed RAI 3.8-26 in conjunction with the information provided in RAI 3.8-25. In its RAI 3.8-26 S01 response, the applicant referenced its response to RAI 3.8-25. The staff agreed with the applicant that resolution of RAI 3.8-25 would also resolve RAI 3.8-26 because RAI 3.8-25 explains how the liner plate is modeled and attached to the concrete sections, and how the strains in the liner are calculated. RAI 3.8-26 was being tracked as an open item in the SER with open items. Since the staff found that all issues in RAI 3.8-25 were resolved, RAI 3.8-26 and its associated open item were resolved.

3.8.1.3.5 Structural Acceptance Criteria

DCD Section 3.8.1.5 provides the structural acceptance criteria for the concrete containment design. It states that the allowable stresses of concrete and reinforcing steel satisfy the acceptance criteria in ASME Code, Section III, Division 2, except for tangential shear stress carried by orthogonal reinforcement, for which a lower allowable is adopted for the ESBWR, as shown in DCD Table 3.8-3. In addition, inclined reinforcement is not used to resist tangential shear in the ESBWR containment design.

The staff found the applicant's discussion under structural acceptance criteria to be acceptable, on the basis that it follows the acceptance criteria in ASME Code, Section III, Division 2, and is consistent with the applicable SRP Section 3.8.1.II acceptance criteria. The exception noted in the DCD, for tangential shear stress carried by orthogonal reinforcement, is acceptable because it is in accordance with the guidance presented in SRP Section 3.8.1.II.5.

3.8.1.3.6 Material and Quality Control and Special Construction Techniques

DCD Section 3.8.1.6 provides information about the material and quality control applicable to the concrete, reinforcing steel, splices of reinforcing steel, and liner plate and appurtenances. The applicant identified no special construction techniques. The materials used in the construction of the containment are in accordance with RG 1.136 and ASME Code, Section III, Division 2, Article CC-2000.

DCD Revision 5 revised Table 3.8-5, which identifies the welding activities and weld examination requirements for the containment vessel. Among the revisions, a new section provided the nondestructive examination (NDE) requirements for the containment liner. The staff asked the applicant to explain why the option of UT (ultrasonic), MT (magnetic particle), or PT (liquid penetrant) examinations are specified for weld Category D (nonbutt welds) and weld Categories E, F, G, J, and full penetration H welds. According to Article CC-5521 of ASME Code, Section III, Division 2, these welds shall be examined by UT or MT. Separately, Article CC-5521, paragraph (f) indicates that PT shall be substituted for an MT examination when austenitic welds are used. In RAI 3.8-124, the staff asked the applicant to explain the welding requirements presented in DCD Table 3.8-5 that do not appear to be consistent with the requirements in Article CC-5521 of the ASME Code.

In its response to RAI 3.8-124, the applicant stated that it will revise Table 3.8-5 to clarify that the PT of Category D (nonbutt welds) and weld Categories E, F, G, J, and full penetration H welds is to be substituted for an MT examination only for austenitic welds, to be consistent with the requirements of Article CC-5521 of the ASME Code. The staff found this acceptable, since the suggested changes to DCD Table 3.8-5 will be consistent with the requirements in Article CC-5521 of the ASME Code. The staff verified that the applicant incorporated the proposed markup changes in the response in DCD, Tier 2, Revision 6. Therefore, RAI 3.8-124 was resolved.

The staff found the applicant’s discussion of the material and quality control to be acceptable on the basis that it follows the requirements in ASME Code, Section III, Division 2, and is consistent with RG 1.136, and the applicable review criteria in SRP Section 3.8.1.II.6.

3.8.1.3.7 Testing and Inservice Inspection Requirements

DCD Section 3.8.1.7 provides a description of the SIT and the preservice and inservice inspections of the containment structure. The DCD refers to Section 6.2.6 for the description of the preoperational and inservice ILRT of the containment.

The SIT of the containment structure is performed in accordance with ASME Code, Section III, Division 2, Article 6000, and RG 1.136 after construction of the containment. The SIT uses a test pressure of 357 kPaG (52 psig), which is 115 percent of the design pressure, and a test pressure of 278 kPad (40 psid) for the differential pressure between the drywell and wetwell. Cracks and displacements are measured during the SIT. For the first prototype containment structure, strains will also be recorded in accordance with the provisions of Subarticle CC-6370 of ASME Code, Section III, Division 2. The staff finds that the description for the SIT is acceptable on the basis that it follows the requirements in ASME Code, Section III, Division 2, Article 6000, and is consistent with the applicable review criteria in SRP Section 3.8.1.II.7.

Revision 1 of DCD, Tier 2, Section 3.8.1.7.3, provides information about preservice and inservice inspection of the containment components. In RAI 3.8-1, the staff requested that the applicant provide additional information about preservice and inservice inspections of the containment components. The staff noted that, while it is understandable that the COL applicants will develop plans for preservice and inservice inspections, the DCD should provide additional preoperational inspection requirements (per IWE-2000) specifically pertinent to the ESBWR containment. In addition, the applicant should revisit the IWE-1220 exclusions cited in DCD Section 3.8.1.7.3.2 to minimize the inaccessible areas in the containment. Also, because of the high-radiation areas in the containment, the DCD should discuss a remote means of monitoring certain structures and components inside the containment.

In its response to RAI 3.8-1, the applicant stated the following:

(1) The requirements for performing the PSI per IWE-2000 are addressed in DCD Section 3.8.1.7.3.3, including pre-operational instruction to ensure PSI is performed after application of any required protective coating.

(2) The reference in DCD Section 3.8.1.7.3.2 to IWE-1220 discusses exclusions in general; the commitment to perform the required inspections per Subsection IWE is in the scope found in DCD Section 3.8.1.7.3.1. Provisions for access to specific areas for inspection are addressed in the detailed design, and discussion of remote tooling would only be included if for some design reason, the required inspections could not be carried out otherwise.

During the December 2006 onsite audit, the applicant indicated that it would revise the DCD to explain that, during the detailed design phase, the number of inaccessible areas will be minimized to reduce the number of permissible exclusions cited in Section 3.8.1.7.3.2 of the DCD. Also, the applicant committed to revising the first sentence in the second paragraph in DCD Section 3.8.1.7.3.1 to read, "The design to perform preservice inspection is in compliance with the requirements of the ASME …." Furthermore, the applicant indicated that the DCD would state that the use of remote tooling for inspections will be done in high-radiation areas, where feasible. The topics discussed during the audit were addressed by the applicant in response to RAI 3.8-1 S01.

In its RAI 3.8-1 S01 response, the applicant stated that it would revise DCD, Tier 2, Sections 3.8.1.7.3.1 and 3.8.1.7.3.2, in the next update and provided a markup of the changes. The staff reviewed the proposed changes and found them acceptable. The staff confirmed that the applicant incorporated these changes in DCD Revision 3.

With the above-noted revisions made in the DCD, the staff found that the preservice and inservice inspections of the containment components described in the DCD are acceptable on the basis that they follow the requirements in ASME Code, Section XI, 2001, with the 2003 Addenda, and the requirements specified in 10 CFR 50.55a. In addition, they are consistent with the applicable review criteria in SRP Section 3.8.1.II.7. Therefore, RAI 3.8-1 was resolved.

In RAI 3.8-126, the staff asked the applicant to mark certain text in DCD Section 3.8 as Tier 2* information. Tier 2* is the information that requires the applicant to obtain NRC approval before making any changes. In its response, dated June 30, 2009, the applicant provided a proposed markup of DCD Section 3.8, including the applicable text, bracketed and italicized, with an asterisk following the square brackets to designate the text as Tier 2*. In addition, an added footnote at the end of the affected subsections indicates that "Text sections that are bracketed and italicized with an asterisk following the brackets are designated as Tier 2*. Prior NRC approval is required to change." The staff verified that the proposed markup changes in the response are consistent with the staff's request in the RAI; however, the applicant has not yet fully incorporated these changes into the appropriate sections of the DCD. Following the submittal of DCD Revision 6, the staff reviewed the changes made regarding the Tier 2* information. The staff concluded that the applicant did not properly present some of the Tier 2* information in DCD Section 3.8 in DCD Revision 6. Therefore, the staff prepared a new

RAI 3.8-129 to address the remaining issues associated with Tier 2* information. Since RAI 3.8-129, discussed below, evaluates these remaining issues, RAI 3.8-126 was resolved.

In RAI 3.8-127, the staff asked the applicant to mark certain tables and figures in DCD Section 3.8 as Tier 2* information. In its response to RAI 3.8-127, the applicant provided a proposed markup of DCD Section 3.8, including the applicable tables and figures, bracketed and italicized, with an asterisk following the square brackets designated them as Tier 2*. In addition, an added footnote at the bottom of the affected tables indicates that "Text sections that are bracketed and italicized with an asterisk following the brackets are designated as Tier 2*. Prior NRC approval is required to change." Similarly, an added footnote at the bottom of the affected figures indicates that "Figures that are bracketed with an asterisk following the brackets are designated as Tier 2*. Prior NRC approval is required to change." The staff verified that the proposed markup changes in the response are consistent with staff's request in the RAI; however, the applicant has not yet fully incorporated these changes into the appropriate tables and figures in the DCD. Following the submittal of DCD Revision 6, the staff reviewed the changes made regarding the Tier 2* information. The staff concluded that the applicant did not properly present some of the Tier 2* information related to tables and figures in DCD Revision 6. Therefore, the staff prepared a new RAI 3.8-129 to address the remaining issues associated with Tier 2* information. Since RAI 3.8-129, discussed below, evaluates these remaining issues, RAI 3.8-127 was resolved.

In RAI 3.8-128, the staff asked the applicant to mark the entire text of Appendix 3B, and the entire text, figures, and tables in Appendix 3F and Appendix 3G as Tier 2* information. In its response to RAI 3.8-128, the applicant provided a proposed markup of the entire text of Appendix 3B with a note below the appendix title indicating that "All text sections of Appendix 3B are bracketed and italicized with an asterisk following the brackets and designated as Tier 2*. Prior NRC approval is required to change." Also, the applicant provided a proposed markup of the entire text, figures, and tables of Appendix 3F and Appendix 3G that are bracketed and italicized with an asterisk following the square brackets designated as Tier 2*, with a note below each appendix title indicating that "All text, tables, and figures of Appendix 3F (or 3G) are bracketed and italicized with an asterisk following the brackets and designated as Tier 2*. Tables and figures that are computer analysis outputs cannot be italicized; they are bracketed with an asterisk following the brackets designating them as Tier 2*. Prior NRC approval is required to change." The staff verified that the proposed markup changes in the response are consistent with the staff's request in the RAI; however, the applicant had not yet fully incorporated these changes into the appropriate appendices of the DCD. Following the submittal of DCD Revision 6, the staff reviewed the changes made regarding the Tier 2* information. The staff concluded that the applicant did not properly present some of the Tier 2* information related to the appendices in DCD Revision 6. Therefore, the staff prepared a new RAI 3.8-129 to address the remaining issues associated with Tier 2* information. Since RAI 3.8-129, discussed below, evaluates these remaining issues, RAI 3.8-128 was resolved.

Based on the staff review of the changes made to DCD Revision 6, the staff noted that the applicant did not properly present some of the Tier 2* information in the DCD. Therefore, in RAI 3.8-129, the staff asked the applicant to revise the DCD to reflect the Tier 2* information that was requested in prior RAIs 3.8-126, 3.8-127, and3.8-128. RAI 3.8-129 also identified Tier 2* information and other editorial changes that the applicant should address in Section 3.7 of the DCD.

In its response, the applicant provided proposed markups to the to address the items identified in RAI 3.8-129. The staff completed its review and found the proposed markups to be acceptable. The staff verified that the proposed markups were incorporated into the appropriate sections of the DCD, Tier2, Revision 7. Therefore, RAI 3.8-129 was resolved.

3.8.1.4 *Conclusion*

The staff concludes that the applicant has demonstrated that the analysis, design, construction, testing, and inservice surveillance of the concrete containment structure conform to established criteria in codes, standards, guides, and specifications acceptable to the staff. The staff has found the use of these criteria to be consistent with the guidance provided in SRP Section 3.8.1 and applicable RGs. Meeting these criteria ensures that the DCD meets the relevant requirements of 10 CFR 50.55a and GDC 1, 2, 4, 16, and 50 of Appendix A to 10 CFR Part 50.

3.8.2 Steel Components of Concrete Containment

Section 3.8.2 of DCD, Tier 2, Revision 7, indicates that the steel components of the ESBWR RCCV consist of (1) personnel air locks, (2) equipment hatches, (3) penetrations, (4) the drywell head, and (5) the PCCS condenser.

3.8.2.1 *Regulatory Criteria*

The staff reviewed DCD Section 3.8.2 and DCD Appendix 3G. The staff considers the applicant's design and analysis procedures, loads and load combination methods, structural acceptance criteria, material, quality control and special construction techniques, and testing and ISIs to be acceptable if they satisfy the criteria, applicable codes and standards, and regulatory guidance delineated in SRP Section 3.8.2. Meeting the guidance of this SRP section will ensure that the DCD meets the relevant requirements of 10 CFR 50.55a and GDC 1, 2, 4, 16, and 50 of Appendix A to 10 CFR Part 50. The following regulatory requirements are relevant to the staff review in Section 3.8.2.

- 10 CFR 50.55a and GDC 1 require that the steel containment be designed, fabricated, erected, and tested to quality standards, commensurate with the importance of the safety functions to be performed.

- GDC 2 requires that the steel containment withstand the most severe natural phenomena, such as winds, tornadoes, floods, and earthquakes, and the appropriate combination of all loads.

- GDC 4 requires that the steel containment withstand the dynamic effects of equipment failures, including missiles and blowdown loads associated with the LOCA.

- GDC 16 requires that the steel containment act as a leaktight membrane to prevent the uncontrolled release of radioactive effluents to the environment.

- GDC 50 requires that the steel containment internal structures be designed with a sufficient margin of safety to accommodate appropriate design loads.

- ASME Code, Section III, Division 1, "Nuclear Power Plant Components," Subsection NE, Class MC, contains the material specifications, design criteria, fabrication and construction requirements, construction testing and examination techniques, and SIT of the steel components of the reinforced concrete containment found in 10 CFR 50.55a.

The staff evaluated the design, materials, fabrication, erection, inspection, testing, and inservice surveillance of steel components of the reinforced concrete containments, based on the industry codes and standards, materials specifications, and the following RGs:

- RG 1.57, “Design Limits and Loading Combinations for Metal Primary Reactor Containment System Components”
- RG 1.94
- RG 1.136

For design certification, paragraph IV(a)(2)(i)(A) of Appendix S to 10 CFR Part 50 provides an option for specifying the OBE. If it is chosen to be less than or equal to one-third of the SSE ground motion, it is not necessary to conduct explicit response or design analyses to satisfy the requirements of paragraph IV(a)(2)(i)(B)(I) of Appendix S to 10 CFR Part 50.

3.8.2.2 *Summary of Technical Information*

3.8.2.2.1 Description of the Steel Components of Concrete Containment

In DCD Section 3.8.2.1, the applicant stated that the steel components of the ESBWR reinforced concrete containment consist of two personnel air locks, three equipment hatches, process piping and electrical penetrations, the drywell head, and the PCCS condenser. The applicant designed these components for the same loads and load combinations as those it used in the design of the concrete containment shell to which these components are attached.

The two personnel air locks provide access to the upper and lower drywell areas. Three equipment hatches provide access to the upper and lower drywell areas and to the suppression chamber airspace. DCD Figures 3G.1-52 through 3G.1-54 illustrate the equipment hatches and air locks.

The major piping penetrations are associated with the high-energy MS and FW lines. These hot penetrations have thermal sleeves to prevent any direct contact with the RCCV. DCD Figures 3.8-6, 3.8-7, 3.8-8, 3.8-9, 3.8-10, and 3.8-11 show the typical details for the containment’s hot and cold mechanical penetrations and electrical penetrations.

The 10,400 mm (34 ft. 1-7/16 in.) diameter opening in the RCCV UD top slab over the RPV is covered with a removable steel torispherical drywell head, which is part of the pressure boundary. DCD Figure 3G.1-51 shows this structure. The applicant designed the drywell head for removal during reactor refueling and for replacement before reactor operation using the RB crane. One pair of mating flanges is anchored in the drywell top slab and the other is welded integrally with the drywell head. The applicant made provisions for testing the flange seals without pressurizing the drywell.

Water in the reactor well is above the drywell head during normal operation. The height of the water is 6.7 m (21 ft. 11-3/4 in.). The SS clad thickness for the drywell head is 2.5 mm (98 mils) and is determined in accordance with the requirements in ASME Code, Section NB-3122.3, so that it results in negligible change to the stress in the base metal.

There are six support brackets attached to the inner surface of the drywell head, equally spaced around the circumference, to support the head on the operating floor during refueling. These support brackets have no stiffening effect and do not resist loads when the head is in the installed configuration.

To provide a leak-resistant refueling seal, the applicant used a structural seal plate with an attached compressible bellows sealing mechanism between the reactor vessel and the UD opening.

The refueling seal is a continuous gusseted radial plate that is anchored to the drywell opening in the top floor slab. A bellows connects to this plate and to a bracket on the RPV, thus providing a refueling seal and allowing for axial thermal expansion of the RPV.

3.8.2.2.2 Applicable Codes, Standards, and Specifications

In DCD Section 3.8.2.2, the applicant stated that, in addition to the codes and standards specified in DCD Section 3.8.1.2.2, ASME Code, Section III, Division 1, Subsection NE (Class MC); ASME Code Case N-284 (buckling analysis); and ANSI/AISC N690-1994s2 (2004), "Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities," are applicable to the steel components of the RCCV. The design limits and loading combinations of the containment's steel components are in accordance with the guidance in RG 1.57.

The steel components of the RCCV are classified as Class MC, in accordance with Subarticle NCA-2130, ASME Code, Section III. The steel components within the boundaries defined in DCD Section 3.8.2.1.2 are designed, fabricated, erected, inspected, examined, and tested in accordance with Subsection NE, Class MC Components and Articles NCA-4000 and NCA-5000 of ASME Code, Section III. Structural steel attachments beyond the boundaries established for the steel components of the RCCV are designed, fabricated, and constructed according to the AISC manual for steel construction.

3.8.2.2.3 Loads and Load Combinations

In DCD Section 3.8.2.3, the applicant stated that it defined the applicable loads in DCD Section 3.8.1.3; DCD Table 3.8-4 provides the load combinations applicable to steel components of the concrete containment.

3.8.2.2.4 Design and Analysis Procedures

In DCD Section 3.8.2.4, the applicant stated that it designed the steel components of the concrete containment in accordance with ASME Code, Section III, Subarticles NE-3100 (General Design), NE-3200 (Design by Analysis), and NE-3300 (Design by Formula). If required by Subarticle NE-3200 of ASME Code, Section III, Division 1, the applicant performs a fatigue evaluation. The applicant designed the nonpressure-resisting components in accordance with the practices given in the manual of steel construction, ANSI/AISC N690.

The personnel air lock consists of four main sections—doors, bulkheads, the main barrel, and the reinforcing barrel with collar. The RCCV wall entirely supports the personnel air locks. The lock barrel is welded directly to the containment liner penetration through the RCCV wall. The applicant analyzed the personnel lock and penetration through the RCCV wall using an FE computer program or manual calculation, or both, based on handbook formulas and tables. It evaluated the discontinuity stresses induced by the combination of external, dead, and live loads, including the effects of earthquake loadings. The required analyses and limits for the resulting stress intensities are in accordance with Subarticles NE-3130, NE-3200, and NE-3300 of ASME Code, Section III, Division 1.

An equipment hatch assembly consists of the equipment hatch cover and the equipment hatch body ring, which is imbedded in the RCCV wall and connects to the RCCV liner. The applicant uses an FE analysis model or manual calculation, or both, to determine the stresses in the body ring and hatch cover of the equipment hatch. The equipment hatch analysis and the stress intensity limits are in accordance with Subarticles NE-3130, NE-3200, and NE-3300 of ASME Code, Section III. The applicant designed the hatch cover with the bolted flange in accordance with Subarticle NE-3326 of ASME Code, Section III.

The applicant subjected the piping penetrations and electrical penetrations to various combinations of piping reactions and mechanical, thermal, and seismic loads transmitted through the RCCV wall structure. It combined the forces resulting from various load combinations with the effects of external and internal pressures. The required analysis and associated stress intensity limits are in accordance with Subarticle NE-3200 of ASME Code, Section III, Division 1, including fatigue evaluation, as required.

The applicant analyzed MS and FW penetrations using the FE method of analysis for applicable loads and load combinations. The resulting stresses meet the acceptance criteria stipulated in Subarticle NE-3200 of ASME Code, Section III, Division 1, including fatigue evaluation, as required.

The applicant analyzed the drywell head, consisting of shell, flanged closure, and drywell-head anchor system, using an FE stress analysis computer program or a manual calculation. It evaluated the stresses, including discontinuity stresses induced by the combination of external pressure or internal pressure, dead load, live load, thermal effects, and seismic loads. The required analyses and limits for the resulting stress intensities are in accordance with Subarticles NE-3130, NE-3200, and NE-3300 of ASME Code, Section III, Division 1. The compressive stress within the knuckle region, caused by the internal pressure, and the compression in other regions, caused by other loads, are limited to the allowable compressive stress values, in accordance with Subarticle NE-3222 of ASME Code, Section III, Division 1, or ASME Code Case N-284.

The PCCS condensers are composed of two modules consisting of drum-and-tube heat exchangers, using horizontal upper and lower drums connected with multiple vertical tubes. Two identical modules are coupled to form one PCCS heat exchanger unit. The condenser assembly forms an integral part of the containment boundary and is submerged in the water of an IC/PCCS pool subcompartment. The pool water lies outside the containment boundary. Three sleeves containing the feed line, return line, and drain lines pass through the RCCV top slab. The condenser, the lines connected to the condenser, and the sleeves are part of the containment boundary. The PCCS condenser parts conform to the design requirements of Subarticles NE-3200 and NE-3300 of ASME Code, Section III, Subsection NE (Class MC). The applicant evaluated the PCCS condenser support in accordance with the ASME Code, Section III, Subsection NF.

3.8.2.2.5 Structural Acceptance Criteria

In DCD Section 3.8.2.5, the applicant stated that it based the structural acceptance criteria for the steel components on ASME Code, Section III, Subsection NE, with regard to allowable stress values, deformation limits, and factors of safety. DCD Section 6.2 provides leakage rate acceptance criteria for steel components. DCD Table 3.8-4 summarizes the stress intensity limits for testing, design, and service level A, B, C, and D conditions. An adequate factor of safety ensures stability against buckling. The allowable stress limits for nonpressure-resisting components are in accordance with ANSI/AISC N690-1994s2 (2004).

3.8.2.2.6 Material and Quality Control and Special Construction Techniques

In DCD Section 3.8.2.6, the applicant stated that the steel components of the containment airlocks, hatches, penetrations, and drywell head are fabricated from the following materials:

- plate (SA-240 type 304L, SA-516 grade 60 or 70)
- pipe (seamless SA-333 grade 1 or 6; or SA-106 grade B or SA-312 type 304L or SA-671 Gr CC70)
- forgings (SA-182F 304L)
- tubes (SA-213 grade TP304L)
- bolting (SA-193-B8 or SA-437 grade B4B bolts; nuts conform to SA-194 or the requirements for nuts in the specification for the bolting material to be used)
- clad (SA-240 type 304L)

3.8.2.2.7 Testing and Inservice Inspection Requirements

In DCD Section 3.8.2.7, the applicant stated that Section 3.8.1.7 describes testing and ISI requirements for the containment vessel, including the steel components. Welding activities conform to the requirements of Section III of the ASME Code. Table 3.8-5 provides the required NDE and acceptance criteria. The shop tests of personnel air locks include operational testing and overpressure testing, and the procedures are repeated until no defects are detectable.

3.8.2.3 *Staff Evaluation*

3.8.2.3.1 Description of the Steel Components of Concrete Containment

DCD, Tier 2, Section 3.8.2.1, provides descriptive information on the steel components of the concrete containment. The staff found the descriptive information, including figures and details of the structural elements of the steel components, to be generally acceptable and in accordance with the guidance given in SRP Section 3.8.2. However, during its initial review of DCD Revision 1, the staff, in RAI 3.8-28, requested that the applicant provide additional details for the containment's miscellaneous mechanical and electrical penetrations. The staff also asked whether the applicant had completed the design for all penetrations or if it considers this to be the responsibility of a COL applicant. The staff further requested that this information be included in DCD, Tier 2, Section 3.8.2 or Appendix 3G, or both.

In its initial response to RAI 3.8-28, the applicant stated that details for the containment's miscellaneous mechanical and electrical penetrations are not currently available and will be developed after the routing of piping and commodities, such as cable trays and ducts, is laid out during detailed design. The applicant stated that it will design these containment penetrations to meet the ASME Code. The applicant indicated that it would revise Section 3.8.2.4.1.3 in the next DCD update.

In response to a staff question during the December 2006 onsite audit subsequently issued as RAI 3.8-28 S01, the applicant stated that it would add typical details for the containment's mechanical and electrical penetrations to DCD Section 3.8 in new Figures 3.8-6 through 3.8-11.

The staff confirmed that the applicant incorporated the proposed changes into Revision 3 of the DCD. However, the staff questioned how the applicant would implement typical design details at the COL application stage. The staff submitted RAI 3.8-28 S02, which asked the applicant to identify, in the DCD, a COL action item that would ensure implementation of the design details for a typical mechanical and electrical penetration. RAI 3.8-28 was being tracked as an open item in the SER with open items.

In its RAI 3.8-28 S02 response, the applicant stated that no COL action item is required, since these mechanical and electrical penetrations are part of the containment boundary, for which the design commitment is an ITAAC, as delineated in DCD, Tier 1, Revision 4, Table 2.15.1-2, Item 2. Based on its review of this table, in RAI 3.8-28 S03, the staff asked the applicant to provide some additional clarification of DCD, Tier 1, Table 2.15.1-1, and to correct a typographical error in DCD, Tier 1, Table 2.15.1-2, Item 2. In its RAI 3.8-28 S03 response, the applicant clarified some of the items raised previously by the staff and corrected the typographical error in DCD, Tier 1, Table 2.15.1-2. However, as indicated during the audit at the applicant's office during the week of June 23, 2008 "Summary of Audit for Resolution of Outstanding Request for Additional Information (RAI) in Section 3.8, June 23-27, 2008," November 5, 2008), the applicant has substantially revised the ITAAC in DCD, Tier 1, Table 2.15.1-2, and the referenced components in DCD, Tier 1, Table 2.15.1-1. As a result, the information in the new ITAAC and DCD, Tier 1, Table 2.15.1-1, is not clearly related to containment penetrations. In RAI 3.8-28 S04, the staff requested the applicant to further clarify this.

Based on the RAI 3.8-28 S04 response, the staff found that the applicant provided technically acceptable information on the design of mechanical and electrical penetrations. In the response, the applicant proposed to: revise Table 2.15.1-1a to include all penetrations; revise Table 2.15.1-1b to delete the item "SP Stainless Steel Liner," which does not belong in the table containing containment mechanical equipment; and revise Table 2.15.1-2 to properly refer to the ASME Code design report(s) in the ITAAC. The staff verified that DCD, Tier 1, Revision 6, included the markup changes proposed in the response. Therefore, RAI 3.8-28 and its associated open item were resolved.

The staff noted that DCD Figure 3G.1-51 indicates an SS cladding on the exterior surface of the drywell head. In RAI 3.8-30, the staff requested that the applicant describe the purpose for the SS cladding, its thickness, and how it is considered in the Service Level A and B pressure and thermal analyses of the drywell head. In its response to RAI 3.8-30, the applicant stated that water in the reactor is well above the drywell head during normal operation. The height of water is 6.7 m. The purpose of the SS cladding is to provide corrosion protection of the carbon steel base plate. The analysis model does not consider cladding, because the strength of cladding is not considered for primary stress, based on ASME Code, Subsection NE-3122.1. The applicant stated that, since ASME Code, Table NE-3217-1, classifies the stress of cladding as peak stress, only fatigue analysis is required for the cladding, and it will perform a fatigue analysis to address RAI 3.8-32. ASME Code, Section NE-3122, does not include a requirement for cladding thickness; however, ASME Code, Subsection NB-3122.3, stipulates that the presence of the cladding may be neglected if the cladding is 10 percent or less of the total thickness of the component. Therefore, the detailed design will determine the cladding thickness, in accordance with requirements in ASME Code, Subsection NB-3122.3, so that it results in negligible stress in the base metal. The applicant also provided a proposed change to DCD Section 3.8.2.1.4.

The staff determined that it needed additional information because the clad thickness had not been specified. In its RAI 3.8-30 S01 response, the applicant stated that it determined the stainless clad thickness for the drywell head to be 2.5 mm, in accordance with the requirements of ASME Code, Subsection NB-3122.3, which results in a negligible change to the stress in the base metal.

The applicant provided proposed changes to DCD Section 3.8.2.1.4 and Figure 3G.1-51. The staff reviewed the applicant's proposed DCD changes and found them acceptable to resolve this issue because they are in accordance with the ASME Code, as required by SRP 3.8.2. The staff confirmed that the applicant had incorporated the proposed changes into Revision 3 of the DCD. Therefore, RAI 3.8-30 was resolved.

The staff also noted that Figure 3G.1-51, Detail C, shows six drywell head support brackets. In RAI 3.8-31, the staff requested that the applicant explain the function of the brackets and how they were modeled in the Service Level A and B pressure and thermal analyses of the drywell head. In its response, the applicant stated that these support brackets are attached to the inner surface of the drywell head circumferentially to support the head on the operating floor during refueling. The support brackets have no stiffening effect and do not resist loads when the head is in the installed configuration (the stiffening effect is local and active only during refueling, when the head is in its stored position). The applicant did not consider them in the design analysis model of the drywell head. The applicant indicated that it would revise DCD Section 3.8.2.1.4 to incorporate this information.

The staff determined that it needed additional information to resolve this issue. The applicant provided an acceptable explanation of the purpose of the brackets. However, the applicant did not analyze the effects on local stresses in the drywell head when subjected to accident pressure and temperature. In its RAI 3.8-31 S01 response, the applicant stated that the drywell head support brackets are only used during refueling to support the drywell head. During accident pressure and temperature conditions, there is no effect on the shell response, since the bracket is not constrained. The applicant included the results of a simplified analysis of the bracket attachment region to demonstrate the negligible effect of the brackets on the stresses in the drywell head.

The staff reviewed the RAI 3.8-31 S01 response and found that the applicant's demonstration of negligible effect provided additional insight. On the basis that the drywell head will be subjected to the design accident pressure and temperature at most once during its lifetime, the staff concluded that any localized stress at the bracket locations would not impair the performance of the drywell head. If the design required significant pressure cycling of the drywell head, then the localized stress would have to be considered in a fatigue evaluation. The staff therefore found the applicant's response acceptable. The staff reviewed the applicant's proposed DCD changes and found them acceptable to resolve this issue. The staff also confirmed that the applicant had incorporated the proposed changes into Revision 3 of the DCD. Therefore, RAI 3.8-31 was resolved.

3.8.2.3.2 Applicable Codes, Standards, and Specifications

The staff finds that the applicant referenced the appropriate codes, standards, and specifications, consistent with SRP Section 3.8.2. However, the staff noted that the applicant referenced the 2004 Edition of ASME Code, Section III, Subsection NE, in DCD, Tier 2, Table 1.9-22, "Industrial Codes and Standards Applicable to ESBWR."

The NRC officially issued RG 1.57, Revision 1, in March 2007. This RG endorses the 2001 Edition through the 2003 Addenda of ASME Code, Section III, Subsection NE, subject to the exceptions cited in the regulatory positions of the RG. In RAI 3.8-110, the staff requested that the applicant compare the 2004 Edition of the ASME Code to RG 1.57, Revision 1, including the regulatory positions; identify any relaxations; and provide a technical justification for each relaxation.

In its response to RAI 3.8-110, the applicant stated that it based the ESBWR design certification on RG 1.57, Revision 0, which was the version in effect 6 months before the design certification application. In addition, the applicant referred to the ASME Code, Section III, comparisons presented in its response to RAI 3.8-5, which included the differences between the 2004 Edition and the 2001 Edition through the 2003 Addenda of the ASME Code. The staff reviewed the comparisons presented in the applicant's supplemental response to RAI 3.8-5. From these comparisons, the staff noted one substantive relaxation identified in the 2004 Edition of ASME Code, Section III, Subsection NE. The change in requirements relates to the examination of Category B butt welds in electrical penetrations. As noted in the RAI 3.8-5 supplemental response, the NRC accepted this revised provision in ASME Code Case N-505, referenced in RG 1.84, "Design, Fabrication, and Materials Code Case Acceptability, ASME Section III." The staff concluded that use of the 2004 Edition of ASME Code, Section III, Subsection NE, is acceptable for the design of the steel components of the RCCV, provided the applicant confirms that the DCD also meets the regulatory positions in the current RG 1.57, Revision 1, which endorses the 2001 Edition through the 2003 Addenda of the ASME Code. RAI 3.8-110 was being tracked as an open item in the SER with open items.

In its RAI 3.8-110 S01 response, the applicant confirmed that the ESBWR design certification meets the regulatory positions stated in RG 1.57, Revision 1, which endorses the ASME Section III, Division 1, Subsection NE, 2001 Edition through the 2003 Addenda. In addition, the applicant revised DCD, Tier 2, Table 1.9-21, and Section 3.8.2.2 to show that RG 1.57, Revision 1, is applicable to the ESBWR design certification. The staff verified that the applicant incorporated the proposed markup changes in the response into the appropriate sections of the DCD and found them acceptable.

In the response, the applicant also stated that, in addition to including RG 1.57, Revision 1, for design certification in Table 1.9-21 and Section 3.8.2.2, it revised Table 3.8-4 to agree with the load combinations in RG 1.57, Revision 1. Also, the applicant made the materials listed in DCD Section 3.8.2.6 consistent with the materials listed in ASME Section III, Division 1, Subsection NE, Article NE-2121. After reviewing these additional changes to the DCD, the staff asked the applicant, in RAI 3.8-110 S02, to provide clarification pertaining to load combinations in DCD Sections 3.8.1 and 3.8.2, to be consistent with the recommendations given in RG 1.57, Revision 1, and RG 1.136, Revision 3, and material specifications in DCD Section 3.8.2.6 and Appendix 3G, to be consistent with the ASME Code. In its RAI 3.8-110 S02 response, the applicant provided these additional clarifications with regard to load combinations and material specifications, based on the technical discussions that took place during the audit at the applicant's offices in the week of June 23, 2008. The staff reviewed the applicant's responses and found them consistent with those discussed during the audit. Therefore, RAI 3.8-110 and its associated open item were resolved.

3.8.2.3.3 Loads and Load Combinations

The staff finds that the applicant's specification of loads and load combinations applicable to the steel components of the RCCV is generally consistent with SRP Section 3.8.2. However, the staff noted that, in DCD Section 3G.1.5.2.2.2, the applicant stated that W, W′, R_o, R_a, Y, SRV, and LOCA are small and are neglected for the drywell head. In RAI 3.8-39, the staff asked the applicant to provide a technical basis for this conclusion for each of these loads and to include this information in DCD Section 3.8.2 or Appendix 3G, or both.

In its response to RAI 3.8-39, the applicant stated that these loads do not act on the drywell head directly. It evaluated the indirect effect under these loads in terms of deformations of the supporting RCCV top slab. The strains of the top slab at the drywell head opening, calculated from the global NASTRAN analysis for these loads, are very small, and as a result, these loads are negligible to the drywell head design. The applicant referenced GEH Report DC-OG-0052, Revision 1, which contains the evaluation method and results for the structural integrity of the containment liner and drywell head. The applicant also indicated that it would revise DCD, Tier 2, Section 3G.1.5.2.2.2, and provided a markup of the proposed change.

The staff reviewed the referenced report during an onsite audit in February 2007 and concurs with the applicant's conclusion that it can neglect W, W′, R_o, R_a, Y, SRV, and LOCA for the drywell head. The staff found the applicant's proposed DCD change to be acceptable and confirmed that the applicant incorporated it into Revision 3 of the DCD. Therefore, RAI 3.8-39 was resolved.

3.8.2.3.4 Design and Analysis Procedures

DCD Sections 3.8.2.4 and 3G.1 describe the design and analysis procedures used for the steel components of the concrete containment. The applicant analyzes steel components using a computerized FE stress analysis or manual calculations. It considers and evaluates the forces from the various load combinations in accordance with the design requirements of Subarticles NE-3130, NE-3200, and NE-3300 of ASME Code, Section III, Division 1. The staff finds that the design and analysis procedures applicable to the steel components of the RCCV are generally consistent with SRP Section 3.8.2. However, during the initial review of DCD Revision 1, the staff identified a number of issues requiring further review, as discussed below.

In RAI 3.8-35, the staff requested that the applicant provide details of the MS and FW penetration analyses for both stress and buckling (if applicable), including a description of all pressure and thermal conditions applicable to the MS and FW penetrations. The staff also asked the applicant to compare the response for each load case to the applicable stress and buckling acceptance criteria.

In its response to RAI 3.8-35, the applicant stated that it developed three-dimensional FEMs to analyze MS and FW penetrations. Calculations consider pressure and temperature for the process piping inside and outside the RCCV. The applicant used reaction loads obtained from the pipe stress analysis of the MS lines in the design of MS penetrations. For FW penetrations, it developed a set of enveloping mechanical loads to obtain a preliminary design. The head fitting sections meet the stress intensity limits prescribed in ASME Code, Subarticle NB-3220. The sleeves, flange plates, and gusset plates meet the stress intensity limits prescribed in ASME Code, Subarticle NE-3220. The applicant used hand calculations to demonstrate that buckling stress values are much higher than the values obtained in the FE analyses. Therefore, buckling is not a controlling case, and the penetrations meet the stability stress limits. The applicant referenced GEH Report 092-134-F-M-03812, “Main Steam and Feedwater RCCV Penetrations Design Report,” Revision 1, which contains the stress evaluation of the MS and FW penetrations. The applicant indicated that it would revise DCD Section 3.8.2.4.1.3 in the next DCD update and provided a markup of the proposed change.

The staff reviewed the referenced report during an onsite audit in February 2007 and found that the MS and FW penetrations were analyzed for stress and buckling in accordance with accepted industry practices and SRP Section 3.8.2, and were shown to meet the stress limits specified in ASME Code, Section III. Therefore, the staff concluded that the applicant had appropriately analyzed the MS and FW penetrations for both stress and buckling. The staff found the applicant’s proposed DCD change to be acceptable and confirmed that the applicant incorporated it into Revision 3 of the DCD. Therefore, RAI 3.8-35 was resolved.

In RAI 3.8-36, the staff requested that the applicant provide details of the two personnel air lock analyses for both stress and buckling (if applicable), including a description of all applicable pressure and thermal conditions. The staff also asked the applicant to compare the response for each load case to the applicable stress and buckling acceptance criteria.

In its response to RAI 3.8-36, the applicant stated that it performed stress and buckling analyses for the upper and lower personnel airlocks for all applicable loads and load combinations. The results confirm that the stresses are within the allowables specified in ASME Code, Section III, Division 1, Subarticle NE-3220; Division 2, Subarticle CC-3400; and Code Case N-284-1, with corrections in RG 1.193, Revision 1. Buckling stresses calculated in accordance with ASME Code Case N-284-1 for ASME Code, Class MC, components do not include thermal stress, since it acts in a direction opposite to the buckling effects. The applicant included, in its response, a number of tables and figures that summarize the results of the stress and buckling analyses. The applicant referenced GEH Report DE-ES-0010, Revision 0, “Stress Analysis Report for Personnel Airlock,” and GEH Report DE-ES-0023, Revision 0, “Buckling Evaluation for Personnel Airlock,” both issued October 2006. The applicant indicated that it would revise DCD Figure 3G.1-54 in the next DCD update and provided a markup of the proposed change.

The staff reviewed the analysis results included in the response and the referenced reports during an onsite audit in February 2007, and found that the personnel airlocks were analyzed for stress and buckling in accordance with accepted industry practices and SRP Section 3.8.2, and were shown to meet the stress limits specified in ASME Code, Section III. Therefore, the staff concluded that the applicant had appropriately analyzed the two personnel airlocks for both stress and buckling. The staff found the proposed DCD change to be acceptable and confirmed that the applicant had incorporated it into Revision 3 of the DCD. Therefore, RAI 3.8-36 was resolved.

In RAI 3.8-37, the staff requested that the applicant provide details of the three containment equipment hatch analyses for both stress and buckling (if applicable), including a description of all pressure and thermal conditions applicable to the equipment hatches. The staff also asked the applicant to compare the response for each load case to the applicable stress and buckling acceptance criteria.

In its response to RAI 3.8-37, the applicant stated that it performed stress and buckling analyses for the wetwell hatch and upper and lower equipment hatches for all applicable loads and load combinations. The results confirm that the stresses are within the allowables specified in ASME Code, Section III, Division 1, Subarticle NE-3220; Division 2, Subarticle CC-3400; and ASME Code Case N-284-1, with corrections in RG 1.193, Revision 1. Buckling stresses calculated in accordance with ASME Code Case N-284-1 for ASME Code, Class MC, components do not include thermal stress, since it acts in a direction opposite to the buckling effects. The applicant included in its response a number of tables and figures that summarize the stress and buckling analysis results. The applicant referenced GEH Report DE-ES-0006, Revision 0, "Stress Analysis Report for Equipment Hatch"; GEH Report DE-ES-0009, Revision 0, "Stress Analysis Report for Wetwell Hatch"; GEH Report DE-ES-0020, Revision 0, "Buckling Evaluation for Equipment Hatch"; and GEH Report DE-ES-0019, Revision 0, "Buckling Evaluation for Wetwell Hatch," all issued October 2006. The applicant indicated that it would revise DCD Figures 3G.1-52 and 3G.1-53 in the next DCD update and provided a markup of the proposed change.

The staff reviewed the analysis results included in the response and the referenced reports during an onsite audit in February 2007, and found that the three equipment hatches were analyzed for stress and buckling in accordance with accepted industry practices and SRP Section 3.8.2, and were shown to meet the stress limits specified in ASME Code, Section III. Therefore, the staff concluded that the applicant had appropriately analyzed the three equipment hatches for both stress and buckling. The staff found the proposed DCD change to be acceptable and confirmed that the applicant had incorporated it into Revision 3 of the DCD. Therefore, RAI 3.8-37 was resolved.

In RAI 3.8-38, the staff requested that the applicant provide details of the drywell head analyses for both stress and buckling, including a description of all pressure and thermal conditions applicable to the drywell head. The staff also asked the applicant to compare the response for each load case to the applicable stress and buckling acceptance criteria.

In its response to RAI 3.8-38, the applicant stated that it performed stress and buckling analyses for the drywell head for all applicable loads and load combinations. The results confirm that the stresses are within the allowables specified in ASME Code, Section III, Division 1, Subarticle NE-3220; Division 2, Subarticle CC-3400; and ASME Code Case N-284-1, with corrections in RG 1.193, Revision 1. Buckling stresses calculated in accordance with ASME Code Case N-284-1 for ASME Code, Class MC, components do not include thermal stress, since it acts in a direction opposite to the buckling effects. The applicant included in its response a number of tables that summarize the results of the stress and buckling analyses. The applicant referenced GEH Report DC-OG-0052, Revision 2, which contains the evaluation method and results for structural integrity of the drywell head; GEH Report DE-OG-0082, Revision 0, "Local Analysis Model for Drywell Head"; GEH Report DE-ES-0001, Revision 0, "Stress Analysis Report for Drywell Head"; and GEH Report DE-ES-0003, all issued October 2006. The applicant indicated that it would revise DCD Table 3G.1-36 and Figure 3G.1-51 in the next DCD update and provided a markup of the proposed change.

The staff reviewed the analysis results included in the response and the referenced reports during an onsite audit in February 2007, and found that the drywell head was analyzed for stress and buckling in accordance with accepted industry practices and SRP Section 3.8.2, and was shown to meet the stress limits specified in ASME Code, Section III. Therefore, the staff concluded that the applicant had appropriately analyzed the drywell head for both stress and buckling. The staff found the applicant's proposed DCD change to be acceptable and confirmed that it incorporated the change into Revision 3 of the DCD. Therefore, RAI 3.8-38 was resolved.

In RAI 3.8-117, the staff asked the applicant to provide a comprehensive description of the PCCS, in view of the rules for Class MC containment vessels in ASME Code, Section III. The requested information included the items listed below.

(a) ASME Code, Section III, Subsection NE (Class MC), Subarticle NE-1120, states "Only containment vessels and their appurtenances shall be classified as Class MC. Piping, pumps, and valves which are part of the containment system (NE-1130) or which penetrate or are attached to the containment vessel shall be classified as Class 1 or 2 by the Design specification and meet the requirements of the applicable Subsection." It appears to the staff that the PCCS condensers and the piping between the condensers and the drywell would be more appropriately classified as Class 1 or Class 2. These sections of the ASME Code (NB-3200 and 3300 or NC-3200 and 3300) provide design and analysis procedures that the staff considers more applicable to piping and components. The staff asked the applicant to clarify the exact meaning of the statement "The PCCS condenser parts conform to the design requirements of Subarticles NE-3200 and NE-3300 of ASME Code, Section III, Subsection NE (Class MC)." The applicant should explain whether it initially designed the condensers and piping to NE, NB, or NC requirements. If NB or NC, the staff asked the applicant whether there were any design modifications necessary to conform to NE. If NE, the applicant should indicate whether any design modifications would be necessary to conform to NB or NC.

(b) The applicant designated the PCCS condensers as part of the containment pressure boundary. This appears to be a unique application of condensers. To develop reasonable assurance that the containment has been adequately designed, the staff asked the applicant to provide a comprehensive description of the condenser and connecting piping. The description should include details and figures showing the individual parts of the condenser and how they are connected; dimensions; materials; the piping and pipe supports between the containment top slab and condenser; and the supporting elements from the condenser to the top slab and lateral supports to the pool walls.

(c) Since the PCCS condensers and piping are part of the containment pressure boundary, the staff asked the applicant to include in the DCD a description of the analysis and design evaluation (including results) comparable to the information provided for other steel components in the containment.

(d) The staff asked the applicant to provide a detailed description of how it will perform the preoperational pressure tests for the PCCS condenser and associated piping, in accordance with the requirements of the applicable subsection of ASME Code, Section III, including a discussion of the provisions of the ASME Code where it is not obvious the design can meet the ASME Code provisions. As an example, the staff asked the applicant to explain how it examines for leakage after the application of test pressure.

(e) The staff asked the applicant to provide a detailed description of how it will effectively implement the preservice and inservice inspection requirements of ASME Code, Section XI, Subsection IWE, for the PCCS condensers and associated piping. The staff notes that the IWE requirements are applicable primarily to accessible shell-type structures.

In its response to RAI 3.8-117, the applicant provided technical information to address each of the items listed above. In addition, the staff conducted a structural audit meeting at the applicant's offices during the week of June 23, 2008, to review some of this information in more detail. Based on the staff's review of the RAI response and the audit held during the week of June 23, 2008, the staff found that the applicant provided sufficient information to adequately describe the PCCS and associated piping and supports, materials, analysis, and design. This information was consistent with the criteria for description, materials, analysis, and design given in SRP Section 3.8.2 for other steel components in the containment, and thus the staff found this information to be acceptable. However, it needed clarification to address Item (e) above. The staff also verified that the applicant had incorporated the proposed markup changes in the response into the appropriate sections of the DCD.

The applicant provided a revised response to RAI 3.8-117 containing technical information to address Item (e) above. The revised response states that the preservice and inservice inspections of the PCCS condensers shall conform to all portions of ASME Code, Section XI, Subsection IWE. Since the inspections of the PCCS condensers conform to ASME Code, Section XI, Subsection IWE, the staff found this acceptable. Therefore, RAI 3.8-117 was resolved.

In RAI 6.2-202, the staff requested the applicant to explain how the ESBWR design would address the possible accumulation of hydrogen and oxygen gases inside the PCCS condensers. The staff noted that in the ESBWR design, the generation of hydrogen and oxygen gas by radiolysis in the reactor core occurs in a stoichiometric ratio at a rate proportional to the core decay heat. During a LOCA event, these gases would escape into the containment and become diluted with steam in the drywell area. The PCCS condensers are designed to receive this mixture of steam and non-condensable gases (hydrogen and oxygen), condense the steam, and return the condensate back to the wetwell. As a result, the non-condensable gases may persistently linger in certain components of the PCCS at concentrations that could originate deflagrations or detonations in these components.

Since the PCCS condensers were analyzed and designed as part of the containment boundary according to ASME Code, Section III, Subsection NE, the deflagration or detonation of non-condensable gases inside the PCCS would introduce new loads that were not previously considered in the design. The applicant was requested to address these issues, including the items listed below.

a. Describe the methodology for assessing the accumulation of non-condensable gases inside the PCCS.

b. Describe the detonation loads affecting the PCCS and explain how these loads are treated in the design load combinations.

c. Describe in detail how the detonation loads are determined, and explain the analysis approach, design procedure, and acceptance criteria used for the design of the PCCS, including its support structure.

d. Address the impact, if any, of detonations inside the PCCS on the reinforced concrete containment vessel design.

e. Revise the relevant sections of DCD, Tier 2, Section 3.8 and Appendix 3G to address the issues described above.

In its initial response to RAI 6.2-202, included with the letter MFN 10-044 dated February 1 2010, the applicant provided some preliminary technical information, which was further discussed during a public meeting with the staff held on March 2, 2010. The applicant identified the following critical PCCS components directly affected by possible detonation loads: the condenser tubes, the lower drums, the vent pipes, and the drain pipes. Other PCCS components are not directly affected by detonations because, during a LOCA, the concentration of non-condensable gases would remain below the lower flammability limit (greater than approximately 80% steam concentration). The applicant stated that critical PCCS components need to be strengthened to withstand internal pressures resulting from detonations of non-condensable gases, such that: (a) the structural integrity of the containment pressure boundary is maintained, and (b) the long term (72 hours) heat removal function of the PCCS is not compromised. The applicant also indicated that a complete structural evaluation of the revised PCCS design would be submitted as part of LTR NEDE-33572P "ESBWR ICS and PCCS Condenser Combustible Gas Mitigation and Structural Evaluation," including a revised FE stress analysis, and that DCD, Tier 2, Section 3.8 and Appendix 3G would be modified accordingly. In particular, Table 3.G.1-60 summarizing the results of the stress analysis would be revised, removed from Appendix 3G, and added to the LTR.

The staff reviewed the applicant's revised response to RAI 6.2-202, the referenced LTR NEDE-33572P Revision 0, and markups of the proposed changes to DCD, Tier 2, Section 3.8 and Appendix 3G, all issued in March, 2010. The staff determined that the equivalent-static methodology proposed to estimate the detonation pressures in the condenser tubes and lower drums of the PCCS effectively bounds the pressures resulting from the complex wave propagation phenomenon associated with the detonation of non-condensable gas and steam mixtures, at various concentrations, following the latest technical literature on the subject. This methodology assumes linear elastic response and uses appropriate amplification factors to take into account wave reflections and other dynamic effects. However, the staff found that the information provided was insufficient to support the stated design intent. Therefore, additional information was requested in RAI 6.2-202 S01, including the items listed below.

a. LTR NEDE-33572P, Revision 0, stated that the acceptance criteria used for the load combinations that include detonation loads is Service Level D per the ASME Code, Section III, Subsection NE. The staff noted that, since the PCCS is required to maintain the integrity of the containment pressure boundary and also meet its functional requirement of heat removal during the 72 hour-period associated with a LOCA, Service Level D may not be appropriate. Service Level D permits stresses beyond yield and may result in distortions such that the PCCS is not able perform its function of heat removal. Furthermore, if the analysis and design allow strains beyond yield, then the proposed equivalent-static methodology to estimate detonation pressures may not be valid because it is based on essentially elastic response. Therefore, the applicant was asked to provide technical justification for the load combinations and corresponding acceptance criteria used in the PCCS design.

b. The applicant indicated that the number of detonations expected to occur during the 72 hour-period associated with a LOCA could be as high as 12. In light of this information, and if plastic deformation does occur within the PCCS, the applicant was requested to address the ratcheting effects of multiple detonations, and the combination with elastically calculated stresses due to other non-detonation load cases (e.g., seismic, dead weight, and thermal).

c. The applicant was asked to provide a detailed discussion on the effect of deflagrations or detonation waves in all components of the PCCS, not only the lower drums and the condenser tubes. In particular, the staff requested a discussion of the loads associated with deflagration-to-detonation transition (DDT). The staff noted that calculations in LTR NEDE-33572P, Revision 0, assume the highest possible concentrations of hydrogen and oxygen (in stoichiometric ratio without steam), which lead to detonations without delay. However, steam could be present in the mixture delaying DDT in the drain and vent pipes, which are relatively long. Delayed DDT could generate higher pressures than those assumed in the LTR.

d. The applicant was asked to address the uncertainty in the non-condensable gas concentrations and the presence of dilutants (e.g., steam); specifically, with regard to possible variations in peak pressure values, detonation wave propagation velocities, and dynamic amplification factors used in the analysis.

e. The applicant was asked to address the effects of stress concentrations and potential plastic deformations at selected locations such as pipe and tube bends, and the weld junctions of the condenser tubes to the upper and lower drums. In particular, the applicant was asked to confirm that the FE mesh used in the stress analysis is sufficiently refined to capture these effects.

f. The response to RAI 6.2-202 indicated that detonations inside the PCCS have negligible impact on the overall containment pressure vessel design. The response also provided the magnitude of the energy released during a detonation event. However, the response did not explain how this energy release is translated into stresses in the PCCS support frame, floor anchors, and other PCCS components not directly affected by the detonation and, therefore, not captured in the stress analysis described in LTR NEDE-33572P. Therefore, the applicant was asked to address the effect of detonations on the entire PCCS assembly, including the PCCS support frame, support frame floor anchors, and connections to the pool liner plate.

g. The response to RAI 6.2-202 indicated that DCD, Tier 2, Section 3.8 and Appendix 3G were being modified to include a description of detonation loads, delete information referring to stress analysis results, and refer to LTR NEDE-33572P for these stress analysis results as well as for other analysis and design details. However, this information was not included in Revision 0 of the LTR. Therefore, the applicant was asked to submit a final version of the LTR, including all of its appendices. In addition, the staff emphasized that the DCD Tier 2 should also contain a summary of analysis and design results from the LTR, as well as sufficient information to support a safety conclusion.

In its response to RAI 6.2-202 S01, the applicant provided additional technical information to address the items listed above. LTR NEDE-33572P, Revision 1, issued May 2010, was also submitted for review. The new technical information included the items listed below.

a. The acceptance criteria used for the load combinations that include detonation loads is Service Level C per the ASME Code, Section III, Subsection NE. The staff determined that, although Service Level C allows for local stresses to be higher than the yield limit, two design objectives could be achieved: (1) the response of the component remains essentially elastic, and (2) ratcheting and other undesirable plastic instabilities are precluded. The stress analysis results presented in LTR NEDE-33572P, Revision 1, indicate that stresses due to detonation loads in the PCCS are within Service Level C limits for all components except for portions of the lower drums. The applicant proposed additional design modifications to bring these stresses to within acceptable limits; however, these modifications were not documented in Revision 1 of the LTR. The applicant further stated that theses additional design modifications would be implemented in the detailed design phase, and compliance with ASME Code acceptance criteria (including Service Level C criteria) would be demonstrated in the closure of ITAAC Item 2a1 in DCD, Tier1, Table 2.15.4-2.

b. LTR NEDE-33572P, Revision 1, indicated that a catalyst module was added to the entrance of the vent pipes to maintain the non-condensable gas accumulation in these pipes below the lower flammability limit. The vent pipes lie outside the jurisdictional boundary of the containment.

c. LTR NEDE-33572P, Revision 1, included a discussion of delayed DDT, as well as a discussion of the uncertainty in non-condensable gas concentrations with regard to possible variations in peak pressure values, detonation velocities, and dynamic amplification factors used in the analysis of the PCCS condenser tubes. The staff found that this discussion was not sufficiently conclusive.

d. The response to RAI 6.2-202 S01 indicated that an additional dynamic analysis was performed to evaluate the effects of detonations on the entire PCCS assembly, including its supporting structure and anchorage. The results of this analysis showed that these effects are smaller in magnitude than those due to seismic loading. However, details of this analysis were not provided to the staff.

Based on its review of the response to RAI 6.2-202 S01 and LTR NEDE-33572P, Revision 1, including the information summarized above, the staff concluded that the LTR and DCD, Tier 2, Revision 7, Section 3.8 and Appendix 3G, still required additional information to support the stated design intent. The staff also raised further questions regarding: thermal effects in the PCCS following a detonation; fatigue evaluation for the total number of postulated detonation events; and certain details of the stress analysis contained in the LTR. Therefore, additional information was requested in RAI 6.2-202 S01, Revision 1.

In its response to RAI 6.2-202 S01, Revision 1, the applicant provided revised technical information to address the staff's concerns. A draft version of LTR NEDE-33572P, Revision 2, and markups of DCD, Tier 2, Revision 8, Section 3.8 and Appendix 3G, all issued in August 2010, were also submitted for review. The staff found that, although some issues were resolved, certain sections of the LTR remained incomplete or were in preliminary form. In particular, the LTR did not include details of the dynamic analysis performed to evaluate the effects of detonations on the entire PCCS assembly, including its supporting structure and anchorage (Appendix C to LTR NEDE-33572P). The resolution of this RAI is discussed in Section 6.2.2 of this report.

3.8.2.3.5 Structural Acceptance Criteria

DCD Section 3.8.2.5 provides the structural acceptance criteria for the design of the steel components of the concrete containment. This section states that the allowable stresses, deformation limits, and factors of safety of the steel components satisfy the acceptance criteria in ASME Code, Section III, Division 1, Subsection NE. The acceptance criteria for the nonpressure-resisting components are in accordance with ANSI/AISC N690-1994s2 (2004).

The staff finds that the structural acceptance criteria applicable to the steel components of the RCCV are generally consistent with SRP Section 3.8.2. However, during the initial review of the DCD, Revision 1, the staff identified a number of issues requiring further review, as discussed below.

The staff noted that DCD Table 3G.1-36 indicates that the Service Level A and B primary + secondary stress condition in the drywell head exceeds the basic ASME Code allowable stress by 75 percent (PL+Pb+Q is 794 MPa calculated versus 456 MPa allowable; where PL = primary local membrane stress, Pb = primary bending stress and Q = secondary membrane plus bending stress). In RAI 3.8-29, the staff requested that the applicant provide a detailed description of the geometry and location of all overstress conditions, explain why Q is 11 times greater than PL+Pb, and identify the loading condition(s) that created this overstress condition (pressure loads, thermal loads, or a combination of the two). The staff also requested that the applicant provide the details of the ASME Code, Subsection NE-3228.3, analysis and the technical basis for relying on the NE-3228.3 analysis, rather than modifying the design to alleviate the high secondary stress.

In its response to RAI 3.8-29, the applicant stated that the high stress value results from thermal loads caused by the LOCA. Since the drywell head is fixed at the cylindrical part to the concrete slab, high discontinuity stresses are present at the joint. This is secondary stress and cannot be alleviated by design modification. Figure 3.8-29(1) illustrates the portion where the high stress occurs. PL+Pb is the primary membrane stress, so it does not include thermal stress, and the stress value is at the center of the plate thickness, while PL+Pb+Q is the primary plus secondary stress, including thermal stress, and the stress value is at the surface of the plate. Therefore, PL+Pb+Q is much greater than PL+Pb. Under this type of secondary stress, the ASME Code, Subsection NE-3228.3, permits a simplified elastoplastic analysis. The applicant referenced GEH Report DC-OG-0052, Revision 1, which contains the evaluation method and results for the structural integrity of the containment liner and drywell head. The applicant indicated that it would include the details of the ASME Code, Subsection NE-3228.3, analysis in Section 3G.1.5.4.1.4 of the next DCD revision and provided a markup of the proposed change.

The staff determined that it needed additional information to resolve this issue. In RAI 3.8-29 S01, the staff asked the applicant to (1) compare the allowable stress limits for Pm (primary general membrane stress), PL+Pb, and PL+Pb+Q, and (2) provide a hand calculation of fully restrained thermal stress for ΔT from construction ambient temperature to 171 degrees C (340 degrees F) and compare it to the computer results for this thermal condition. In its response to RAI 3.8-29 S01, the applicant provided tabulated results for PL, PL+Pb, and PL+Pb+Q, for each service level in DCD Tables 3.8-29(1) through (5). DCD Figure 3.8-29(2) identifies the locations of interest. The applicant stated that it did not evaluate Pm, because the membrane stress is categorized as PL at these locations. The applicant provided a comparison of the computer analysis result (from Table 5-47 of GEH Report DC-OG-0052) with a hand calculation for fully restrained thermal stress. The thermal stress predicted by each method agrees to within 3 percent.

The staff reviewed the information included in the supplemental response and the referenced report during an onsite audit in February 2007 (see audit report "Summary of February 7, 2007, Public meeting with General Electric Company Regarding ESBWR Containment Capacity

Audit," March 23, 2007). The staff concluded that the applicant's technical approach is in accordance with ASME Code, Subsection NE-3228.3 and therefore is acceptable for this special condition. The staff found the applicant's proposed DCD change to be acceptable and confirmed that the applicant had incorporated it into Revision 3 of the DCD. Therefore, RAI 3.8-29 was resolved.

The staff noted that the DCD did not address fatigue failure for the drywell head. In RAI 3.8-32, the staff requested that the applicant include information about fatigue analysis of the drywell head in DCD Section 3.8.2 or Appendix 3G, or both. In its response to RAI 3.8-32, the applicant stated that it evaluated fatigue for the metal components of the RCCV, including the drywell head, in accordance with ASME Code, Section III, Subsection NE-3221.5(d), in which the limits on peak stress intensities, as governed by fatigue, are considered and satisfied when the service loading meets the stipulated condition. The applicant referenced GEH Report DE-ES-0022, Revision 0, "Fatigue Evaluation for Metal Parts of RCCV," issued October 2006, which contains the evaluation method and results for the fatigue analysis of the containment's metal components.

The staff reviewed the referenced report during an onsite audit in February 2007, and concluded that the applicant had conducted an adequate fatigue evaluation for the drywell head. The staff also confirmed that a brief description of the fatigue evaluation was added to Section 3G.1.5.4.1.4 in Revision 3 of the DCD. Therefore, RAI 3.8-32 was resolved.

The staff noted that the DCD did not address fatigue failure for the MS, FW, and other hot penetrations. In RAI 3.8-33, the staff requested that the applicant include information about its fatigue analysis of the MS, FW, and other hot penetrations in DCD Section 3.8.2 or Appendix 3G, or both. In its response to RAI 3.8-33, the applicant stated that it evaluated fatigue for the MS penetrations using the same three-dimensional FEM that was developed for the stress analysis (see applicant's response to RAI 3.8-35). In addition to pressure and temperature loads, it took into account the cyclic dynamic loads when calculating the total stress intensity (including peak stress) for each event. It found the maximum cumulative usage factor to be 0.0036. This small cumulative usage factor indicates that fatigue is not a controlling parameter for the design of MS penetrations. Since cyclic loading conditions are similar, a detailed fatigue evaluation for the FW and other hot penetrations is not considered necessary at this stage and will be performed during detailed design, in accordance with the acceptance criteria stated in the DCD. The applicant referenced GEH Report 092-134-F-M-03812, Revision 1, which contains the fatigue evaluation of the MS penetrations. The applicant also indicated that it would revise DCD Section 3.8.2.4.1.3 and provided a markup of the proposed change.

The staff reviewed the referenced report during an onsite audit in February 2007 and concluded that the applicant had conducted an adequate fatigue evaluation for the MS, FW, and other hot penetrations, since the evaluation is performed in accordance with industry practice, SRP Section 3.8.2, and ASME Code, Section III. The staff found the applicant's proposed DCD change to be acceptable and confirmed that it incorporated the change into Revision 3 of the DCD. Therefore, RAI 3.8-33 was resolved.

The staff noted that the DCD did not address fatigue failure for the cold penetrations, equipment hatches, and personnel airlocks. In RAI 3.8-34, the staff requested that the applicant include information about a fatigue analysis of the cold penetrations, equipment hatches, and personnel airlocks in DCD Section 3.8.2 or Appendix 3G, or both. In its response to RAI 3.8-34, the applicant stated that it will perform a fatigue evaluation for cold penetrations in the detailed design, in accordance with the acceptance criteria stated in the DCD. A fatigue evaluation is performed for the metal components of the RCCV, including equipment hatches and personnel airlocks, in accordance with ASME Code, Section III, Subsection NE-3221.5(d), in which the limits on peak stress intensities, as governed by fatigue, are considered and satisfied when the service loading meets the stipulated condition. The applicant referenced GEH Report DE-ES-0022, which contains the evaluation method and results for the fatigue analysis of the containment's metal components. The applicant also provided a proposed change to DCD, Tier 2, Section 3.8.2.4.1.3.

The staff reviewed the referenced report during an onsite audit in February 2007 and concluded that the applicant had conducted an adequate fatigue evaluation for the equipment hatches and personnel airlocks. The applicant will not evaluate fatigue for cold penetrations until the detailed design stage, because it has only developed typical design details to date. However, the staff determined that the cyclic stress demand on cold penetrations is minimal and that the ASME Code will not require a formal calculation of peak stress and cumulative fatigue usage for the cold penetrations. The staff found the proposed DCD change to be acceptable and confirmed that the applicant had incorporated it into DCD Revision 3. Therefore, RAI 3.8-34 was resolved.

3.8.2.3.6 Material and Quality Control and Special Construction Techniques

In DCD Revision 4, Section 3.8.2.6, the applicant inserted additional bolting materials, for consistency with DCD Figures 3G.1-51 through 3G.1-53. The DCD 3.8, Revision 3 to Revision 4 Change List Summary, Item 46, indicates that the applicant added SA-540 Gr. B24 Class 3 bolting material and SA-479 Type 304 nut material. The staff noted that this bolt material is not recognized in the 2004 Edition of ASME Code, Section III, Division 1, Subsection NE, Table NE-2121(a)-2. The table does not list acceptable nut materials; however, NE-2128(a) specifies SA-194 or a nut material compatible with the bolt material.

In RAI 3.8-118, the staff asked the applicant to provide its technical basis for specifying a bolt material for the drywell head (Figure 3G.1-51), the equipment hatch (Figure 3G.1-52), and the wetwell hatch (Figure 3G.1-53), that is not listed in Table NE-2121(a)-2. The staff also asked the applicant to clarify the basis for specifying SA-479 Type 304 nut material.

In addition, the staff noted that DCD Section 3.8.2.6 states that ASTM A325 or A490 may be used as an alternative material for nuts. Since this material designation is considered to be applicable to bolts, the staff asked applicant to explain why it identified this material for nuts. Furthermore, since bolting material designations ASTM A325 and A490 are not recognized in the 2004 Edition of ASME Code, Section III, Division 1, Subsection NE, Table NE-2121(a)-2, the staff asked the applicant to explain why it included them in DCD Section 3.8.2.6.

In its response to RAI 3.8-118, the applicant stated that it used the bolting material SA-437 Gr. B4B, listed in the 2004 Edition of ASME Code, Section III, Division 1, Subsection NE, Table NE-2121(a)-2, instead of SA-540 Gr. B24 Class 3. The applicant will revise DCD, Tier 2, Section 3.8.2.6, and Figures 3G.1-51 through 3G.1-53 of DCD, Tier 2, Appendix 3G.

Since the maximum allowable stress of SA-437 Gr. B4B is lower than that of SA-540 Gr. B24, Class 3, it also affects the level C pressure capability evaluation for the bolted flange of the drywell head, equipment hatch, and wetwell hatch. Therefore, the applicant should also revise DCD, Tier 2, Tables 19B-9 and 19B-10.

Regarding plate material, the applicant used SA-240 type 304L, SA-516 grade 60 or 70, for pressure-retaining components. Regarding nut material, the applicant deleted ASTM A325 and A490 and SA-479 Type 304 and replaced SA-194-7 with SA-194, in DCD, Tier 2, Section 3.8.2.6.

Because the applicant did not use castings, cold finished steel, bar or machine steel for pressure-containing components, it deleted them from DCD, Tier 2, Section 3.8.2.6. The staff reviewed all responses by the applicant and found them acceptable, since the new materials are consistent with the ASME Code. The staff also verified that the applicant incorporated the proposed markup changes in the response into the appropriate sections of the DCD. Therefore, RAI 3.8-118 was resolved.

3.8.2.3.7 Testing and Inservice Inspection Requirements

The staff reviewed Section 3.8.2.7 of the DCD. This section refers to DCD Section 3.8.1.7 for information on testing and ISI requirements for the steel components of the containment structure. Based on its review, the staff concluded that DCD Section 3.8.1.7 adequately describes the testing and ISI requirements for the steel components of the containment structure, in accordance with NRC regulations and the applicable provisions of ASME Code, Section XI, Subsection IWE. Therefore, the staff finds the applicant’s commitment for testing and ISI of the steel components of the containment structure to be acceptable.

In addition to its review of testing and ISI requirements in accordance with SRP 3.8.2, the staff also evaluated compliance with Generic Issue B-26, “Structural Integrity of Containment Penetrations,” contained in NUREG-0933. This generic issue concerns whether or not the configuration and accessibility of the welds in the design and the procedures proposed for performing volumetric examination permit implementation of in-service examination in compliance with the requirements of the ASME Code, Section XI, at an augmented frequency in break exclusion regions, as required by SRP Section 3.6.2. In the event that penetration designs are found inadequate with respect to conducting current in-service inspections, alternative surveillance or analysis methods would be implemented to ensure that inspections can be completed.

As discussed in NUREG-0933, a reevaluation of the issue by the staff concluded that further expenditure of resources was unwarranted. The staff believed that the increase in occupational radiological exposure (ORE) from additional inspections would negate the small potential risk reduction associated with the issue. NUREG-0933 stated that the issue was resolved and no new requirements were established. Therefore, Issue B-26 was resolved for the ESBWR design.

3.8.2.4 *Conclusion*

Pending resolution of the remaining open item, the staff concludes that the applicant has demonstrated that the analysis, design, construction, testing, and inservice surveillance of the steel components of the containment conform with established criteria in codes, standards, guides, and specifications acceptable to the staff. The staff finds the use of these criteria to be consistent with the guidance provided in SRP Section 3.8.2 and applicable RGs. Meeting these criteria ensures that the DCD meets the relevant requirements of 10 CFR 50.55a and GDC 1, 2, 4, 16, and 50 of Appendix A to 10 CFR Part 50.

3.8.3 Containment Internal Structures

The ESBWR containment internal structures are constructed of reinforced concrete and structural steel and include the (1) DF, (2) VW, (3) GDCS pool walls, (4) RSW, (5) RPVSBs, and (6) miscellaneous platforms. The containment internal structures support the reactor vessel radiation shielding, piping, and equipment and form part of the pressure suppression chamber boundary.

3.8.3.1 Regulatory Criteria

The staff reviewed DCD, Tier 2, Section 3.8.3, “Concrete and Steel Internal Structures of the Concrete Containment,” and DCD, Tier 2, Appendix 3G. The staff considers the applicant’s design and analysis procedures, loads and load combination methods, structural acceptance criteria, material, quality control and special construction techniques, and testing and ISIs to be acceptable if they satisfy the criteria, applicable codes and standards, and regulatory guidance delineated in SRP Section 3.8.3. Meeting the guidance of this SRP section will ensure that the DCD meets the relevant requirements of 10 CFR 50.55a; GDC 1, 2, 4, 5, “Sharing of Structures, Systems, and Components,” and 50 of Appendix A to 10 CFR Part 50; and Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants,” to 10 CFR Part 50. The following regulatory requirements are relevant to the staff review in Section 3.8.3.

- 10 CFR 50.55a and GDC 1 require that the containment internal structures be designed, fabricated, erected, and tested to quality standards, commensurate with the importance of the safety functions to be performed.

- GDC 2 requires that the containment internal structures withstand the most severe natural phenomena, such as winds, tornadoes, floods, and earthquakes, and the appropriate combination of all loads.

- GDC 4 requires that the containment internal structures withstand the dynamic effects of equipment failures, including missiles and blowdown loads associated with the LOCA.

- GDC 5 requires that there be no sharing of structures important to safety between nuclear power units, unless it can be shown that such sharing will not significantly impair their validity to perform their safety functions.

- GDC 50 requires that the containment internal structures be designed with a sufficient margin of safety to accommodate appropriate design loads.

- Appendix B to 10 CFR Part 50 requires that the safety-related structures be designed with QA criteria applicable for nuclear power plants.

The staff evaluated the design, materials, fabrication, erection, inspection, testing, and inservice surveillance of components of the containment internal structures, based on industry codes and standards, materials specifications, and the following RGs:

- RG 1.57

- RG 1.136

- RG 1.142

- RG 1.160, "Monitoring the Effectiveness of Maintenance at Nuclear Power Plants," Revision 2, issued March 1997

- RG 1.199

For design certification, paragraph IV(a)(2)(i)(A) of Appendix S to 10 CFR Part 50 provides an option for specifying the OBE. If it is chosen to be less than or equal to one-third of the SSE ground motion, it is not necessary to conduct explicit response or design analyses to satisfy the requirements of paragraph IV(a)(2)(i)(B)(I) of Appendix S to 10 CFR Part 50.

3.8.3.2 *Summary of Technical Information*

3.8.3.2.1 Description of the Containment Internal Structures

In DCD, Tier 2, Section 3.8.3.1, the applicant stated that the internal structures inside the ESBWR containment include the DF slab, VW, GDCS pool walls, RSW, RPVSBs, and miscellaneous platforms. The DF slab separates the drywell and the suppression chamber and is supported on the reinforced concrete containment wall at its outer periphery and on the VW at its inner periphery. The VW structure is anchored at the bottom into the RPV pedestal and is restrained at the top by the DF slab. Twelve vent pipes and 12 SRV downcomer pipes with sleeves from the drywell pass through this wall into the SP.

The DF slab supports three GDCS pools; the outer sides of these pools are contained by the reinforced concrete containment wall and the inner sides by structural steel walls. The RSW surrounds the RPV and is supported by the RPVSBs. Eight RPVSBs are located at the junction of the RPV pedestal and the VW structure.

Miscellaneous steel platforms provide access and support for equipment and piping. Platforms are classified as seismic Category I structures when they support safety-related functions. Otherwise, they are classified as seismic Category II. Other miscellaneous structural components inside containment that do not support safety-related functions are also classified as seismic Category II. The applicant referred to DCD Sections 3.8.4.1.6 and 3.8.4.1.7 for cable trays; conduits; and heating, ventilation, and air conditioning (HVAC) ducts and their supports.

3.8.3.2.2 Applicable Codes, Standards, and Specifications

In DCD, Tier 2, Section 3.8.3.2, the applicant stated that the design of the concrete and steel internal structures of the containment uses the applicable codes, industry standards, and specifications and regulations listed in DCD Table 3.8-6. The applicant also stated that it anchored the steel internal structures using the guidelines of RG 1.199.

3.8.3.2.3 Loads and Load Combinations, Including Hydrodynamic Loads

In DCD, Tier 2, Section 3.8.3.3, the applicant stated that DCD Section 3.8.1.3 defines the applicable loads and DCD Table 3.8-7 lists the load combinations applicable to the containment internal structures.

3.8.3.2.4 Design and Analysis Procedures

In DCD, Tier 2, Section 3.8.3.4, the applicant stated that it designed the steel containment internal structure components in accordance with the practices given in ANSI/AISC N690, including S02. It refers to DCD Table 3.8-7 for more details. For accessibility to equipment, valves, instrumentation, welds, supports, and the like for operation, inspection, or removal, the applicant refers to DCD Section 3.8.3.7.

The FEM described in Section 3.8.1.4.1.1 includes the DF, RPVSB, RSW, VW, and GDCS pool wall. The applicant based the design and analysis using this model on the elastic method. It considered the miscellaneous platforms as additional mass in the FEM.

3.8.3.2.5 Structural Acceptance Criteria

In DCD, Tier 2, Section 3.8.3.5, the applicant stated that the acceptance criteria for the steel containment internal structure components for both safety and non-safety applications are in accordance with ANSI/AISC N690 and referred to DCD Table 3.8-7 for more details.

3.8.3.2.6 Material and Quality Control and Special Construction Techniques

In DCD, Tier 2, Section 3.8.3.6, the applicant stated that the materials conform to all applicable requirements of ANSI/AISC N690 and ACI-349. The applicant also identified specific ASTM standards for material specifications applicable to individual components.

3.8.3.2.7 Testing and Inservice Inspection Requirements

In DCD, Tier 2, Section 3.8.3.7, the applicant stated that the testing and ISI of the DF and VW are directly related to the functioning of the containment system and referred to DCD Section 3.8.1.7.

The applicant does not plan for a formal program of testing and ISI for the internal structures, except the DF and VW. The other internal structures are not directly related to the functioning of the containment system; therefore, they do not require testing or inspection. However, during the operating life of the plant, the condition of these other internal structures is monitored in accordance with the requirements of 10 CFR 50.65, “Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants” (also known as the Maintenance Rule), as clarified in RG 1.160 and in accordance with Section 1.5 of RG 1.160.

The ESBWR design uses a three-dimensional model for space control and interference checking. The model includes all safety-related and non-safety-related SSCs. Items are added to the model as it is being developed by stages, depending on the item's criticality to the plant and its construction sequence. The design maintains accessibility to equipment, valves, instrumentation, welds, supports, and the like for operation, inspection, or removal by ensuring sufficient space to allow unobstructed access and reach of site personnel. Therefore, the applicant reviews aisles, platforms, ladders, and handrails, for example, as it plans the layout of the components. It constantly monitors interferences with access ways, doorways, walkways, truck ways, lifting wells, and similar spaces. The applicant maintains and documents this method of configuration control during the plant layout process. It considers remote tooling only if, for some layout reason, the required inspection could not be carried out otherwise.

3.8.3.2.8 Welding Methods and Acceptance Criteria for Structural and Building Steel

In DCD, Tier 2, Section 3.8.3.8, the applicant stated that it performs welding activities in accordance with the AISC manual of steel construction. The visual acceptance criteria comply with American Welding Society (AWS) Structural Welding Code D1.1 and Nuclear Construction Issue Group (NCIG) standard NCIG-01, "Visual Weld Acceptance Criteria for Structural Welding at Nuclear Plants," dated September 1987 (also known as EPRI NP-5380).

3.8.3.3 *Staff Evaluation*

3.8.3.3.1 Description of the Containment Internal Structures

DCD, Tier 2, Section 3.8.3.1, describes the containment internal structures. The staff found the descriptive information, including figures and details, to be generally acceptable and in accordance with the guidance given in SRP Section 3.8.3. However, some information was lacking regarding certain structural elements of the containment internal structures. Therefore, in RAI 3.8-40, the staff requested the following from the applicant:

(a) Provide information (description, plans, and sections) for several structures inside the containment that are not presented in the DCD. These structures include the RPV stabilizer, quenchers, the RPV insulation, and the connection of the DF to the VW. The description should include the analysis and design information comparable to the other containment internal structures, including an explanation of how the quenchers are anchored to the SP.

(b) Provide additional design details that are not included in the configuration details presented in the figures of Appendix 3G.1. This applies to the RPVSB, VW, shield wall, GDCS pool, DF, and miscellaneous platforms. Taking the RPVSB as an example, missing design information includes the thickness and dimensions of the plates; weld types, sizes, and lengths; and the length of anchor bars embedded in the containment that connect to the RPVSB.

In its response to RAI 3.8-40, the applicant stated the following:

> a. The RPV stabilizer, quenchers and RPV insulation are not in the main load path of the containment internal structures, hence they are not included in the global structural analysis. The RPV stabilizer is part of the RPV assembly as shown in DCD Figure 5.3-3. It is supported by the RSW and its supporting effects (such as reactions) are considered in the RSW design. The quenchers for the SRV discharge lines, shown in DCD Figure 6.2-1, are similar to those in the existing BWR plants except they

are anchored to the elevated suppression pool slab. The detail design will be done in the next design phase. The RPV insulation does not perform structural functions and the details will be developed in the detailed design phase. The connection of the DF to the VW is a welded joint.

b. All thicknesses and dimensions of the steel plates for the RPVSB, VW, shield wall, GDCS pool wall, and DF are shown in DCD Figures 3G.1-56 through 3G.1-59. Other information such as weld sizes/lengths and anchorage into the containment are considered to be local design details and will be determined in the detail design phase. Similarly the design of miscellaneous platforms will be performed in the detailed design phase.

During its onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, CA, the staff discussed the requested information in further detail with the applicant, in conjunction with the related discussion concerning RAI 3.8-3. The applicant stated that (1) it addressed the RPV stabilizer separately in RAI 3.8-3, (2) it did not consider insulation attached to the shield wall to be a structural element, (3) it did not consider the SRV quenchers to be mechanical components and did not describe them in DCD Section 3.8, and (4) it considered SRV quencher attachments to the pool floor and the RPV insulation details to be COL action items.

In its subsequent detailed evaluation of the applicant's RAI 3.8-40I response and the July 2006 audit discussions, the staff noted the following:

a. The RPV stabilizer is in the load path and should be included in the global structural analysis. The applicant provided details of the RPV stabilizer under RAI 3.8-27. If anchorage for quenchers is to be performed in the next design phase, the staff asked the applicant to explain whether it identified this as a COL action item in the DCD. If RPV insulation will be developed in the detailed design phase, explain whether it also identified this as a COL action item in the DCD. Information for connecting the DF to the VW is acceptable.

b. The DCD does not show some design details for the RPVSB, VW, shield wall, GDCS pool wall, DF, and platforms (e.g., weld sizes and lengths, anchorage, some plate thicknesses). If the applicant considered these to be local design details and will determine them in the detail design phase, explain if it identified them as a COL action item in the DCD.

The staff discussed these issues with the applicant at the December 2006 onsite audit. To address Part (a), the applicant confirmed that the global structural analysis does include the RPV stabilizer and agreed to revise the wording to indicate that the quencher anchorage design is in accordance with Appendix B to ACI 349-01. The applicant presented a sketch depicting the details of the quencher anchorage that it will include in a revision to the DCD. To address Part (b), the applicant indicated that the details of the major structural components listed are not COL action items. Based on these discussions, the staff requested in RAI 3.8-40 S01 that the DCD include complete design details (including weld types, sizes, and lengths; anchorage; all plate thicknesses) for the RPVSB, VW, shield wall, GDCS pool wall, and DF. The additional topics discussed during the audit were also addressed by the applicant in response to RAI 3.8-40 S01.

In its RAI 3.8-40 S01 response, the applicant stated the following:

a. The RPV stabilizer is modeled in the global structural analysis as indicated by spring K3 shown in DCD, Tier 2, Figure 3A.7-4. Details of the RPV stabilizer mechanism are provided in the response to NRC RAI 3.8-27, S03. DCD, Tier 2, Revision 3, Subsection 3.8.1.1.2 requires that anchorage design be performed in accordance with ACI 349-01, Appendix B. In addition, DCD, Tier 2, Revision 3, Figure 3.8-5 shows the typical detail for the quencher anchorage that is integrally welded to the containment liner. No COL action item is required for the quencher anchorage. The pages (pp. 3.8-2 and 3.8-62) revised in DCD, Tier 2, Revision 3 for this response are attached.

b. Design details (including weld types/sizes/lengths, anchorage and all plate thicknesses) for the RPVSB, VW, RSW, GDCS pool wall, DF and DF slab anchors are provided in DCD, Tier 2, Revision 3, Figures 3G.1-55, 3G.1-56, 3G.1-57, 3G.1-58 and 3G.1-59. No COL action item is required for these details. The pages (pp. 3G-179, 3G-180, 3G-181, 3G-182 and 3G-183) revised in DCD, Tier 2, Revision 3 for this response are attached.

The staff reviewed the applicant's RAI 3.8-40 S01 response and determined that the details and description of the RPV stabilizer provided in the response to RAI 3.8-27 S03, are acceptable and address the concerns raised under this RAI. The applicant has added typical details for the SRV quencher anchorage to Revision 3 of the DCD, and the RAI response indicates that the applicant designed the anchorage in accordance with Appendix B to ACI 349-01. The staff also noted that the applicant provided additional design details for the RPVSB, VW, RSW, GDCS pool wall, DF, and DF slab anchorage. DCD, Tier 2, Revision 3, Figures 3G.1-55, 3G.1-56, 3G.1-57, 3G.1-58, and 3G.1-59, present these details. The details presented in the revised DCD figures provide the additional descriptive information requested, consistent with the review criteria of SRP Section 3.8.3. Therefore, the applicant's response is acceptable and RAI 3.8-40 was resolved.

DCD Sections 3.8.3.1.1 and 3.8.3.1.4 indicate that the DF and VW are constructed from steel plates filled with concrete. DCD Section 3G.1.4.1 indicates that the infill concrete is conservatively neglected in the analysis model. The staff noted that neglecting the mass and stiffness of the concrete may not be conservative. Therefore, in RAI 3.8-41, the staff requested that the applicant explain how it considered the infill concrete in the analysis and design of these structures and how it considered the mass, stiffness, and strength when analyzing the DF and VW structures for each applicable loading condition. For analysis of thermal transients, the staff asked the applicant to describe how it modeled the infill concrete in the heat transfer analyses and how it considered the constraint to thermal growth and contraction of the steel plates in the thermal-stress analyses.

In its response to RAI 3.8-41, the applicant stated that it conservatively neglected concrete strength and stiffness in both the structural and the seismic analysis models. It considered the mass of concrete in both models.

For the linear thermal analysis, the applicant neglected concrete strength and stiffness and, thus, did not consider the constraint to thermal expansion or contraction of the steel plates from the infill concrete. However, for the nonlinear analyses, it explicitly included the infill concrete in the VW and DF as brick elements with strain compatibility between the steel and concrete interfaces, using the respective values for the coefficient of thermal expansion for concrete and steel. This modeling includes the effect of the constraint to thermal expansion or contraction to both the concrete and steel components. Note that concrete cracking is also included, and this would relieve some of the thermal-induced stress. The effect of this infill concrete on thermal constraint from the nonlinear model is then transferred to the linear thermal-stress design model through scaling using thermal ratios. The applicant obtained concrete-cracking effects from thermal loads by a nonlinear, concrete-cracking analysis, using the ABAQUS/ANACAP program, as described in Appendix 3C to the DCD.

For thermal transients in the heat transfer analysis performed to determine temperature distribution, the applicant neglected the heat transfer coefficient of concrete in the DF and the wetwell for the linear analysis but included concrete in the nonlinear model. By using the thermal ratios to account for the thermal stresses, the linear analysis implicitly addresses the effect of infill concrete on the heat transfer.

During its onsite audit, conducted July 11–14, 2006, at the applicant’s offices in San Jose, CA, the staff discussed the requested information in further detail with the applicant. The staff noted that the response did not adequately address the general issue of how neglecting the infill concrete affects the overall response and the distribution of internal forces and moments associated with applied loads. The staff concluded that, for the VW and DF, the applicant should demonstrate why the approach is conservative. If the infill concrete is considered in the analysis, then the frequency would increase, which could lead to higher accelerations for seismic or hydrodynamic loads, or both. This phenomenon may also be important for models that develop FRS (seismic and hydrodynamic loads). Since the stick model for the VW and DF did not use concrete properties, the applicant should determine the effect of a frequency shift when considering the concrete, even if it is cracked, in generating FRS to qualify equipment and piping. For thermal analyses other than LOCA, the applicant should still address the issue of neglecting the infill concrete. The additional topics discussed during the audit were addressed by the applicant in response to RAI 3.8-41 S02.

In its RAI 3.8-41 S02 response, the applicant indicated that, to address the effect of infill concrete on the fundamental frequency of the VW and DF, it adjusted the stiffness properties of the two structures in the seismic model to include contribution of concrete stiffness. Since the infill concrete is unreinforced, it would likely crack under the SSE. The applicant thus assumed an effective concrete stiffness equal to 50 percent of the nominal uncracked stiffness. The resulting fundamental frequency was found to be 113 percent higher for the VW and 26 percent higher for the DF, as compared to the base model, without consideration of the infill concrete stiffness.

The applicant evaluated the effect of the frequency shift on the FRS by an additional parametric SSI analysis for generic uniform sites with single envelope ground-motion input. It compared the results with the enveloping results obtained from GEH Report SER-ESB-033, Revision 0, “Parametric Evaluation of Effects on SSI Response,” submitted to the NRC as Enclosure 2 to its response to RAI 3.8-41 S02. As shown in Figures 3.8-41(1) through 3.8-41(25) of the supplemental response for spectra comparison at selected locations, the existing site-envelope spectra without the infill concrete stiffness consideration do not completely bound the spectra with infill concrete. In view of this comparison, the applicant indicated that it will include the results of the infill concrete stiffness parametric evaluation in the site-envelope seismic design loads.

The applicant also stated that it is performing an additional parametric seismic analysis to address the effect of containment LOCA flooding (see theapplicant's response to RAI 3.8-8) and the effect of updated modeling properties of containment internal structures for more consistency with the design configuration. The applicant will document the final seismic loads in the next update of Appendix 3A to the DCD.

The staff reviewed the RAI 3.8-41 S02 response and discussed several items with the applicant during the December 2006 onsite audit. The staff was concerned that using 50 percent of the uncracked concrete stiffness may not be an appropriate assumption. If the applicant had used 75 percent or 100 percent of the uncracked concrete stiffness, the frequency increase would be greater. The staff asked the applicant to provide its technical basis for the 50-percent assumption for the confined unreinforced infill concrete.

In addition, the staff noted that the RAI 3.8-41 S02 response only discussed seismic loading. The applicant should provide an assessment of the effect of the infill concrete on response spectra generated from hydrodynamic loads (SRV and LOCA). Furthermore, the staff requested that the applicant confirm that it had adjusted all thermal loading conditions analyzed using NASTRAN (including normal operating conditions) to account for the presence of the concrete infill, using thermal ratios obtained from the ABAQUS/ANACAP thermal-stress analyses.

The above topics discussed during the December 2006 onsite audit were addressed by the applicant in its response to RAI 3.8-41 S03.

In its RAI 3.8-41 S03 response, the applicant referred to Table 3.8-41(2), which shows that the frequency change is insignificant as the stiffness increases from 50 to 100 percent, and the frequency shift (10 percent for VW and 8 percent for DF) is well within the 15-percent spectral broadening. Therefore, the applicant stated that the consideration of 50-percent effective stiffness is sufficient. It has evaluated the effect of infill concrete stiffness on hydrodynamic response for the same two conditions—no concrete stiffness and 50-percent concrete stiffness—as the seismic analysis considered. The results indicate that the response spectra are mostly affected at the VW and DF locations. Figures 3.8-41(26) through 3.8-41(31) show the representative response spectra from the reanalysis for various hydrodynamic loads.

The applicant also indicated that it had adjusted the DBA thermal-loading conditions analyzed using NASTRAN to account for the presence of the concrete infill in the VW and DF, using thermal ratios obtained from the ABAQUS/ANACAP thermal-stress analyses. The normal operating temperature is much lower than the DBA, and the applicant did not consider any thermal ratios for normal operating conditions, which is conservative.

Based on its review of the applicant's RAI 3.8-41 S03 response, the staff determined that it needed the following additional information before it could resolve the technical issues raised in RAI 3.8-41:

(1) Based on the substantial increase in frequency results obtained considering 50 percent of the concrete stiffness versus no concrete stiffness, the applicant should explain how the natural frequencies could rise only 8 to 10 percent when 100 percent of the concrete stiffness values were used.

(2) For evaluating the effects of the infill concrete on hydrodynamic response spectra generation, spectra were provided at representative locations for AP, safety relief valve,

CHUG, and CO loadings. However, there was no comparison to show how the spectra for the 50-percent infill concrete case differ from the original (no infill concrete) case, as was done for the seismic case.

(3) In addition to the effect of the infill concrete on the generation of FRS, the applicant still has not confirmed whether the member design loads (for seismic and hydrodynamic loading) for the VW and DW are affected by a shift in the natural frequencies of these two structures (i.e., whether the accelerations could increase because of a shift in frequency).

(4) For the thermal loading condition, the applicant indicated that the normal operating temperature is much lower than for a DBA, and no thermal ratios were used for normal operating conditions, which is conservative. The staff asked the applicant to explain whether this implies that the DBA thermal loading is used for all load combinations, even those that specify the normal operating condition. If not, then the applicant should explain why neglecting the thermal ratios is conservative.

RAI 3.8-41 was being tracked as an open item in the SER with open items. In its RAI 3.8-41 S04 response, the applicant provided information to address the four items listed above. The response indicated that the analyses will consider the entire range of concrete stiffnesses. An additional parametric SSI analysis for generic soil sites is performed for the 100-percent stiffness case, in addition to the 0-percent and 50-percent stiffness cases considered previously. The applicant has revised DCD, Tier 2, Appendix 3A, to reflect the updated seismic design envelope for both member forces and response spectra. For SRV and other hydrodynamic loading, the results of all concrete stiffness cases are also enveloped for use in design. The applicant updated DCD, Tier 2, Appendix 3F, to reflect this change. The applicant also explained why not using thermal ratios for normal operating conditions is appropriate.

During the audit at the applicant's offices during the week of June 23, 2008, the applicant indicated that it will consider the following changes in the final design calculation: (1) consideration of the 100-percent infill concrete stiffness, in addition to 0-percent and 50-percent stiffness values, (2) consideration of the revised containment thermal DBA time history (identified in RAI 6.2-180 S01), and (3) widening of the buffer pool gate. In RAI 3.8-41 S05, the staff asked the applicant to provide the results of the evaluations for each of these three items.

In its RAI 3.8-41 S05 and S06,responses, the applicant provided a description and the results of the evaluations for the range of the infill concrete stiffness values and the widening of the buffer pool gate. The RAI 3.8-41 S05 response described the use of the 0-percent, 50-percent, and 100-percent infill concrete for the VW and DF structures for seismic and hydrodynamic loading. This was to develop FRS, as well as to design the structural members. Where some spectra exceeded the previous cases considered, the envelop spectra are used. For member forces, if any exceedances occurred, the design remained within the allowable limits. Therefore, this item, which is related to the range of infill concrete stiffness values in the VW and DF, is acceptable. The RAI 3.8-41 S06 response also provided the additional information requested relating to the widening of the buffer pool gate. The response described the analysis and identified areas where the increase in member loads required a redesign. The response also provided the revised design information for these members. Therefore, this item related to the widening of the buffer pool gate is acceptable.

The RAI 3.8-41 S07 response indicated that the applicant's response to RAI 6.2-180 S01 addressed the remaining item in the RAI, related to the revised containment DBA time history. The response contained the applicant's evaluation of the effect of the higher thermal transient profiles on the structural design. This evaluation resulted in the need to revise the design of the RCCV top slab, the RB floor slab outside the RCCV, the pool girder, and the IC/PCCS pool walls. Based on the description provided in the RAI response, the staff found the analysis and design used to address the revised thermal loadings to be in accordance with the analysis and design guidance procedures presented in SRP 3.8.3, and thus considered them to be acceptable.

The staff review of DCD Revision 6 confirmed that the applicant incorporated all of the markups provided in the responses to this RAI. Therefore, RAI 3.8-41 and its associated open item were resolved.

DCD Section 3.8.3.1.6 discusses platforms that are classified as seismic Category I and seismic Category II. However, the applicant does not describe how they are analyzed or designed. DCD Section 3.7 provides some information and states that seismic Category II SSCs are "designed and/or physically arranged such that the SSE would not cause unacceptable structural interaction or failure." It also states that the methods of seismic analysis and design acceptance criteria for seismic Category II SSCs are the same as for Category I; however, the procurement, fabrication, and construction requirements for Category II SSCs are in accordance with industry practices. In RAI 3.8-42, the staff requested that the applicant provide additional information by addressing the following items:

(a) Explain what is meant by the statement "designed and/or so physically arranged that the SSE would not cause unacceptable structural interaction or failure." Provide sufficient information for the staff to confirm that the approach satisfies the three criteria presented in SRP Section 3.7.2.II.8 for all seismic Category II SSCs.

(b) Describe any other SSCs inside the containment that are seismic Category II.

In its response to RAI 3.8-42, the applicant stated the following:

> a. DCD Section 3.7 will be revised to delete the words "physically arranged." The methods of seismic analysis and design acceptance criteria for seismic Category II (C-II) SSCs are the same as C-I SSCs. C-II SSCs meet the SRP Section 3.7.2.II.8 criteria and are designed to prevent their collapse under an SSE.
>
> b. SSCs inside containment are classified as seismic Category II if they do not perform or support safety-related functions.
>
> DCD Sections 3.7 and 3.8.3.1.6 will be revised in the next update as noted in the attached markups.

The staff reviewed the applicant's RAI 3.8-42 response and noted that the proposed change to DCD Section 3.7 is not consistent with SRP Section 3.7.2.II.8. It states that seismic Category II SSCs are designed such that the SSE will not cause unacceptable structural interaction or failure. SRP Section 3.7.2.II.8 states that the non-Category I structures will be analyzed and designed to prevent their failure under the SSE in a manner such that the margin of safety of these structures is equivalent to that of the Category I structure. If the statement in the RAI response that, “The methods of seismic analysis and design acceptance criteria for seismic Category II (C-II) SSCs are the same as C-I SSCs,” is accurate, then the proposed change to the DCD should state this.

In its RAI 3.8-42 S01 response, the applicant noted that the inconsistency between the criteria would be corrected, as stated in the NRC assessment, and committed to revising the fourth paragraph of DCD, Tier 2, Section 3.7, accordingly, in the next DCD update. The staff confirmed that the applicant incorporated the change into DCD Revision 3. The staff finds that the resolution for this RAI is technically acceptable on the basis that the revised DCD is consistent with the criteria in SRP Section 3.7.2.II.8 for seismic Category II SSCs. Therefore, RAI 3.8-42 was resolved.

3.8.3.3.2 Applicable Codes, Standards, and Specifications

DCD Section 3.8.3.2 provides the applicable codes, standards, and specifications for the containment internal structures consisting of the DF, RPVSB, VW, RSW, GDCS pool wall, and miscellaneous platforms. These structures are constructed from steel. In the case of the DF and VW, these structures are constructed from steel plates filled with unreinforced concrete. DCD Table 3.8-6 identifies the specific codes, standards, and specifications for these structures. The staff found that, in general, it was evident that the codes, standards, and specifications are in accordance with industry practice and SRP Section 3.8.3.II.2 criteria. For several items, however, the staff requested additional clarification about their use, as discussed below.

DCD Section 3.8.3.2 indicates that the design of all containment internal structures conforms to ANSI/AISC N690-1994, including S02 (2004). In RAI 3.8-43, the staff asked the applicant to justify the use of this updated standard with respect to the version of the standard that was endorsed by the staff at that time. Subsequently, the applicant revised SRP Sections 3.8.3 and 3.8.4 to endorse ANSI/AISC N690-1994, including S02 (2004), which is in agreement with the version of the standard identified in DCD Section 3.8.3.2. However, the applicant identified an exception in the DCD to ANSI/AISC N690-1994, including S02 (2004), regarding ductility ratios, to satisfy a staff position on ductility ratios in Appendix A to SRP Section 3.5.3.

The staff discussed this with the applicant during the December 2006 onsite audit. During this meeting, the staff identified two items that might need to be considered as exceptions to ANSI/AISC N690-1994, including S02 (2004). They are the exceptions to ductility ratios and the QA requirements for the painting (or coating) of structural steel in accordance with ANSI N101.4, as endorsed by RG 1.54, “Service Level I, II, and III Protective Coatings Applied to Nuclear Power Plants.” The applicant noted that it addressed both items in its proposed DCD change. The staff confirmed that Revision 3 of the DCD included the changes. Therefore, the staff found that the use of ANSI/AISC N690-1994, including S02 (2004), the specified ductility ratios in DCD Table 3.8-6, and the QA requirements for painting (or coating) are acceptable, on the basis that they are consistent with the criteria in SRP Section 3.8.3.II.2, SRP Section 3.5.3, and RG 1.54, respectively. Therefore, RAI 3.8-43 was resolved.

DCD Section 3.8.3.2 indicates that the design of all containment internal structures conforms to ANSI/ASME NQA-1-1989 and Addenda 1a-1989, 1b-1991, and 1c-1992, as indicated in DCD Table 3.8-6. A note in this table states that more recent revisions exist; however, they are not used. DCD Section 17.1 indicates that the QA for the ESBWR design complies with ANSI/ASME NQA-1-1983 and NQA-1a-1983 for certain aspects of QA (QA program, inspection, and audits). RG 1.28, Revision 3, “Quality Assurance Program Requirements (Design and Construction),” issued August 1985, accepts ANSI/ASME NQA-1-1983 and NQA-1a-1983

Addenda, subject to the additions and modifications identified in the RG. Based on the above, the QA program requirements in DCD Section 3.8.3.2 are not consistent with the commitments presented in DCD Section 17.1. Therefore, in RAI 3.8-44, the staff requested that the applicant either clarify which commitments apply and make the necessary revisions in the DCD or justify the use of different QA requirements for the containment internal structures.

In its response to RAI 3.8-44, the applicant proposed a revision to DCD, Tier 2, Table 3.8-6, Item 18 to cite ANSI/ASME NQA-1-1983 and reference DCD, Tier 2, Section 17. The applicant committed to revising DCD, Tier 2, Table 3.8-6, in the next update and provided a markup of the proposed changes.

The staff reviewed the revised DCD markup and noted that Table 3.8-6 references ANSI/ASME NQA-1-1983, while DCD Section 17 references ANSI/ASME NQA-1-1983 and NQA-1a-1983 Addenda, as endorsed by RG 1.28, Revision 3. In its RAI 3.8-44 S01 response, the applicant stated that it had revised DCD, Tier 2, Table 3.8-6, Item 18, to cite ANSI/ASME NQA-1a-1983 and NQA-1a-1983 Addenda. The staff confirmed that Revision 3 of the DCD includes the change. Therefore, RAI 3.8-44 was resolved.

DCD Table 3.8-6 lists codes, standards, specifications, and regulations used in the design and construction of seismic Category I internal structures of the containment. In RAI 3.8-45, the staff requested that the applicant explain why it identified ASME Code, 2004 Edition, in this table. In its response to RAI 3.8-45, the applicant stated that it would delete ASME Code, 2004 Edition, from DCD Table 3.8-6. The staff confirmed that Revision 3 of the DCD included this change. The staff finds that the deletion of the ASME Code, 2004 Edition, from DCD Table 3.8-6 is acceptable, on the basis that the containment internal structures are designed in accordance with ANSI/AISC N690-1994, including S02 (2004), which is in agreement with the criteria in SRP Section 3.8.3.II for steel structures inside containment. As noted in DCD Section 3.8.3.2, anchorage of steel internal structures complies with RG 1.199. This RG endorses the use of ACI 349 with certain regulatory positions. Therefore, RAI 3.8-45 was resolved.

3.8.3.3.3 Loads and Load Combinations, Including Hydrodynamic Loads

In DCD Section 3.8.3.3, the applicant described the loads and load combinations used for the analysis and design of the containment internal structures. The DCD states that the loads described in Section 3.8.1.3 are used to design the containment internal structures. Table 3.8-7 details the load combinations and associated acceptance criteria. The staff found that, in general, it was evident that the load definitions and load combinations were in agreement with ANSI/AISC N690-1994, including S02 (2004), which are the criteria presented in SRP Section 3.8.3.II.3. In a few cases, however, the staff needed additional information, as discussed below.

In RAI 3.8-46, the staff requested that the applicant address the following items for SRV and LOCA loads:

(a) DCD Table 3.8-7 identifies loads P_l and P_s, which are not attributed to any load combinations. Explain what these loads represent and what load factors would be applicable.

(b) Provide a description of the different subcategories for SRV discharge (e.g., single valve, two valve, ADS, and all valves) and for LOCA (large, intermediate, and small), if applicable, and how they are treated in the load combinations. Also, provide a description and the basis for the method used to combine the various dynamic loads that can occur simultaneously. Include in the description the cyclic loading (i.e., number of events and number of cycles per event) for pressure and temperature loads applicable to the various containment internal structures and how the number of cycles were considered in the design.

(c) For the SRV and LOCA loads, in addition to the direct pressure loads acting on the boundary of the suppression pool walls and floor, provide a description of the other loads associated with these hydrodynamic loads (e.g., jet loads and drag loads on structural members and quenchers), if applicable. Include a discussion of the analysis method and design approach used to evaluate the effects of these loads on the structural members.

(d) DCD Table 3.8-7 identifies LOCA loads as CO, CHUG, vent line clearing (VLC), and PS, and indicates that Appendix 3B includes the sequence of occurrence. Appendix 3B does not contain a description of VLC loads, and the sequence of VLC with respect to the other loads is omitted in Figure 3B-3 of Appendix 3B. Therefore, provide a description and sequence for the VLC loads.

(e) Some containment internal structures are subjected to AP loads. However, it is not clear from DCD Table 3.8-7 where the AP loads are specified. Therefore, indicate where the load combination and acceptance criteria for AP loads are identified in DCD Table 3.8-7.

In its response to RAI 3.8-46, the applicant stated the following:

a. LOCA (large, intermediate, and small break) are described in Containment Load Definition [CLD] report (NEDE-33261P). The drywell pressure associated with the Intermediate Break Accident is labeled as Pi, while the drywell pressure associated with the Small Break Accident is labeled as Ps. The bounding pressure and temperature values are used as LOCA loads in the load combinations for design. Pi and Ps will be deleted from DCD Table 3.8-7.

b. LOCA (large, intermediate, and small break) and SRV discharges (single valve first actuation, single valve subsequent actuation, and multiple valves) are discussed in CLD (NEDE-33261P). The bounding pressure and temperature values are used for the LOCA loads, in load combinations for design. The SRV pressure values for these three limiting conditions (single valve first actuation, single valve subsequent actuation, and multiple valves) are furnished in NEDE-33261P. The multiple valves case bounds ADS. The SRV pressure values for these three limiting conditions cover the different subcategories of SRV discharge (e.g., single valve, two valve, ADS, and all valves). The bounding values of these three limiting conditions are shown in DCD Figure 3B-1 and are considered as SRV loads in DCD Section 3.8.1.3 and in the DCD load combination Tables 3.8-4 and 3.8-7. The SRV P_a are applied throughout the entire suppression pool as axisymmetric SRV (DCD Section 3.8.1.4.1.1.2), which represents the all (or multiple) valves case. The SRV P_a are applied on half of the entire suppression pool as non-axisymmetric SRV loads (DCD Section 3.8.1.4.1.1.1), which represents the single valve or two-valve case. Because the total load for the axisymmetric SRV load case is greater than those for the non-axisymmetric cases, only the former is considered in the RCCV and VW design. The SRV pressure time history and other related information are presented in DCD Appendix 3B.

LOCA pressure, temperature, SRV, PS, CO or CHUG are combined in accordance with the loading combinations shown in DCD Table 3.8-2 for RCCV or DCD Table 3.8-7 for steel structures inside the containment. Regarding the concurrence of these loads, the combination is based on the time relationship shown in DCD Figure 3B-3.

The total number of cycles based on the number of events and number of cycles per event for cyclic loadings such as SSE, SRV, CO, CHUG will be considered for the fatigue evaluation in the detailed design phase for the steel components of the RCCV according to the requirements of NE-3200. Fatigue consideration is not included in the design of steel structures inside containment. A check will be made in the detailed design phase.

c. For the SRV and LOCA loads, the suppression pool walls and floor slab, including liners, are subjected to direct P_a (including hydrostatic pressure) only. Other associated loads such as jet loads and drag loads are applicable to submerged structures only. Submerged Structure Loads are discussed in CLD (NEDE-33261P). Design of quenchers will be conducted in the detailed design phase.

d. VLC has a very short duration and occurs prior to PS. Because there are no structures in the pool directly opposite the vent exits, the water jets created during VLC have no impact. In addition, the VLC pressure response in the pool is bounded by the peak PS pressure. For these reasons, VLC has not traditionally been considered in containment load responses, and it is neither provided in DCD Appendix 3B nor CLD (NEDE-33261P). VLC will be deleted from DCD Section 3.8.1.3.5, Tables 3.8-2, 3.8-4 and 3.8-7.

e. A statement will be added at the end of item #3 of DCD Table 3.8-7: "LOCA includes AP loads."

The applicant indicated that it would revise DCD Tables 3.8-2, 3.8-4, and 3.8-7 and Section 3.8.1.3.5 in the next DCD update and provided a markup of the proposed changes.

During its onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, CA, the staff discussed the requested information in further detail with the applicant. The staff audited and the applicant discussed supplemental information demonstrating that the axisymmetric SRV loads govern over the nonaxisymmetric loads. The staff indicated that the DCD should specify the applicant's commitment to perform a fatigue evaluation for steel structures inside containment and the number of events and cycles for all applicable loads. The applicant indicated that the combination method for seismic loads and for the various hydrodynamic loads is algebraic combination (+ and -), which considers all permutations of loads. The applicant stated that it would revise the DCD to indicate that, in addition to hydrodynamic building pressure loads on the building structural boundaries and response spectra, there are also direct pressure loads on submerged structures and components and on components above the SP surface. The applicant indicated that its response to RAI 3.8-46 S01 would revise the DCD and include all of the additional information provided to the staff at the audit.

In its RAI 3.8-46 S01 response, the applicant stated that the major sectional force caused by SRV loads is membrane tensile or compressive force in the hoop direction. For this sectional force, axisymmetric load cases (uniformly positive and negative) and nonaxisymmetric load cases are compared. For these sectional forces, the calculations show that the axisymmetric load cases envelop the nonaxisymmetric load cases. Unlike axisymmetric loads, nonaxisymmetric SRV loads generate horizontal forces. For these forces, the calculations show that the in-plane forces from the nonaxisymmetric case are negligible in comparison with the seismic load.

For fatigue effects on containment internal structures, the applicant stated that these effects are insignificant, since the total number of loading cycles for all events combined (pressure, temperature, and dynamic loads, such as SSE, SRV, and LOCA) is less than 20,000. Since the total number of loading cycles for all events is less than 20,000, a fatigue evaluation is not required, in accordance with ANSI/AISC N690, Table QB1.

The applicant stated that the peak responses of dynamic loads do not occur at the same instant, and so the SRSS method to combine peak dynamic responses is allowed. However, for conservatism, the applicant combined the resulting forces or stresses from one dynamic load with those from other dynamic loads in the most conservative manner by systematically varying the sign (+ or -) associated with dynamic loads for the design of the RCCV structures. The applicant used the ABS method for containment internal steel structures. The applicant indicated that it would add a footnote to DCD Tables 3.8-2, 3.8-4, and 3.8-7.

Since other loads, such as jet loads and drag loads associated with SRV and LOCA hydrodynamic loads, are applicable to submerged structures and to those above the SP water surface, the applicant stated that it would add a footnote to DCD Table 3.8-7. The applicant also stated that it would revise DCD Tables 3.8-2, 3.8-4, and 3.8-7 in the next DCD update and provided a markup of the proposed changes.

In its RAI 3.8-46 S02 response, the applicant stated that, for steel structures, DCD Revision 2, Tables 3.8-4 and 3.8-7, permit the use of SRSS for a combination of peak dynamic responses. However, the applicant indicated that it would clarify Appendix 3G to the DCD to indicate that the ABS method is actually used to analyze steel structures, except for the GDCS pool, to which the SRSS method is applied. The applicant referenced its response to RAI 3.8-9 for further information on this subject. The applicant also noted that DCD, Tier 2, Revision 2, Table 3.8-7, has an additional Footnote 6, which states, "Other loads such as jet loads and drag loads associated with SRV and LOCA hydrodynamic loads are applicable to submerged structures and those above suppression pool water surface. Methodology for calculation of these loads is given in CLD (NEDE-33261P)." The applicant indicated that it would revise DCD, Tier 2, Section 3G.1.5.4.2, in the next update and provided a markup of the proposed changes.

Based on the applicant's RAI 3.8-46 response the staff agrees that the P_l and P_s can be deleted from DCD Table 3.8-7, because the bounding pressure and temperature values are used as LOCA loads in the load combinations for design. In its RAI 3.8-46 S01 and S02 responses, the applicant provided additional information requested by the staff about the various SRV and

LOCA loads and how they are treated in the load combinations. The applicant is separately addressing, under RAI 3.8-9, the adequacy of the combination method (i.e., varying + and - or ABS versus SRSS) for dynamic loads of SSCs. For the question related to fatigue, since the applicant indicated that the total number of loading cycles for all events combined is less than 20,000, the staff agrees that a fatigue evaluation is not required, in accordance with the provisions in ANSI/AISC N690, Table QB1. To address the requirement to consider other loads on submerged structures in the wetwell, such as jet loads and drag loads associated with SRV and LOCA hydrodynamic loads, the applicant revised DCD Table 3.8-7. This table also refers to the methodology for calculating these loads. The applicant's explanation for deleting the vent clearing load in the DCD is acceptable, because it has a very short duration, there are no structures in the pool directly opposite the vent exits, and the VLC pressure response in the pool is bounded by the peak PS pressure. The additional statement added in Footnote 3 of DCD Table 3.8-7 is acceptable, since it indicates that the AP load is considered in the LOCA load definition. The staff confirmed that the applicant had revised Table 3.8-7 in the DCD to include this clarification. Based on the above, RAI 3.8-46 was resolved.

DCD Section 3.8.3.3.1 seems to single out the RSW for consideration of the AP loads, which the DCD states are loads and pressures directly on the RSW, caused by a rupture of a pipe within the annulus region of the reactor vessel shield wall. Therefore, in RAI 3.8-47, the staff requested that the applicant confirm that the loads and effects of the AP are considered not only for the RSW but for all applicable containment internal structures, such as the RPVSB, RPV stabilizer, and RPV insulation. The staff also asked the applicant to explain whether the AP loads generate building dynamic spectral loads and displacements (similar to the other hydrodynamic loads), which should be considered in the analysis and design of other SSCs.

In its response to RAI 3.8-47, the applicant stated that it considered AP loads and effects, not only for the RSW but also for the RPVSB, DF, and VW structure. The RPV stabilizers are not a part of steel internal structures of the containment, but the reactions are considered in the RSW design. RPV insulation is not part of the steel internal structures of the containment. Response spectra and displacements generated by AP loads and other hydrodynamic loads, such as SRV, CO, and CHUG, are to be used for the analysis and design of SSCs located inside the RCCV. Appendix 3F to the DCD documents the dynamic analyses and their results. The design considers the building dynamic spectral loads and displacements generated by the AP loads.

During an audit at the applicant's offices in Wilmington, NC, on May 16–17, 2007, the staff reviewed GEH Report DC-OG-0053, Revision 3. This report demonstrates that the effects of AP loads, as well as the other hydrodynamic loads (e.g., CO, CHUG, PS, and SRV), were applied to the various containment internal structures, such as the DF, VW, RSW, and RPVSB. To address the question concerning the generation of displacements and FRS, the staff audited two reports, GEH Report 092-134-F-C-00009, Issue 2, "SRVD, LOCA Hydrodynamic & AP Dynamic Responses in RBFB and RCCV," dated January 29, 2007, and GEH Report 092-134-F-C-00008, Issue 1, "SRVD, LOCA & AP Dynamic Responses in RPV and RSW," dated June 20, 2007. GEH Report 092-134-F-C-00009 documents the analysis and results for the response of the RB, FB, RCCV, and containment internal structures (except the RSW subjected to LOCA, SRV, and pipe break loads). GEH Report 092-134-F-C-00008 documents the analysis and results for the response of the RPV and the shield wall subjected to the various LOCA, SRV, and pipe-break loads. Both reports describe the models used and present the response of the structures in terms of displacements, accelerations, member forces, and FRS generated at various locations. Based on the applicant's responses and a review of these reports, the staff concludes that the applicant provided the additional information requested in the RAI, and the staff considers the methods of analysis to be acceptable, because they are consistent with the criteria presented in SRP Section 3.8.3.II. Therefore, RAI 3.8-47 was resolved**.**

From the information provided in DCD Section 3.8.3 and Appendix 3G, the staff questioned whether there were any other pipe-rupture loads acting on containment internal structures other than the FW and RWCU breaks, that induce AP loads on the RSW. Therefore, in RAI 3.8-53, the staff requested that the applicant explain whether any other pipe-break loads act on containment internal structures and describe the loads, models, analysis, and design approach for these loads.

In its response to RAI 3.8-53, the applicant stated that pipe-rupture loads contain not only AP pressure acting on the RSW but also the nozzle jet, jet impingement, and pipe whip restraint loads, as stated in DCD Section 3G.1.5.2.12. The applicant generated AP pressure time histories for the FW and RWCU breaks in the annulus between the RPV and the RSW. A steamline break occurring outside the annulus does not induce AP pressure. The applicant calculated the time histories of the nozzle jet, impingement jet, and pipe whip restraint loads induced by steamline, FW, and RWCU breaks. The design considered these breaks not only for the RSW but also for the RPVSB, DF, and VW structure.

The design considers building dynamic spectral loads and displacements generated by the AP loads. Appendix 3F to the DCD documents the dynamic analyses and their results. Response spectra and displacements generated by AP loads are to be used for the analysis and design of SSCs located inside the RCCV.

The staff discussed the RAI response with the applicant at the December 2006 onsite audit, and noted that the original RAI had not been fully answered. The staff needed additional descriptions of the loads, models, analysis, and design approach for assessment of containment internal structures caused by pipe breaks other than AP. During the audit, the applicant indicated that it would address this RAI under the first part of RAI 3.8-51.

In its RAI 3.8-53 S01 response, the applicant referred to its response to RAI 3.8-51 S01. The staff reviewed the applicant's response to RAI 3.8-51. Pipe breaks considered inside containment are those associated with the FW, RWCU, and MSLs. Some of these breaks lead to AP loads. In addition, the analysis considers nozzle jet, jet impingement, and pipe whip restraint loads resulting from these pipe breaks. Since the applicant explained what pipe breaks are postulated and how they are analyzed, and these are consistent with the guidance in SRP Sections 3.8.1, 3.8.2, and 3.8.3, the staff concluded that the responses to RAIs 3.8-51 and 3.8-53 are acceptable. Therefore, RAI 3.8-53 was resolved.

3.8.3.3.4 Design and Analysis Procedures

DCD Sections 3.8.3.4 and 3G.1 describe the design and analysis procedures used for the containment internal structures. The FEM described in DCD Sections 3.8.1.4.1.1 and 3G.1.4 includes the various steel structures, consisting of the DF, RPVSB, RSW, VW, and GDCS pool. The FEM includes the entire RB, RCCV, the containment internal structures, and the FB. The model uses quadrilateral, triangular, and beam elements to represent the various structural components. The VW and DF are concrete-filled structures consisting of steel plates and concrete. For the GDCS pool, the applicant performed a detailed stress evaluation, using a local model. It based the design of the containment internal structures on the elastic method. In general, the staff finds these design and analysis procedures to be acceptable, on the basis that they are consistent with the design and analysis procedures given in SRP Section 3.8.3.II.4. However, in some areas, the staff noted differences or needed clarifications. These areas are discussed below.

The staff noted that Appendix 3F to the DCD is not referenced anywhere in DCD Section 3.8 or Appendix 3G. Therefore, the staff required additional information to clarify how the applicant analyzed the dynamic effects of the hydrodynamic loadings and how it included the results in the design calculations for the affected structures. In RAI 3.8-48, the staff requested that the applicant do the following:

(a) Provide the computer code used for the hydrodynamic analyses described in Appendix 3F.

(b) Provide detailed information on how the symmetric and asymmetric hydrodynamic loads are applied in the time history analysis.

(c) In Appendix 3F, horizontal and vertical FRS are presented for four locations. Describe the significance of these four locations, compared to any other location. Were response spectra generated at additional locations for future use in subsystem analyses?

(d) From the response spectral plots, it appears that the zero period acceleration (ZPA) frequency is above 100 Hz for several of the loadings; however, the plot is truncated at 100 Hz. Provide an explanation for this.

(e) Describe how the hydrodynamic response spectra were or will be used in the ESBWR detailed design.

(f) Describe how the structure responses to the hydrodynamic loadings were incorporated into the design evaluation of the affected structures, for load combinations that include hydrodynamic loads.

In its response to RAI 3.8-48, the applicant stated the following:

a. ANSYS software is used for the hydrodynamic load analysis. DCD Section 3C.6 addresses ANSYS documentation.

b. Symmetric loads have an axisymmetric pressure distribution on the SP walls and floors. Asymmetric loads have cosine pressure distribution on the SP walls and floor.

c. The 4 locations for FRS included in DCD Appendix 3F are intended to be representative. FRS are generated at all locations of interest for use in the subsystem analysis.

d. The Fourier spectra (amplitude) have been obtained for loads that contain high frequencies (CO and CHUG loads). The spectra obtained show a rapid reduction of amplitude with frequency. The energy content of the wave at a given frequency is a function of the square of the Fourier amplitude. For CHUG loads at 100 Hz, the energy content is 36 times less than at frequencies <10 Hz and 20 times less than for frequencies <20 Hz. For CO loads, the factors are even higher. Consequently, the truncation at 100 Hz in response spectra is conservative since the actual ZPA values are at higher frequencies.

e. The use of hydrodynamic and AP load response spectra in combination with other loads will be included in the system and equipment design specifications in the detailed design.

f. The design evaluation of the affected structures for hydrodynamic loads was performed using equivalent static pressure input equal to a DLF of two times the peak dynamic pressure. The resulting forces or stresses were combined with those due to other loads in the most conservative manner by systematically varying the signs associated with dynamic loads.

The applicant also indicated that it would revise Appendix 3F to the DCD and DCD Sections 3.8.1.4.1.1.1 and 3.8.1.4.1.1.2, to add a reference to Appendix 3F in the next DCD update, and provided the markups as part of its response.

During the staff's onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, CA, the staff discussed the response in further detail with the applicant. The staff asked the applicant to address the following (corresponding to Items a. through f. above): (a) confirm that this is an axisymmetric model, (b) clarify the definition of asymmetric loads, using Fourier harmonics, and explain whether both n = 0 and n = 1 components are used to get the proper asymmetric pressure distribution on the SP walls, (c) provide, for review, the full set of response spectra, (d) clarify the energy ratios cited and also identify any past precedent for truncation at 100 Hz, (e) provide examples of system and equipment design specifications, explain whether this is a COL applicant responsibility, and explain how compliance and adequacy are assured, and (f) describe this process in greater detail, showing the distributed pressure distributions used in the NASTRAN model.

The applicant responded that an axisymmetric model using the ANSYS computer code was used to analyze hydrodynamic loads to generate FRS. For axisymmetric loads, the harmonic n = 0 was used, while for nonaxisymmetric loading, n = 1 (cosine shape) was used. The applicant indicated that, for the nonaxisymmetric loading, n = 1 was sufficient without higher harmonics, because the structural shell wall is a reinforced concrete structure on which higher harmonics would not have a significant effect. The applicant showed the response spectra for those loads that were truncated at 100 Hz and demonstrated that the spectral amplitudes diminish at frequencies above 100 Hz. Therefore, leaving 100 Hz as the cutoff is conservative. The applicant does not have examples of design specifications for distribution systems and equipment. These would be developed at a later date, following the criteria contained in the DCD. This would be considered a COL action item to be confirmed. The applicant noted that Appendix 3B to the DCD provides the details of the pressure distributions. During the audit, the applicant indicated that its response to RAI 3.8-48 S01 would clarify its initial response to Parts (b) and (d). The applicant would also address how the correct asymmetric pressure distribution can be applied to the ANSYS axisymmetric model using only the n = 1 harmonic. The staff noted that this produces negative pressure (i.e., external pressure) on one side of the axisymmetric structure.

In its RAI 3.8-48 S01 response, the applicant stated that, for the analysis of the asymmetric loads, it considered only the first two terms in the Fourier series ($F(\theta) = A0 + A1 \cos \theta$). They were analyzed up to the first harmonic, because the structure of the containment has very thick concrete walls and is constrained horizontally at different levels by the slabs of the RB, and so the contribution of the higher order harmonics around the circumference is not significant. Furthermore, the assumption of an asymmetric load with the discharge of all the valves is conservative, since it encompasses the asymmetric load associated with the actuation of one or two valves. In addition, the applicant made editorial changes to Parts (d) and (f) of its original response. For Part (d), the applicant revised the last sentence to read, "Consequently, the truncation at 100 Hz in response spectra is conservative since the actual spectrum values beyond 100 Hz are lower than that at the 100 Hz cut-off frequency." For Part (f), the last sentence was revised to read "The resulting forces or stresses were combined with those due to other loads in the most conservative manner by systematically varying the sign (+ or -) associated with dynamic loads."

In its RAI 3.8-48 S02 response, the applicant stated that ANSYS allows the use of axisymmetric structural elements with harmonic loads (nonaxisymmetric) by specifying the number of waves (harmonic order) and the symmetry/no symmetry condition (cosine/sine term). Using only the n = 1 harmonic is a simulation of asymmetric pressure loading over the entire SP boundary following the cosine spatial distribution with the peak pressure at 0 degrees (positive) and 180 degrees (negative). This is considered a conservative analysis, since the actual asymmetric loads are localized to portions of the pool boundary. The applicant also indicated that, in addition to seismic loads, other appropriate hydrodynamic loads such as CO and AP loads are enveloped and are imposed on vendors supplying equipment to the applicant by means of procurement specifications. This is typical for seismic Category I procured equipment subject to dynamic loads. Vendors use these loads to analyze and test the equipment being furnished. Since these loads comply with the DCD, an open COL item is not deemed necessary. Examples of the applicant's design specifications for equipment procured for recent BWR projects are available for NRC audit at the applicant's offices. No DCD changes were identified for this response supplement.

During the its December 2006 onsite audit, the staff requested that the applicant explain a contradiction that appears between its RAI 3.8-48 S01 and S02 responses with respect to the treatment of asymmetric loads. S01 indicates that both the n = 0 and n = 1 harmonic terms are used, while S02 indicates that only the n = 1 term is used. This discrepancy would be addressed by the applicant in its response to RAI 3.8-48 S03.

In its RAI 3.8-48 S03 response, the applicant stated that both n= 0 and n = 1 terms are used for asymmetric loads, and the total response is the summation of both Fourier harmonic terms. The applicant provided markups of Appendix F to DCD Tier 2 and Sections 3.8.1.4.1.1.1 and 3.8.1.4.1.1.2 in the RAI 3.8-48 S03 response and has incorporated these markups into DCD Tier 2.

The staff reviewed the applicant's use of the computer code ANSYS to perform the various hydrodynamic load analyses, as described in Appendix 3F to the DCD, and finds it acceptable. The nuclear industry has, in the past, used the n = 0 harmonic to represent the axisymmetric pressure load and the n = 0 and n = 1 to represent the asymmetric pressure load applied to the SP boundary, and the staff has considered these uses acceptable. The generation of FRS at all locations of interest for use in the subsystem analysis is acceptable. The applicant explained that the acceleration values beyond 100 Hz are equal to or less than the values at 100 Hz, and therefore, the staff finds acceptable the use of a cutoff of 100 Hz for generating FRS. The additional information provided in the supplemental responses clarifies how the applicant used hydrodynamic response spectra in the ESBWR detailed design and how it performed the design evaluation of the affected structures subjected to the hydrodynamic loads. In addition to the above, the staff confirmed that the applicant had revised Appendix 3F and Sections 3.8.1.4.1.1.1 and 3.8.1.4.1.1.2 of the DCD to clarify the information lacking in previous DCD revisions. Therefore, RAI 3.8-48 was resolved.

From the finite-element NASTRAN model shown in various figures in Appendix 3G to the DCD, the staff questioned how the RPV has been represented in the model. In RAI 3.8-49, the staff requested that the applicant describe how the RPV is included in the model. If it is not modeled discretely as a separate structure or component, then the applicant should discuss how its mass and stiffness have been represented in the overall NASTRAN model.

In its response to RAI 3.8-49, the applicant stated that the NASTRAN model does not explicitly include the RPV. In the NASTRAN analysis, the RPV reaction forces are applied to the interface locations as nodal forces. The RPV reaction forces, obtained from a coupled building-RPV dynamic analysis for seismic and hydrodynamic loads, include the mass and stiffness effects of the RPV.

During the staff's onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, CA, the staff discussed the requested information in greater detail. The applicant explained that the RPV model is not included in the NASTRAN model, but it is included in the seismic stick model and the hydrodynamic building models. The reaction forces from the seismic model and the hydrodynamic building models are then applied at the NASTRAN RPV support and the RPV stabilizer locations. Since the RPV reaction forces were obtained from the dynamic seismic and hydrodynamic analyses, they already contain the effects of any dynamic load amplification. Therefore, the staff concluded that the approach used to consider the loads from the RPV in the NASTRAN overall building model is acceptable.

During an onsite audit at the applicant's offices in Wilmington, NC, on May 16–17, 2007, the staff reviewed GEH Report 26A6558, Revision 2, "General Civil Design Criteria," dated November 27, 2006, which contains the design criteria for ESBWR structures. The staff also audited several other reports that were more suited to answer the questions raised by this RAI (GEH Report 092-134-F-C-00009, Issue 2, and GEH Report 092-134-F-C-00008, Issue 1). GEH Report 09-2-134-F-C-00009 documents the analysis and results for the response of the RB and FB, the RCCV, and the containment internal structures (except the RSW subjected to LOCA loads, SRV loads, and pipe-break loads). This report presents the FEM of the RB/FB, including the RPV detailed model. GEH Report 092-134-F-C-00008 documents the analysis and results for the response of the RPV and the shield wall, subjected to the various LOCA loads, SRV loads, and pipe-break loads. This report presents the stick model representation of the RB/FB, including the RPV detailed model. For seismic loading, DCD Revision 3 and GEH Report 26A6647, Revision 2, "Seismic Analysis of Reactor/Fuel Building Complex," dated March 27, 2007, present the seismic stick model, which also includes the detailed RPV model. These reports indicate that the models for analyzing SRV, LOCA, and AP loads include the detailed RPV model. The reports describe the models used and present the response of the structures in terms of displacements, accelerations, member forces, and FRS generated at various locations. The staff considers the approach described in these reports acceptable, on the basis that the approach is consistent with industry practice and the analysis methods prescribed in SRP Section 3.8.3.II.4. Therefore, RAI 3.8-49 was resolved.

DCD Section 3.8.3.4.2 states that the RPV feet can slide radially, and, therefore, no thermal expansion loads from the RPV support act on the RPVSB. Since frictional resistance has the potential to induce thermal expansion loads during the radial thermal growth of the RPV, in RAI 3.8-50, the staff requested that the applicant do the following:

a. Describe the RPV feet/RPVSB design features that minimize frictional resistance to sliding, including the coefficient of friction between the surfaces in contact.

b. Although a description is provided about the design of the RPVSB allowing unrestrained radial growth, it does not discuss how the design resists horizontal loads. Provide a description of how the RPVSB resists horizontal forces for all applicable loads.

In its response to RAI 3.8-50, the applicant stated the following:

a. In order to provide a low friction coefficient (~0.15) that minimizes the resistance to sliding in the RPV foot/RPVSB interface, bearing plates of Lubron alloy GA50 are placed between the sliding components. Therefore, there are no significant thermal expansion loads from the RPV supports acting on the RPVSBs.

b. Two steel guide blocks at both sides of each RPV foot resist and transmit the horizontal (tangential) forces to the RPVSB.

The applicant stated that it would revise Section 3.8.3.4.2 in the next DCD update and provided a markup of the proposed change.

The staff agrees that the use of Lubron plates with a low coefficient of friction of about 0.15 should minimize the resistance to sliding and avoid significant thermal expansion loads from the RPV supports. The use of two steel guide blocks at both sides of each RPV foot to resist and transmit the horizontal tangential loads to the RPVSB is acceptable, because it allows radial thermal movements but restrains lateral movements from forces caused by seismic or hydrodynamic loads. The staff confirmed that DCD Revision 3 includes the description of the RPV supports, as given in the applicant's response. Therefore, RAI 3.8-50 was resolved.

From the information presented in DCD Section 3.8.3.4 and Appendix 3G, the staff questioned how the applicant obtained individual member forces from thermal, seismic, hydrodynamic, and other loads from the FEM. In RAI 3.8-51, the staff requested that the applicant do the following:

(a) Provide a description of what type of analyses (e.g., static, response spectra, time history) it used with the FEM for each of the applicable loads to obtain individual member forces for design.

(b) For thermal loading consideration, define the transient and steady-state T_a, nonlinear temperature distributions, analysis approach, model, and design approach used for the major containment internal structures.

In its response to RAI 3.8-51, the applicant stated the following:

a. The type of analyses for various loads considered for the containment internal structures, such as DF, VW, RPVSB, RSW, and GDCS Pool (GDCSP) are:

(i) Dead Load—Static analysis was performed for the dead load to all containment internal structures. Hydrostatic loads of pool water were also applied statically to VW and GDCSP.

(ii) Pressure load—Static analysis was performed for the pressure load (P_o and P_a) applied to DF and VW.

(iii) Thermal load—Static analysis was performed for the thermal load (T_o and T_a) to all internal structures.

(iv) Seismic load—Static analysis was performed for the seismic load on DF, VW, RPVSB and RSW in the integral NASTRAN model, while response spectra analysis was performed for the GDCSP local model. In this response spectra analysis, it is assumed that all pool water mass is distributed uniformly on the GDCDP wall and RCCV wall. This is considered as a conservative assumption; therefore, sloshing was not considered in the GDCSP local model. For the integral NASTRAN model, however, the sloshing load was considered as the static pressure load on the DF upper surface and static reaction load from the GDCSP wall. The results from the integral NASTRAN model due to these loads were used for the structural integrity evaluation of the structures other than the GDCSP, while the results from the GDCSP local model were used for the evaluation of the GDCSP itself.

(v) Hydrodynamic load—Static analysis was performed for the hydrodynamic load (CO, CHUG and SRV) on VW taking DLF = 2 into account.

(vi) Pipe Break loads consist of AP load, jet impingement and pipe-whip restraint loads.

(vii) These loads acting on the RSW were first analyzed for dynamic response using the NASTRAN beam model. The resulting maximum values of bending moment and shear force were then applied to the integral NASTRAN static analysis model.

b. All steel temperature is the same as atmospheric temperature. The temperature of the intermediate node of VW rib plate is the average value of outer and inner plates. Further discussion of thermal analysis is described in the response to RAI 3.8-41.

The applicant indicated that it would revise DCD Section 3G.1.5.4.2 in the next DCD update and provided the markup as part of its response.

During the staff’s onsite audit, conducted July 11–14, 2006, at the applicant’s offices in San Jose, CA, the staff discussed the response in greater detail with the applicant. The applicant indicated that it included the impulsive (rigid) portion of the water in all pools in the models as dead weight. The design considered the convective (sloshing) effect of the water for all pools except the GDCS pool. In the case of the GDCS pool, calculations demonstrated that the convective (sloshing) pressures are much smaller than the impulsive pressures. In addition, the SRSS method combines the convective and impulsive pressures, which further diminishes the effect of the sloshing pressures for this pool. The applicant also explained that, for the VW, it used the drywell temperature on one side and the wet well temperature on the other side. The temperature of the VW rib plate used in the thermal analysis is the average of the drywell and wetwell temperatures. The applicant indicated that it would revise the DCD to describe the application of impulsive and convective loads for all pools except the GDCS pool, where it was shown that the convective load was sufficiently small. The topics discussed during the audit were addressed by the applicant in its response to supplemental RAI 3.8-51 S02.

In its RAI 3.8-51 S02 response, the applicant stated that the water mass in all pools was treated as an impulsive mass rigidly attached to the pool structure in the stick model for seismic analysis. In the stress analysis for all pools, except for the GDCS pool and SP, the applicant calculated the seismic-induced hydrodynamic pressures for impulsive and convective components separately and then combined by the SRSS method. For the GDCS pool and SP, the total pressure was conservatively considered to be all impulsive. The applicant indicated that it would revise DCD, Tier 2, Section 3.8.4.3.1.1, in the next update, as noted in the markup attached with the response.

During its December 2006 onsite audit, the staff asked the applicant to explain why the RAI 3.8-51 S02 response for Item a(vi) above does not include pipe-break loads associated with pipe breaks other than AP. In addition, the staff informed the applicant that it should provide the technical basis for the statement: "For the GDCS and the suppression pools, the total pressure was conservatively considered to be all impulsive." The addition of the convective load (depending on the frequency of sloshing and spectral acceleration) could possibly increase the total pressure loads on the pools.

During the audit, the applicant indicated that the only pipe-break load that needs to be considered for the evaluation of containment internal structures is the AP pipe-break load (MS, FW, and RWCU), which consists of pressurization in the annulus and associated jet impingement, missile load, and reaction load. DCD Section 3.6 contains the basis for this assertion. In response to the second item raised by the staff, the applicant provided additional information that compares the response acceleration values for the convective and impulsive modes. Because the contribution of the convective mode is very small, considering the entire water mass in the impulsive mode is acceptable.

The above topics discussed during the December 2006 onsite audit were addressed by the applicant in its response to supplemental RAI 3.8-51 S03.

In its RAI 3.8-51 S03 response, the applicant stated that AP loads include all high-energy line breaks (MS, FW, and RWCU) in the drywell. Pipe-break loads consist of AP and other pipe breaks. In addition, the response acceleration to sloshing is much lower than the impulsive response. Therefore, it is conservative to use an impulsive response for the total mass of the pool water.

The staff found the analysis methods described in the applicant's response, along with the descriptions, in DCD Section 3.8 and Appendices 3F and 3G, for each type of load applied to the containment internal structures to be acceptable, on the basis that they are consistent with the analysis methods described in SRP Section 3.8.3.II.4. For the AP and pipe-break loads, the applicant explained that these loads consist of pipe breaks associated with the MS, FW, and RWCU lines, based on the information contained in DCD Section 3.6. Also, the applicant provided the technical basis demonstrating that its treatment in the ESBWR design of convective and impulsive modes for water sloshing during a seismic event is acceptable. The applicant described the thermal loading consideration of containment internal structures and referred to the response to RAI 3.8-41 for more details.

The staff confirmed that the proposed DCD revisions identified in the applicant's response are included in DCD Revision 3. Based on the above, the questions raised by this RAI related to the analysis methods have been resolved, and the remaining questions related to thermal-loading analysis are addressed separately under RAI 3.8-41. Therefore, RAI 3.8-51 was resolved.

The staff noted that DCD Sections 3.9.2 and 3.10.3.2 provide some limited information on the analysis and design of supports for cable tray, conduit, and ventilation ducts but not for the conduits, cable trays, and ducts themselves. Therefore, in RAI 3.8-52, the staff asked the applicant to describe the analysis and design criteria (i.e., description; applicable codes, standards, and specifications; loads and load combinations; acceptance criteria; and analysis and design procedures) used for cable trays, conduits, and ventilation ducts inside the containment.

In its RAI 3.8-52 response, the applicant stated that the type and spacing of supports for seismic Category I commodities, such as cable trays, conduits, and ventilation ducts, are governed by rigidity and stress. The applicant designed these commodities to the loads, loading combinations, and allowable stresses, in accordance with applicable codes, standards, and regulations consistent with seismic Category I steel structures, as shown in DCD Tables 3.8-6 and 3.8-9. The applicant stated that it will add DCD Sections 3.8.4.1.6 and 3.8.4.1.7 in the next DCD update and provided a markup of the proposed changes.

The staff discussed the RAI response with the applicant during the December 2006 onsite audit, and noted that the references cited do not provide analysis criteria; therefore, the applicant should explain, in the DCD, whether the analysis methods will follow those presented in DCD, Tier 2, Sections 3.7 and 3.8. If the applicant uses cold-formed sections, then ANSI/AISC N690 does not apply, and the applicant should reference other applicable standards (e.g., those of the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) or the Institute of Electrical and Electronic Engineers (IEEE)). During the audit, the applicant indicated that it would revise Section 3.8.3 to provide criteria similar to, or reference the criteria in, Sections 3.8.4.1.6 and 3.8.4.1.7 for cable trays, conduits, HVAC ducts, and their supports and that it would add other applicable codes and standards to Tables 3.8-6 and 3.8-9. The topics discussed during the audit were addressed by the applicant in response to supplemental RAI 3.8-52 S01.

In its RAI 3.8-52 S01 response, the applicant stated that the following codes and standards will be included in DCD, Tier 2, Tables 3.8-6 and 3.8-9:

a. ASME N509-2002, Nuclear Plants Air-Cleaning Units and Components

b ASME/ANSI AG-1-2003, Code on Nuclear Air and Gas Treatment

c. AISI [American Iron and Steel Institute]-2001 and 2004 Supplement, AISI Specification for the Design of Cold Formed Steel Structural Members

d. SMACNA 1481, Third Edition, 2005, HVAC Duct Construction Standards-Metal and Flexible.

Analysis methods for cable trays, conduits, HVAC ducts, and their supports will follow the methods presented in DCD, Tier 2, Sections 3.7 and 3.8.

The applicant also stated that it would revise DCD, Tier 2, Sections 3.8.4.1.6 and 3.8.4.1.7 and Tables 3.8-6 and 3.8-9, and would add Section 3.8.3.1.7 in the next DCD update; it provided a markup of the proposed DCD changes.

The staff determined that the additional criteria to describe the analysis and design approach for cable tray, conduit, and HVAC, as well as their supports, are acceptable, on the basis that they follow industry practice and applicable codes and standards and are consistent with the criteria in SRP Sections 3.7 and 3.8. The staff confirmed that DCD Revision 3 includes the applicable changes to Sections 3.8.3.1.7, 3.8.4.1.6, and 3.8.4.1.7 and Tables 3.8-6 and 3.8-9. Therefore, RAI 3.8-52 was resolved.

DCD Section 3.8.3.4.1 describes the analysis and design of the DF, and DCD Figure 3G.1-55 provides a drawing of the DF. From this information, it is not clear whether the DF is attached to the radial support beams in a manner that makes them respond as an integral member. Therefore, in RAI 3.8-56, the staff requested that the applicant describe in DCD Section 3.8.3.4.1, and show in DCD Figure 3G.1-55, how the DF and radial support beams are connected.

In its RAI 3.8-56 response, the applicant stated that the radial support beams are welded to the DF, so they form an integral structure. The applicant stated that it would revise DCD Section 3.8.3.4.1 and DCD Figure 3G.1-55 in the next update, as noted in the markup attached to the response.

The staff found the proposed change to DCD Section 3.8.3.4.1 acceptable. However, the staff's detailed review of the applicant's proposed change for DCD Figure 3G.1-55 determined that information about the welded connection between the radial support beams and the DF needed clarification. If the radial support beams and DF are to be attached in a manner that makes them respond as an integral member, then the welding notes should show this to be the case.

In its RAI 3.8-56 S01 response, the applicant formally submitted its proposed change to DCD Figure 3G.1-55. This figure shows that continuous welds on both sides of the flange of the radial beam join the radial beam to the DF. The staff found that the revised figure demonstrates that the radial support beams and DF act as integral members. The staff confirmed that this information is included in DCD Revision 3. Therefore, RAI 3.8-56 was resolved.

3.8.3.3.5 Structural Acceptance Criteria

DCD Sections 3.8.3.5.1 through 3.8.3.5.6 state that the structural acceptance criteria for each of the containment internal structures are in accordance with ANSI/AISC N690. In RAI 3.8-54, the staff asked the applicant to explain why these statements do not also note that the structural acceptance criteria for each of the containment internal structures are in accordance with Table 3.8-7, which specifies the acceptance criteria for each load combination, and where (as noted in Footnote 5 of DCD Table 3.8-7) the allowable elastic working stress is defined as the allowable stress limit specified in Part 1 of ANSI/AISC N690-1994, including S02 (2004).

In its RAI 3.8-54 response, the applicant stated that invoking the structural acceptance criteria for each of the containment internal structures to be in accordance with ANSI/AISC N690 is the same as referencing DCD Table 3.8-7, because the information in this table is consistent with ANSI/AISC N690. The applicant also stated that it would revise DCD Sections 3.8.3.4 and 3.8.3.5 in the next DCD update and provided a markup of the proposed change.

The staff reviewed the proposed DCD change and noted that DCD Sections 3.8.3.4 and 3.8.3.5 refer to Table 3.8-7 (structures inside the containment), which, in Footnote 1, refers to DCD Section 3.8.4.5.1 (other structures—not structures inside the containment) for acceptance criteria. DCD Section 3.8.4.5.1 refers to Table 3.8-16, which is applicable to other structures (structures outside containment). This path for acceptance criteria of internal structures should not appear in Table 3.8-16, which applies to structures outside containment.

In its RAI 3.8-54 S01 response, the applicant stated that it would revise Footnote 1 to DCD Tier 2, Table 3.8-7, to read, "The loads are described in Subsection 3.8.3.3 and acceptance criteria in Subsection 3.8.3.5." The staff found the text of the proposed revision to be acceptable because it clarifies the design and analysis procedures, as well as the acceptance criteria. The staff confirmed that DCD Revision 3 includes the applicable changes to DCD Sections 3.8.3.4 and 3.8.3.5 and Table 3.8-7. Since the structural acceptance criteria in DCD Section 3.8.3.5 and DCD Table 3.8-7 are consistent with SRP Section 3.8.3.II.5 for steel structures, RAI 3.8-54 was resolved.

3.8.3.3.6 Material, Quality Control, and Special Construction Techniques

DCD Section 3.8.3.6 describes the materials used for the containment internal structures. The staff based its evaluation of quality control on the various codes and standards and RGs referenced in DCD Section 3.8.3. No special construction techniques were identified.

For many of the containment internal structures, the DCD lists several material types (e.g., ASTM A572 or A709 HPS 70W). In RAI 3.8-57, the staff requested that the applicant explain whether (1) both materials are listed because each type is used in a different location, or (2) different material choices are available to the COL applicant. Also, the staff asked the applicant to identify and compare the key material properties of the different materials listed.

In its response to RAI 3.8-57, the applicant stated the following:

a. RPV Bracket—The materials specified for the RPVSB are used depending on the thickness of each part in DCD Section 3.8.3.6.2.

b. RSW—The materials specified for the RSW are used depending on the thickness of each part in DCD Section 3.8.3.6.3.

c. Other Containment Internal Structures—The materials specified for other containment internal structures are choices available for use in construction.

The RAI response also provided the thickness, yield point, tensile strengths, and elongation properties for the various materials used for the containment internal structures. The applicant stated that it will revise DCD Section 3.8.3.6 in the next DCD update and provided a markup of the proposed change.

The staff determined that the applicant's response adequately explained that it specified multiple materials for a number of the containment internal structures because the selection of the material depends on the thickness of each part. The staff finds the proposed DCD change to be acceptable. The staff confirmed that DCD Revision 3 includes the applicable changes to Section 3.8.3.6. Therefore, RAI 3.8-57 was resolved.

To address quality control, the staff noted that DCD Table 3.8-6 identifies ANSI/ASME NQA-1-1983, "Quality Assurance Program Requirements for Nuclear Facilities" (including NQA-1a-1983 Addenda), and RG 1.94. Quality control is also addressed by compliance with other industry codes and standards referenced in the DCD, which include ANSI/AISC N690; AWS D1.1/D1.1M, "Structural Welding Code—Steel"; EPRI NP-5380, "Visual Weld Acceptance Criteria for Structural Welding at Nuclear Power Plants"; and various ACI standards listed in DCD Table 3.8-6. The staff finds that the use of these industry codes and standards and RG 1.94 for quality control is acceptable, on the basis that they are consistent with the criteria in SRP Section 3.8.3.II.6.

The staff noted that DCD Revision 4, Appendix 3G, presents revisions in the various design load tables and stress result tables for all of the structures. As a result, in RAI 3.8-120, the staff asked the applicant to address the following items:

(a) DCD, Tier 2, Chapter 3, Revision 3 to Revision 4 Change List (Appendices 3G–3L) indicates that the numerous changes are due to "reanalysis incorporating updated design conditions" and "reanalysis reflecting the change of hydrodynamic load." Provide an explanation for the expressions: "updated design conditions" and "change of hydrodynamic load."

(b) The stress result tables compare the calculated stress results against allowable stresses. To do so, the specific material properties must have already selected or assumed. However, in a number of cases presented in DCD Revision 4, the applicant does not identify the grade of the steel material. For example, Section 3.8.3 does not identify the grade for ASTM A-572, A-516, and A-668. The steel material grade should be specified, because it defines the yield strength from which the allowable stresses are obtained. The staff requested that applicable sections of the DCD be revised to identify the material grade for the various steel materials used so that they will be consistent with the material properties assumed in the design.

(c) DCD Section 3.8.3.6.3 indicates that the RSW may be constructed from steel material ASTM A-709 HPS 70W. DCD Section 3.8.3.1.3 indicates that the plate thickness varies along the elevation and is 160 mm (6-5/16 in.), 210 mm (8-1/4 in.), and 260 mm (10-1/4 in.). In addition, DCD Figure 3G.1-58 shows the variation in thickness of the steel material of the RSW. Since ASTM A-709 HPS 70W steel is not manufactured in thicknesses greater than 102 mm (4 inches), explain whether one of the other material choices in the DCD will be used or how the analysis and design considers this limitation. The staff also raised a concern under RAI 5.2-50 related to welding the A-709 material to the steel liner of the containment and the acceptability of a code case for this type of welding. GEH should resolve this issue, as well.

In its response to RAI 3.8-120, Part (a), the applicant stated that the change list reference to "updated design conditions" means the change of the seismic category of the CB for the portions above grade. The seismic reclassification from C-II to C-I caused the applicant to modify the seismic loads, dead loads, wind loads and tornado loads, and design details accordingly. The reference to "the change of hydrodynamic load" means DW head and GDCS pool local analysis models input of hydrodynamic loads, and the NASTRAN integral model input of hydrodynamic loads for the RPV reactions; GDCS pool reactions are changed to maintain consistency with the results of the hydrodynamic response analysis described in DCD Appendix 3F. The staff found that Part (a) of the response is acceptable, since the applicant explained the meanings of "updated design conditions" and "the change of hydrodynamic load."

Based on the review of the Part (b) and Part (c) responses, the staff asked the applicant, in supplemental RAI 3.8-120 S01, to further clarify the following additional concerns:

- Part (b)

  (1) In Part (b) of the RAI response, the applicant revised the applicable sections of DCD Sections 3.8.2 and 3.8.3 to identify the material grade for the various steel materials so they would be consistent with the material properties assumed in design. However, for all locations in DCD Section 3.8.3, where the material A-709 HPS 70W is given, a footnote was added that refers to ASME Code Case N-763. Since DCD Section 3.8.3 applies to the containment internal structures, which are designed using the ANSI/AISC N690 specification, please explain the reason for referencing the ASME Code Case.

  (2) The applicant's response to RAI 5.2-50 indicates that A-709 HPS 70W material is being added to the DCD as an option for the containment liner. Use of A-709 HPS 70W material for the containment liner is currently under review by the ASME Standards Committee under a new code case (ASME Code Case N-763). Thus, this needs to be approved by the ASME Code Committee before it can be used for the containment liner. The staff requests that the applicant explain why it gave an option for use of the A-709 HPS 70W material. Also, based on the proposed revisions to the DCD, it is not clear what portions of the containment liner and appurtenances will use the currently specified ASME SA-516 Gr.-70 or the newly proposed material of ASTM A-709 HPS 70W. The applicant should give clear explanations for the above.

  (3) If the A-709 HPS 70W material will also be used for the containment liner and appurtenances, then the applicant is asked to explain how the change in material (including the much higher yield strength) affects the analysis and design of the containment. This should include the effects of this new material on the overall FE analysis of the entire containment structure for mechanical and thermal loads, as well as the localized design of the liner and liner anchorages.

- Part (c)

  In Part (c) of the RAI response, the applicant indicated that the portion of the RSW, using ASTM A-709 HPS 70W material with thicknesses exceeding 102 mm (4 in.), may be fabricated using one of the multiple layer construction techniques identified in ASME Code, Section VIII, Division 1. The staff notes that the RSW is not a pressure vessel, and if it were a pressure vessel for use in nuclear power plants, it would be subject to the rules of ASME Code, Section III, not Section VIII. Regulations in 10 CFR 50.55a, which is the basis for endorsing applicable sections of the ASME Code, do not endorse ASME Code, Section VIII. If the applicant still wants to use some other method (such as ASME Code, Section VIII, Division 1), rather than a conventional engineering design approach, for treating multiple layers of cylindrical structures, then the applicant should fully describe the specific analytical approach to be used and demonstrate the technical adequacy of the approach. Simply referring to some code and stating that using the construction techniques of that code allows the multiple layer shells to act as a solid wall is not sufficient.

In its RAI 3.8-120 S01 response, the applicant provided additional clarification to the staff's concerns in both Part (b) and Part (c).

Based on its review of the Part (b) response, the staff found that Items 1 and 2 would be acceptable pending staff review and approval of ASME Code Case N-763. Since the RAI response explained where the ASTM A-709 HPS 70W material is used, why it is given as an option, and why the ASME Code is referenced for parts of the containment internal structures, Part (b) Items (1) and (2) are acceptable.. For Item (3), the applicant explained that the use of this new higher strength material has no significant effect on the analysis and design, and therefore, Item (3) is also acceptable. The staff found the use of ASME Code Case N-763 acceptable for ESBWR as discussed in section 6.1.1.3.1 of this report.

For the Part (c) response, the staff found that the technical information regarding the analysis approach for the multilayered RSW is acceptable, since it demonstrated that the approach used is sufficiently accurate to predict the structural response of the RSW. Therefore, Part (c) is considered to be acceptable.

The staff verified that the proposed markup changes in all responses are acceptable and confirmed that the applicant has incorporated them into DCD Revision 6. Therefore, RAI 3.8-120 was resolved.

3.8.3.3.7 Testing and Inservice Inspection Requirements

DCD Section 3.8.3.7 indicates that the applicant is not planning a formal program of testing and ISI for the internal structures, except for the DF and VW, because only these two structures are directly related to the functioning of the containment system. DCD Section 3.8.1.7 discusses the testing and ISI of the DF and VW.

The staff noted that, although DCD Section 3.8.3.7 states that Section 3.8.1.7 discusses the DF and VW testing and ISI, that section does not discuss the ISI of these two structures. Therefore, in RAI 3.8-55, the staff asked the applicant to describe the ISI of the DF and VW and to include this information in DCD Section 3.8.3.7.

In its response to RAI 3.8-55, the applicant stated that it would revise the first paragraph in DCD Section 3.8.1.7.3.4 to add the sentence: "The diaphragm floor and VW will receive a visual, VT-3, examination once during each inspection interval." DCD Section 3.8.3.7 would then address this information by reference to DCD Section 3.8.1.7. The applicant also stated that it would revise DCD Section 3.8.1.7.3.4 in the next DCD update and provided a markup of the proposed change.

The staff finds that, because this examination requirement is in accordance with ASME Code, Section XI, Subsection IWE, it is acceptable. The staff confirmed that DCD Revision 3 includes the applicable change to Section 3.8.1.7. Therefore, RAI 3.8-55 was resolved.

The staff noted that DCD Section 3.8.3.7 indicates that that applicant has no plans for testing or inspecting the containment internal structures, other than the DF and VW, because they are not directly related to the functioning of the containment system. In RAI 3.8-58, the staff asked the applicant to confirm that the provisions in RG 1.160 and 10 CFR 50.65 for monitoring structures are applicable to the containment internal structures as well. If this is not the case, the applicant should provide the technical basis.

In its response to RAI 3.8-58, the applicant stated that it would revise DCD Section 3.8.3.7 to read as follows:

> A formal program of testing and in-service inspection is not planned for the internal structures except the DF, and VW. The other internal structures are not directly related to the functioning of the containment system; therefore, no testing or inspection is performed. However, during the operating life of the plant the condition of these structures should be monitored by the COL holder to provide reasonable confidence that the structures are capable of fulfilling their intended functions.

The staff discussed this RAI response with the applicant at the December 2006 onsite audit, and noted that the response did not address whether RG 1.160 and 10 CFR 50.65 requirements for monitoring apply to the containment internal structures of the ESBWR. If they do not apply, the applicant should include a technical basis in DCD Section 3.8.3.7. During the audit, the applicant stated that containment internal structures are monitored according to 10 CFR 50.65, as clarified by RG 1.160. The topics discussed during the audit were addressed by the applicant in its response to supplemental RAI 3.8-58 S01.

In its RAI 3.8-58 S01 response, the applicant stated that it would revise the second and third paragraphs in DCD, Tier 2, Section 3.8.3.7, as follows:

> However, during the operating life of the plant, the condition of these other internal structures is monitored per 10 CFR 50.65 as clarified in RG 1.160, in accordance with Section 1.5 of RG 1.160.
>
> Testing and in-service inspection of the DF and VW are directly related to the functioning of the containment system and are discussed in Subsection 3.8.1.7.

In addition, the applicant referenced its response to RAI 3.8-59 S01, which adds a paragraph to DCD, Tier 2, Section 3.8.3.7.

The staff reviewed the proposed change to the DCD and found it acceptable, because it directly references the requirements in 10 CFR 50.65 and RG 1.160. The staff confirmed that DCD Revision 3 includes the applicable change to Section 3.8.3.7. Therefore, RAI 3.8-58 was resolved.

The staff noted that GDC 53, in part, requires that the reactor containment be designed to permit appropriate periodic inspection of all important areas. RAI 3.8-1 requested that the applicant address this for the concrete and steel elements of the ESBWR containment structure. A stated industry design criterion for advanced reactors is to accommodate ISI of critical areas. The staff considers that monitoring and maintaining the condition of containment internal structures is essential for plant safety. DCD Section 3.8.3 does not address any special design provisions (e.g., providing sufficient physical access, providing alternative means for identifying conditions in inaccessible areas that can lead to degradation, remote visual monitoring of high-radiation areas) to accommodate an ISI of containment internal structures. Therefore, in RAI 3.8-59, the staff asked the applicant to describe any special design provisions for containment internal structures in DCD Section 3.8.3.7. If the ESBWR design did not incorporate such provisions, the staff informed the applicant that it should provide the technical basis for concluding that they are not necessary.

In its response to RAI 3.8-59, the applicant stated the following:

1. Areas of the containment are subject to periodic inspection in accordance with ASME Section XI, Subsections IWE and IWL as described in DCD, Tier 2, Section 3.8.1.7.3.1. Specific provisions for access from IWE-1231 are incorporated by this reference. Further, those Subsections require inspection of the accessible areas, and areas that will be rendered inaccessible must meet the requirements of IWE-1232 for exemption of such areas as explained in DCD, Tier 2, Section 3.8.1.7.3.2.

   Space Control is exercised in the ESBWR by means of a 3D model. It is the means by which interference checking and space control is accomplished. It includes all safety and non-safety-related SSC's. Items are added to the model as it is being developed by stages depending on criticality to the plant and construction sequence of the item. Accessibility to equipment, valves, instrumentation, welds, supports, etc. for operation, inspection or removal is characterized by sufficient space to allow unobstructed access and reach of site personnel. Therefore, aisles, platforms, ladders, handrails, etc. are reviewed as the components are laid out. Interferences with access ways, doorways, walkways, truck ways, lifting wells, etc. are constantly monitored.

2. As indicated in item (1) above, accessibility is constantly monitored, maintained and documented during the plant layout process. ESBWR is committed to perform the required inspections per ASME Section XI and the supplemental requirements of 10 CFR 50.55a. Remote tooling would only be included if for some layout reasons the required inspection could not be carried out otherwise.

The staff finds the response to be acceptable because the approach followed to permit periodic inspection of all areas was in accordance with ASME Code, Section XI, supplemented by provisions in10 CFR 50.55a. However, the applicant should include in the DCD the information provided in its response. During the December 2006 onsite audit, the applicant proposed a DCD change. Following discussion, the applicant agreed to revise the proposed DCD wording to properly capture Item (2) in the applicant's RAI response. The topics discussed during the audit were addressed by the applicant in its response to supplemental RAI 3.8-59 S01.

In its RAI 3.8-59 S01 response, the applicant stated that it would include Item (1) above in DCD, Tier 2, Section 3.8.3.7. In addition, the applicant would include, in DCD, Tier 2, Section 3.8.3.7, the statement, "This method of configuration control is maintained and documented during the plant layout process. Remote tooling is considered only if for some layout reasons the required inspection could not be carried out otherwise." The supplemental response also stated that the applicant would add a statement to DCD, Tier 2, Section 3.8.3.4 ("Design and Analysis"), to reference Section 3.8.3.7 ("Testing and ISI Requirements"). The sentence would read, "See

Subsection 3.8.3.7 for accessibility to equipment, valves, instrumentation, welds, supports, etc. for operation, inspection or removal."

The staff finds that the proposed DCD changes adequately address the RAI and are acceptable, on the basis that the approach relies on design provisions and space control to accommodate an ISI of containment internal structures. The staff confirmed that DCD Revision 3 includes the applicable changes to DCD Sections 3.8.3.4 and 3.8.3.7. Therefore, RAI 3.8-59 was resolved.

As a result of the resolution of the above RAIs, the staff finds that the testing and ISI of the containment internal structures described in the DCD are acceptable. This finding is based on the pressure testing of the DF and the VW, in accordance with Article CC-6000 of ASME Code, Section III, Division 2, and RG 1.136, after completion of the containment construction. In addition, it is based on the ISI of the DF and VW, in accordance with ASME Code, Section XI, Subsection IWE, and the ISI of the other containment internal structures in accordance with 10 CFR 50.65 and RG 1.160. The testing and ISI of containment internal structures also meet the criteria in SRP Section 3.8.3.II.7.

3.8.3.3.8 Welding Methods and Acceptance Criteria for Structural and Building Steel

DCD Section 3.8.3.8 indicates that the welding activities are performed according to written procedures, combined with the requirements of the AISC manual of steel construction, AWS Structural Welding Code—D1.1, and EPRI NP-5380 (NCIG-01). The staff notes that ANSI/AISC N69-0-1994 (including S02 (2004)), which the applicant identifies as applicable in DCD Table 3.8-6, also provides requirements for welds and refers to all three of the welding-related documents listed above. The staff finds the applicant's description of welding methods and acceptance criteria for structural and building steel to be acceptable, on the basis that they are consistent with industry practice and SRP Section 3.8.3.II.

3.8.3.4 *Conclusion*

The staff concludes that the applicant has demonstrated that the analysis, design, construction, testing, and inservice surveillance of the containment internal structures conform to established criteria in codes, standards, guides, and specifications acceptable to the staff. The use of these criteria has been found to be consistent with the guidance provided in SRP Section 3.8.3 and applicable RGs. Meeting these criteria ensures that the DCD meets the relevant requirements of 10 CFR 50.55a; GDC 1, 2, 4, 5, and 50 of Appendix A to 10 CFR Part 50; and Appendix B to 10 CFR Part 50.

3.8.4 Other Seismic Category I Structures

Other ESBWR seismic Category I structures include the RB, CB, FB, and FWSC. Although the RW building houses non-safety-related facilities and is not a seismic Category I structure, it is designed to meet the requirements defined in RG 1.143, "Design Guidance for Radioactive Waste Management Systems, Structures, and Components Installed in Light-Water-Cooled Nuclear Power Plants," under safety class RW-IIa.

3.8.4.1 *Regulatory Criteria*

The staff reviewed DCD, Tier 2, Section 3.8.4, "Other seismic Category I Structures," and DCD, Tier 2, Appendix 3G. The staff considers the applicant's design and analysis procedures, loads and load combination methods, structural acceptance criteria, material, quality control and special construction techniques, and testing and ISIs to be acceptable if they satisfy the criteria, applicable codes and standards, and regulatory guidance delineated in SRP Section 3.8.4. Meeting the guidance of this SRP section will ensure that the DCD meets the relevant requirements of 10 CFR 50.55a; GDC 1, 2, 4, and 5 of Appendix A to 10 CFR Part 50; and Appendix B to 10 CFR Part 50. The following regulatory requirements are relevant to the staff review in Section 3.8.4.

- 10 CFR 50.55a and GDC 1 require that the safety-related structures be designed, fabricated, erected, and tested to quality standards, commensurate with the importance of the safety functions to be performed.

- GDC 2 requires that the safety-related structures withstand the most severe natural phenomena, such as winds, tornadoes, floods, and earthquakes, and the appropriate combination of all loads.

- GDC 4 requires that the safety-related structures withstand the dynamic effects of equipment failures, including missiles and blowdown loads associated with the LOCA.

- GDC 5 requires that there be no sharing of structures important to safety, unless it can be shown that such sharing will not significantly impair their ability to perform their safety functions.

- Appendix B to 10 CFR Part 50 requires that the safety-related structures be designed with QA criteria applicable for nuclear power plants.

The staff evaluated the design, materials, fabrication, erection, inspection, testing, and inservice surveillance of components of the safety-related structures, based on the following industry codes and standards, materials specifications, and RGs:

- ACI 349-01

- ANSI/AISC N-690

- RG 1.69, “Concrete Radiation Shields for Nuclear Power Plants”

- RG 1.91, “Evaluations of Explosions Postulated to Occur on Transportation Routes Near Nuclear Power Plants”

- RG 1.115, “Protection Against Low Trajectory Turbine Missiles”

- RG 1.142

- RG 1.143

- RG 1.160

- RG 1.199

For design certification, paragraph IV(a)(2)(i)(A) of Appendix S to 10 CFR Part 50 provides an option for specifying the OBE. If the OBE is chosen to be less than or equal to one-third of the

SSE ground motion, the applicant need not conduct explicit response or design analyses to satisfy paragraph IV(a)(2)(i)(B)(I) of Appendix S to 10 CFR Part 50.

3.8.4.2 *Summary of Technical Information*

3.8.4.2.1 Description of Other Seismic Category I Structures

In DCD, Tier 2, Section 3.8.4.1, the applicant describes the RB as a rigid, box-type, shear wall structure made of reinforced concrete that encloses the concrete containment and its internal SSCs, including the IC/PCC, expansion pools, and service pools for storage of the dryer/separator on top of the concrete containment. MS and FW lines are routed to the TB through the MS tunnel.

The CB, which is also a reinforced concrete, box-type, shear wall structure consisting of walls and slabs supported on a foundation mat, houses the essential electrical, control, and instrumentation equipment. Similar in construction, the FB is integral to the RB. The FB houses the spent fuel pool (SFP) facilities and their supporting systems and HVAC equipment. All of these buildings are classified as seismic Category I structures, except for the penthouse in the FB, which is classified as seismic Category II.

The FWSC consists of two firewater storage (FWS) tanks and a fire pump enclosure (FPE) that share a common basemat. The FWS tanks have cylindrical reinforced concrete walls and a dome-shaped reinforced concrete roof. The FPE is a reinforced concrete box-type structure that encloses and protects the pumps and tanks inside it.

The RW building is a reinforced concrete box-type structure that houses the equipment and floor drain tanks, sludge phase separators, resin holdup tanks, detergent drain tanks, concentrated waste tank, chemical drain collection tank, associated pumps, and mobile systems for the radioactive liquid and solid waste treatment systems. This building is an NS category structure but is designed to meet the requirements in RG 1.143, under safety class RW-IIa.

3.8.4.2.2 Applicable Codes, Standards, and Specifications

In DCD, Tier 2, Section 3.8.4.2, the applicant stated that the design of the concrete and steel structures uses the applicable codes, industry standards, and specifications and regulations listed in DCD Table 3.8-9.

The applicant also stated that all pool liner welds, including the SFP liner welds, are visually inspected in accordance with AWS Structural Welding Code D1.1, before any other NDE method is used. The DCD requires liquid penetrant examinations on all liner plate butt, fillet, corner, and tee welds, in accordance with ASME Code, Section V, Article 6, requirements. The acceptance criteria are in accordance with the requirements of ASME Code, Section III, NE 5352. The DCD specifies helium sniffer tests or vacuum box techniques that meet the requirements of ASME Code, Section V, Article 10. Any evidence of leakage is unacceptable. After construction is finished, each isolated pool receives a leak test. The liner welds for all pools outside the RCCV, including the SFP, are backed by leak chase channels and a leak detection system to monitor any leakage during plant operation. The design groups the leak chase channels according to the different pool areas and directs any leakage to area drains. This allows both leak detection and determination of the origin of the leaks. The DCD requires that the functioning of the leak chase channels be checked before completion of the pool liner installation.

3.8.4.2.3 Loads and Load Combinations

In DCD, Tier 2, Section 3.8.4.3, the applicant described the loads applicable to the RB as follows:

> D—Dead load of structure plus any other permanent loads, including vertical and lateral pressure of liquids.
>
> L—Conventional floor or roof live loads, movable equipment loads, and other variable loads, such as construction loads.
>
> Live Load includes floor area live loads, laydown loads, nuclear fuel and fuel transfer casks, equipment handling loads, trucks, railroad vehicles, and similar items. The floor area live load is omitted from areas occupied by equipment whose weight is specifically included in dead load. Live load is not omitted under equipment where access is provided, for instance, an elevated tank on four legs.
>
> The inertial properties include all tributary mass expected to be present in operating conditions at the time of earthquake. This mass includes dead load, stationary equipment, piping, and appropriate part of live load established in accordance with the layout and mechanical requirements. In the ESBWR design, additional mass equivalent to 25 percent of floor live load and 100 percent of the roof snow load is included in the seismic inertia load.
>
> R_o—Pipe reactions during normal operating or shutdown conditions, based on the most critical transient or steady-state condition.
>
> R_a—Pipe reactions under thermal conditions generated by the postulated break and including R_o.
>
> Y_r—Equivalent static load on a structure generated by the reaction on the broken high energy pipe during the postulated break and including a calculated dynamic factor to account for the dynamic nature of the load.
>
> Y_j—Jet impingement equivalent static load on a structure generated by the postulated break and including a calculated dynamic factor to account for the dynamic nature of the load.
>
> Y_m—Missile impact equivalent static load on a structure generated by or during the postulated break, like pipe whipping, and including a calculated dynamic factor to account for the dynamic nature of the load.
>
> W—Wind force (Subsection 3.3.1)
>
> W_t—Tornado load (Subsection 3.3.2) (tornado-generated missiles are described in Subsection 3.5.1.4, and barrier design procedures in Subsection 3.5.3.).
>
> P_a—Accident pressure at MS tunnel due to high energy line break.
>
> F—Internal pressures resulting from flooding of compartments.

E′—SSE loads as defined in Section 3.7, including hydrodynamic pressures caused by the SSE.

T_o—Thermal effects induced by normal thermal gradients existing through the RB wall and roof. Both summer and winter operating conditions are considered. In all cases, the conditions are considered to be of long enough duration to result in a straight line temperature gradient. The temperatures are listed in Table 3.8-10. The stress-free temperature for the design is 15.5 degrees C.

T_a—Thermal effects (including T_o) may occur during a design basis accident.

H—Loads caused by static or seismic earth pressures and water in the soil.

DCD Tables 3.8-15 and 3.8-16 list the loads, load combinations, and load factors used in the design of safety-related concrete and steel structures for the RB.

The applicant provided similar load and load combination methods applicable to each of the buildings discussed in this section.

3.8.4.2.4 Design and Analysis Procedures

In DCD, Tier 2, Section 3.8.4.4, the applicant stated that it analyzed the RB, CB, and FB, using linear elastic FE analysis methods and the computer program NASTRAN. Since the RB and FB are integrated into one building, it analyzed these structures using a common FEM that includes the RB, the FB, and the concrete containment. It analyzed the CB using a separate FEM. Appendix 3G to the DCD discusses the details of these analysis models.

The applicant designed the RW building in accordance with RG 1.143 for safety class RW-IIa. It analyzed the FWSC structures using a common FE analysis model that includes the two FWS tanks and the FPE structure. Appendix 3G to the DCD discusses the details of the analysis and design for the FWSC structures.

3.8.4.2.5 Structural Acceptance Criteria

In DCD Tier 2, Section 3.8.4.5, the applicant stated that the acceptance criteria for the safety-related steel structures are in accordance with ANSI/AISC N690-1994s2 (2004). DCD Table 3.8-15 includes the acceptance criteria for the design of the safety-related reinforced concrete structure. In addition, structural acceptance criteria and materials criteria for the RW building are in accordance with RG 1.143 for safety class RW-IIa.

3.8.4.2.6 Material, Quality Control, and Special Construction Techniques

In DCD, Tier 2, Section 3.8.4.6, the applicant stated that this section contains information related to the materials, quality control, and special construction techniques used in the construction of the other seismic Category I structures.

Concrete material is the same as described in DCD Section 3.8.1.6.1, except that the specified compressive strength is 27.6 MPa (4,000 psi) for the foundation mat and 34.5 MPa (5,000 psi) for other structures. The concrete is batched and placed according to ACI 349-01. Reinforcing steel is the same as described in DCD Section 3.8.1.6.2. Splices of reinforcing steel are the same as described in DCD Section 3.8.1.6.3, except that their placing and splicing are in accordance with ACI 349-01. Quality control is the same as described in DCD Section 3.8.1.6.5, except that the construction specification will reference ACI 349-01 and applicable RGs. Welding requirements for reinforcing bars conform to ASME Code, Section III, Division 2.

The applicant stated that it used no special construction techniques, other than for some components, such as rebar cages, that are preassembled and lifted into place.

3.8.4.2.7 Testing and Inservice Inspection Requirements

In DCD, Tier 2, Section 3.8.4.7, the applicant stated that other seismic Category I structures are monitored according to NUREG-1801, "Generic Aging Lessons Learned (GALL) Report," Revision 1, issued September 2005, and 10 CFR 50.65, as clarified in Section 1.5 of RG 1.160.

3.8.4.3 *Staff Evaluation*

3.8.4.3.1 Description of Other Seismic Category I Structures

In DCD, Tier 2, Sections 3.8.4 and 3.8.4.1 describe the other seismic Category I structures. The staff found the descriptive information, including figures and details of other seismic Category I structures, to be generally acceptable and in accordance with the guidance given in SRP Section 3.8.4. However, some information was lacking or required clarification regarding certain details of the structures. Therefore, the staff requested that the applicant provide additional information.

In an earlier version of the DCD, the staff noted that DCD Section 3.8.4 stated: "The MS tunnel walls protect the RB from potential impact by rupture of the high-energy MS pipes that extend to the TB. Thus the RB walls of the MS tunnel are designed to accommodate the guard pipe support forces." In RAI 3.8-60, the staff asked the applicant to explain whether guard pipes protect all high-energy lines in the MS tunnel. If not, the applicant should explain why the tunnels are designed only for "guard pipe support forces." Also, the staff noted that DCD Section 3.6.2.4 states that the ESBWR does not require guard pipes. The staff asked the applicant to explain this discrepancy and identify where the DCD discusses criteria for the design of any guard pipes used in the ESBWR design.

In its response to RAI 3.8-60, the applicant stated that no guard pipes exist in the ESBWR because the MS and FW piping inside the MS tunnel, from the RCCV penetrations to the seismic restraints located close to the TB, comply with the break exclusion stress and fatigue limits, in accordance with BTP MEB 3-1 of SRP Section 3.6.2, Revision 1. Therefore, the applicant designed the RB walls of the MS tunnel to accommodate the penetrations and pipe support forces, as well as the postulated pipe break P_a. DCD Section 3.6.2.1 discusses the postulated pipe-break locations and the general criteria for their configuration.

The proposed DCD revision provided in response to this RAI stated: "Thus the RB walls of the MS tunnel are designed to accommodate the pipe support forces and the environmental conditions during and after the postulated high-energy pipe break." The staff noted the need for a definition of the "environmental conditions" for which the tunnel is being designed.

In its RAI 3.8-60 S01 response, the applicant stated that, according to SRP Section 3.6.2, longitudinal breaks (of at least 0.093 m^2 (1 square ft)) have to be postulated inside the steam tunnel, even though the design meets BTP MEB 3-1 and circumferential breaks can be excluded. This is required to evaluate the effects of jet impingement and to determine environmental conditions for qualifying safety-related equipment. Outside the steam tunnel, a circumferential break is postulated as the result of noncompliance with BTP MEB 3-1. Therefore, the tunnel must be able to resist pressurization resulting from the following:

- longitudinal break inside the tunnel (minimum of 0.093 m^2 (1 square ft))
- circumferential break outside the tunnel

The applicant further stated that the steam tunnel is an open space that connects directly (without any flow restrictions) to the TB. Therefore, the effects of pressurization in the tunnel are small and do not govern its design. DCD, Tier 2, Sections 6.2.3.2 and 3G.1.5.2.1.10, discuss the MS tunnel design conditions. The applicant also indicated that it would revise DCD, Tier 2, Sections 3.8.4, 3G.1.5.2.1.10, and 6.2.3.2, in the next update and provided a markup of the proposed changes.

The staff finds the applicant's supplemental response to be acceptable because it clarifies the basis for the design pipe-break-induced loads on the steam tunnel. The staff also reviewed the applicant's proposed DCD changes and confirmed that it incorporated them in a revision to the DCD formally submitted to the NRC. Therefore, RAI 3.8-60 was resolved.

In an earlier version of the DCD, the staff noted that Section 3.8.4 stated that the design does not use seismic Category I masonry walls. In RAI 3.8-61, the staff asked the applicant to explain if the ESBWR design contains any non-safety-related masonry walls. If this is the case, then the applicant should provide the criteria used to design such walls to ensure that their failure does not affect any safety-related SSCs.

In its response to RAI 3.8-61, the applicant stated that the ESBWR design does not use masonry wall construction. The design calls for removable shield blocks designed to seismic Category II acceptance criteria that provide equivalent shielding. The applicant indicated that it would revise DCD Section 3.8.4 in the next update and provided a markup of the proposed changes. The applicant stated that it would also update Figures 1.2-1 and 1.2-3 in the next DCD revision, by changing "Concrete Block" to "Shield Block."

The staff determined that the applicant should explain the seismic design criteria for the removable shield blocks, to ensure that their failure does not affect any safety-related SSCs. The staff discussed this with the applicant during the December 2006 onsite audit. The applicant stated that it would design a steel frame retainer structure to seismic Category II requirements to prevent sliding or overturning under the SSE event and agreed to submit a supplemental response to the RAI. The topics discussed during the audit were addressed by the applicant in its response to supplemental RAI 3.8-61 S01.

In its RAI 3.8-61 S01 response, the applicant stated that removable shield blocks typically consist of metallic forms filled with grout or concrete. It will design them as seismic Category II components, as stated in the original RAI 3.8-61 response. They will have a removable structural steel frame, also designed to seismic Category II requirements, to prevent the shielding blocks from sliding or tipping during seismic events. The applicant also indicated that it would revise DCD, Tier 2, Section 3.8.4, in the next update and provided a markup of the proposed change.

The staff found the applicant's RAI 3.8-61 S01 response acceptable, because it clarifies the seismic design basis for the removable shield blocks. The staff also reviewed the applicant's proposed DCD changes and confirmed that it incorporated them in a formally submitted DCD revision. Therefore, RAI 3.8-61 was resolved.

In an earlier version of the DCD, the staff noted that Section 3.8.4 mentioned several seismic Category II structures (e.g., CB above grade and FB penthouse). In RAI 3.8-62, the staff requested that the applicant describe all seismic Category II structures and explain each structure's physical relationship to seismic Category I structures. The staff asked the applicant to provide the structural design criteria used for all seismic Category II structures, to ensure that they do not affect the performance of seismic Category I SSCs under all loading conditions. The staff also asked the applicant to provide sufficient information for the staff to confirm that the approach satisfies one of the three criteria presented in SRP Section 3.7.2.II.8 for all Category II SSCs.

In its response to RAI 3.8-62, the applicant stated that DCD, Tier 2, Table 3.2-1, provides the seismic categorization of structures, and Figures 1.2-1 through 1.2-20 provide the physical arrangement of seismic Category I and Category II structures. Since the methods of seismic analysis and design criteria for seismic Category II SSCs are the same as those for Category I SSCs, Category II SSCs meet the criteria in SRP Section 3.7.2. II.8 and are not postulated to fail. The applicant also referenced its response to RAI 3.8-42.

The staff determined that, in its supplemental response to RAI 3.8-42, the applicant revised DCD Section 3.7 to state that "the methods of seismic analysis and design acceptance criteria for seismic Category II (CII) SSCs are the same as C-I."

The staff finds the applicant's supplemental response to be acceptable, because it clarifies the seismic design basis for seismic Category II SSCs. The staff also reviewed the applicant's proposed DCD changes and confirmed that it incorporated them in a formally submitted revision to the DCD. Therefore, RAI 3.8-62 was resolved.

It is the staff's understanding that the CB is supported on a foundation mat that is independent of the RB and FB. In RAI 3.8-63, the staff requested that the applicant provide plan and section views showing the relationship of the CB and RB/FB foundation mats and superstructures and confirm that these structures are independent of each other.

In its response to RAI 3.8-63, the applicant stated that DCD Figures 1.2-2, 1.2-3, 1.2-4, 1.2-5, and 1.2-11 show the relationship of the CB and RB/FB foundation mats and superstructures. These structures are independent of each other. The applicant indicated that it would revise DCD Sections 3.8.4.1.2 and 3G.2.3 in the next update and provided a markup of the proposed change.

During its July 2006 onsite audit, the staff discussed the RAI response with the applicant. The staff requested additional information on clearances between the buildings and the technical bases for these clearances. The applicant provided details of the clearances between the RB/FB, CB, and access tunnel. To avoid seismic response interaction between the access tunnel and the RB/FB and CB, a 100-mm gap is kept between them. The applicant presented plots of the seismic displacement of the RB/FB and CB, which demonstrate that this gap width is sufficient, and drawings showing that the gap is filled with soft material (e.g., polystyrene board). The applicant agreed to provide the additional information presented at the audit in a supplemental response to the RAI. In addition, the staff asked the applicant to state that it would provide a minimum 100-mm gap between all independent structures, including the seismic Category II tunnel, the CB, and the RB; confirm that this gap is sufficient, based on current seismic analyses; and confirm the sufficiency of the gap again when it has completed all reanalyses, based on the single-envelope ground spectrum curve. The topics discussed during the audit were addressed by the applicant in its response to supplemental RAI 3.8-63 S01.

In its RAI 3.8-63 S01 response, the applicant stated that it provided seismic gaps capable of a minimum 100-mm free movement between independent nuclear island buildings to eliminate seismic interaction between buildings and provided the figures requested by the staff. The applicant stated that the displacements shown in Figure 3.8-63(2) include the analysis results using the single-envelope ground spectrum. The applicant also indicated that it would revise DCD Section 3.8.4 in the next update and provided a markup of the proposed change.

The staff found the applicant's RAI 3.8-63 S01 response to be acceptable, because it confirms that there are sufficient gaps to preclude seismic interaction. The staff also reviewed the applicant's proposed DCD changes and confirmed that it incorporated them in a formally submitted DCD revision. Therefore, RAI 3.8-63 was resolved.

DCD Section 3.8.4.1.2 states that the CB frame members, such as beams or columns, are designed to resist vertical loads and to accommodate deformations of the walls, in case of earthquake conditions. Similar statements appeared in DCD Section 3.8.4.1.3 for the FB and in DCD Section 3.8.4.1.4 for the emergency breathing air system (EBAS) building, which was subsequently deleted from the DCD. In RAI 3.8-64, the staff requested that the applicant provide the structural design criteria, including the deformation limits, used to design these frame members.

In its response to RAI 3.8-64, the applicant stated that the three-dimensional NASTRAN model explicitly includes frame members. As a result, the analysis automatically accounts for the interaction with building walls and slabs. DCD Section 3.8.4.5, "Structural Acceptance Criteria," presents the criterion for frame members. The applicant referenced GEH Report 26A6655, Revision 1, "FB Structural Design Report," issued November 2005, which contains the structural design details of the FB.

During the staff's onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, CA, the staff discussed the requested information in further detail with the applicant. The staff requested that the applicant add a subsection under DCD Section 3.8.4.5 to present the structural acceptance criteria for the EBAS building. The audit team reviewed selected portions of GEH Report 26A6655, containing the structural design details of the FB, and other supplemental information provided by the applicant at the audit. The applicant designed the reinforced concrete frame members in accordance with ACI 349-01 and designed the steel frame members in accordance with ANSI/AISC N690-1994s2 (2004). In the supplemental information provided at the audit, the applicant indicated that evaluations for the deformation for design loads "are not strictly performed," since the deformations resulting from design loads "are not so large." In support of this position, the applicant provided the calculated displacements for FB and CB frame members attributable to horizontal seismic load. The selected calculations support the applicant's position; however, the staff needed more information to conclude that the applicant's approach was applicable to the design of all frame members. The applicant indicated that it would include the additional information provided during the audit in a supplement to the initial RAI response. The applicant also indicated that it would provide more information about its evaluation of the deformation for design loads and broaden its response to address all frame members.

During its review of the FB design report, the staff noted that the evaluation of the automobile tornado missile is performed at the detailed design stage. The applicant indicated that it evaluated this missile for the structures and that it would provide more information on this subject. Following the audit, the staff also asked the applicant to evaluate the RB and FB exterior walls for the automobile tornado missile.

The above topics discussed during the July 2006 onsite audit were addressed by the applicant in its response to supplemental RAI 3.8-64 S01.

In its RAI 3.8-64 S01 response, the applicant proposed DCD changes to address the EBAS building. The applicant subsequently deleted these changes from the DCD, since it deleted the EBAS building from the ESBWR.

In the same RAI 3.8-64 S01 response, the applicant provided additional information regarding frame members and deformation under design loads. The applicant stated that the structural design of reinforced concrete frame members is performed in accordance with ACI 349-01 and confirmed that section forces and moments generated in members for design load combinations do not exceed the design strengths specified in ACI 349-01. The applicant also stated that the structural design of steel frame members is in accordance with ANSI/AISC N690-1994s2 (2004) and confirmed that stresses generated in members for design load combinations do not exceed the allowable stresses specified in ANSI/AISC N690-1994s2 (2004). The applicant explained that, since the RB, FB, and CB are relatively rigid, shear-wall-type buildings, deformations resulting from basic design loads are small. The applicant demonstrated that the calculated deformations from seismic loads are also very small, as shown in Figures 3.8-64(1) and 3.8-64(2), included with the response. Since the deformations are less than the allowable drift limits (see Table 5-2, ASCE 43-05), the applicant concluded that it did not need other analyses. For concrete frame members, the applicant confirmed that their thicknesses satisfy the requirement for the minimum thickness specified in ACI 349-01, Section 9.5.1.1, Table 9.5(b), for deflection control.

Since the three-dimensional NASTRAN model explicitly included the frame members and the applicant designed them in accordance with ACI-349 and ANSI/AISC N690, and since the deformations are very small, the staff finds the response to the RAI regarding the design of frame members to be acceptable.

In its RAI 3.8-64 S02 response, the applicant provided additional information on the evaluation of the RB/FB exterior walls for the automobile tornado missile. The applicant stated that it evaluated the automobile tornado missile for the RB/FB exterior walls and roof slabs in accordance with SRP Section 3.5.1.4, to confirm that the walls and slabs are adequately designed to resist the tornado-generated automobile missile loads. The applicant reported that it estimated the impact load generated by an automobile missile by the method described in Bechtel Power Corporation’s Topical Report BC-TOP-9A, Revision 2, “Design of Structures for Missile Impact,” issued September 1974. Using the estimated load, it performed evaluations for punching shear and bending. For punching shear, the applicant confirmed that shear resulting from the impact load is less than the punching shear strength calculated in accordance with ACI 349-01. The RB/FB global FEM analyses, in which the impact loads were applied to several critical elements, evaluated bending moments resulting from the automobile missile. The applicant reported that it combined the resulting bending moments in critical elements with moments resulting from other loads, including the tornado wind pressure, and confirmed that the resultant moments do not exceed the bending capacities. The applicant concluded that the

RB/FB exterior walls and roof slab are adequately designed to resist the tornado-generated automobile missile loads and stated that the evaluation details appear in GEH Report SER-ESB-041, Revision 0, “Reactor Building/Fuel Building Automobile Tornado Missile Impact Assessment,” which is available for NRC review at the applicant’s offices.

During the staff’s onsite audit, conducted December 12–14, 2006, at the applicant’s offices in San Jose, CA, the staff discussed the applicant’s evaluation of the automobile tornado missile. The staff stated that the applicant should refer to SRP Section 3.5.3, as well as SRP Section 3.5.1.4, for the design to resist automobile missile loads. DCD Section 3.5.3 does not reference BC-TOP-9A. If the applicant wants to use this topical report, it should reference it in DCD Section 3.5.3 for evaluation by the staff. The applicant stated that it will revise Section 3.5.3 of the DCD to reference BC-TOP-9A.

The staff also asked if the applicant had checked the large concrete wall (approximately 18 mx48 mx1 m thick) in the FB for missile impact loads. The applicant stated that it had evaluated the large concrete wall for missile impact loads, and GEH Report SER-ESB-041 contains the summary of this evaluation.

The above topics discussed during the December 2006 onsite audit were addressed by the applicant in its response to supplemental RAI 3.8-64 S03.

In its RAI 3.8-64 S03 response, the applicant stated that DCD Sections 3.5.3 and 3.5.1.4 already reference the SRP sections noted and that it will add a reference to BC-TOP-9A to DCD, Tier 2, Section 3.5.5, in the next DCD update. The proposed DCD change adds BC-TOP-9A as Reference 3.5-9 to the reference list in DCD Section 3.5.5.

The staff noted that DCD Section 3.5.3 does not specify the use of BC-TOP-9A. While the applicant added BC-TOP-9A as Reference 3.5-9 in DCD Section 3.5.5, there is no reference to it in DCD Section 3.5.3. If the applicant used BC-TOP-9A to evaluate the RB/FB exterior walls for the automobile tornado missile, it should revise DCD Section 3.5.3 accordingly. If not accepted, the applicant should evaluate the RB/FB exterior walls for the automobile tornado missile, using the procedures currently referenced in DCD Section 3.5.3.

In its RAI 3.8-64 S04 response, the applicant stated that the cited Reference 3.5-7 in DCD, Tier 2, Section 3.5.3.2, should be Bechtel Topical Report BC-TOP-9A. The applicant will replace Reference 3.5-7, Williamson and Alvy, with BC-TOP-9A and will delete Reference 3.5-9. The applicant also provided a markup of the proposed change to DCD, Tier 2, Section 3.5.5, and stated that it would revise the DCD in the next update.

The staff evaluated the applicant’s response and, in RAI 3.8-64 S05, it asked the applicant to provide adequate justification to demonstrate that the results obtained using BC-TOP-9A, Revision 2, are comparable to those obtained using the method specified in SRP Section 3.5.3. In its RAI 3.8-64 S05 response, the applicant provided information to address the staff’s request. Section 3.5.3 of this report presents a further evaluation of this supplemental response. In Section 3.5.3, the staff documented acceptance of the use of BC-TOP-9A to evaluate the overall damage prediction resulting from missile impact. In RAI 3.5-19, the staff asked the applicant to clearly state in the DCD that it used BC-TOP-9A to evaluate missile impacts or to provide justification if it used any other similar method. The staff addressed this issue under RAI 3.5-19 in Section 3.5.3 of this report. Therefore, RAI 3.8-64 was resolved.

The staff noted that the TB, service building (SB), and RW building are in proximity to seismic Category I structures. In RAI 3.8-79, the staff requested that the applicant confirm that it designed these structures to seismic Category II requirements or provide justifications for using different design requirements.

In its response to RAI 3.8-79, the applicant stated that DCD, Tier 2, Table 3.2-1, shows the seismic category classifications for the TB, SB, and RW building. The TB is classified as seismic Category II, and the SB is classified as NS. Since the SB is close to the RB/FB, the applicant would change its classification to seismic Category II in DCD, Tier 2, Table 3.2-1. The RW building is remotely located from seismic Category I structures and is classified as NS. It is, however, designed to the special prescriptive provisions of RG 1.143, category RW-IIa. The applicant stated that it would revise DCD, Tier 2, Table 3.2-1, in the next update and provided a markup of the proposed change.

The staff found the applicant's response for the SB to be acceptable, since it is designed to seismic Category II requirements. However, the staff determined that the applicant should define "remotely located" in reference to the RW building. The RB/FB and the RW building appear to be relatively close, based on DCD Figure 1.1-1. The staff questioned whether the RW building meets the criteria in SRP Section 3.7.2.II.8.a, which states that the collapse of any non-Category I structure will not cause the non-Category I structure to strike a seismic Category I structure or component.

The staff discussed this issue with the applicant during the December 2006 onsite audit. The applicant indicated that it would document the fact that the distance between the RW building and any seismic Category I SSC is greater than the height of the RW building above grade.

However, in its supplemental RAI 3.8-79 S01 response, the applicant stated that, in DCD, Tier 2, Revision 2, Section 3.5.3.3, it took an exception for the RW building to the requirement that any NS structure be located at least a distance of its height above grade from Category I or II structures, as shown in the DCD Tier 2 excerpt below:

> 3.5.3.3 Impact of Failure of Non-safety-Related Structures, Systems and Components
>
> Non-safety-related structures could be either seismic Category II (C-II) or NS. C-II structures are designed not to collapse under tornado wind loads. NS structure (except the Radwaste Building) is located at least at a distance height above grade from C-I or C-II structures. Per Section 3.5.2, Offgas Charcoal Bed Adsorbers are provided with missile protection.

The applicant stated that the RW building is 12 m above grade and is at least 10 m away from the RB (measured corner to corner). The RW building is designed to RG 1.143 (Category RW-IIa), which exceeds NS requirements for seismic design. Therefore, a potential failure of the RW building under a full SSE will have a negligible impact on seismic Category I or II structures.

The staff determined that DCD, Tier 2, Section 3.7, had not identified this exception, and the staff has not reviewed it for acceptability. Given the possibility that the RB may be impacted by the collapse of the RW building, in RAI 3.8-79 S02, the staff requested a detailed technical evaluation to support the conclusion that there would be no unacceptable damage to the RB.

This applicant should document this information in the DCD. RAI 3.8-79 was being tracked as an open item in the SER with open items.

In its subsequent RAI 3.8-79 S02, S03, and S04 responses, the applicant provided revisions to the analysis and design of seismic Category II structures to address interaction effects with seismic Category I structures. The applicant indicated that it would perform SSI analyses for the seismic Category II structures using the same methods as for the seismic Category I structures. This would include consideration of the effect of structure-SSI with adjacent seismic Category I structures. The applicant would also revise the ITAAC and the design description preceding the ITAAC, for the TB, SB, and ancillary diesel building, to state that the analysis and design is the same as for a seismic Category I structure, including the load combinations and acceptance criteria. Since the applicant will analyze and design seismic Category II structures as seismic Category I structures, the staff concluded that the issues raised regarding seismic interaction of seismic Category II structures have been adequately addressed. Furthermore, the use of the revised ITAAC will ensure that when the TB, SB, and ancillary diesel building are analyzed and designed, they will meet the DCD Sections 3.7 and 3.8 criteria for seismic Category II structures. The staff verified that the proposed markup changes in the response are acceptable. When DCD Revision 6 was issued, the staff also confirmed that the proposed markups in the RAI responses were properly incorporated into the appropriate sections of the DCD. The staff evaluated the remaining issue related to the RW building separately under RAI 3.8-80 below. Therefore, RAI 3.8-79 and its associated open item were resolved.

The staff noted that the applicant designed and evaluated the RB, FB, and CB to applicable acceptance criteria. In RAI 3.8-80, the staff asked the applicant to identify what other buildings have also been designed and evaluated. The staff also asked the applicant to discuss the status of the EBAS and RW building designs. The discussion should address the COL applicant's responsibilities and identify the standard plant design restrictions, limitations, and requirements for the design of buildings not covered in the DCD. The staff requested that the applicant include this information in DCD Section 3.8.4.

In its response to RAI 3.8-80, the applicant stated that the analytical design of the RB, CB, and FB was complete and documented in Appendices 3A and 3G to DCD Tier 2. The preliminary design of the EBAS was completed. The applicant had not started the RW design. DCD, Tier 2, Section 3.8.6, addresses the COL applicant's responsibilities.

The staff found the applicant's response to be incomplete for the EBAS building and the RW building. It was unclear whether the applicant would complete the designs in time for the staff to review them before it issued its safety evaluation, or if this would be the COL applicant's responsibility. The staff also noted that DCD Section 3.8.6 is titled "COL Information," not "COL Applicant Responsibilities." The only item currently identified in DCD Section 3.8.6 refers to the SIT of the ESBWR containment.

The staff discussed this issue with the applicant during the December 2006 onsite audit. The applicant indicated that RAI 3.8-65 addresses the status of the EBAS design. Since the RW building is not a seismic Category I or II structure, the applicant stated that it does not need to be designed as part of the design certification nor identified as a COL action item. The applicant also presented supplemental information to address the questions related to DCD Section 3.8.6. The topics discussed during the audit were addressed by the applicant in its response to supplemental RAI 3.8-80 S01.

In its RAI 3.8-80 S01 response, the applicant referred to the response to RAI 3.8-65 S01, for the status of the EBAS building, and stated that the RW building is a not a Category I structure. The applicant also indicated that it has moved the SIT information previously contained in DCD, Tier 2, Section 3.8.6, to DCD, Tier 1, Table 2.15.1-1, Item 5, and identified it as an ITAAC item, in response to RAI 14.3-101. Consequently, there will be no COL action items in DCD, Tier 2, Section 3.8, Revision 3. The applicant also indicated that it will revise DCD, Tier 2, Sections 3.8.1.7.3.12 and 3.8.6, in the next update and provided markups of the proposed changes.

The introductory paragraph in DCD Section 3.8.4 discusses the RW building as if it were part of the design certification scope. In its response to RAI 3.8-79, the applicant identified the RW building height above grade, its distance from the RB, and the potential for impact on the RB if the RW building should collapse in a seismic event. However, during the December 2006 audit discussion, the applicant indicated that the RW building does not need to be designed as part of the design certification nor identified as a COL action item. Consequently, the staff is unclear about the status of the RW building, with respect to design certification or COL applicant responsibility. In RAI 3.8-80 S02, the staff asked the applicant to clearly define the design responsibility for this essential building in accordance with RG 1.143. It should document this information in the DCD. RAI 3.8-80 was being tracked as an open item in the SER with open items.

The applicant's RAI 3.8-80 S02, S03, and S04 responses provided the proposed markups to the DCD to address the questions raised in the RAI. The applicant will revise the ITAAC for the RW building and the text preceding the ITAAC in DCD Tier 1, to state that the method of analyzing the RW building is the same as for a seismic Category I structure, including the load combinations and acceptance criteria. Also, the RW building is designed in accordance with RG 1.143, Classification RW-IIa, and the earthquake loading is for the full SSE instead of the one-half SSE, as shown in RG 1.143. The staff concluded that this ensures the design of the RW building will meet RG 1.143 criteria and also addresses concerns related to seismic interaction with adjacent seismic Category I structures. The staff verified that the proposed markup changes in the response are acceptable. When DCD Revision 6 was issued, the staff also confirmed that the applicant had properly incorporated the proposed markups in the RAI responses into the appropriate sections of the DCD. Therefore, RAI 3.8-80 and its associated open item were resolved.

During its review of DCD Revision 3, the staff noted that the revision includes changes to the design of the CB and now identifies the entire building as a seismic Category I structure. In RAI 3.8-112, the staff asked the applicant to confirm that it had completed the design and analysis of the entire CB in accordance with seismic Category I design criteria or discuss when it would be completed and by whom. Also, the staff requested that information in Section 3G.2 of DCD, Tier 2, Revision 3, be updated to reflect the change in design. For example, Figure 3G.2-11 still indicates that the building above grade is seismic Category II. In addition, the staff requested that all the tables in DCD Section 3G.2 be updated to report the applicable information for the walls in the CB above Elevation 4,650 and the floor slabs at Elevation 9,060 and Elevation 13,500. RAI 3.8-112 was being tracked as an open item in the SER with open items.

In a response to RAI 3.8-112, the applicant stated that it had updated the design and analysis of the entire CB in accordance with seismic Category I design criteria. The staff verified that the applicant has incorporated this into the appropriate sections of the DCD. Therefore, RAI 3.8-112 and its associated open item were resolved.

3.8.4.3.2 Applicable Codes, Standards, and Specifications

DCD Section 3.8.4.2 provides the applicable codes, standards, and specifications for the other seismic Category I structures. DCD Table 3.8-9 lists the specific codes, standards, and specifications for these structures. The staff found that, in general, the codes, standards, and specifications are in accordance with industry practice and SRP Section 3.8.4.II.2 criteria. For several items, however, the staff required additional clarification, as discussed below.

The staff noted that DCD Table 3.8-9 does not list RG 1.91; RG 1.127, "Inspection of Water-Control Structures Associated with Nuclear Power Plants"; and RG 1.160. DCD Table 1.9-21, "NRC Regulatory Guides Applicability to ESBWR," indicates that these guides apply only during the detailed design, construction, fabrication, and erection of the ESBWR and that the COL applicant will address the applicability of these guides. The staff finds this acceptable, since these guides apply to site-specific matters.

The staff also noted that DCD Table 3.8-9 does not list RG 1.115. However, DCD Table 1.9-21 indicates that this guide is applicable to the ESBWR. DCD Sections 3.5.1.1.1.2 and 10.2.4 discuss compliance with this guide, and the corresponding sections of this report include the staff's evaluation.

In RAI 3.8-66, the staff requested that, for each item in Table 3.8-9, the applicant identify and explain any exceptions to the codes and standards used for the ESBWR design.

In its response to RAI 3.8-66, the applicant stated that, in the title of DCD Table 3.8-9, it would change the phrase "Regulations" to "Regulatory Guides." Regarding Item 2 of DCD Table 3.8-9, ANSI/AISC N690-1994s2 (2004), the applicant replaced the ductility factors in Table Q1.5.8.1 with the ductility factors in Appendix A to SRP Section 3.5.3, to comply with Appendix G to NUREG-1503, "Final Safety Evaluation Report Related to the Certification of the Advanced Boiling-Water Reactor Design, Main Report," issued July 1994, for impact and impulsive loads. In addition, the applicant would add RG 1.54, "Service Level I, II, and III Protective Coatings Applied to Nuclear Power Plants," to DCD Table 3.8-9. The applicant indicated that it would revise DCD Table 3.8-9 in the next update and provided a markup of the proposed changes.

The staff discussed this issue with the applicant during the December 2006 onsite audit. The staff and the applicant reviewed NUREG-1503 and confirmed that the reference to RG 1.54 and the restriction for ductility ratios are in accordance with Appendix G to NUREG-1503. On this basis, the staff finds the applicant's response to be acceptable. The staff reviewed the applicant's proposed DCD changes and confirmed that it incorporated them in a formally submitted DCD revision. Therefore, RAI 3.8-66 was resolved.

The staff noted that DCD Section 3.8.4.2.1 states that Table 3.8-9 shows the applicable documents for the RB design, except for Items 4, 11, 30, and 32. With regard to the exceptions listed, the staff requested, in RAI 3.8-67, that the applicant (1) explain why there is no exception to Item 3 (ASME Code, Subsection CC) while there is an exception to Item 4 (ASME Code, Subsection NE) and Item 30 (RG 1.136 for concrete containments), and (2) explain the exception to Item 11 (2005 AISC Specification for Structural Steel Building).

In its response to RAI 3.8-67, the applicant stated that (1) as indicated in DCD Section 3.8.1.1.3, structural components that are integral to the containment structure are treated the same in the design, insofar as loads and loading combinations are concerned. Since Item 3 (ASME Code, Subsection CC) specifies the load combinations for the containment design, it applies to the design of other seismic Category I structures that share a common basemat with the containment structure. Items 4 and 30 have no relation to other seismic Category I structures, and (2) Item 11 is excluded because the design of safety-related steel structures conforms to Item 2 (ANSI/AISC N690).

The staff discussed this issue with the applicant during the December 2006 onsite audit. The staff noted that the response is acceptable. However, Items 3 and 30 in DCD Table 3.8-9 also relate to RAI 3.8-4, which requests additional information on the jurisdictional boundary for the applicability of Subsection CC. The staff and the applicant agreed to address this item under the review of RAI 3.8-4. Therefore, RAI 3.8-67 was resolved.

DCD Section 3.8.4.2.3 discusses the applicable documents for the FB design but does not specifically discuss the criteria for the design of the SFP racks and associated structures. Therefore, in RAI 3.8-69, the staff asked the applicant to provide a description of them. In its response to RAI 3.8-69, the applicant indicated that DCD, Tier 2, Section 9.1, contains the criteria for the SFP racks and structures. The staff noted that the criteria reference Appendix D to SRP Section 3.8.4; however, the loading combinations specified in DCD Section 9.1 are not in agreement with those in Appendix D to SRP Section 3.8.4.

In its RAI 3.8-69 S01 response, the applicant stated that it had reconciled the loads and load combinations in DCD, Tier 2, Section 9.1.2.4, with Appendix D to SRP Section 3.8.4. The applicant stated that it would revise DCD, Tier 2, Section 9.1.2.4, in the next update. The applicant provided a markup of the proposed DCD change.

The staff found the supplemental RAI 3.8-69 S01 response to be acceptable, since the criteria for the design of the spent fuel racks and associated structures meet the staff's technical position described in Appendix D to SRP Section 3.8.4. The staff reviewed the applicant's proposed DCD change and confirmed it incorporated the change in a formally submitted DCD revision. Therefore, RAI 3.8-69 was resolved.

The staff noted that DCD Section 3.8.4.2.5 discusses the welding and subsequent inspections of pool liners during construction. In RAI 3.8-70, the staff requested that the applicant indicate whether these procedures apply to all pool liners, including the SFP liner. For the SFP liner, the staff asked the applicant to explain whether the liner welds will include leak chase channels to monitor any SFP leakage during operation. If so, the applicant should describe the design of the system and what is expected of the COL applicant. If not, the applicant should describe how the potential for SFP leakage will be monitored during operation.

In its response to RAI 3.8-70, the applicant stated that liner welds of SFPs are backed by leak chase channels. The design groups the leak chase channels according to the different pool areas and directs any leakage to area drains. This allows both leak detection and the determination of the origin of the leaks. The functioning of the leak chase channels should be checked before completion of the pool liner installation. Construction details of the location of drains and pipes that collect this leakage are not available at this time. The COL licensee will determine the need to develop procedures for monitoring any potential pool leakage. The applicant provided generic examples of the leak chase channel in Figure 3.8-70(1), included in the response.

The staff determined that, while the response is acceptable, the applicant should include this information in the DCD. The staff discussed this issue with the applicant during the

December 2006 onsite audit. The applicant agreed to document, in the DCD, the response given to the RAI. In addition, the applicant agreed to state, in the DCD, that the welding and the subsequent inspections of pool liners apply to all pool liners, including the SFP liner. The topics discussed during the audit were addressed by the applicant in its response to RAI 3.8-70 S01.

In its RAI 3.8-70 S01 response, the applicant stated that leak chase channels collect potential SFP or other pool leakage. The design groups the leak chase channels by different areas of a pool and directs any leakage to area drains. This allows both leak detection and the determination of the origin of the leaks. Downstream of the drains, the leakage is directed to sight glasses, to tanks with level switches, or to a leak detection control panel. Thus, the design of the leak collection system permits monitoring of leakage of any pool during operation. The applicant further stated that no COL action is needed. The applicant indicated that it would revise DCD, Tier 2, Section 3.8.4.2.5, in the next update and provided a markup of the proposed change.

The staff reviewed the applicant's proposed DCD change and confirmed that it was incorporated in a formally submitted DCD revision. In addition to addressing the above information, the change to the DCD also addresses the inspection of all pool liner welds, including the SFP liner welds.

The staff found the applicant's supplemental response to be partially acceptable, since it explains the inspections for all pool liner welds and how the SFP and other pools outside the RCCV can be monitored for leakage during the plant's operating life. However, the applicant's response also stated that no COL action is needed. The staff considered unresolved the question of whether the applicant should define, in the DCD, a COL action to monitor the leakage of all pools during the plant's operating life. This issue, however, is closely related to RAI 3.8-81. As a result of the applicant's response to RAI 3.8-81 S01, it revised DCD, Tier 2, Section 3.8.4.7, to reference NUREG-1801, 10 CFR 50.65, and RG 1.160. The inclusion of this information in the DCD is sufficient to define the actions needed to monitor the performance of seismic Category I structures, such as the pools discussed under this RAI. Therefore, RAI 3.8-70 was resolved.

The staff noted that DCD Section 3.8.4.2 indicates that the design of the seismic Category I structures conforms to ANSI/AISC N690-1994s2 (2004). The March 2007 version of SRP Sections 3.8.3 and 3.8.4 accepts ANSI/AISC N690-1994s2 (2004) without exception. Therefore, this is acceptable.

DCD Section 3.8.4.2 indicated that the design of other seismic Category I structures conforms to ANSI/ASME NQA-1-1989 and Addenda 1a-1989, 1b-1991, and 1c-1992. DCD Section 17.1 indicates that the QA for the ESBWR design complies with ANSI/ASME NQA-1-1983 and with NQA-1a-1983 for certain aspects of QA (QA program, inspection, and audits). RG 1.28 accepts NQA-1 and NQA-1a-1983 Addenda, subject to the additions and modifications identified in the RG. Based on the preceding, the QA program requirements in DCD Section 3.8.4.2 are not consistent with the commitments presented in DCD Section 17.1. In RAI 3.8-84, the staff requested that the applicant clarify which commitments apply and make the necessary revisions in the DCD or justify the use of different QA requirements for the other seismic Category I structures.

In its response to RAI 3.8-84, the applicant proposed a revision to DCD, Tier 2, Table 3.8-9, Item 5, to cite NQA-1-1983 and also to reference DCD, Tier 2, Section 17. The applicant stated that it would revise DCD, Tier 2, Table 3.8-9, in the next update and provided a markup of the proposed change.

The staff discussed this issue with the applicant during the December 2006 onsite audit, and noted that DCD, Tier 2, Table 3.8-9, Item 5, should also cite NQA-1a-1983 Addenda. In its supplemental RAI 3.8-84 S01 response, the applicant stated that it had revised DCD, Tier 2, Table 3.8-9, Item 5, to also cite NQA-1a-1983 Addenda. The staff reviewed the applicant's proposed DCD change and confirmed that it incorporated the change in a formally submitted DCD revision. Therefore, RAI 3.8-84 was resolved.

The staff noted that DCD Section 3.8.4.2 indicates that the design and construction of other seismic Category I structures conform to ACI 349-01 and RG 1.142, Revision 2, issued November 2001, as indicated in Table 3.8-9. RG 1.142 states the staff's position on the use of the 1997 Edition of ACI 349 (hereafter referred to as ACI 349-97). Since the staff has not formally reviewed and endorsed ACI 349-01 at this time, it asked the applicant, in RAI 3.8-85, to identify all deviations between ACI 349-97/RG 1.142 and ACI 349-01 that affect the ESBWR design. The staff also asked the applicant to provide the technical basis for ensuring that a comparable level of safety is achieved for each such deviation.

In its response to RAI 3.8-85, the applicant provided a table that compares and summarizes the differences between ACI 349-01 and ACI 349-97/RG 1.142 (with NRC-accepted supplemental requirements) that affect the ESBWR design. The applicant identified the following items as the most important ones affecting the design of ESBWR structures:

- Design load combinations shown in DCD, Tier 2, Table 3.8-15, satisfy the requirements of ACI 349-97 (including the exceptions of RG 1.142) and SRP Section 3.8.4.

- The design of the containment and buildings considers two kinds of dynamic fluid effects. One is hydrodynamic load in the suppression pool resulting from LOCA/SRV discharge, and the other is sloshing loads that result from earthquakes.

- DCD, Tier 2, Section 3.8, does not postulate loads that result from malevolent vehicle assault, aircraft impact, and accidental explosion.

The staff discussed this issue with the applicant during the December 2006 onsite audit. The staff noted that the table provided in the response compares the 15 NRC regulatory positions presented in RG 1.142 against ACI 349-97, ACI 349-01, and the ESBWR. The RAI requested that the applicant compare the staff's current position (ACI 349-97, supplemented by RG 1.142) to the unreviewed ACI 349-01, taking into consideration the qualifications identified in RG 1.142. The staff stated that it would be acceptable to make this comparison only for those provisions in the two sets of codes used in the ESBWR design and for those provisions that are less stringent (i.e., less conservative). The staff also asked the applicant to provide the technical basis for accepting the provisions. The topics discussed during the audit were addressed by the applicant in its response to RAI 3.8-85 S01.

In its RAI 3.8-85 S01 response, the applicant stated that there are two main changes in ACI 349-01 versus ACI 349-97. First, ACI 349-01 is based on the 1995 Edition of ACI 318, "Building Code Requirements for Structural Concrete," except for Chapter 12, which is based on the 1999 Edition of ACI 318, while ACI 349-97 is based on the 1989 Edition of ACI 318 (revised in 1992), except for Chapter 12, which is based on 1995 Edition of ACI 318. ACI 349 is a dependent code to ACI 318, and most of the changes in ACI 318 are incorporated in subsequent editions of ACI 349. ACI 318 contains a commentary for the changes introduced. In general, these changes do not reduce margins and are updates to clarify the code language, based on questions received from practitioners. The second major change affects Appendix B to ACI 349-01 and involves going from the concrete-failure cone method to the concrete capacity design method. Later versions of Appendix D to ACI 318 also address this change. The NRC, in RG 1.199, accepted Appendix B to ACI 349-01 with some exceptions. The ESBWR design meets the positions in RG 1.199. A table attached to the response summarizes the differences between ACI 349-01 and ACI 349-97 for the provisions applicable to the ESBWR design. The applicant concluded that ACI 349-01 is more stringent than ACI 349-97.

The staff concurs with the applicant's response that the ACI 349-01 code is based on the more recent 1995 Edition of ACI 318 (except for Chapter 12, which is based on the 1999 Edition of ACI 318). ACI 318 has long been the basis for the design of concrete buildings in the United States, and revisions to ACI 318 are periodically incorporated into updates of the ACI 349 code. The staff reviewed the table provided by the applicant, which identifies the differences between ACI 349-01 and ACI 349-97 (as accepted in RG 1.142, with additional regulatory positions) that apply to the ESBWR design. Based on its review of this table, the staff agrees with the applicant that the applicable changes in ACI 349-01 generally clarify the requirements, make editorial changes, implement more stringent requirements, or, in some cases, are not applicable to the ESBWR design. For the changes made in Section 11.6 of ACI 349-01 related to the design for torsion, the provisions in ACI 349-01 are in accordance with the guidance in RG 1.142 and are acceptable. For requirements regarding anchorage to concrete, the provisions in Appendix B to ACI 349-01 are in accordance with those in RG 1.199, except that additional regulatory positions noted in the RG must also be satisfied. Since the applicant references RG 1.199 in the ESBWR design criteria, the use of ACI 349-01 is acceptable. The staff reviewed the remaining differences noted in the applicant's table and concluded that the changes made in ACI 349-01 do not affect the level of safety of the ESBWR concrete structures. Therefore, RAI 3.8-85 was resolved.

3.8.4.3.3 Loads and Load Combinations

In DCD Section 3.8.4.3, the applicant described the loads and load combinations used for the analysis and design of the other seismic Category I structures. DCD Table 3.8-15 presents the load combinations and associated acceptance criteria for safety-related reinforced concrete structures, and DCD Table 3.8-16 presents this information for safety-related steel structures. The staff found that, in general, the load definitions and load combinations agreed with those in ACI 349-97 and RG 1.142 for concrete structures and ANSI/AISC N690-1994, including S02 (2004), for steel structures, which are the criteria presented in SRP Section 3.8.4.II.3. In a few cases, however, the staff needed additional information from the applicant, as discussed below.

The staff noted that DCD Section 3.8.4.3.1.1 identifies the loads for the RB. P_a is defined as the accident pressure at the MS tunnel resulting from a high-energy line break. T_a is defined as the thermal effects (including T_o) that may occur during a design accident. It is noted that the RB is structurally connected to the containment walls at all floor elevations. The containment structure is also supported on the same foundation as the RB. Therefore, the staff requested, in RAI 3.8-71, that the applicant explain why the RB is not designed for the effects of R_a, T_a, P_a, CO, CHUG, VLC, and PS, as defined in DCD Section 3.8.1.3.5, for the containment, and for the effects of SRV loads, as defined in DCD Section 3.8.1.3.1. Some of these loads may not have a direct effect on the RB, but since the RB supports the containment, the loads are transmitted to the RB floors and walls. The staff also asked the applicant to explain why the design of the entire RB does not consider the dynamic effects of the above loads.

In its response to RAI 3.8-71, the applicant stated that DCD Section 3.8.4.3.1.1 presents only the loads that are applied to the RB directly. The RB design also considers other loads that are only applied to the RCCV but have some effect on the RB structures because of a common foundation mat, such as P_a and T_a. The applicant referred to DCD Table 3G.1-11 for an example of such application. The applicant also referenced GEH Report 26A6651, Revision 1, which contains the structural design details of the RB. The applicant indicated that it would revise DCD Section 3.8.4.3.1.1 and DCD Table 3G.1-11 in the next update and provided markups of the proposed changes.

The staff discussed this issue with the applicant during the December 2006 onsite audit. The staff asked what other loads besides P_a and T_a are considered in the RB design, noted that all loads included in the RB design should be defined in DCD Section 3.8.4.3.1.1, and asked why the dynamic effects of the above loads are not considered in the design of the entire RB. The applicant stated that it would add a footnote in DCD Tables 3.8-15 and 3.8-16 to state that the effects of SRV and LOCA dynamic loads originating inside the containment will be considered applicable. The topics discussed during the audit were addressed by the applicant in its response to RAI 3.8-71 S01.

In its RAI 3.8-71 S01 response, the applicant stated that it would revise DCD Tables 3.8-15 and 3.8-16 to clarify the applicability of loads generated in the RCCV to the entire RB by including, in the footnotes, the statement that: "The effects of SRV and LOCA dynamic loads that originate inside the containment are considered as applicable." The applicant indicated that it would revise DCD, Tier 2, Tables 3.8-15 and 3.8-16, in the next update and provided markups of the proposed change. The staff found this response to be acceptable, since it confirmed that the entire RB will be designed for the applicable effects of SRV and LOCA dynamic loads that originate inside the containment.

The staff reviewed the applicant's proposed DCD change and confirmed that it incorporated the change in a formally submitted DCD revision. Therefore, RAI 3.8-71 was resolved.

The staff noted that DCD Section 3.8.4.3.1.2, for concrete members, and Section 3.8.4.3.1.3, for steel members, in the earlier versions of the DCD, state that the maximum codirectional responses to each of the excitation components for seismic loads are combined by the 100/40/40 method, as described in DCD Section 3.8.1.3.6. The staff requested, in RAI 3.8-72, that the applicant confirm that the application of the 100/40/40 method for combining directional responses is consistent with the staff-accepted method, as delineated in DG-1127, "Combining Modal Responses and Spatial Components in Seismic Response Analysis" (draft guide to what is currently identified as RG 1.92, Revision 2, published in 2006). If the application of the 100/40/40 method is not consistent with DG-1127, the applicant should provide the technical basis for the differences.

In its response to RAI 3.8-72, the applicant referred to RAI 3.7-41, which requests the same information, and stated that the 100/40/40 method used is consistent with the requirements of DG-1127.

The staff discussed this issue with the applicant during the December 2006 onsite audit. The staff had concluded, based on its review of data submitted to support its confirmatory analysis, that the applicant's implementation of the 100/40/40 method was not consistent with DG-1127. The topics discussed during the audit were addressed by the applicant in its response to RAI 3.8-72 S01.

In its RAI 3.8-72 S01 response, the applicant referred to RAI 3.8-107 S01, for information on the use of the 100/40/40 method for the combination of responses resulting from three directions of seismic loading. The staff addressed this technical issue under RAI 3.8-107 in Section 3.8.5.3.4 of this report. Therefore, RAI 3.8-72 was resolved.

The staff noted that DCD Section 3.8.4.3.2 states that accident pressure loads (P_a) do not exist for the CB. Section 3G.2.5.2.1.6 states that thermal loads (T_a) for the CB are evaluated for abnormal LOCA conditions. In RAI 3.8-73, the staff requested that the applicant explain how LOCA thermal loads affect the CB. The staff also asked the applicant to provide the technical basis for the decision that the dynamic effects of LOCA, SRV discharge, CO, and CHUG are not applicable to the design of the CB.

In its response to RAI 3.8-73, the applicant stated that T_a is not a DBA LOCA load but is associated with the loss of HVAC function. This postulated loss of HVAC function is caused by a loss of offsite power and delivers the maximum thermal load, T_a, to the CB because of the concurrent LOCA. The CB is a stand-alone structure isolated from the RB, which houses the containment. As a result, the dynamic effects of LOCA, SRV discharge, CO, and CHUG loads originating inside the containment are not applicable to the design of the CB. The applicant indicated that it would revise DCD, Tier 2, Sections 3.8.4.3.2 and 3G.2.5.2.1.6, in the next update and provided markups of the proposed changes. Since the CB is a separate stand-alone structure isolated from the RB, and the accident thermal load T_a is defined as the maximum thermal load which results from a loss of offsite power, the staff concluded that the applicant's response is reasonable and found the proposed changes to the DCD to be acceptable. The staff reviewed the applicant's proposed DCD change and confirmed that it incorporated the change in a formally submitted DCD revision. Therefore, RAI 3.8-73 was resolved.

The staff noted that DCD Section 3.8.4.3.3 states that accident pressure loads (P_a) do not exist for the FB. In Section 3.8.4, the DCD states that the RB and FB are built on a common foundation mat and are structurally integrated into one building. The RB is also structurally connected to the containment walls at all floor elevations, and the containment structure is supported on the same foundation as the RB. Therefore, in RAI 3.8-74, the staff requested that the applicant explain why the FB is not designed for the effects of R_a, T_a, P_a, CO, CHUG, VLC, and PS, as defined in DCD Section 3.8.1.3.5 for the containment, and for the effects of SRV loads, as defined in DCD Section 3.8.1.3.1. Some of these loads may not have a direct effect on the FB, but the loads may be transmitted to the FB floors and walls. In addition, the staff asked the applicant to explain why it did not consider the dynamic effects of the above loads in the design of the entire FB. The staff also noted that DCD Section 3G.3.5.2.1.1 does not define either P_a or T_a for the FB, but Table 3G.3-4 includes P_a and T_a in two of the three selected load combinations (LOCA (1.5 P_a) 72 hours and LOCA + SSE 72 hours). Therefore, the staff requested that the applicant explain the LOCA loads considered in these two load combinations and revise the loads defined in DCD Sections 3G.3.5.2.1.1 and 3.8.4.3.3 accordingly.

In its response to RAI 3.8-74, the applicant stated that DCD Section 3.8.4.3.3 presents only the loads that are applied to the FB directly. The FB design also considers other loads, such as P_a and T_a, that are applied only to the RCCV but have some effect on the FB structures because of a common foundation mat. The applicant referred to DCD Table 3G.3-4 for an example of an application. The applicant also referenced GEH Report 26A6655, which contains the structural design details of the FB. The applicant indicated that it would revise DCD Section 3G.3.5.2.1 and Table 3G.3-4 in the next update and provided markups of the proposed changes.

The staff discussed this issue with the applicant during the December 2006 onsite audit. Similar to its question in RAI 3.8-71, which is related to the RB, the staff asked what other loads it considered, besides P_a and T_a, in the FB design; noted that all loads included in the FB design should be defined in DCD Section 3.8.4.3.1.1; and asked why the design of the entire FB does not consider the dynamic effects of the above loads. The applicant stated that it would document, by the addition of a footnote in DCD Tables 3.8-15 and 3.8-16, that it will consider the effects of SRV and LOCA dynamic loads originating inside the containment as applicable. The topics discussed during the audit were addressed by the applicant in response to supplemental RAI 3.8-74 S01.

In its RAI 3.8-74 S01 response, the applicant referred to its RAI 3.8-71 S01 response, which addressed the same issues for the RB. The staff finds this response to be acceptable, since it confirms that the applicant will design the FB for the applicable effects of SRV and LOCA dynamic loads that originate inside the containment.

The staff reviewed the applicant's proposed DCD change to address RAI 3.8-71 and concluded that it also addresses RAI 3.8-74. The staff confirmed that the applicant incorporated the change in a formally submitted DCD revision. Therefore, RAI 3.8-74 was resolved.

DCD Section 3G.1.5.2.2.4 states that, based on previous experience, critical load combinations are selected for the RB design. Table 3G.1-11 shows the selected load combinations. In RAI 3.8-82, the staff asked the applicant to explain why Table 3G.1-11 does not include Load Combination 7 from Table 3.8-15, which includes the effects of tornado loads, as a critical load combination. The staff expects that tornado loads would have a significant effect on the design of the exterior walls of the RB. The staff also asked the applicant to explain why Load Combination 4 in Table 3G.1-11 is considered to be a more critical load combination than Load Combination 3 in Table 3.8-15, and to clarify that the design engineer considered all the required load combinations in the final design of all seismic Category I structures. The staff asked that the applicant include this information in Appendix 3G to the DCD.

In its response to RAI 3.8-82, the applicant stated that it performed design calculations for all load combinations in DCD Table 3.8-15, excluding those that are obviously not critical or where loads are negligibly small. Among the combinations, it selected the ones that are controlling in critical sections, and the DCD describes their results. The applicant performed design calculations for the load combinations, including tornado loads, but found them to be less critical than other combinations, such as LOCA plus SSE. Therefore, the DCD does not describe their results.

The applicant also stated that temperature loads in winter are one of the most severe loads for the exterior wall design. Load Combination 4 in DCD Table 3G.1-11 includes the temperature load, while Load Combination 3 in DCD Table 3.8-15 does not. Therefore, the former is more critical than the latter. The applicant referenced GEH Report 26A6651, which contains the structural design details of the RB.

During the staff's onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, CA, the staff discussed the requested information in further detail with the applicant. The staff reviewed GEH Report 26A6655 and found that the combined force and moment tables in the report did not tabulate results for all the load combinations discussed in the report. The staff asked the applicant to provide load combination results for the FB and RB external walls subject to wind (W) and tornado (W_t) load combinations and compare them with the seismic results, to demonstrate that they do not govern the design. The applicant stated that it would supplement its RAI response, to clarify the process and to illustrate the results at four selected elements on the exterior walls of the RB and FB for load combinations, including tornado, wind, seismic, and thermal loads. The topics discussed during the audit were addressed by the applicant in response to supplemental RAI 3.8-82 S01.

In its RAI 3.8-82 S01 response, the applicant stated that it has revised and clarified the first sentence of the first paragraph in its initial response to read, “Design calculations were performed for all building elements for all load combinations in DCD Table 3.8-15, excluding those which are obviously not critical or whose loads are negligibly small.” The applicant revised the first sentence of the second paragraph to read, “Temperature loads in winter, in combination with other loads, are one of the most severe loads for the exterior wall design.”

In its RAI 3.8-82 S01 response, the applicant also compared forces and stresses in the exterior walls for Load Combinations 3 and 4, defined in DCD Table 3.8-15. Based on the comparison of forces and stresses, the staff agrees that Load Combination 4 (which includes temperature) is more critical than Load Combination 3 (which has higher load factors but no T_a), and therefore, the use of Load Combination 4 in Table 3.G.1-11 is appropriate.

Also, at the staff’s request, the applicant evaluated stresses at four selected elements on the exterior walls of the RB and FB. Based on the comparison of forces and stresses, the staff agrees that the load combination that includes seismic loads is more critical than the load combination that includes tornado loads, and therefore, the approach used by the applicant is acceptable.

At a subsequent audit on May 16–17, 2007, at the applicant’s offices in Wilmington, NC, the staff reviewed GEH Report 26A6651, Revision 2. The staff noted that Section 6.2.2.1 of the report states, “Structures of the FB located above EL 22,500 are not included in the model, because they are seismic Category II structures.” Since the FB structure above Elevation 22,500 (identified as the penthouse by the applicant) is not included in the model, the staff posed several questions during the audit. Based on the explanations provided by the applicant during the audit, the staff concurred that it is not necessary to explicitly include the penthouse in the model. The applicant stated that it would document the information provided during the audit discussions in response to RAI 3.8-82 S02.

In its RAI 3.8-82 S02 response, the applicant described how it analyzed and designed the penthouse for seismic and other loads. The RB and FB seismic analysis model includes the mass and stiffness of the penthouse. The mass is included in the nodal mass at the appropriate elevations of the stick model, and the stick model also includes the stiffness of the penthouse external walls. The penthouse effective mass in the vertical direction is considered in the slab oscillators at Elevation 22,500 of the seismic stick model. For design, the applicant applied the loads resulting from the FB penthouse to the global NASTRAN model. It applied the dead load, live load, and seismic loads to the model as nodal forces. The penthouse structure is designed for all loads considered in the FB seismic Category I portions, except tornado missile loads (which are not applicable). The applicant used the same methodologies for the load combinations, stress analysis, and section design calculations as for the seismic Category I portions. The staff finds that the approach described above for the analysis and design of the penthouse structure is in accordance with industry methods and with those described in SRP Sections 3.7 and 3.8 and thus is acceptable. Therefore, RAI 3.8-82 was resolved.

The staff noted that DCD Section 3G.1.5.3, “Stability Requirements,” does not include the load combinations for W and W_t, as defined in DCD Table 3.8-14. In RAI 3.8-83, the staff requested that the applicant explain why Appendix 3G to the DCD does not include these load combinations.

In its response to RAI 3.8-83, the applicant stated that, because the effect of seismic load on the stability is larger than the effects of wind and tornado, DCD Section 3G.1.5.3 excludes the load combinations for W and W_t. Only the controlling combinations are reported. The applicant indicated that it would revise Appendix 3G.1.5.3 in the next DCD update and provided a markup of the proposed change.

During the staff’s onsite audit, conducted July 11–14, 2006, at the applicant’s offices in San Jose, CA, the staff discussed the requested information in further detail with the applicant. The staff reviewed selected portions of GEH Report 26A6652, Revision 2, “Stability Analysis of Reactor/Fuel Building Complex,” dated April 28, 2006. The report discussed the procedures for determining the factors of safety for seismic loads and flotation. The staff will evaluate these procedures in the review of DCD, Tier 2, Section 3.7. For flotation, the report assumed a maximum flood level of 0.3 m below grade and a water height of 19.7 m. The buoyant force was then calculated and compared to the dead load of the building. This resulted in a factor of safety against buoyancy of 3.5, which exceeds the acceptance criteria in SRP Section 3.8.5.II.5. The report also stated that the basic wind load and tornado wind load are not considered, since their effects on foundation stability are negligible. During the audit, the applicant provided a table comparing the horizontal forces resulting from seismic loads, tornado loads, and wind loads, which showed that the wind and tornado loads are negligible when compared to the seismic loads. The staff performed some hand calculations and concluded that the applicant’s results are reasonable.

The staff reviewed the applicant’s proposed DCD change and confirmed that it was incorporated in a formally submitted DCD revision. Therefore, RAI 3.8-83 was resolved.

The staff review of the SFP identified an accident thermal load condition for the spent fuel storage pool that is not specifically addressed in DCD Section 3.8. In RAI 3.8-113, the staff asked the applicant to provide the technical details of how it considered temperature effects in the design of the SFP structure, to account for boiling the pool water for up to 72 hours at 100 degrees C (212 degrees F). The staff asked the applicant to identify which load category (e.g., T_a or T_o) and load combinations in DCD Table 3.8-15 consider this thermal condition for the reinforced concrete walls. The applicant should document this information in the DCD. RAI 3.8-113 was being tracked as an open item in the SER with open items.

In its response to RAI 3.8-113, the applicant provided the information related to how it considered the temperature effects of the boiling water in the SFP. The staff verified that the proposed markup changes in the response are acceptable and confirmed that the applicant incorporated them into the appropriate sections of DCD Revision 6. Therefore, RAI 3.8-113 and its associated open item are resolved.

During the review of DCD Section 3.8, the applicant submitted Licensing Topical Report NEDC-33373P, Revision 1, “Dynamic, Load-Drop and Thermal-Hydraulic Analysis for ESBWR Fuel Racks.” This report presents the structural analysis of the spent fuel high-density fuel storage racks (FSRs) for the spent fuel storage pool located in the FB. The report indicates that the design of the FSRs has been revised such that they are no longer anchored to the pool floor. The FSRs are evaluated as free-standing racks on the pool floor. While the report evaluates the adequacy of the FSRs and provides some information about the loads on the SPF structure, it does not appear to contain information regarding how these loads are used in the design of the SPF structure. Therefore, in RAI 3.8-125, the staff asked the applicant to describe the evaluation of the pool structure (reinforced concrete floor and walls and steel liner) resulting from all loads generated by the new analyses for the FSRs.

In its response to RAI 3.8-125, the applicant stated that the structural evaluation of the SPF structure for these localized loads generated from the FSRs will be performed in the detail design phase to meet the requirements stipulated in DCD, Tier 1, Section 2.16.7, and DCD, Tier 2, Section 3.8.4.3.3. Even though the response indicates that the evaluation of the SPF structure will be performed in the detail design phase, the staff still maintains that the applicant should perform some assessment at this time, during the design certification phase, to demonstrate that the current design of the SPF structure is adequate to withstand the expected loads from the new free-standing FSRs. The evaluation to be performed at this time should consider the effects of the revised FSRs on the seismic analysis of the pool structure and FB and the effects on the design of the pool structure. In addition, the applicant should assess the potential localized impact loads on the pool's concrete walls and floors and on the liner. Therefore, in RAI 3.8-125 S01, the staff asked the applicant to perform a quantitative evaluation to demonstrate that the SPF structure is adequate to withstand loads from the new free-standing FSRs.

In its RAI 3.8-125 S01 and S02 responses, the applicant provided information on the design of the SPF to demonstrate its structural adequacy. The applicant indicated that the analysis of the FSRs demonstrated that the racks do not impact the pool walls. Since the FSRs do not interact with the pool walls under an SSE, the only dynamic interaction occurs at the base slab. The applicant indicated that the fully loaded FSR masses were included in the base slab as part of the FB basemat model. At the locations of the FSR legs, embedded plates will be provided to carry the rack support reaction loads to the FB mat. The SFP concrete mat is 5.5 m thick and is adequate to withstand loads from the FSR. The staff reviewed this information and concluded that it demonstrates the structural adequacy of the SFP subjected to the loadings from the FSRs. The applicant also provided markups to the DCD to address revised gap requirements between the racks and to describe the rack-bearing pads that rest on embedded plates in the SFP basemat. The staff verified that the proposed markups were incorporated into the appropriate sections of the DCD, Tier2, Revision 7. Therefore, RAI 3.8-125 was resolved.

In addition to its review of loads and load combinations in accordance with SRP 3.8.4, the staff also evaluated compliance with Generic Letter 89-022, "Potential for Increased Roof Loads and Plant Area Flood Runoff Depth at Licensed Nuclear Power Plants Due to Recent Change in Probable Maximum Precipitation Criteria Developed by the National Weather Service," issued October 1989, and New Generic Issue 156.6.1, "Pipe Break Effects on Systems and Components," contained in NUREG-0933, as discussed below.

a) Generic Letter 89-022 concerns the revised probable maximum precipitation (PMP) criteria adopted by the staff since 1989, and contained in NOAA/NWS Hydrometeorological Reports (HMR) Nos. 49, 51, 52, 53, and 55. In particular, these HMRs provide PMP estimates for drainage areas as small as 1 square mile and durations as small as 5 minutes. The revised criteria call for higher rainfall intensities over shorter time intervals and smaller areas than had been previously considered. In some cases, such events could result in higher site flooding levels and greater roof ponding loads than had been used in the past.

In DCD, Tier 2, Revision 7, Appendix 1C, the applicant indicated that the issues raised by Generic Letter 89-022 were taken into consideration in the parameters listed in DCD, Tier 2, Revision 7, Tables 2.0-1 and 3G.1-2. Based on its review of DCD, Tier 2, Revision 7, Table 3G.1-2, under the heading "Site Design Parameters, Maximum Rainfall," the staff found that the design rainfall was based on a PMP estimated per HMR No. 52, with roof drainage designed independently to handle the PMP. Therefore, the roof ponding issues raised by Generic Letter 89-022 were resolved for the ESBWR design. Site flooding issues are addressed in Section 2.4 of this report.

b) New Generic Issue 156.6.1 concerns the effects of pipe breaks on systems and components inside and outside of the containment structure. In particular, this includes the specific structural and environmental effects of pipe whip, jet impingement, impact, flooding, etc., on systems and components relied on for safe reactor shutdown. In DCD, Tier 2, Revision 7, Section 1.11, the applicant indicated that seismic Category I structures were designed to withstand the loads resulting the dynamic effects of pipe breaks. They also indicated that DCD, Tier 2, Revision 7, Section 3.8.1.3.5 defines the specific design loads resulting from pipe breaks considered in the design of the containment and its internal structures, while DCD, Tier 2, Revision 7, Section 3.8.4.3.1 defines design loads affecting the Reactor Building structure. Sections 3.8.1 and 3.8.4 of this report discuss the staff's review of the corresponding DCD Tier 2 sections.

As discussed in NUREG-0933, a technical assessment of Issue 156.6.1 was undertaken by the staff in 2007 and recommended that it could be closed with no further action by the staff. The issue was closed in December 21, 2007. Therefore, Issue 156.6.1 was resolved for the ESBWR design.

3.8.4.3.4 Design and Analysis Procedures

DCD Section 3.8.4.4 and Appendix 3G describe the design and analysis procedures used for the other seismic Category I structures. The applicant analyzed the RB, CB, and FB, using the linear elastic FE computer program NASTRAN, which is described in Appendix 3C to the DCD. The RB and FB are integrated into one building and analyzed using a common FEM, which is described in DCD Section 3G.1.4.1. The model also includes the concrete containment and uses quadrilateral, triangular, and beam elements to represent the various structural components. DCD Section 3G.2.4.1 describes the FE analysis model of the CB, which includes the entire structure. The applicant based the design of the other seismic Category I structures on the elastic method. The staff has determined that the design and analysis procedures are acceptable, on the basis that they are consistent with the design and analysis procedures given in SRP Section 3.8.4.II.4. However, some areas needed further clarification. These are discussed below.

The staff noted that DCD Sections 3.9.2 and 3.10.3.2 provide some limited information on the analysis and design of supports for cable tray, conduit, and ventilation ducts but not for the conduits, cable trays, and ducts themselves. Therefore, in RAI 3.8-77, the staff requested that the applicant describe the analysis and design criteria (i.e., description; applicable codes, standards, and specifications; loads and load combinations; acceptance criteria; and analysis and design procedures) used for cable trays, conduits, and ventilation ducts in other Category I structures.

In its response to RAI 3.8-77, the applicant referred to its response to RAI 3.8-52. The staff discussed this issue with the applicant during the December 2006 onsite audit. The applicant stated that it would revise DCD Tables 3.8-6 and 3.8-9 by including the applicable codes and standards to address both this RAI and RAI 3.8-52. The topics discussed during the audit were addressed by the applicant in response to supplemental RAI 3.8-77 S01.

In its RAI 3.8-77 S01 response, the applicant referred to its supplemental response to RAI 3.8-52. The staff reviewed the supplemental response to RAI 3.8-52 and concluded that it adequately addresses RAI 3.8-77. The staff's evaluation of RAI 3.8-52 is in Section 3.8.3.3.4 of this report. Therefore, RAI 3.8-77 was resolved.

The staff noted a large disparity in element sizes in the NASTRAN model of the RB/FB structure. In RAI 3.8-104, the staff requested that the applicant explain how it checked and verified the numerical stability of the solution. In addition, the staff noted that a number of triangular elements around penetrations have large height-to-base aspect ratios and are likely to produce less accurate results. Therefore, the staff asked the applicant to discuss any limitations on the use of the numerical results for these elements.

In its response to RAI 3.8-104, the applicant stated that the large disparity in element sizes and triangular elements that have large height-to-base aspect ratios is mainly found in the areas around the RCCV openings in the NASTRAN model. However, the design of the RCCV wall around large penetrations uses refined local FEMs to consider stress concentrations. In the local models, the large disparity of element sizes is eliminated, and elements with smaller aspect ratios are used. In addition, the applicant compared the stresses in triangular elements of large aspect ratios in other locations with the stresses in rectangular elements that surround the triangular elements, to check the reasonableness of the results. The applicant referenced GEH Report 26A6651, which contains the structural design details of the RB.

During the staff's onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, CA, the staff discussed the requested information in greater detail. The applicant explained during the audit that there is no concern about disparity of element sizes excluding regions of large stress or high-stress gradients, in the case of elastic analysis. The applicant referenced the MSC/NASTRAN Common Question and Answer Section, which responded to the question, "What are the accuracy checks for static stress analysis?" As noted in its response, the applicant compared stresses in triangular elements with large aspect ratios to the stresses in rectangular elements around the triangular elements, to check the reasonableness of the results. As an example, the applicant presented plots of the stresses of the drywell top slab for drywell unit pressure loading. There were no unique stress discontinuities. For this structure, the applicant also presented a local FEM that it will create using rectangular elements. The applicant also presented figures depicting the refined local FEMs that it will use to design the RCCV wall around large penetrations. It has eliminated the triangular elements that have large height-to-base aspect ratios in the global model. The applicant stated that it would include the information discussed during the audit in a supplement to its initial RAI response. The topics discussed during the audit were addressed by the applicant in response to supplemental RAI 3.8-104 S01.

In its RAI 3.8-104 S01 response, the applicant stated that the reasonableness of the results obtained in the regions of triangular elements with large aspect ratios is evident in Figures 3.8-104(1) and (2), which show the stresses under drywell internal unit pressure (1 MPa) on the bottom surface of the top slab in the X-axis and Y-axis direction, respectively. Similarly, Figures 3.8-104(3) and (4) show the stress distributions around the MS/FW piping penetrations under the same load condition. There is no unique stress discontinuity from rectangular to triangular elements in these figures, so the analysis result is applicable to the member design. Figure 3.8-104(5) shows the application of drywell wall unit pressure.

The applicant also stated that it designed the RCCV wall around large penetrations using refined local FEMs, as shown in Figures 3.8-104(6), (7), and (8), to take into account the stress concentrations. Therefore, the triangular elements that have large height-to-base aspect ratios in the global model are eliminated. Similarly, Figure 3.8-104(9) shows an example of the top slab local model.

After reviewing the figures provided with the RAI 3.8-104 S01 response, the staff concluded that the applicant has adequately addressed the issue raised in this RAI. Therefore, RAI 3.8-104 was resolved.

The staff noted that the desirable mesh shown in DCD Figure 3G.1-13 for the SP slab is not duplicated for the top slab shown in DCD Figure 3G.1-12 and that the mesh shown in Figure 3G.1-12 is not symmetrical with respect to the 90–270 degree plane. In RAI 3.8-105, the staff requested that the applicant explain these observations.

In its response to RAI 3.8-105, the applicant stated that the SP slab is annular in shape. It is convenient to map the mesh in polar coordinates. As for the top slab, although an annular plate by itself, it is connected to pool girders and pool walls, to which the polar coordinates are difficult to apply. The NASTRAN model needs to consider connections with these walls. This explains why the mesh for the top slab differs from that of the SP slab. The pool girders running in the 0–180 degree direction and the location of the pool walls are not symmetrical with respect to the 90–270 degree plane. Therefore, the applicant developed an asymmetrical mesh with respect to the 90–270 degree plane. The applicant referenced GEH Report 26A6651, Revision 1, which contains the structural design details of the RB.

The staff finds the applicant’s response to be acceptable, because it adequately describes the basis for the FEM mesh patterns. Therefore, RAI 3.8-105 was resolved.

The staff observed that there is (1) movement in the -x direction under dead load in DCD Figure 3G.1-30, (2) movement in the +x direction under drywell unit pressure in DCD Figure 3G.1-3, and (3) a slight rotation about y under vertical seismic load in DCD Figure 3G.1-38. In RAI 3.8-106, the staff requested that the applicant explain these movements.

In its response to RAI 3.8-106, the applicant stated that, because of the weight imbalance between the RB and FB (i.e., the RB is heavier than the FB), the basemat slightly rotates about the Y axis under the dead load and vertical seismic load. This basemat rotation causes movement in the -x direction under dead load. In the case of drywell unit pressure, if the model is symmetrical, both ends of the basemat would tend to deform upwards equally. However, the RB/FB foundation mat is not symmetrical with respect to the 90–270 degree plane; therefore, the soil springs underneath the mat restrain this deformation of the basemat at the FB side. As a result, the basemat slightly rotates about the Y axis, and the movement in the +x direction is generated. The applicant referenced GEH Report 26A6651, Revision 1, which contains the structural design details of the RB.

During the staff’s onsite audit, conducted July 11–14, 2006, at the applicant’s offices in San Jose, CA, the staff discussed the requested information in greater detail with the applicant. The staff noted that the response appears to indicate that there is a net upward force on the foundation mat resulting from the unit drywell pressure and that it is partly resisted by the springs under the FB. This requires clarification, as one would expect a zero net force on the foundation mat as the result of unit drywell pressure. The applicant stated that it would sum the forces on the springs for the unit drywell pressure analysis, to demonstrate that there is zero net force on the foundation mat as the result of unit drywell pressure. The topics discussed during the audit were addressed by the applicant in response to supplemental RAI 3.8-106 S01.

In its RAI 3.8-106 S01 response, the applicant stated that the summation of forces in the soil springs for the drywell unit pressure is 0.72 MN. Although the value is not exactly zero, it can be regarded as zero in comparison with the total applied load (upward or downward) of 1,017.9 MN.

The staff found the applicant's supplemental response to be acceptable, because it confirms that there is no net vertical force resulting from drywell pressure. Therefore, RAI 3.8-106 was resolved.

In DCD Revision 4, the applicant revised Sections 3.8.4.1.1 and 3.8.4.6.5 to describe the use of composite structures for most reactor building slabs. These composite structures are constructed from reinforcing bars, steel plates, steel beams, concrete, and studs. The applicant calculated the strength of the slab using reinforced concrete design methodology, except that it treated the steel plate as being equivalent to two orthogonal rebars with the same sectional area as the plate. The applicant designed the studs to ANSI/AISC N690, and the stresses in the rebar, steel plates, and concrete meet the allowable stresses in ASME Code, Section III, Division 2, Subsection CC. There is essentially no guidance on the design of such composite floor members in Subsection CC of the ASME Code; therefore, in RAI 3.8-121, the staff asked the applicant to describe the approach being used in greater detail. This should include the basis for treating the steel plates as two orthogonal rebars, since the steel plates are subjected to biaxial tension and the individual rebars are not. Also, the staff asked the applicant to explain how it determined the forces acting in different directions in designing the studs and how it determined the allowable stresses for the steel beams and steel plates, since Subsection CC of the ASME Code does not contain the allowables for these steel members.

The applicant provided several responses to this RAI to clarify the Japanese approach for designing steel plate reinforced concrete members. However, in its response to RAI 3.8-121 S02, the applicant revised the design by removing the use of composite floor slabs and, instead, relying on conventional reinforced concrete slabs. Since composite floor slabs are not used, the staff concluded that the issues raised by this RAI are no longer applicable. The staff reviewed the proposed markup for the DCD and confirmed that reinforced concrete slabs are being used rather than composite floor slabs. The applicable text, tables, and figures have been revised to incorporate this change in design. The staff confirmed that the applicant incorporated the proposed markups submitted in the RAI response into DCD Revision 6. Therefore, RAI 3.8-121 was resolved.

3.8.4.3.5 Structural Acceptance Criteria

In DCD, Tier 2, Section 3.8.4.5, the applicant stated that DCD Table 3.8-15 includes the acceptance criteria for the design of the safety-related reinforced concrete structures. This table refers to acceptance criteria based on the strength design method specified in ACI 349. DCD Table 3.8-9 references RG 1.142, which augments the ACI 349 requirements for safety-related concrete structures. The acceptance criteria for the safety-related steel structures appear in

DCD Table 3.8-16, which refers to acceptance criteria specified in Part 1 of ANSI/AISC N690-1994s2 (2004). The staff found the structural acceptance criteria to be acceptable, on the basis that they are consistent with those given in SRP Section 3.8.4.II.5.

3.8.4.3.6 Material, Quality Control, and Special Construction Techniques

Revision 1 of the ESBWR DCD did not provide information on materials, quality control, or special construction techniques for other seismic Category I structures. In RAI 3.8-76, the staff asked the applicant to provide this information and noted that SRP Section 3.8.4 provides guidance as to the type of information that the staff expects to review. The staff requested that the applicant include this information in a new DCD Section 3.8.4.6.

In its response to RAI 3.8-76, the applicant agreed to include the information on materials, quality control, and special construction techniques for other seismic Category I structures in DCD, Tier 2, Section 3.8.4.6, and provided a markup of the proposed change.

The staff noted that the applicant's proposed DCD Section 3.8.4.6 referenced only ACI 349-01 and applicable RGs for splices. SRP Section 3.8.4.I.6 requires, by reference to SRP Section 3.8.3.I.6, that the welding of reinforcing bars (splices) comply with the applicable sections of ASME Code, Section III, Division 2. The staff discussed this issue with the applicant during the December 2006 onsite audit, and the applicant stated that it would include the requirements of SRP Sections 3.8.4.I.6 and 3.8.3.I.6 in DCD Section 3.8.4.6. The topics discussed during the audit were addressed by the applicant in response to supplemental RAI 3.8-76 S01.

In its RAI 3.8-76 S01 response, the applicant stated that it did not intend for welded bar splices to be used in the ESBWR design. If they are used, inspection and documentation requirements conform to ASME Code, Section III, Division 2, consistent with SRP Section 3.8.3.I.6.c. The applicant indicated that it would revise DCD, Tier 2, Section 3.8.4.6.4, in the next update and provided a markup of the proposed change.

The staff noted that the proposed DCD revision addressed only the inspection and documentation of welded bar splices. The staff's position is that welding of reinforcing bars should comply with all the applicable sections of ASME Code, Section III, Division 2, not just those associated with inspection and documentation. This position applies to all seismic Category I concrete structures inside and outside containment. The applicant should revise DCD Sections 3.8.3 and 3.8.4 to address this position. RAI 3.8-76 was being tracked as an open item in the SER with open items.

In its RAI 3.8-76 S02 response, the applicant indicated that the statement, "Welding of reinforcing bars complies with all the applicable requirements of ASME Code Section III, Division 2," is included in DCD, Tier 2, Revision 4, Section 3.8.4.6.3. The staff verified this in the DCD and found it acceptable. The applicant also stated that the welding of reinforcing bars is not applicable to DCD, Tier 2, Section 3.8.3, because none of the structures included in this DCD section are of reinforced concrete construction. The staff found this acceptable, since there is no such construction in the containment internal structures of the ESBWR design. Therefore, RAI 3.8-76 and its associated open item were resolved.

DCD Section 3.8.4.6.1, Revision 4, which discusses the concrete material for other seismic Category I structures, deleted the sentence, "The specified compressive strength is 34.5 MPa (5,000 psi)." As a result, this section now reads, "Concrete material is the same as described in

DCD Subsection 3.8.1.6.1 with the following exception: Concrete is batched and placed according to ACI 349-01." DCD Section 3.8.1.6.1 states that the specified compressive strength of concrete at 28 days, or earlier, is 34.5 MPa (5,000 psi) for the containment and 27.6 MPa (4,000 psi) for the foundation mat. This section does not specify the material strength for any other structures; therefore, in RAI 3.8-122, the staff asked the applicant to specify, in either DCD Section 3.8.1.6.1 or DCD Section 3.8.4.6.1, the concrete material strength for all seismic Category I structures. Also the staff asked the applicant to indicate that all of the information included in DCD Section 3.8.1.6.1 is also applicable to the other seismic Category I structures, with the exception previously noted that "concrete is batched and placed according to ACI 349-01." If not, the applicant should provide the comparable information in DCD Section 3.8.4.6.1.

In a related matter, the staff noted that DCD Section 3.8.5.6 states that the foundations of seismic Category I structures are constructed of reinforced concrete, using proven methods common to heavy industrial construction, and references DCD Section 3.8.1.6 for further discussion. The staff noted that DCD Section 3.8.1.6 provides the materials and quality control requirements for the concrete containment. Therefore, by reference to this section, the applicant appeared to be committing to the use of the materials and quality control requirements specified for the concrete containment for the foundations of all seismic Category I structures. The staff asked the applicant, also in RAI 3.8-122, to confirm that this is the intent. If not, the applicant should revise DCD Section 3.8.5.6 to include the applicable information.

In its response to RAI 3.8-122, the applicant stated that the concrete material strength for all seismic Category I structures is the same as the RCCV (i.e., 27.6 MPa (4,000 psi) for the foundation mat and 34.5 MPa (5,000 psi) for other structures). All of the information included in DCD Section 3.8.1.6.1 is also applicable to the other seismic Category I structures with the exception noted. The materials and quality control requirements of the foundations of all seismic Category I structures conform to Section 3.8.1.6 for the containment foundation and Section 3.8.4.6 for the other seismic Category I structures. The staff found this response acceptable, since the applicant explained the concrete strengths and their applicability to all seismic Category I structures, including their quality control requirements. The staff also verified that the applicant incorporated all acceptable markup changes into the appropriate sections of the DCD. Therefore, RAI 3.8-122 was resolved.

Materials and quality control are addressed by compliance with the industry codes and standards referenced in DCD Table 3.8-9, which include ANSI/AISC N690, AWS D1.1/D1.1M, and ACI 349, as augmented by RG 1.142. To further address quality control, the staff notes that DCD Table 3.8-9 identifies ANSI/ASME NQA-1-1983 and RG 1.94. The staff finds that the use of these industry codes and standards and RGs for materials and quality control is acceptable, on the basis that they are consistent with the criteria in SRP Section 3.8.4.II.6.

3.8.4.3.7 Testing and Inservice Inspection Requirements

The staff noted that DCD Revision 1 did not discuss testing and ISI requirements for other seismic Category I structures. This information is normally included in Section 3.8.4.7 but does not appear in the ESBWR DCD. Therefore, in RAI 3.8-81, the staff requested that the applicant describe any requirements for testing and ISI of other seismic Category I structures. The staff asked the applicant to explain whether RG 1.160 and 10 CFR 50.65 requirements related to structures monitoring and maintenance apply to the other ESBWR seismic Category I structures. If not, the staff asked the applicant to explain why not. The staff requested that the applicant include this information in a new DCD Section 3.8.4.7.

In its response to RAI 3.8-81, the applicant stated that it would refer to RG 1.160 in a new DCD, Tier 2, Section 3.8.4.7, for monitoring the seismic Category I structures of the ESBWR listed in DCD, Tier 2, Table 19.2-4. The applicant indicated that it would add Section 3.8.4.7 in the next update and provided a markup of the proposed DCD change.

The staff noted that, while the new DCD Section 3.8.4.7, "Testing and In-Service Inspection Requirements," refers to monitoring seismic Category I structures, in accordance with Section 1.5 of RG 1.160 for those structures listed in DCD Table 19.2-4, the staff could not locate Table 19.2-4 in the DCD. The staff further noted that the applicant should reference 10 CFR 50.65, along with RG 1.160, and that ESBWR seismic Category II structures are also subject to 10 CFR 50.65 and RG 1.160.

In addition, the proposed DCD Section 3.8.4.7 did not discuss any special postconstruction testing or inservice surveillance programs for other seismic Category I structures. The recent SRP Section 3.8.4.I.7 update specifically identifies this as an issue for staff review. The programs may include periodic examination of inaccessible areas, monitoring of ground water chemistry, monitoring for degradation of reinforced concrete, porous concrete, or mud mat foundations as the result of flowing ground water, and monitoring of settlements and differential displacements.

The staff discussed this issue with the applicant during the December 2006 onsite audit. The applicant stated that it would delete the reference to DCD Table 19.2-4 and referred to its response to RAI 3.8-58, which addresses the same issue for the containment internal structures. The applicant also indicated that it would define condition monitoring and consideration of lessons learned from current operating plants as a COL action item in the DCD. The topics discussed during the audit were addressed by the applicant in its response to supplemental RAI 3.8-81 S01.

In its RAI 3.8-81 S01 response, the applicant stated that it had revised DCD, Tier 2, Section 3.8.4.7, to reference NUREG-1801, 10 CFR 50.65, and RG 1.160. The applicant addressed inaccessible areas in the response to RAI 3.8-59 S01. Concrete specified in the ESBWR is watertight, and a crystalline powder admixture waterproofing is used in the foundation. (See also the response to RAI 3.8 96 S01, Item (6).) Settlements are similarly investigated at the start of the COL approval activities. The applicant addressed allowable differential settlements in the ESBWR in response to RAI 3.8-93 S01. No seismic Category I buried tanks, piping, or components need to be included in special inspection programs in the ESBWR design. Firewater piping is located inside concrete trenches that are easily accessible for maintenance and inspection. The only liner portion of the RCCV not accessible for visual inspection is the portion under the sacrificial concrete located under the RPV. This liner portion is a small fraction of the entire liner surface area and will be subject to preservice examinations described in DCD, Tier 2, Sections 3.8.1.7.3 and 3.8.1.7.3.12. All other portions of the liner are accessible for visual inspection.

The staff found the applicant's response to be acceptable, on the basis that it directly references 10 CFR 50.65 and RG 1.160. The staff confirmed that the applicant incorporated the proposed DCD changes in a formally submitted DCD revision. Therefore, RAI 3.8-81 was resolved.

The staff noted that GDC 53, in part, requires that the reactor containment be designed to permit appropriate periodic inspections of all important areas. RAI 3.8-1 requested that the applicant address this requirement for the concrete and steel elements of the ESBWR containment structure. A stated industry design criterion for advanced reactors is to accommodate ISI of critical areas. The staff considers that monitoring and maintaining the condition of other seismic Category I structures are essential for plant safety. However, DCD Section 3.8.4 does not address any special design provisions (e.g., for sufficient physical access, for alternative means to identify conditions in inaccessible areas that can lead to degradation, and for remote visual monitoring of high-radiation areas) to accommodate ISI of other seismic Category I structures. Therefore, in RAI 3.8-86, the staff asked the applicant to describe, in a new DCD Section 3.8.4.7, any special design provisions for other seismic Category I structures. If the ESBWR design does not incorporate such provisions, the staff asked the applicant to provide the technical basis for concluding that they are not necessary.

In its response to RAI 3.8-86, the applicant stated that, in support of the monitoring of the seismic Category I structures listed in DCD, Tier 2, Table 19.2-4, as described in the new DCD, Tier 2, Section 3.8.4.7 (added in response to RAI 3.8-81), the detailed design process will consider access. The ESBWR design uses a three-dimensional model for interference checking and space control. The model includes all safety- and non-safety-related SSCs. Items are added to the model as it is being developed by stages, depending on the item's criticality to the plant and its construction sequence. Accessibility to equipment, valves, instrumentation, welds, supports, and other items for operation, inspection, or removal is characterized by sufficient space to allow unobstructed access and reach of site personnel. Therefore, aisles, platforms, ladders, handrails, and other components are reviewed as they are laid out. Interferences with access ways, doorways, walkways, truckways, lifting wells, and similar structures are constantly monitored.

The applicant further stated that accessibility is constantly monitored, maintained, and documented during the plant layout process. Remote tooling would be included only if, for layout reasons, the required inspection could not be carried out otherwise.

The staff discussed this issue with the applicant during the December 2006 onsite audit; it found the applicant's response to be generally acceptable, except for the erroneous reference to DCD Table 19.2-4 (added in response to RAI 3.8-81). The staff also noted that RAI 3.8-59 addresses the same issue for the containment internal structures. The applicant stated that it would submit a response to supplemental RAI 3.8-86 S01. The staff noted that, when received, the response to RAI 3.8-86 S01 should be consistent with the responses to RAIs 3.8-58, 3.8-59, and 3.8-81.

In its RAI 3.8-86 S01 response, the applicant referenced its responses to RAI 3.8-59 S01 and RAI 3.8-81 S01. The staff found this acceptable; changes have been made to the DCD as a result of the responses to supplemental RAIs 3.8-59 S01 and 3.8-81 S01. The discussion of space control, as described in the response to RAI 3.8-86, is the same as in the response to RAI 3.8-59. The applicant added this discussion, which covers all safety-related and non-safety-related SSCs, to DCD Section 3.8.3.7. Therefore, the applicant is not required to repeat this discussion in DCD Section 3.8.4.7.

The staff found that the proposed DCD changes adequately address the RAI and are acceptable, on the basis that the approach relies on design provisions and space control to accommodate ISIs of all safety-related and non-safety-related SSCs. Therefore, RAI 3.8-86 was resolved.

3.8.4.4 *Conclusion*

The staff concludes that the applicant has demonstrated that the analysis, design, construction, testing, and inservice surveillance of other seismic Category I structures conform to established criteria in codes, standards, guides, and specifications acceptable to the staff. It found the use of these criteria to be consistent with the guidance provided in SRP Section 3.8.4 and applicable regulatory guides. Meeting these criteria ensures that the DCD meets the relevant requirements of 10 CFR 50.55a; GDC 1, 2, 4, and 5 of Appendix A to 10 CFR Part 50; and Appendix B to 10 CFR Part 50.

3.8.5 Foundations

The ESBWR RB, including the containment structure, and the FB are built on a common foundation mat and are separated from the foundations of the CB and FWSC.

3.8.5.1 *Regulatory Criteria*

The staff reviewed DCD, Tier 2, Section 3.8.5, “Foundations,” and Appendix 3G. The applicant’s design and analysis procedures, loads and load combination methods, structural acceptance criteria, material, quality control and special construction techniques, and testing and ISIs are acceptable if they meet the criteria, applicable codes and standards, and regulatory guidance delineated in SRP Section 3.8.5. This will ensure that the design meets the relevant requirements of 10 CFR 50.55a and GDC 1, 2, 4, and 5 of Appendix A to 10 CFR Part 50, as well as Appendix B to 10 CFR Part 50. The relevant regulatory requirements are discussed below:

- 10 CFR Part 50.55a and GDC 1 require that the foundations be designed, fabricated, erected, and tested to quality standards, commensurate with the importance of the safety functions to be performed.

- GDC 2 requires that the foundations withstand the most severe natural phenomena, such as winds, tornadoes, floods, and earthquakes, and the appropriate combination of all loads.

- GDC 4 requires that the foundations withstand the dynamic effects of equipment failures, including missiles and blowdown loads associated with the LOCA.

- GDC 5 requires that there be no sharing of structures important to safety, unless it can be shown that such sharing will not significantly impair their ability to perform their safety functions.

- Appendix B to 10 CFR Part 50 requires that the safety-related structures be designed with QA criteria applicable to nuclear power plants.

The staff evaluated the design, materials, fabrication, erection, inspection, testing, and inservice surveillance of foundations, based on the relevant portions of industry codes and standards, materials specifications, and RGs listed in Sections 3.8.1.1, 3.8.3.1, and 3.8.4.1 of this report.

For design certification, paragraph IV(a)(2)(i)(A) of Appendix S to 10 CFR Part 50 provides an option for specifying the OBE. If it is chosen to be less than or equal to one-third of the SSE ground motion, it is not necessary to conduct explicit response or design analyses to satisfy paragraph IV(a)(2)(i)(B)(I) of Appendix S to 10 CFR Part 50.

3.8.5.2 *Summary of Technical Information*

3.8.5.2.1 Description of Foundations

In DCD, Tier 2, Section 3.8.5.1, the applicant states that the RB and FB are supported on a common 70.0 m x 49.0 m rectangular reinforced concrete mat foundation, which is constructed of cast-in-place conventionally reinforced concrete. This common foundation supports the containment structure, reactor pedestal, other internal structures, and the balance of the RB and FB structures. Although the containment structure foundation is integral, the applicant refers to it as a separate entity in subsequent sections of the DCD. The portion of the foundation within the perimeter of the containment structure is thicker (5.1 m) than the nominal foundation thickness (4.0 m). The foundation thickness under the SFP in the FB is also thicker (5.5 m) than the nominal foundation thickness.

The CB is supported on a separate 30.3 m x 23.8 m rectangular reinforced concrete foundation that is 3.0 m thick. The FWSC is supported on a separate 52 m x 20 m rectangular reinforced concrete foundation that is 2.5 m thick.

3.8.5.2.2 Applicable Codes, Standards, and Specifications

In DCD, Tier 2, Section 3.8.5.2, the applicant stated that DCD Section 3.8.1.2 discusses the applicable codes, standards, specifications, and regulations for the containment foundation, and Section 3.8.4.2 discusses the other seismic Category I foundations.

3.8.5.2.3 Loads and Load Combinations

In DCD, Tier 2, Section 3.8.5.3, the applicant stated that DCD Section 3.8.1.3 gives the loads and load combinations for the containment foundation. DCD Section 3.8.4.3 gives the loads and load combinations for the other seismic Category I structure foundations. Table 3.8-14 lists the loads and load combinations for all seismic Category I foundations for the evaluation of sliding and overturning resulting from earthquakes, winds, and tornadoes, as well as flotation resulting from floods.

3.8.5.2.4 Design and Analysis Procedures

In DCD, Tier 2, Section 3.8.5.4, the applicant stated that it analyzed the foundations of seismic Category I structures using the methods where the transfer of loads from the foundation mat to the supporting foundation media is determined by elastic methods that use the linear elastic FE computer program NASTRAN, as described in DCD Sections 3.8.1.4.1.1, 3.8.4.4.1, and 3.8.4.4.3. Bearing walls and columns carry all the vertical loads from the structure to the foundation mat. Lateral loads are transferred to shear walls by the roof and floor diaphragms. The shear walls then transmit the loads to the foundation mat.

The design of the mat foundations for the structures of the plant primarily involves determining shear and moments in the reinforced concrete and determining the interaction of the substructure with the underlying foundation medium. For a mat foundation supported on soil or rock, the main objectives of the design are (1) to maintain the bearing pressures within allowable limits, particularly because of overturning forces, and (2) to ensure that there is adequate frictional and passive resistance to prevent the structure from sliding when subjected to lateral loads.

To evaluate the effect of the potential uplift of the basemat under seismic loads, the soil springs in tension are removed through an iterative process. This iterative process is continued until there are no more springs in tension. The analysis results confirm the adequacy of the basemat design. DCD Section 3G.1.5.5.1 provides details.

The selected waterproofing material for the bottom of the basemat is a chemical crystalline powder that is added to the mud mat mixture, forming a waterproof barrier when cured. The DCD uses no membrane waterproofing under the foundations in the ESBWR.

The applicant developed the standard ESBWR design using a range of soil conditions, as detailed in Appendix 3A to the DCD. DCD Table 2.0-1 furnishes the minimum requirements for the physical properties of the site-specific subgrade materials. DCD Table 2.0-2, Section 2.5.4, addresses COL actions. Settlement of the foundations and differential settlement between foundations for the site-specific foundations media are calculated, and safety-related systems (e.g., piping, conduit) are designed for the calculated settlement of the foundations. The applicant evaluated the effect of the site-specific subgrade stiffness and calculated settlement on the design of the seismic Category I structures and foundations.

3.8.5.2.5 Structural Acceptance Criteria

In DCD, Tier 2, Section 3.8.5.5, the applicant stated that the main structural criteria for the containment portion of the foundation are to provide adequate strength to resist loads and sufficient stiffness to protect the containment liner from excessive strain, and it referred to DCD Section 3.8.1.5. DCD Section 3.8.4.5 describes the structural acceptance criteria for the RB, CB, FB, and FWSC foundations.

DCD Table 3.8-14 lists the required factors of safety applicable to the ESBWR structures for overturning, sliding, and flotation. Appendix 3G to the DCD shows the calculated factors of safety. The factor of safety against overturning because of earthquake loading is determined by the energy approach described in DCD Section 3.7.2.14.

The factor of safety against sliding is defined as the following:

FS = (Fub +Fus + Fr + Fus’ + Fr’)/(Fv + Fo),

where Fub is the friction resistance provided by the basemat bottom, Fus is the skin friction resistance provided by the basemat side parallel to the direction of motion, Fr is the lateral resistance pressure along the wall and basemat perpendicular to the direction of motion, Fus’ is the skin friction resistance force provided by shear key sides parallel to the direction of motion (when shear keys are used), Fr’ is lateral resistance pressure along the shear key perpendicular to the direction of motion (when shear keys are used), Fv is the applied base shear at the basemat bottom, and Fo is the lateral soil force caused by the surcharge load of the adjacent structure, where applicable.

3.8.5.2.6 Material, Quality Control, and Special Construction Techniques

In DCD, Tier 2, Section 3.8.5.6, the applicant stated that the foundations of seismic Category I structures are constructed of reinforced concrete, using proven methods common to heavy industrial construction. DCD Sections 3.8.1.6 and 3.8.4.6 provide additional discussion.

3.8.5.2.7 Testing and Inservice Inspection Requirements

In DCD, Tier 2, Section 3.8.5.7, the applicant stated that the foundations of seismic Category I structures are monitored in accordance with NUREG-1801 and 10 CFR 50.65, as clarified in RG 1.160, in accordance with Section 1.5 of RG 1.160.

3.8.5.3 *Staff Evaluation*

The staff discusses its evaluation of the information in the DCD in Sections 3.8.5.3.1 through 3.8.5.3.7. The staff also performed a confirmatory analysis of the RB/FB foundation mat, and Section 3.8.5.3.8 presents the results of this analysis.

3.8.5.3.1 Description of Foundations

DCD, Tier 2, Section 3.8.5, and Appendix 3G describe the foundations of seismic Category I structures. The staff found the descriptive information, including figures and details of the foundations, to be generally acceptable and in accordance with the guidance given in SRP Section 3.8.5. However, the staff lacked some information or required clarification of certain details of the structures, including the foundations. Sections 3.8.1.3 and 3.8.4.3 of this report discuss these issues and evaluate them in detail, as appropriate.

3.8.5.3.2 Applicable Codes, Standards, and Specifications

DCD Section 3.8.5.2 states that DCD Section 3.8.1.2 discusses the applicable codes, standards, specifications, and regulations for the containment foundation, and Section 3.8.4.2 presents this information for the other seismic Category I foundations. The staff found that, in general, the codes, standards, and specifications are in accordance with industry practice and SRP Section 3.8.5.II.2 criteria for foundations, which refer to acceptable documents in SRP Section 3.8.1.II.2, for containment foundations, and SRP Section 3.8.4.II.2, for foundations for other seismic Category I structures. However, the staff needed additional clarification regarding the use of several items, as discussed and evaluated below and in Sections 3.8.1.3 and 3.8.4.3 of this report.

The staff noted that DCD Section 3.8.5.2 implies that the applicant used two separate sets of codes, standards, and specifications for the common RCCV/RB/FB foundation. In RAI 3.8-101, the staff requested that the applicant explain whether it actually designed the common foundation supporting the RCCV, RB, and FB using two different sets of codes, standards, and specifications, as indicated, or whether it employed a uniform design basis. If it used two different design bases, the staff asked the applicant to explain how this was implemented and to justify the jurisdictional boundary.

In its response to RAI 3.8-101, the applicant stated that it designed portions included in the RCCV in accordance with the ASME Code and designed other portions outside containment in accordance with ACI 349. For conservatism, it considered the loads and load combinations that cover both codes for the whole basemat. The applicant also referred to the response to RAI 3.8-4.

The staff determined that the response does not adequately address RAI 3.8-101 and the related RAIs 3.8-102 and 3.8-103, which are discussed below. There is no discussion of the evaluation of jurisdictional boundaries. Also, the staff questioned (a) how the loads and load combinations that cover both codes were considered for the whole basemat, (b) whether the code-specific acceptance criteria were applied to the whole basemat for the code-specific load combinations, and (c) whether there was redundancy in the evaluation to effectively qualify the whole basemat in accordance with both codes.

During the December 2006 audit, the staff and the applicant agreed to address these issues under RAI 3.8-4. In its response, dated February 1, 2007, the applicant referred to the response to RAI 3.8-4 S01 for further clarification of jurisdictional boundaries. Since RAI 3.8-4 is now resolved, the applicant should revise DCD Section 3.8.5.2 to reflect the resolution. RAI 3.8-101 was being tracked as an open item in the SER with open items.

In the supplemental response, the applicant added to DCD, Tier 2, Section 3.8.5.2, a reference to DCD, Tier 2, Section 3.8.1.1.3, for the jurisdictional boundary for applying ASME Code, Section III, Division 2, to the concrete containment foundation. The staff verified that the applicant incorporated the proposed markup changes in the response into the appropriate section of the DCD. Therefore, RAI 3.8-101 and its associated open item were resolved.

3.8.5.3.3 Loads and Load Combinations

DCD Section 3.8.5.3 states that DCD Section 3.8.1.3 gives the loads and load combinations for the containment foundation, and DCD Section 3.8.4.3 gives the loads and load combinations for the other seismic Category I structure foundations. DCD Table 3.8-14 lists the loads and load combinations for all seismic Category I foundations used to evaluate the sliding and overturning resulting from earthquakes, winds, and tornadoes, as well as flotation as the result of floods.

The staff found that, in general, the loads and load combinations are in accordance with industry practice and SRP Section 3.8.5.II.3 criteria for foundations, which also refers to acceptable loads and load combinations in SRP Section 3.8.1.II.3, for containment foundations, and SRP Section 3.8.4.II.3, for foundations of other seismic Category I structures. However, for several items, the staff needed additional information, as discussed and evaluated below and in Sections 3.8.1.3 and 3.8.4.3 of this report.

The staff noted that DCD Section 3.8.5.3 implies that the applicant used two different sets of loads and load combinations for the design of the common RCCV/RB/FB foundation. For the common foundation supporting the RCCV, RB, and FB, the staff requested, in RAI 3.8-102, that the applicant explain how two different sets of loads and load combinations were implemented and justify the jurisdictional boundary.

In its response to RAI 3.8-102, the applicant referred to the response to RAI 3.8-101 discussed in Section 3.8.5.3.2 of this report.

In its RAI 3.8-102 S01, S02, and S03l responses, the applicant referred to the response to RAI 3.8-4 S01 for further clarification of jurisdictional boundaries. Since RAI 3.8-4 is now resolved, the applicant should revise DCD Section 3.8.5.3 to reflect the resolution. RAI 3.8-102 was being tracked as an open item in the SER with open items.

In the supplemental responses, the applicant stated that it added to DCD, Tier 2, Section 3.8.5.3, that the loads and load combinations for the foundations of the RCCV, RB, CB, FB, and FWSC are the same as those for the superstructures, with additional foundation stability requirements, consistent with SRP Section 3.8.5, Section II.3. The staff verified that the applicant incorporated the proposed markup changes in the response into the appropriate section of the DCD. Therefore, RAI 3.8-102 and its associated open item were resolved.

3.8.5.3.4 Design and Analysis Procedures

DCD Section 3.8.5.4 and Appendix 3G describe the design and analysis procedures used for the foundations of seismic Category I structures. The concrete foundation of the RB, FB, and containment is included in the common FEM, which is described in Appendix 3G to the DCD, Section 3G.1.4.1. The soil foundation is represented by soil springs using spring constants acting in the vertical and two horizontal directions. The soil springs, which have perfectly elastic stiffness, provide restraint at the nodes of the base slab FEs. Similarly, the foundations of the CB and FWSC are included in separate FEMs of the CB and FWSC, which are described in DCD Sections 3G.2.4.1 and 3G.4.4.1, respectively. The soil foundation of the CB and FWSC are also represented by soil springs using spring constants acting in the three global directions. All of the loads are applied statically to the FEMs and analyzed using the linear elastic method with the NASTRAN computer code. Bearing walls and columns carry the vertical loads from the structure to the foundation mat. The lateral structural loads are transferred to the shear walls by the roof and floor diaphragms. Then, the shear walls transmit the lateral loads to the foundation. Lateral soil pressures, consisting of surcharge loads, soil pressure, and hydrostatic pressure, are also applied to the external walls below grade. The staff has determined that the design and analysis procedures are acceptable, on the basis that they are consistent with those given in SRP Section 3.8.5.II.4. However, the staff had questions in some areas and needed further clarifications. These are discussed below.

Section 3.8.5.4 indicates that the design of the RB/FB foundation mat involves determining shear and bending moments of the substructure, including interaction of the basemat with the underlying foundation materials. However, DCD Section 3.7 indicates that the applicant performed dynamic analyses using simplified frequency-independent impedance functions, which implies that it performed the dynamic analyses using rigid base assumptions. In RAI 3.8-87, the staff requested that the applicant describe the procedures it used to determine the bending moments induced in the basemat under applied seismic loads in DCD Section 3.8.5 or Appendix 3G.

In its response to RAI 3.8-87, the applicant stated that it calculated bending moments induced in the foundation mat by using the three-dimensional NASTRAN static analyses for all design loads, including seismic loads. In the NASTRAN model, the foundation mat is modeled using thick shell elements, as described in the response to RAI 3.8-100, and soil springs corresponding to soft soil are attached to the foundation mat to represent the stiffness of underlying foundation soil, as described in DCD Section 3G.1.4.2. Under seismic loads, the foundation mat resists out-of-plane forces applied from superstructures and foundation soil. The applicant evaluated bending moments in the foundation mat for the resultant out-of-plane forces.

During the staff's onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, CA, the staff discussed the requested information in further detail with the applicant. The staff reviewed selected portions of GEH Report 26A6651, containing the structural design details of the RB. Other RAI responses discuss how seismic loads are applied in the NASTRAN model and the assumptions used to define the soil springs. RAIs 3.8-90, 3.8-91, and 3.8-100 in this section of the report discuss the results of the staff's review of the basemat design.

In RAI 3.8-87 S01, the staff requested that the applicant provide the total loads on the foundation from the static NASTRAN analysis of seismic loading and compare them to the total loads on the rigid foundation obtained from the dynamic seismic analysis.

In its RAI 3.8-87 S01 response, the applicant provided a comparison of the total loads applied in the NASTRAN analysis and the design seismic loads. The staff noted that, in this comparison, the applicant stated that "additional shear force is applied to the basemat to reproduce the maximum soil spring reaction obtained by the dynamic analysis." During the staff's December 2006 audit, the staff asked the applicant to discuss the basis for this statement and to explain how it determined and applied the seismic stick model loads to the NASTRAN model. The topics discussed during the audit were addressed by the applicant in response to supplemental RAI 3.8-87 S02.

In its RAI 3.8-87 S02 response, the applicant stated that it took the design shear forces applied to the NASTRAN model directly from SSI analysis results using the stick model. It obtained the additional shear forces shown in the RAI 3.8-87 S01 response by multiplying the mat mass times its acceleration to match the total shear at the bottom of the basemat calculated from the SSI analysis.

The applicant adjusts the input moments in NASTRAN to match the moments from the stick model results. It determines the overturning moment applied to each story in such a way that the sum of the applied moment and the one attributable to shear forces applied to the stories above is equal to or larger than the overturning moment obtained by SSI analysis. The applicant adjusts the moment considering the difference between the height where the design seismic loads are defined and the height where the nodal forces are applied in the NASTRAN model. Therefore, it maintains a compatible set of shears and moments for both models.

The staff found the applicant's response to be acceptable, on the basis that the procedures used to determine the bending moments induced in the basemat under applied seismic loads are consistent with industry methods and procedures described in SRP Section 3.8.5. The staff also reviewed the applicant's proposed DCD changes, as described in the original response to RAI 3.8-87, and confirmed that DCD Revision 3 includes them. Therefore, RAI 3.8-87 was resolved.

DCD Section 3.8.5.4 indicates that a main objective of the design of the foundation is to ensure that there is adequate frictional and passive resistance to prevent the structure from sliding when subjected to lateral loads. However, the DCD did not indicate how the analysis would be performed and how lift-off effects, if appropriate, were to be captured in this analysis. An earlier version of the DCD indicated that the capability of the foundation to transfer shear is evaluated when waterproofing is used beneath the basemat. In RAI 3.8-88, the staff requested that the applicant describe, in the DCD, the procedures employed to assess such effects for a potential range of site conditions, varying from soil sites with shear wave velocities on the order of 305 meters per second (1,000 feet per second) to hard rock sites.

In its responses to RAI 3.8-88, the applicant referred to the response to RAI 3.8-96. The staff and the applicant agreed to address this issue under RAI 3.8-96. Therefore, RAI 3.8-88 was resolved.

An earlier version of DCD Section 3.8.5.4 stated that the capability of the foundation to transfer shear with waterproofing is a COL item and referred to DCD Section 3.8.6.1, which states that the COL applicant shall demonstrate the capability of foundations to transfer shear loads where foundation waterproofing is used. In RAI 3.8-89, the staff requested that the applicant provide additional information on this subject and explain the technical issue in detail. With respect to waterproofing, the staff asked the applicant to describe the ESBWR standard plant assumption used in conducting the foundation sliding analyses. The staff asked the following questions:

- Why is the capability to transfer shear with waterproofing a COL item?

- How does a COL applicant confirm that it is in compliance with the standard plant foundation design assumptions for a selected site-specific waterproofing material?

In its response to RAI 3.8-89, the applicant stated that it would delete foundation waterproofing as a COL item. The selected waterproofing material for the bottom of the basemat is a chemical crystalline powder that is added to the mud mat mixture to form a waterproof barrier. The ESBWR uses no membrane waterproofing under the foundations. However, membrane waterproofing is applied to the outer walls. The DCD does not evaluate friction at sidewalls as one of the forces resisting seismic loads; therefore, membrane waterproofing is appropriate for sidewalls. The applicant also indicated that it would revise DCD, Tier 2, Section 3.8.5.4, in the next update and provided the markup as part of its response.

The staff finds the applicant's response to be acceptable, since no membrane waterproofing is used under the foundations in the ESBWR. The staff also reviewed the applicant's proposed DCD changes and confirmed that it included them in a formally submitted revision to the DCD. The staff discusses its review of the mud mat under RAI 3.8-96. Therefore, RAI 3.8-89 was resolved.

DCD Section 3.8.5.4 indicates that the foundations are evaluated for the worst resulting forces from the superstructure but does not indicate how the worst-case scenario is to be determined. In RAI 3.8-90, the staff requested that the applicant describe, in DCD Section 3.8.5.4, the procedures used to evaluate the worst conditions.

In its response to RAI 3.8-90, the applicant stated that the worst-case scenario for the foundation basemat design is soft soil, since it is subject to the largest deformation. From the NASTRAN analysis, the results are scanned for the worst loads in the mat sections. The worst loads are selected for structural evaluation. This enveloping of the most severe loading is applied to all loading conditions considered in the analysis.

During the staff's onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, CA, the staff discussed the requested information in further detail with the applicant. During the audit, the applicant provided comparisons of the basemat deformation and basemat moments for soft soil and hard rock springs for dead load. The basemat deformation and moments for the soft soil springs were larger than those for the hard rock springs across the entire basemat. Therefore, the applicant concluded that it designed the basemat for the worst possible conditions. In response to the staff's request, the applicant provided similar comparisons for the load combination of LOCA + SSE. The comparisons also showed that the moments across the mat for the soft soil springs were always larger than the moments for the hard rock springs. However, the staff observed that, under the load combination of LOCA + SSE, there is a small uplift on the south side of the mat. The applicant explained during the audit that these results also include dead load. The staff concluded that the soil springs in this area are in tension, which indicates foundation uplift. RAI 3.8-13 covers this uplift concern about soil springs in tension.

In RAI 3.8-90 S01, the staff requested that the applicant consider nonuniform soil conditions under the mat and noted that such studies exist for design certification of the nuclear island for another advanced reactor.

In its RAI 3.8-90 S01 and S02 responses, the applicant stated that the response provided to RAI 3.8-13 S01 shows the deformation and stresses of the basemat in both cases for soft and hard soil conditions, to demonstrate the conservatism in the basemat design. The applicant also noted that this request is similar to additional topics under RAI 3.8-13 S01, and that it will provide the discussion about nonuniform soil conditions under the mat in response to RAI 3.8-94.

The issue regarding soft and hard soil conditions was resolved, based on the staff's assessment of the response to RAI 3.8-13, Part (a), as discussed in Section 3.8.1.3.4 of this report. RAIs 3.8-93 and 3.8-94, which are discussed below, address the effect of nonuniform soil conditions on the design of the basemat. Therefore, RAI 3.8-90 was resolved.

DCD Section 3.8.5.4 states that the foundations are analyzed using "well-established methods." In RAI 3.8-91, the staff requested that the applicant identify the references and describe the "well-established methods" used to analyze the foundations and also demonstrate the conformance of these methods to the requirements of SRP Section 3.8.5.

In its response to RAI 3.8-91, the applicant stated that, as described in DCD Section 3.8.1.4.1.1, it used the linear elastic FEM for the analyses of the building structures, including the foundation mat, and the foundation soil is modeled with elastic springs in the FEM. The modeling method is the same as for the ABWR standard design, which the NRC reviewed and approved; hence, it is considered to be a well-established method. SRP Section 3.8.5.II.4.a requires that the seismic Category I foundation design consider the SSI, and the method mentioned above satisfies this SRP requirement.

During the staff's onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, CA, the staff discussed the response in greater detail with the applicant. The staff reviewed the details of the mat reinforcement below the RCCV and asked the applicant to discuss the transition from radial and hoop reinforcement to orthogonal reinforcement, including whether it provided sufficient development length in the transition zone. The applicant explained that circumferential rebars are continuous in the transition region. Radial rebars are terminated at the end of the transition region, ensuring the required development length. N-S and E-W bars are either continuous or are terminated at the end of the transition region, ensuring the required development length. The applicant explained that, in section design calculations, it evaluated both cases of orthogonal rebars and radial-circumferential rebars for the region.

To confirm the size and quantity of designed steel reinforcement, the staff requested the total factored moment and shear forces for three identified critical elements. GEH Report 26A6651, Revision 1, did not include this information. The staff asked the applicant to demonstrate how it combined the individual load cases to arrive at the total loads and how it applied these total loads to critical sections. The applicant provided a table of maximum stress ratios that included the three locations in the basemat.

The above topics discussed during the July 2006 onsite audit were addressed by the applicant in response to supplemental RAI 3.8-91 S01.

In RAI 3.8-91 S01, the staff determined that it needed the applicant to do the following:

(1) Describe the details of the mat reinforcement beneath the RCCV, where the reinforcement changes from a circumferential or radial pattern to an orthogonal pattern, and demonstrate that it provides an adequate development length for the reinforcement.

(2) Provide additional information in the DCD to describe the "well-established" methods.

(3) Submit the total factored moment and shear forces for the three identified critical elements discussed at the audit, demonstrate how the individual load cases are combined to arrive at the total loads, and how the total loads are applied to the critical sections.

(4) Provide more description of how the mat is designed, including how the loads from walls are transferred to the mat.

In its RAI 3.8-91 S01 response, the applicant provided the following information:

(1) In response to item (2) above, the applicant stated that "well-established methods" is an ambiguous statement and that it would be removed from the DCD. The applicant stated that DCD Section 3.8.5.4 would be revised in the next update, and provided a mark-up of the proposed changes.

(2) In response to item (3) above, the applicant provided a table which shows the combined section forces and moments of the basemat elements discussed at the audit. The applicant also provided an example description of the combination method of section forces and moments.

(3) In response to item (4) above, the applicant explained that the loads from the walls are transferred to the mat by means of rigid links and are included in the global NASTRAN model. The stress resultants (forces, moments, etc.) of the mat are extracted from the mat shell elements, and used as input to the concrete cracking analysis performed by the SSDP computer program. The output is a tabulation of stresses in concrete and rebars and a list of allowable stresses.

In its RAI 3.8-91 S02 and S03 responses, the applicant provided additional information in response to Item (1) above. The applicant stated that, in the basemat around the cylindrical wall below the RCCV wall, it installed rebars in two coordinate systems (i.e., orthogonal and cylindrical coordinates). Circumferential rebars are continuous. Other rebars terminate at the end after ensuring the required development length. In section design calculations, it evaluated orthogonal rebars and radial rebars for adequate development length.

The staff determined that the applicant's RAI 3.8-91 S01, S02, and S03 responses address the questions raised by the staff during the audit. However, to demonstrate the adequacy of the design approach, the staff needed additional information for the most critical basemat element and the most critical wall element (i.e., those with the highest stress ratios for concrete and steel reinforcement, with the recognition that a different element and different load combination may govern for the concrete versus the steel). Specifically, the staff needed the individual loads, combined loads, and a hand calculation performed in accordance with the design code of record for both concrete and steel reinforcement (for flexure and membrane forces and for the corresponding shear forces), and the comparable results of the SSDP analysis for the same elements, which will allow a direct comparison to the hand calculation results. RAI 3.8-91 was being tracked as an open item in the SER with open items.

In its RAI 3.8-91 S04 response, the applicant provided the hand calculation procedure and results for two critical elements selected for the walls and basemat. The staff reviewed the information and found them technically acceptable, because the results of these hand calculations matched the SSDP computer results. Therefore, RAI 3.8-91 and its associated open item were resolved.

The staff noted that the applicant carried out elastic analyses of the complete nuclear island structure, including the RCCV, for separate load conditions, using a static NASTRAN FEM. It stored, in a computer file, the internal element loads for all the finite elements in the complete structure for a specific applied load. For each applied load, it produced a specific file. It used these computer files as input files, along with the rules for combining the individual load files to the SSDP, which assumes that linear superposition applies between different load combinations. Also provided as input information to the SSDP are the top, bottom, and shear reinforcement areas associated with each FE. In the postprocessing phase, SSDP checks demand against available reinforcement areas. The staff questioned how the SSDP package treats the tangential shear reinforcement. In addition, during its audit in July 2006, the staff reviewed the SSDP validation package and found that it did not contain several items of interest to the staff. Therefore, in RAI 3.8-107, the staff requested that the applicant answer the following questions:

(a) How does SSDP flag instances where the reinforcement provided is less than the demand?

(b) How does SSDP identify governing load combinations and the corresponding loads on a given FE?

(c) How does SSDP apply the reinforced concrete codes used in the United States, such as ACI 349, ASME Code, Section III, Division 2, and how are the code editions that are accepted by the NRC incorporated in SSDP to keep it current?

(d) How is the reinforcement pattern (radial and circumferential or rectangular grid) interpreted in SSDP?

(e) How does SSDP identify critical sections of a structure?

(f) In the reinforced concrete containment structure, how does SSDP evaluate the tangential shear stress to demonstrate compliance with the ASME Code?

In its response to RAI 3.8-107, the applicant stated the following:

> a. In the post-processing routine of the SSDP-2D, the maximum calculated stresses are compared with the allowable stresses, and stress ratios, i.e., ratio of calculated stress to allowable stress, are calculated. The maximum stress ratios obtained can be plotted on the finite element meshes as shown in Figure 3.8-107(1) in the RAI response. In the figure, stress ratios exceeding 1.0, i.e., the maximum stress is larger than the

allowable, are identified in a different color. This procedure is used to find the elements where reinforcement provided is less than the demand.

b. The ID numbers of the load combinations which generate the maximum stress ratios are also indicated in Figure 3.8-107(1). The governing load combinations are also shown on the figure.

c. SSDP-2D calculates the stresses of concrete and reinforcements for the axial forces and bending moments. Calculated stresses are compared with the allowable stresses specified in the applicable Codes as described in Items a) and b). SSDP-2D has supplemental subroutines for the tangential shear and transverse shear, and it is confirmed that the provided sections satisfy the Code requirements for shears. The validation of SSDP-2D provides confirmation that calculation results meet the requirements of Code editions which are specified for the project.

d. The directions of reinforcements, i.e., angles to a reference axis, are provided as input data. In the SSDP-2D, the reference axis is set to the x-direction of the element coordinate system. The reinforcement is regarded as a material which has stiffness in only one direction which is defined in the input data.

e. Since SSDP-2D only has a function to calculate stresses, it cannot identify critical sections of a structure. However, critical sections can be found by plotting stress ratios in a structure like Figure 3.8-107(1).

f. Same response as Item c).

The applicant also provided a revised SSDP-2D validation report as an enclosure to the response, which supersedes the earlier version of the validation report provided in response to RAI 3.7-55.

The staff determined that it needed a detailed review of the validation report to resolve this RAI. During its review, the staff noted that the 100/40/40 method implemented by the applicant to combine three directions of seismic response is not consistent with RG 1.92, Revision 2. The applicant had previously stated that the method is consistent with the guidance.

During the December 2006 audit, the staff and the applicant discussed this issue. The applicant indicated that, in “most cases,” its approach for implementing the 100/40/40 method is conservative. In RAI 3.8-107 S01, the staff asked the applicant to provide additional information regarding the input data and equations used in the SSDP postprocessor software.

In its RAI 3.8-107 S01 response, the applicant provided a study to show that the DCD process used to combine stresses produces results that are higher than those using the SRSS and RG 1.92 100/40/40 method. The applicant stated that, since the SRSS method is its alternative to the present method, it has satisfied the intent of RG 1.92, which calls for the use of conservative approaches in obtaining final stresses.

The staff’s assessment of the RAI 3.8-107 S01 response and the revised validation report for SSDP-2D is as follows:

(A) The staff reviewed the numerical data provided in the supplemental response and did not reach the same general conclusion as the applicant concerning the conservatism of the DCD results, compared to the SRSS and the RG 1.92 100/40/40 methods for combining responses from three directions of motion. The staff determined that the applicant should address the following issues:

(1) From a review of the data, it appears that the calculation for combined loading uses different values for the DCD method and for the SRSS/RG 1.92 100/40/40 methods. The staff asked the applicant to address this apparent discrepancy.

(2) Since the data presented are based on a limited subset of locations and two load combinations that include SSE, identify any locations and load combinations where the allowable stress limit is exceeded by any of the three spatial combination methods and quantify the degree of exceedance.

(3) Since the data show one point where the SRSS and RG 1.92 100/40/40 methods of spatial combination produce results significantly higher than the DCD method, the staff requires an explanation for this large difference and the technical basis for considering this large difference to be acceptable.

(4) The staff requires an explanation for the fact that, for combined loading cases, the DCD method of combination (ASCE 4-98 implementation of the100/40/40 rule) produces higher results than the RG 1.92 implementation procedure for the 100/40/40 rule at approximately 50 percent of the locations in the comparison tables.

(B) The staff also reviewed the revised validation report for SSDP-2D, provided in the applicant's initial response to RAI 3.8-107. Based on this review, the staff noted the need for the following clarifications:

(1) The use of inconsistent units for Table 7 (in terms of MPa) and Table 8 (in terms of psi) needs to be explained.

(2) Comparing the results in Table 7 to the results in Table 8, Row 1 and Row 5 shows differences, while the remaining rows show consistency. These differences need to be explained.

(3) The applicant should provide, for review, the referenced journal article used for the membrane section force calculation in Section 4.1 of the validation report. For Section 4.2 of the validation report, the applicant should identify the source of the equations used for the axial force and bending moment calculation.

(C) The staff also noted that the calculation of F_{OT}, used in demonstrating the combined loading comparisons, uses a unique "thermal ratio" for each individual internal force and moment resultant calculated by the linear elastic thermal stress analysis using NASTRAN. For element 1824 used in the demonstration calculation, the "thermal ratio" varies substantially (e.g., 1.69 for Nx and 0.14 for Ny).

It is the staff's understanding that the applicant obtained the above ratios based on the results of two ABAQUS/ANACAP analyses. The first was a linear elastic thermal stress analysis, and the second was a nonlinear thermal stress analysis that considered internal force and moment redistribution resulting from concrete cracking and inelastic material behavior. The wide variation in the thermal ratios and the significant reduction in the maximum elastically calculated results indicate that nonlinear behavior and redistribution of internal forces and moments are very significant. The staff questioned whether it is appropriate to combine the nonlinear thermal stress analysis results with the elastically calculated results for other loads.

RAI 3.8-107 was being tracked as an open item in the SER with open items. In its RAI 3.8-107 S02 response, the applicant made corrections to the calculations comparing the SRSS method and the 100/40/40 method. However, this no longer applies, since the applicant revised the SSE directional combination method to use the SRSS method, which is in accordance with RG 1.92. This change addresses the concerns under Item (A) above. For Items (B)(1) and (2) above, the applicant made corrections to the applicable table and provided explanations for the differences in the results noted by the staff. These were found to be acceptable. For Item (B)(3), the information provided in the RAI response did not address the concerns raised. Therefore, in RAI 3.8-107 S03, the staff asked the applicant to verify the equations used in the SSDP computer code by comparing the quantitative results for the sample problems performed in the validation report with the use of the equations presented in a conventional concrete textbook. Regarding Item (C), the applicant performed a study to show that the use of uncracked properties for mechanical loads is acceptable for determining the concrete stresses. However, the staff determined that the study did not adequately demonstrate the approach because, in some instances, the stress ratios comparing the two sets of analyses (cracked and uncracked) were greater than 1.0. Therefore, in RAI 3.8-107 S04, the staff asked the applicant to address this concern.

In its RAI 3.8-107 S03 and S04 responses, the applicant verified the equations used in the SSDP-2D computer code by comparing the quantitative results for the most representative sample problem, for a partially cracked concrete section, with the results from equations presented in a conventional concrete textbook. The results were very close for the two cases, and, therefore, this item has been adequately addressed. In addition, the applicant provided a technical justification to show that, if it used cracked properties for thermal and pressure loading, the rebar and concrete stresses and strains of the containment are below the limits in ASME Code, Section III, Subsection CC. Therefore, RAI 3.8-107 and its associated open item were resolved.

The staff noted that, in prior versions of the DCD, Section 3.8.5.4 indicated that the applicant developed the standard design using a range of soil conditions, as detailed in Appendix 3A to the DCD. Appendix 3A describes the range in shear wave velocities considered in SSI analyses and focuses only on assumed uniform site conditions. Section 3.8.5.4 also states that total and differential settlements of the foundations must be considered but refers to Section 3.8.6.2 for COL information. Section 3.8.5.4 does not indicate whether the applicant incorporated any potential effects of static or dynamic differential settlement into the design of the standard plant, nor does it give the magnitude of settlement that it considered. It also fails to address the effect of settlement on construction procedures.

In RAI 3.8-92, the staff requested that the applicant describe, in DCD Section 3.8.5.4, how it incorporated settlement issues into the generic design of the standard plant and identify limitations on the magnitude of settlements. Specifically, the applicant should (a) explain how it considered the potential for settlement in the ESBWR standard plant design and (b) provide the allowable settlement that can be accommodated by the ESBWR foundations and structures.

In its response to RAI 3.8-92, the applicant stated that it considered three types of soil conditions in the DCD (soft, medium, and hard) as uniform subgrades and referred the staff to its response to RAI 3.8-93 for clarification of settlement issues.

The staff decided to address this issue under RAI 3.8-93, which it discusses below. Therefore, RAI 3.8-92 was resolved.

The staff noted that, in a prior version of the DCD, Section 3.8.5.4 stated that total and differential settlements of the foundations must be considered but referred to Section 3.8.6.2 for COL information. In RAI 3.8-93, the staff requested that the applicant describe, in the DCD, how it incorporated settlement issues into the generic design of the standard plant and identify limitations on the magnitude of settlements, so that the COL applicant can ensure compliance with the standard design. The staff asked the applicant to define the COL applicant actions required to confirm that the predicted site-specific settlement meets the standard plant design assumptions.

In its response to RAI 3.8-93, the applicant stated that it would incorporate the stipulated settlements into the total plant design as a requirement. As part of its response and to clarify the settlement issues, it provided an evaluation entitled “Settlement Effect on Basemat Design.” The COL licensee will have to demonstrate that differential settlements at the site do not exceed this value by instituting a settlement monitoring program or justify, in the COL application, why such a program would not be necessary.

The applicant further stated that it confirmed the settlement effect on basemat design by parametric analysis, considering a variety of soil conditions and construction sequences as shown in the above-referenced evaluation. As a result, the basemat stresses reported in the DCD are not affected by horizontal variations in spring stiffness. Also, basemat stresses during construction are much smaller than DCD design stresses.

In its assessment of the RAI 3.8-93 response, the staff noted that the applicant had deleted DCD Section 3.8.6.2 (identifying COL information) from the DCD. The applicant should identify where in the DCD it will document that “The COL holder will have to demonstrate that differential settlements at the site do not exceed this value by instituting a settlement monitoring program or justify in the COL why it would not be necessary.” Based on the staff’s review of “Settlement Effect on Basemat Design,” the applicant should (1) clarify “this value” in the previous sentence, (2) explain why the evaluation considers only dead load and clarify what loads are included in the dead load, (3) explain why the pedestal area is the only area considered to have a potential “hard spot,” (4) explain the sentence, “Assumed sequence is as follows, but this is imaginary since these portions are constructed in short time periods,” (5) clarify whether the two construction sequences (Case A and Case B) are a COL requirement, and if not, explain why not, and (6) state why hard spots are not considered in the construction phase. The staff’s concerns were summarized in supplemental RAI 3.8-93 S01.

During the December 2006 audit, the applicant discussed the above issues identified in RAI 3.8-93 S01. In its RAI 3.8-93 S01 response, the applicant stated that it had deleted DCD, Tier 2, Section 3.8.6.2, since it performed an analysis of the settlement issue using generic soil parameters, which are subject to confirmation by the COL applicant in DCD, Tier 2, Chapter 2. Therefore, no additional COL requirements need to be stated in DCD, Tier 2, Section 3.8.6. The applicant also provided the following information:

(1) The allowable total and differential settlements within SC [seismic Category] I buildings will be quantified in the next DCD Tier 2 revision. The evaluation, “Assessment of Building Settlement,” included as part of the RAI 3.8-93 S01 response, discusses and sets limits for building settlement. The total settlement is defined as the maximum vertical displacement in the building basemat, and the differential settlement is defined as the maximum relative vertical displacement between two opposite corners along the longest dimension of the building basemat. The allowable differential settlement between the RB/FB and CB is the relative displacement evaluated using the total settlements of two buildings.

(2) Only DL [dead load] is considered because during construction of the mat, it imposes the worst loading condition. It consists of all permanent dead loads considered in the design for the “Normal Operation Phase” and the weights of the structures in accordance with the sequence considered in the “Construction Phase.” Construction live loads on the order of 100 psf (4.8 kN/m^2) are ignored since the magnitude is only a small fraction (about 5%) of the basemat weight.

(3) Analyses for the inverted soil spring variation, i.e., stiffer springs around the peripheral area of the RPV Pedestal, were performed. The results are described in the evaluation, “Basemat Design Considering Horizontal Variation of Soil Springs,” included as part of the RAI 3.8-93 S01 response. Based on the results, the DCD Tier 2 design envelopes the result of horizontal variation of soil spring under the condition that the ratio of the largest to the smallest shear wave velocity over the mat foundation width at foundation level does not exceed 1.7. This will be a COL item in DCD, Tier 2, Chapter 2.

(4) Settlement is time dependent. Stiffening walls will be constructed within a few days after the mat pour. For conservatism in the analysis, it is assumed that the stiffening walls will be built a long time after the mat is poured.

(5) The construction sequence is not considered as a COL item since it is shown that under the worst loading condition, the mat can adequately handle the resulting stresses. Basemat construction sequence has no effect on the basemat design. The applicant provided an evaluation entitled, “Effect of Basemat Construction Sequence,” as part of the RAI 3.8-93 S01 response, to clarify the effect of the basemat concrete pour sequence to the basemat stress.

(6) The original response to RAI 3.8-93 shows that the Construction Phase is not as severe as the Normal Operation Phase for the uniform soil condition. Additional evaluation is performed to address the effect of the horizontal variation of soil springs on the basemat design during the Construction Phase. As part of the RAI 3.8-93 S01 response, the applicant provided an evaluation entitled, “Basemat Design for Construction Phase Considering Horizontal Variation of Soil Springs,” to

show the results of the hard spot condition and confirm that the basemat stress during construction is smaller than the design stress.

(7) The evaluation, “Basemat Design Considering Horizontal Variation of Soil Springs,” mentioned in Item 3 above, also includes the resulting wall bending moments due to the horizontal variation the soil springs. It is found that the “Soft Spot” condition controls the basemat design forces. Per Item 3 above, the COL applicant is to confirm the uniformity of the shear wave velocity at the foundation level for a given site.

(8) The bending moment distributions were compared for three cases of horizontal soil stiffness variation under the basemat in the original response to RAI 3.8-93. In the original response, the Softx3 case exceeded the base case. The evaluation mentioned in Item 3 above, “Basemat Design Considering Horizontal Variation of Soil Springs,” clarifies the result of horizontal variation of soil springs. It is found that the “Hard Spot” condition results in a different pattern of relative displacements when compared against the DCD Tier 2 analysis results. As a result, a limitation for the maximum variation of horizontal soil stiffness in terms of shear wave velocity is imposed as a COL item stated in Item 3 above.

The applicant stated that it has revised DCD, Tier 2, Table 2.0-1, and Section 3G.1.5.5, and added Sections 3G.1.5.5.2, 3G.1.5.5.3, 3G.1.5.5.4, and 3G.2.5.5.1.

In RAI 3.8-93 S02, the staff identified the need for the following additional information, based on its review of the RAI 3.8-93 S01 response:

(1) The staff noted that the settlement values in DCD, Tier 2, Table 2.0-1, are the same as those specified in DCD, Tier 1, Table 5.1-1. The DCD should clearly state that the COL applicant must estimate the settlement by an analysis using actual site conditions and show that they are acceptable, when compared to the values specified in DCD, Tier 1, Table 5.1-1.

(2) DCD, Tier 1, Table 5.1-1, and DCD, Tier 2, Table 2.0-1, now require that the ratio of the largest to the smallest shear wave velocity over the mat foundation width at the foundation level should not exceed 1.7. The applicant should explain that this requirement is imposed to ensure that the bending moments on the basemat do not exceed the design allowable for horizontal soil spring variations, which may vary by a factor of 3 from the basemat center to the basemat edge, and describe how it considered such a variation in shear wave velocity over the mat foundation in the seismic analysis of the RB/FB and CB buildings.

(3) In response to this RAI, the applicant has studied several construction sequences and concluded that they have no effect on the basemat design. However, it is difficult to conclude that the worst loading condition has been considered. The criteria in DCD, Tier 1, Table 5.1-1, and DCD, Tier 2, Table 2.0-1, should require the COL applicant to review the construction sequences considered by the applicant in the design of the RB/FB and CB buildings. If the COL applicant proposes to use a construction sequence that is substantially different from that studied by the applicant, the COL applicant should be required to demonstrate that their proposed sequence does not cause a problem.

(4) Figure 3.8-93 (12)-d compares basemat moments resulting from differential settlement that are higher than the moments used for the DCD design condition. The applicant should address why these higher moments are acceptable.

(5) The applicant should clarify what is meant by the phrase “slightly less than 3x soft or hard conditions is used,” compare the moments shown in two figures provided in the RAI response with the basemat moment design capacities in both directions across the entire basemat, and provide the technical justification for predicted moments that are higher than the design allowable.

As discussed above, the staff needed additional information to complete its assessment of RAI 3.8-93. RAI 3.8-93 was being tracked as an open item in the SER with open items.

In its RAI 3.8-93 S02 response, the applicant provided information to address five items related to the foundation and soil settlement, seismic soil shear wave velocity requirement, construction sequences, and soil stiffness studies. To address Item (5) in the RAI 3.8-93 S01 response, the staff asked the applicant, in RAI 3.8-93 S03, to clarify whether the COL applicant or someone else will determine if the construction sequence is substantially different from the sequences considered in the design and, if substantially different, who will ensure that they will not adversely affect the basemat design. The applicant should also include the commitment regarding the construction sequence, with this additional clarification, in DCD, Tier 2, Section 2.

In its RAI 3.8-93 S03 response, the applicant stated that the construction sequence studies performed and discussed in previous supplemental responses to this RAI and documented in DCD, Tier 2, Section 3G.1.5.5.3, have taken into account all possible variations in common construction practice and demonstrate that the construction sequence has negligible impact on basemat stresses. The applicant further stated that it will revise the last paragraph of DCD, Tier 2, Section 3G.1.5.5.3, to read: “The actual construction sequence will be consistent with the sequences evaluated above and will be reflected in the construction specification.” The staff concludes that this proposed change to the DCD is acceptable and confirmed that the applicant incorporated into DCD Revision 6. Therefore, RAI 3.8-93 and its associated open item were resolved.

The staff noted that, in prior versions of the DCD, Section 3.8.5.4 indicated that the design incorporates an evaluation of the worst loads resulting from the superstructures and loads directly applied to the foundation mat as the result of static and dynamic load combinations. However, the DCD does not identify the maximum allowable toe pressure that is acceptable for the basemat design under the worst-case static and dynamic loads. This information is needed to make evaluations at the COL stage for site-specific conditions. In RAI 3.8-94, the staff requested that the applicant include, in DCD Table 3.8-13, the maximum toe pressure used in the basemat design.

In its response to RAI 3.8-94, the applicant stated the following:

(1) Maximum soil bearing stresses involving SSE are summarized in DCD, Tier 2, Table 3G.1-58 for soft, medium and hard site conditions. Maximum soil bearing stress due to dead plus live loads is 699 kPa as shown in DCD, Tier 2, Appendix 3G.1.5.5. The site specific allowable bearing capacities need to be larger than the maximum stress depending on its site condition.

(2) The values indicated in DCD, Tier 2, Table 3G.1-58 are evaluated by using the Energy Balance Method, which is described in the Reference cited in response to RAI 3.7-48 S01. In the evaluations, the basemat is assumed to be rigid, and uplift of the basemat is considered.

(3) The soil pressures obtained from the RB/FB global FEM analyses used for the basemat section design are summarized in Table 3.8-94(1). This table also includes the results of the basemat uplift analyses, which were performed to respond to RAI 3.8-13. Seismic loads used for the finite element (FE) analyses are worst-case loads, i.e., the enveloped values for all site conditions included in DCD, Tier 2, Table 3G.1-58. In the FE analyses, the basemat is assumed to be flexible.

(4) As shown in Table 3.8-94(1) of the RAI response, the bearing pressures obtained by the FE analyses are less than the worst case maximum bearing pressure in DCD, Tier 2, Table 3G.1-58, which is 5.33 MPa for the hard site. Therefore, it can be concluded that the maximum bearing pressures in DCD, Tier 2, Table 3G.1-58, are evaluated conservatively.

In its assessment of this response, the staff noted that the applicant's response refers to Table 3G.1-58, which provides the maximum soil-bearing stress involving an SSE, and determined that the applicant should explain that the values in Table 3G.1-58 represent the maximum soil-bearing stress for all load combinations. The applicant should indicate whether the comparisons to the bearing pressures in Table 3.8-94(1) are for the same load combinations.

During the December 2006 audit, the applicant discussed the issues identified above. In supplemental RAI 3.8-94 S01, the staff indicated that the applicant should clarify the RAI response and provide the comparison of the maximum bearing pressures reported in Tables 3.8-94(1) and 3.G.1-58. The applicant should also explain why the toe pressures reported in Table 3G.1-58 are conservative when considering the variation of horizontal soil springs, as discussed in RAI 3.8-93.

In its RAI 3.8-94 S01 response, the applicant stated the following:

(1) The values in DCD, Tier 2, Table 3G.1-58 represent the maximum soil bearing stress for all combinations calculated using the Energy Balance Method for the RB/FB. They are the maximum bearing stresses for the three generic soil conditions. The toe pressures presented in Table 3.8-94(1) are calculated using the global FEM for design seismic forces which envelope the responses of three soil conditions. The methods of analysis are different in the two calculations. Table 3.8-94(2) compares the maximum soil bearing pressures calculated by the Energy Balance Method and the linear FEM analysis. The results show that the Energy Balance Method is a more conservative method to use for the determination of soil bearing pressures.

(2) The variations of horizontal soil spring ("Hard Spot" and "Soft Spot" as shown in the response to NRC RAI 3.8-93 S01) are also considered in this study. The DCD envelope is based on uniform soil conditions.

Despite the fundamental difference in the treatment of the soil stiffness distribution, the maximum soil bearing pressures of the non-uniform soil condition are similar to those of the uniform soil condition.

Based on the review of the RAI 3.8-94 S01 response, the staff identified its need for the following additional information in RAI 3.8-94 S02:

(1) The bearing stresses reported in DCD, Tier 2, Table 3G.1-58, for soft, medium, and hard site conditions are 2.7 MPa (56.4 kips per square feet (ksf)), 7.3 MPa (152.6 ksf) and 5.4 MPa (112.9 ksf). These values are extremely large, compared to known soil and rock capacities. The applicant should explain how the COL applicant will satisfy this criterion and also why the bearing stress reported for the medium site condition (7.3 MPa) is higher than the hard site condition (5.4 MPa).

(2) How does the COL applicant use the maximum bearing pressures reported in DCD, Tier 2, Table 3G.1-58 and Table 3G.2-27, when conditions for a specific site fall between the tabulated values for soft, medium, and hard site conditions?

(3) The minimum dynamic bearing capacities should be clearly specified in Table 5.1-1 as Tier 1 information, consistent with the criteria in DCD, Tier 2, Table 2.0-1.

(4) For the nonuniform soil conditions considered in the RAI response, the applicant should include comparisons of the bending moments across the basemat, in both directions, that demonstrate that the DCD design moments bound the moments for the nonuniform soil condition.

RAI 3.8-94 was being tracked as an open item in the SER with open items. In subsequent responses to RAIs 3.8-94 S03, S04, and S05, the applicant revised the analysis approach for calculating the maximum soil-bearing pressure. The RAI responses provided the derived formulation for calculating the maximum soil-bearing pressure, based on a rectangular footing that considers uplift. The approach uses a “Modified Energy Balance” (MEB) method that considers basemat uplift effects. The applicant calculated the rotation, moment, and soil pressures in accordance with the MEB method, using the SASSI (computer code) SSI analysis forces as input. As a check,the applicant demonstrated that the MEB calculated soil pressures are higher than the maximum SASSI soil pressure results. The applicant adequately addressed the remaining questions in the RAI by revising its analytical approach. Based on the staff’s review of the revised analytical approach and comparison to the SASSI soil pressure results, the applicant has addressed the issues raised under this RAI. Therefore, RAI 3.8-94 and its associated open item were resolved.

The staff noted that, in previous versions of the DCD, Section 3.8.5.4 indicated that site-specific allowable bearing capacities are no less than the calculated static and dynamic bearing pressures, and it referred to Section 3.7.5.1 for COL information. Section 3.7.5.1 states that the site allowable foundation-bearing capacities are no less than the values in Section 3G.1.5.5 for the RB, Section 3G.2.5.5 for the CB, and Section 3G.3.5.5 for the FB. Section 3G.1.5.5 refers to Table 3G.1-58, Section 3G.2.5.5 refers to Table 3G.2-24, and Section 3G.3.5.5 refers again to Section 3G.1.5.5. In RAI 3.8-95, the staff requested that the applicant expand the discussion of bearing capacities as a function of site conditions (soft, medium, hard) in DCD Section 3.8.5.4 and directly reference the Appendix 3G tables that contain the pertinent information.

In its response to RAI 3.8-95, the applicant stated that it will delete the following statement from DCD, Tier 2, Section 3.8.5.4: "The site-specific allowable bearing capacities are no less than the calculated static and dynamic bearing pressures. See Subsection 3.7.5.1 for COL information." DCD, Tier 2, Section 3.7.5.1, is a more appropriate location to capture seismic design parameters. The applicant also stated that it would revise DCD, Tier 2, Section 3.8.5.4, in the next update and provided markups of the proposed change.

During the December 2006 audit, the applicant stated that it would collect COL actions for site-related parameters in DCD Chapter 2. The applicant stated that it would revise DCD Section 3.8.5 to reference the appropriate section in Chapter 2 for site-related parameters, including site-specific soil-bearing capacity requirements. The topics discussed during the audit were addressed by the applicant in response to supplemental RAI 3.8-95 S01.

In its RAI 3.8-95 S01 response, the applicant stated that it would revise DCD, Tier 2, Section 3.8.5.4, to state that DCD, Tier 2, Table 2.0-1, furnishes the minimum requirements for the physical properties of the site-specific subgrade materials. The revision would also state that DCD, Tier 2, Table 2.0-2, Section 2.5.4, addresses COL actions for site-related parameters. The applicant also stated that it would revise DCD, Tier 2, Table 2.0-1, and Sections 3.7.1, 3.7.1.1, 3.7.1.1.3, 3.7.5, and 3.8.5.4, in the next update and provided markups of the proposed changes.

The staff finds the applicant's response to be acceptable, on the basis that the applicant agreed to revise the DCD to refer to DCD, Tier 2, Table 2.0-1, for site-specific subgrade soil properties, and to Table 2.0-2, for COL actions for site-related parameter criteria. The staff reviewed the applicant's proposed DCD changes and confirmed that it included them in DCD Revision 3. Therefore, RAI 3.8-95 was resolved.

DCD Figure 3G.1-9 shows the FEM of the RB/FB foundation mat. From the information provided, it was not evident what type of elements the applicant used in the model. Therefore, in RAI 3.8-100, the staff asked the applicant to describe the type of finite elements used to model the foundation mat. The staff asked the applicant to indicate whether they are classical thin-plate/shell-type elements that have only membrane and bending behavior, or "thick-shell" elements that also account for shear deformation. The staff also requested an explanation of how it modeled the transition between the 5.1-m thick portion of the mat and the 4-m thick portion of the mat. Given that the thickness of the foundation mat identified in Table 3.8-13 varies from 4 m to 5.1 m, the applicant should supply the technical basis for using plate/shell-type elements.

In its response to RAI 3.8-100, the applicant stated that the type of FE used to model the foundation mat is the thick-shell element, which also accounts for out-of-plane shear deformation. In the NASTRAN model and in the section design calculations, the thickness of basemat shell elements is uniformly set to 4.0 m. At the central portion of the mat, where the thickness is 5.1 m, the extra 1.1 m is neglected for conservatism, because this region is fully constrained by the RPV pedestal and is limited in size, compared to the total mat. Furthermore, this extra thickness is treated as a nonload-carrying element. However, the thickened region of the mat is considered in the temperature distribution analysis to evaluate the design temperature of the central portion of the basemat.

During the staff's onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, CA, the staff discussed the response in greater detail with the applicant. The staff noted that it had selected the basemat for detailed confirmatory analysis and discussed the model and loading information required for this analysis. The staff indicated that it planned to evaluate the adequacy of using thick-shell elements for the basemat and the effects of basemat thickness variation. Subsequent to the onsite audit, the staff became aware that the basemat thickness under the SFP is 5.5 m. Therefore, the staff's confirmatory analysis model also includes this thickness increase. Section 3.8.5.3.8 of this report discusses the staff's confirmatory analysis of the basemat, which uses three-dimensional solid FEs and considers the variation in basemat thickness.

In supplemental RAI 3.8-100 S01, the staff requested that the applicant supplement its initial RAI response to assess the effect of the 5.1-m thickened portion on the structural behavior of the mat, by performing sample analyses to show that neglecting it in the analysis is a conservative measure.

In its RAI 3.8-100 S01 response, the applicant provided the results of a sample calculation showing that the assumption of a uniform 4-m basemat thickness is adequate. Two models were analyzed, one with a 4-m thickness and the other with a 5.1-m thickness, in the inside region of the RPV pedestal. The 4-m thickness corresponds to the assumed thickness used in the DCD analysis and design. The applicant stated that the influence on the basemat from the two different thicknesses is limited to the region inside the pedestal. Bending moments increase almost 30 percent at the center because of the greater basemat thickness at the center. This increased moment is resisted by a thicker section of 5.1 m in depth and therefore should be acceptable.

During the December 2006 audit, the staff discussed its assessment of the RAI 3.8-100 S01 response and the results, which show that the bending moments increase almost 30 percent at the center because of the thicker basemat. Since the applicant's primary reinforcement design is based on a 4-m depth and the effective height of the section for reinforcement design does not increase, the amount of reinforcing steel required should increase. In supplemental RAI 3.8-100 S02, the staff asked the applicant to clarify the bases for the reinforcement design, in light of its study, and explain the technical bases for the procedure used to determine the size of the reinforcing bars located in the top surface of the thickened portion to prevent the development of concrete cracking.

In its RAI 3.8-100 S02 response, the applicant stated that it revised the NASTRAN model to include the effect of the thickened portion of the foundation. The calculated section forces and moments are conservatively used in sizing the mat reinforcement and verifying concrete stresses based on a 4-m-thick section. The thickened portion is reinforced to meet the minimum requirements in ASME Code, Section III, Division 2, Subsection CC-3535(b). The staff finds the applicant's response to be acceptable, on the basis that the NASTRAN model now includes the actual thickened mat dimension within the RPV pedestal region and the resulting member forces are then used to design the concrete section in a conservative manner by using a 4-m-thick section. The staff reviewed the applicant's proposed DCD changes and confirmed that it included them in DCD Revision 3. Therefore, RAI 3.8-100 was resolved.

DCD Section 3G.4.5.5, which discusses foundation stability for the FWSC, states that the applicant used shear keys under the basemat to resist sliding. These shear keys are shown in Figures 3G.4-1 and 11 and appear to be a critical element for ensuring the stability of the FWSC against sliding. However, there is no information on these shear keys that relates to the forces and moments, concrete and rebar stresses, transverse shear forces, and steel reinforcement details. In RAI 3.8-123, the staff asked the applicant to include this information in the DCD in a manner similar to that provided for other critical sections and to explain, in the DCD, how it included the effect of the shear keys in the base details of the NASTRAN model. The applicant should also describe how it designed the shear keys, based on the results of the NASTRAN analysis.

In its response to RAI 3.8-123, the applicant stated that it used a NASTRAN analysis to evaluate the forces and moments in the shear keys. The NASTRAN model includes the shear keys, as shown in Figure 3.8-123(1). In the model, the top nodes of the shear key elements are connected with the corresponding basemat nodes by rigid links. The design method of the shear keys is the same as that of other concrete portions of the FWSC. The applicant used the NASTRAN analysis results to calculate concrete and rebar stresses and transverse shear forces for the section design and confirmed that they do not exceed the allowable values. Figure 3.8-123(2) shows the reinforcement details of the shear keys. The staff found this acceptable, since the applicant provided the details of the NASTRAN model and its analysis and the results are within the allowable limits. The staff also verified that the applicant incorporated all acceptable markup changes into the appropriate sections of the DCD. Therefore, RAI 3.8-123 was resolved.

3.8.5.3.5 Structural Acceptance Criteria

In DCD, Tier 2, Section 3.8.5.5, the applicant stated that Section 3.8.1.5 presents the acceptance criteria for the design of the containment portion of the foundation mat. Section 3.8.4.5 presents the acceptance criteria for the RB, CB, FB, and FWSC foundations. Table 3.8-14 gives the allowable factors of safety for overturning, sliding, and flotation of the structures. The staff found the structural acceptance criteria to be acceptable, on the basis that they are consistent with those given in SRP Section 3.8.5.II.5. However, the staff had several questions regarding the approach used to make the comparison to the acceptance criteria. These are discussed below.

The staff noted that, in prior versions of the DCD Section 3.8.5.5 presented two specifications of appropriate safety factors for the foundation design. The safety factors against sliding indicated that sliding resistance is judged as the sum of both shear friction along the basemat and passive pressures induced by embedment effects. However, the DCD does not indicate (1) how the analysis of these effects considers consistent lateral displacement criteria (that is, the displacement effect on passive pressure is not the same as on friction development) and (2) how waterproofing affects the development of the basemat friction capacity. In RAI 3.8-96, the staff requested that the applicant clearly describe, in DCD Section 3.8.5.5, how it incorporated these effects into the standard plant design for the range of acceptable site conditions considered.

In its response to RAI 3.8-96, the applicant stated that, in the response to RAI 3.7-35, SASSI analyses addressed the embedment effect. The applicant confirmed that the base shears calculated by the SASSI analyses, which consider the embedment effect, are less than those obtained by design seismic analyses that neglect the embedment effect. The use of higher base shears, calculated without the beneficial effect of embedment, is deemed conservative for the sliding evaluation, without explicit consideration of consistent lateral displacement criteria for passive pressure and friction resistance. The applicant also referred to its RAI 3.8-89 response concerning the effect of waterproofing.

The staff's assessment of the applicant's response concluded that the applicant should clarify the response and revise Section 3.8.5.5 to be consistent with the response. The staff questioned whether the safety factors against sliding consider only the basemat shear friction.

If not, the method used required explanation. In supplemental RAI 3.8-96 S01, the staff asked the applicant to (1) clarify whether the exterior walls need to be designed for passive pressures, as implied in the last sentence of Item (a) of the response, (2) clarify whether both base shear and passive pressures are relied on for lateral restraint, (3) explain the friction coefficient used in the analysis and its technical bases, (4) show how the sliding analysis captures liftoff effects, (5) address the capacity of the mud mat to resist applied loads, and (6) clarify the effect of the chemical crystalline powder in the mud mat on the assumed structural properties. The applicant is reviewing potential leaching of the mud mat by ground water under RAI 3.8-81.

In its RAI 3.8-96 S01 response, the applicant provided the following information for each item listed above:

(1) & (2) Table 3.8-96(1), included with the response, summarizes the evaluation results of the foundation sliding analyses for generic site conditions. The seismic loads used in the evaluation are obtained by seismic response analysis using the lumped soil spring stick model (DAC3N analyses). Since the lumped soil spring model does not consider embedment effects, the resulting shear loads are larger than those calculated by SASSI analyses. The use of higher base shear is conservative for the foundation stability evaluation. Sliding resistance is composed of the following:

- Friction force at the basemat bottom surface
- Cohesion force at the basemat bottom surface
- Passive soil pressure at the basemat side surface.
- Passive soil pressure on walls.

(3) Only the static coefficient of friction is used for stability evaluation. Coefficient of friction, μ, is calculated by the following equation: $\mu = \min(\tan \Phi, 0.75)$ where, Φ = Angle of internal friction (30^o for soft and medium soil, 40^o for hard soil). The minimum angle of internal friction will be specified to be 30^o in DCD, Tier 2, Table 2.0-1 as a site requirement.

(4) Sliding resistance is composed of passive soil pressure, friction and cohesion forces at the basemat bottom. Uplift of the basemat has no effect on the passive soil pressure. The friction force at the basemat bottom is also not influenced by the uplift, because the friction force is calculated by (normal compressive force) x (friction coefficient). Because the basemat uplift has no effect on both the normal compressive force and friction coefficient, the resulting friction force is unchanged even if uplift occurs. As for the cohesion force, since it is calculated by (cohesion stress) x (contact area of basemat), the value is reduced if the basemat is uplifted. However, the contribution of the cohesion force to the total resistance is relatively small. The reduction of the cohesion force due to uplift has little impact on the total resistance.

(5) The mud mat construction is performed in accordance with the same standards and requirements as the basemat to avoid possibility of errors in the field.

(6) The crystalline powder used is the same material approved for use in AP-1000 and has no deleterious effect on concrete. It forms a substantial waterproofing barrier to prevent water infiltration or ex-filtration.

Based on its review of the RAI 3.8-96 S01 response, the staff concluded that the applicant has not used a consistent set of criteria to determine the safety factor against sliding. In RAI 3.8-96 S02, the staff asked the applicant to provide the technical bases for the calculation of passive soil pressure, the value used for frictional resistance of the soil, the selection of the soil internal friction of 30 degrees, the approach used for soil cohesive resistance, COL requirements for the backfill material, and the 100/40/40 directional combination method for the SSE. RAI 3.8-96 was being tracked as an open item in the SER with open items.

In subsequent RAI 3.8-96 S02, S03, S04, and S05 responses, the applicant revised the analysis approach for evaluating the sliding stability of seismic Category I structures. The new approach required the addition of shear keys for the RB/FB and the FWSC to assist the structures in resisting sliding during an SSE. The calculation for sliding stability consisted of sliding resistance caused by friction at the bottom of the foundation, lateral soil resistance pressure on embedded walls and shear keys perpendicular to the direction of motion, and friction provided by basemat and shear key vertical edges parallel to the direction of motion. The applicant calculated the factor of safety as a function of time throughout the SSE time history, considering the phasing between the vertical and horizontal seismic force components. All of the factors of safety were shown to meet the acceptance criteria in SRP Section 3.8.5 II.5. Since the applicant took this approach in accordance with the guidance presented in SRP Section 3.8.5 II.3 for load combinations and SRP Section 3.8.5 II.5 for acceptance criteria, the staff found the sliding stability evaluation acceptable. The remaining items identified by the staff are for the applicant to include all of the key soil properties used in these and other evaluations in DCD, Tier 1, Table 5.1-1, and to incorporate the proposed markups presented in the RAI response into the DCD.

The RAI responses referred to above contained additional information to address the staff's concerns regarding the use of crystalline material to provide adequate waterproofing of the foundations. Based on the information provided, the staff found that the use of the crystalline material within the concrete mud mat mixture and additional spray-type crystalline material on the top horizontal surface of the mud mat and vertical edges of the basemat is acceptable. However, the staff informed the applicant that it should also revise the DCD to indicate that crystalline material is used on the vertical edges of the basemat. The foundation walls above the basemat will have sheet-applied waterproofing membranes.

The applicant subsequently submitted Revision 1 to its RAI 3.8-96 S05 response and included DCD markups addressing the remaining items stated above. The staff reviewed the revised supplemental responses and found them acceptable. The staff verified that the proposed markups were incorporated into the appropriate sections of the DCD, Tier 2, Revision 7. Therefore, RAI 3.8-96 was resolved.

The staff noted that DCD Section 3.8.5.5 presents the appropriate safety factors for foundation design. The safety factors consider the full calculated dead load to counteract the potential effects of buoyancy. However, because of the uncertainty in the calculation of plant dead loads, it is typical to limit the effective dead load to a fraction of the best estimate dead load (typically limited to 0.90 of the full dead load). In RAI 3.8-97, the staff requested that the applicant describe, in DCD Section 3.8.5.5, how it will define the dead load for this uplift evaluation, including the treatment of the stored volume of water in the pools.

In its response to RAI 3.8-97, the applicant stated that it considered the full dead load in the buoyancy calculations. Since the factors of safety are sufficiently large, it is not deemed necessary to use 0.90 of the dead load to check overturning. For flotation, the RAI response provided a table that showed that, even if 90 percent of the dead load was used, the factors of safety still meet the acceptance criteria.

During the December 2006 audit, the staff asked the applicant to clarify how it defined the dead load for the buoyancy calculations and what effect the stored volume of the water in the pools has on the factor of safety for flotation. The topics discussed during the audit were addressed by the applicant in response to supplemental RAI 3.8-97 S01.

In its RAI 3.8-97 S01 response, the applicant stated that it used the full dead load, as described in the original response to RAI 3.8-97. The volume of water in the pools represents a small fraction of the total building weight, and the factor of safety against flotation, using 90 percent of the design dead load, is very large.

The staff finds the applicant’s response to be acceptable, on the basis that, even if 90 percent of the dead load is used for overturning and flotation stability calculations, the acceptance criteria are satisfied. Therefore, RAI 3.8-97 was resolved.

The staff noted that DCD Section 3.8.5.5 describes the structural acceptance criteria for foundations and states that the containment portion of the foundation follows DCD Section 3.8.1.5, while the rest of the foundations follow DCD Section 3.8.4.5. In RAI 3.8-103, the staff requested that the applicant explain whether it actually designed the common foundation supporting the RCCV, RB, and FB to two different sets of structural acceptance criteria, as indicated, or whether it used uniform structural acceptance criteria. If it used two different structural acceptance criteria, the applicant should explain how this was done and justify the jurisdictional boundary.

In its response to RAI 3.8-103, the applicant referred to the assessment in its response to RAI 3.8-101, discussed in Section 3.8.5.3.2 of this report.

During the December 2006 audit, the staff and applicant agreed to address this issue under RAI 3.8-4. In its RAI 3.8-103 S01 response, the applicant referred to the response to RAI 3.8-4 S01 for further clarification of jurisdictional boundaries. Since RAI 3.8-4 is now resolved, the applicant should revise DCD Section 3.8.5.5 to reflect the resolution. RAI 3.8-103 was being tracked as an open item in the SER with open items.

In its RAI 3.8-103 S02 and S03 responses, the applicant noted its addition to DCD, Tier 2, Section 3.8.5.5, stating that the structural acceptance criteria for the foundations of the RCCV, RB, CB, FB, and FWSC are the same as those for the superstructures with additional foundation stability requirements, consistent with SRP Section 3.8.5.II.5. The staff verified that the applicant incorporated the proposed markup changes in the response into the appropriate section of the DCD. Therefore, RAI 3.8-103 and its associated open item were resolved.

3.8.5.3.6 Material, Quality Control, and Special Construction Techniques

DCD, Tier 2, Section 3.8.5.6, states that the foundations of seismic Category I structures are constructed of reinforced concrete using proven methods common to heavy industrial construction, and it references DCD Section 3.8.1.6 for further discussion. The staff notes that DCD Section 3.8.1.6 provides the materials and quality control requirements for the concrete containment. Therefore, by reference to this section, the applicant is committed to the use of the materials and quality control requirements specified for the concrete containment for the foundations of all seismic Category I structures. This approach is acceptable to the staff, since the requirements specified for the concrete containment are considered to provide the highest level of quality concrete construction. Section 3.8.1.3.6 of this report discusses the staff's evaluation of DCD Section 3.8.1.6.

3.8.5.3.7 Testing and Inservice Inspection Requirements

The staff noted that an earlier version of DCD Section 3.8.5.7 indicated that there are no testing or ISI requirements for the foundations. The staff requested, in RAI 3.8-99, that the applicant explain whether there was a commitment to RG 1.160 for monitoring structures to meet the requirements of 10 CFR 50.65. If there was such a commitment, then the applicant should modify DCD Section 3.8.5.7 to indicate this. If not, the applicant should provide the technical basis in DCD Section 3.8.5.7.

In its RAI 3.8-99 response, the applicant stated that it would reference RG 1.160 in a revised DCD, Tier 2, Section 3.8.5.7, for monitoring the seismic Category I structures of the ESBWR listed in DCD, Tier 2, Table 19.2-4, and it provided a markup as part of its response.

During the December 2006 audit, the staff and the applicant agreed to address this RAI under RAI 3.8-81. The revised wording in the DCD would address structures covered by DCD Sections 3.8.4 and 3.8.5. The topics discussed during the audit were addressed by the applicant in response to supplemental RAI 3.8-99 S01.

In its RAI 3.8-99 S01 response, the applicant stated that it had revised DCD, Tier 2, Section 3.8.5.7, to reference NUREG-1801, 10 CFR 50.65, and RG 1.160. The applicant also stated that the concrete specified in the ESBWR is watertight and a crystalline powder admixture waterproofing is used in the foundation. The applicant referred to the response to RAI 3.8-96 S01, Item (6). The applicant also stated that settlements are similarly investigated at the start of the COL approval activities and that allowable differential settlements in the ESBWR are addressed in response to RAI 3.8-93. The applicant provided a markup of the DCD revision with the response.

The staff finds the applicant's response to be acceptable, on the basis that it directly references 10 CFR 50.65 and RG 1.160. The staff confirmed that the applicant incorporated the proposed DCD changes in a formally submitted DCD revision. Therefore, RAI 3.8-99 was resolved.

3.8.5.3.8 Confirmatory Analysis

During the staff's onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, CA, the staff informed the applicant that it had selected the basemat for detailed confirmatory analysis and discussed with the applicant the model and loading information required for this analysis. The staff indicated that it planned to evaluate the adequacy of the applicant's analytical approach, use of thick-shell elements for the basemat, assumption of uniform basemat thickness, and computerized solutions using the NASTRAN code. The staff's confirmatory analysis of the basemat would use three-dimensional solid FEs, actual basemat thickness beneath the containment, and the ANSYS computer code.

During the December 2006 audit, the staff and the applicant conducted a detailed comparison of results obtained for the truncated RB/FB model (basemat and short portion of connecting walls), which both parties agreed to use for the confirmatory analysis. As a result of the comparisons conducted, the applicant committed to submitting additional information to help reconcile differences between the staff's confirmatory analysis results and the applicant's results. In its response, dated April 2, 2007, the applicant provided the additional information, as agreed during the December 2006 audit.

Following its review of the applicant's April 2, 2007, submittal, the staff prepared a new RAI 3.8-114 to document the December 2006 audit results, to summarize the staff's review of the applicant's April 2, 2007, response, and to identify the remaining issues.

During the onsite audit, the NRC staff and the applicant's staff held two breakout meetings on confirmatory analysis review. In addition, several informal exchanges of ideas occurred on how to minimize the modeling differences between the applicant's NASTRAN model and the staff's ANSYS model. The subjects covered included (1) comparison of results, (2) modeling differences, and (3) future actions to resolve differences in results.

Based on an agreement between the staff and the applicant, seven major walls and three basemat sections were selected for the purpose of comparing results in the confirmatory analysis. During the audit, the NRC staff discussed the detailed comparison of the internal forces and moments for two representative walls and one basemat section. Because of time constraints, the comparisons were made by reading results from the plots submitted by the applicant and the plots produced by the staff, without overlapping the two sets of data on one set of plots. Displacement comparisons were approximated until the staff and the applicant reached an agreement on where and how the comparisons would be made. Some of the comparisons between the truncated ANSYS solid model and the truncated NASTRAN shell model were acceptable, but in some cases, the differences were significant. Some were easily explained by the modeling differences. The staff described the ANSYS solid model and the application of the six load cases. While there were differences in how the loads were applied in the two models, the loads for both models were judged to be equivalent.

The audit report for the December 2006 audit identified 12 postaudit actions. Appendix C to GEH report SER-ESB-038, Revision 5, submitted by the applicant as part of its April 2, 2007, response to the December 2006 audit discussions, addresses many of these. The applicant also submitted a large file of NASTRAN computer results.

On one set of plots, the staff plotted the internal forces and moments from both analyses. The spikes on curves from ANSYS results are attributable to stress concentration at wall joints and will not be considered in the comparison. Appendix C to SER-ESB-038, Revision 5, explains that such stress concentrations do not affect the design of the reinforced concrete sections. The staff concurs.

For many cases, the results from NASTRAN and ANSYS are very close. For cases that do not match closely, NASTRAN generally predicts results that are more conservative than ANSYS results. There are a number of exceptions. Some of the large differences between NASTRAN and ANSYS results are not of concern, because the absolute magnitudes are small and the quantities are not the major forces resisted by those components (e.g., out-of-plane moment for shear walls). Furthermore, the large differences in some quantities may not affect the final design, if the controlling force or moment is taken as the maximum along the section or wall. The following discussion addresses each of the 12 items identified for action at the December 2006 audit:

(1) There is a gate in wall IW-F10 in the structural drawing, which the applicant modeled as a zero-width gap between adjacent shell elements; this gate had been closed until SER-ESB-038, Revision 4. As indicated in this report, the model has been corrected. However, the staff's ANSYS confirmatory model does not have this gap, because it was not identified during the review of the modified truncated NASTRAN model. The applicant agreed to close the gap in the modified truncated NASTRAN model, to be consistent with the ANSYS model, because it is difficult to add this gap to the ANSYS model. Item (1) is resolved, based on the review of the NASTRAN analysis results presented in SER-ESB-038, Revision 5.

(2) An apparent discrepancy between the results of SER-ESB-038, Revision 3 and Revision 4, is that the critical seismic combination has changed. The only modeling change was the gap condition discussed above. Since this modeling change would not be expected to have such an effect, the change in the critical seismic combination needs further review. The applicant agreed to investigate this. In Appendix C to SER-ESB-038, Revision 5, the applicant confirmed that Revision 4 is correct. Item (2) is resolved.

(3) The applicant provided displacement plots at the top of the walls in SER-ESB-038, Revision 4, for which the staff needs to develop corresponding plots for comparison. The staff did compare displacements at one nodal location, for dead load, hydrostatic load, and three seismic loads. The NASTRAN results are typically conservative by about 20–30 percent, compared to the ANSYS results. Once the applicant submits the new results that resolve the other open items in this list, the staff can then conduct a more thorough comparison of displacements. Item (3) was identified as a staff action item.

(4) The total number of internal forces and moments is seven, namely N, Qx, Qy, Mx (group 1 in section) and Qz, Nz, and Mz (group 2 in perpendicular section). The applicant provided six of the seven quantities for each location in the NASTRAN element coordinate system. The missing data from SER-ESB-038, Revision 4, are for the in-plane shear, which is very important for lateral seismic loadings. The applicant will provide a table showing, for each location, the correlation between the NASTRAN quantities and the sectional forces and moments, as illustrated during the meeting. The data provided by the applicant would be in Excel files, in addition to the plots in SER-ESB-038. The Excel files would include the coordinates and the seven internal forces and moments. The staff would make comparisons using the data in these Excel files.

In SER-ESB-038, Revision 5, the applicant provided the requested data. The staff compared these data with the staff's results for N, Qx, Qy, Mx, and Mz. The staff still needed to program ANSYS macros to calculate Qz and Nz to compare these quantities.

During its comparison, the staff noted an incompatible result in the NASTRAN analysis results at the intersection of Sections BB and CC in the basemat. For load case EW earthquake (EQ), the NASTRAN results in Figure 5-237 show that the in-plane moment

Mx (My, in NASTRAN terminology) in Section CC at this intersection is 6.2 MNm/m; the out-of-plane moment Mz (My, in NASTRAN terminology) in Section BB at the same location is 13 MNm/m from Figure 5-219. The ANSYS results show these two quantities to be the same. The staff also noted that the NASTRAN magnitude of Mx (My, in NASTRAN terminology) in Section CC is nonconservative, compared to the ANSYS result. Therefore, the staff requested that the applicant review the NASTRAN results at this location, and possibly other locations, and explain this apparent incompatibility. Item (4) is open.

(5) Some of the internal forces and moments reported in SER-ESB-038, Revision 4, are opposite in sign to the ANSYS solution, with no apparent consistency from location to location. During the audit, the staff and applicant agreed on the positive directions of all sections. The applicant and the staff will present the internal force and moment results, consistent with the agreement to facilitate the comparison.

Figure 5-2 of SER-ESB-038, Revision 5, does not completely match the positive directions agreed to during the audit. The staff had to reverse the sign of some NASTRAN output to compare it with the ANSYS results. Because the staff was able to make the necessary sign corrections, Item (5) is resolved.

(6) The applicant took the internal forces and moments in the walls at the center of the first row of shell elements in the walls (-11.0 m). The staff took the corresponding results from the bottom of the wall (-11.5 m). The staff moved the cut plane for the ANSYS results to Elevation -11.0 m to match the NASTRAN results. Item (6) is resolved.

(7) The shell elements for sections of varying thickness should have the correct offset. The basemat under the SFP has the correct offset in the shell elements, but the thickened portion of wall F3 does not. The applicant will change the modified truncated NASTRAN model to correct the offset for the elements in the thickened portion of wall F3. However, the applicant indicated in the meeting that it will not adjust the offset in wall F3 in the full model.

In SER-ESB-038, Revision 5, the applicant modeled the centerline offsets for the thickened portions of wall F3 and the basemat beneath the RPV and the fuel storage pool.

For the walls and sections of the fuel storage pool (i.e., walls RAFA and F3 and Section B), there are significant differences in the internal forces and moments between the NASTRAN and ANSYS results. The NASTRAN results are generally higher than the ANSYS results, but some are lower. The NASTRAN and ANSYS results match very well for the same walls and sections at locations away from the pool, where the reference surface is not offset in the NASTRAN model. Since the ANSYS model is a solid element representation, there are no reference surface offsets, as are needed in the NASTRAN shell element representation. The differences may be related to the modeling of the offset for the basemat under the pool and for the thickened portion of wall F3 in the NASTRAN model. Until the applicant could explain the cause of the differences and address them, Item (7) was open.

(8) Sections AA and CC in the basemat are not straight sections in the NASTRAN model. The applicant stated that it would check whether the internal forces and moments can be taken along straight sections.

In Appendix C of SER-ESB-038, Revision 5, the applicant indicated that it is difficult to obtain the internal forces and moments along straight lines for these sections in NASTRAN, and it provided a reasonable explanation for determining that the effect of this difference (ANSYS uses straight sections) would be small. Item (8) is resolved.

(9) The basemat within the boundary of the RPV pedestal has been changed to 5.1 m in the full NASTRAN model, but its reinforcements are proportioned using a thickness of 4 m. The modified truncated NASTRAN model used a thickness of 4 m. The applicant stated that it would increase the thickness to 5.1 m in the truncated model with correct offset.

The applicant increased the thickness of the basemat to the correct value of 5.1 m and presented results in Appendix C to SER-ESB-038, Revision 5, that agree more closely with the ANSYS results. Item (9) is resolved.

(10) The soil springs in the NASTRAN model are applied at the center of the basemat, while they are applied at the bottom of the basemat in the ANSYS model. However, the applicant performed a sensitivity study on the location of the soil springs and found that the resultant change in the responses was minimal.

The axial force and in-plane and out-of-plane moments in the basemat sections predicted by NASTRAN are generally 30 to 100 percent higher than the ANSYS results. The main difference between the models is the attachment location for the soil springs. The staff requests that the applicant revisit its prior study that concluded the spring attachment location had minimal effect on the results. If that result is confirmed, then the applicant should try to identify other potential sources for the significant differences in results. Item (10) was open.

(11) Hydrostatic pressure load in the truncated and full NASTRAN model is applied at the centers of the surrounding walls and basemat. This approach results in a larger area for the hydrostatic pressure load. The applicant stated that it would update the model appropriately, considering the true area for hydrostatic pressure, possibly in a way similar to that for the pressure load application in the RPV. The SER-ESB-038 report would document the final implementation of this action.

The staff checked the application of the hydrostatic pressure load in the fuel storage pool in the ANSYS model and found no evidence of an inappropriate application of the hydrostatic pressure. The applicant updated the hydrostatic pressure in the truncated NASTRAN model using the “actual magnitude” in Revision 5. Although the results in the pool area still do not match well between the NASTRAN model and the ANSYS model as discussed in Item (7), the effect of this change cannot be assessed until the applicant can resolve the other open items in this list. Item (11) was open.

(12) The applicant will try to identify why some of the plots show sharp knuckles or large gradients, which do not exist in the results of the ANSYS model. The staff and the applicant will try to identify possible reasons for some of the significant differences in the responses between the modified truncated NASTRAN and ANSYS models that were not immediately obvious during the audit. In particular, the applicant will verify that there are sufficient in-plane integration points in the wall elements to establish an adequate constraint to the basemat.

The staff has some question about the explanation provided in Appendix C to SER-ESB-038, Revision 5, for the knuckles in the out-of-plane shear distribution. A possible reason is that the mesh in the NASTRAN model is not fine enough at regions close to the joints.

During the audit, the staff asked the applicant to check the number of in-plane integration points for the shell elements, because this may be important for the constraint effect of the walls to the basemat. The applicant had not addressed this request.

Several predicted force and moment results do not match well between NASTRAN and ANSYS, without any reasonable explanation. From its review of the 300 comparison plots it generated, the staff noted five output quantities from NASTRAN that are significantly nonconservative, when compared to the ANSYS results. These quantities (NASTRAN terminology in parentheses) are the in-plane moment Mx (My) and the out-of-plane moment Mz (Mx) in Section CC for EW EQ, the in-plane shear Qx (Nxy) in wall F3 for NS EQ, the in-plane shear Qx (Nxy) in wall R7F1 for EW EQ, and the out-of-plane shear Qy (Qy) in wall RPV for NS EQ.

RAI 3.8-114 was being tracked as an open item in the SER with open items. In its response, dated November 13, 2007, the applicant provided information requested by the staff for the remaining outstanding items discussed above. With the applicant's new analysis results and information presented in the November 13, 2007, response, the staff was able to make a meaningful comparison between the staff's ANSYS model analysis and the applicant's NASTRAN model analysis. Based on the reasonable comparison of results along with the clarifying information provided in the RAI response, RAI 3.8-114 and its associated open items were resolved.

Part 5 of the supplemental response to RAI 3.7-61, as futher discussed in Section 3.7.2.3.4 of this report, states that the four items deleted from DCD, Tier 2, Section 3.8.6, Revision 1, will be added back to DCD, Tier 2, Section 3.8.6, with pointers to DCD, Tier 1, Table 2.15.1-2; DCD, Tier 2, Table 2.0-1; and DCD, Tier 2, Section 3.8. The applicant proposed text for these four items and it has revised the section from the DCD, Tier 2, Revision 1 version. Based on the proposed new text, in RAI 3.8-116, the staff asked the applicant to revise the DCD again to address the following items:

(1) The second bullet, "Site-specific physical properties and foundation settlement," should include, in its list of requirements, the minimum soil friction value of 30 degrees. This parameter is currently in DCD, Tier 2, Table 2.0-1, and DCD, Tier 1, Table 5.1-1, and is also relied upon in the response to RAI 3.8-96 to address the sliding capability of seismic Category I structures.

(2) The second bullet indicates that the soil property requirement for "maximum settlement values for seismic Category I building" is presented in DCD, Tier 2, Table 2.0-1. While this requirement is included in DCD, Tier 2, Table 2.0-1, it should also be included in the corresponding DCD, Tier 1, Table 5.1-1.

In its response to RAI 3.8-16, the applicant updated DCD Section 3.8.6 and Table 2.0-2 to include the angle of internal friction and to address settlement and differential settlements. If the facility does not meet the maximum settlement values, a site-specific settlement analysis can be performed in the COL application. The staff reviewed the responses and found them acceptable, since the applicant revised the DCD to address the items noted above. The staff also verified that the applicant incorporated the proposed markup changes in the response into the appropriate sections of the DCD. Therefore, RAI 3.8-116 was resolved.

3.8.5.4 *Conclusion*

The staff concludes that the applicant has demonstrated that the analysis, design, construction, testing, and inservice surveillance of foundations conform with established criteria in codes, standards, guides, and specifications acceptable to the staff. The use of these criteria has been found to be consistent with the guidance provided in SRP Section 3.8.5 and applicable regulatory guides. Meeting these criteria ensures that the DCD meets the relevant requirements of 10 CFR 50.55a; GDC 1, 2, 4, and 5 of Appendix A to 10 CFR Part 50; and Appendix B to 10 CFR Part 50.

3.9 Mechanical Systems and Components

3.9.1 Special Topics for Mechanical Components

In accordance with the guidelines in SRP Section 3.9.1, draft Revision 3, issued June 1996, the staff of the NRC reviewed the information in ESBWR DCD, Tier 2, Revision 3, Section 3.9.1, related to the following:

- the design transients used in the design and fatigue evaluations for ASME Boiler and Pressure Vessel Code (hereafter referred to as the ASME Code) Class 1 components, component supports, core support (CS) structures, and reactor internals

- the methods of analysis and computer programs used in the design and analysis for seismic Category I components, component supports, CS structures, and reactor internals designated as Class 1, 2, 3, and CS under Section III of the ASME Code and those not covered by the ASME Code

- experimental stress analysis techniques that may be used in lieu of theoretical stress analysis

- elastic-plastic stress analysis methods that the applicant may elect to use in the design of the above-noted components

- the environmental conditions to which all safety-related components will be exposed over the life of the plant

The staff compared the SRP version used during the review with the 2007 version of the SRP. The 2007 version does not include any requirements, generic issues, bulletins, generic letters, or technically significant acceptance criteria beyond those identified in the version used by the staff. Therefore, the staff finds that the use of draft Revision 3 of SRP Section 3.9.1, issued in 1996, is acceptable for this review.

3.9.1.1 *Regulatory Criteria*

The following regulatory requirements provide the basis for the acceptance criteria for the staff's review:

- GDC 1 in Appendix A to 10 CFR Part 50 as it relates to the design, fabrication, erection, construction, testing, and inspection of components important to safety in accordance with the requirements of applicable codes and standards commensurate with the importance of the safety function to be performed

- GDC 2 as it relates to designing mechanical components of systems to withstand the effects of earthquakes without loss of capability to perform their safety function

- GDC 14 as it relates to the design of the RCPB so as to have an extremely low probability of abnormal leakage, rapidly propagating failure, and gross rupture

- GDC 15 as it relates to the design of mechanical components of the RCS with sufficient margin to ensure that the design conditions of the RCPB are not exceeded during any condition of normal operation, including anticipated operational occurrences

- Appendix B to 10 CFR Part 50, as it relates to design quality control

- Appendix S, to 10 CFR Part 50, as it relates to the ability of structures, systems, and components important to safety to withstand the effects of earthquakes

To meet the requirements of the regulations identified above, the DCD must include the following information:

- a complete list of transients to be used in the design and fatigue analysis of ASME Code, Section III, Class 1 and Class CS components within the RCPB

- a list of computer programs that will be used to determine the structural and functional integrity of seismic Category I mechanical components, including a description of the methods used for computer program qualification

- if experimental stress analysis methods are used in lieu of analytical methods for any seismic Category I mechanical components, sufficient information to allow the staff to determine their acceptability when compared to the requirements of Appendix II to Section III of the ASME Code

- if inelastic analysis methods, including ASME Code, Section III, Service Level D limits, are used for any seismic Category I mechanical components, conformance of the analytical methodology used to calculate stresses and deformations to the methods specified in Appendix F to Section III of the ASME Code

3.9.1.2 *Summary of Technical Information*

3.9.1.2.1 Design Transients

In DCD, Tier 2, Revision 7, Table 3.9-1, GEH listed the fluid system design transients for five operating conditions and the number of cycles for each transient considered in the design and fatigue analyses of RCS ASME Code Class 1 components, other Class 1 components, RCS supports, and reactor internals. The operating conditions are as follows:

- ASME Service Level A—normal conditions
- ASME Service Level B—upset conditions, incidents of moderate frequency
- ASME Service Level C—emergency conditions, infrequent incidents
- ASME Service Level D—faulted conditions, low-probability postulated events
- test conditions

DCD, Tier 2, Revision 7, Section 3.9.1.1, discusses the basis for the number of cycles for the transients in Table 3.9.1. The number of cycles is a conservative estimate of the magnitude and frequency of the temperature and pressure transients that may occur during plant operation based, in part, on operating experience of current BWRs, adjusted for a 60-year ESBWR plant life. The transients also include 20 safe SSE cycles for ASME Code, Section III, Service Level B conditions, and one each of SSE transient and loss-of-coolant accident (LOCA) transient for ASME Code, Section III, Service Level D conditions.

DCD, Tier 2, Revision 7, Table 3.9-2, shows the load combinations and acceptance criteria for safety-related ASME Code Class 1, 2, and 3 components, component supports, and CS structures. DCD, Tier 2, Revision 7, Table 3.9-9, shows specific load combinations and acceptance criteria for ASME Code, Section III, Class 1 piping systems and components.

3.9.1.2.2 Computer Programs

The applicant used computer programs to analyze mechanical components. Appendix B to 10 CFR Part 50 requires design control measures to verify the adequacy of the design of safety-related components. In SRP Section 3.9.1, the staff provides guidelines for measures sufficient to meet Appendix B requirements. DCD, Tier 2, Revision 7, Section 3.9.1.2, refers to Appendix 3D to DCD, Tier 2, Revision 7, for a list of the computer programs used in the design of major safety-related components. The list includes programs to perform hydraulic transient load analyses and dynamic and static analyses of mechanical loads, stresses, and deformations of seismic Category I components and supports. In addition, each program listed in Appendix 3D also includes a description of the method of verification.

3.9.1.2.3 Experimental Stress Analysis

In DCD, Tier 2, Revision 7, Section 3.9.1.3, the applicant identified several components for which experimental stress analysis is performed, in conjunction with analytical evaluations. The components that have been tested to verify their design adequacy consist of piping seismic snubbers, pipe whip restraints, and the prototype fine motion control rod drive (FMCRD).

3.9.1.2.4 Considerations for the Evaluation of Faulted Conditions—Inelastic Analyses

In DCD, Tier 2, Revision 7, Section 3.9.1.4, the applicant stated that all seismic Category I equipment is evaluated for the faulted (ASME Code, Section III, Service Level D) loading conditions identified in Tables 3.9-1 and 3.9-2. The analyses of all components that are evaluated for faulted conditions are based on elastic methods of analysis and the ASME Code, Section III, Service Level D allowables for such methods. The applicant stated that, in all cases, the calculated actual stresses are within the allowable Service Level D limits.

The applicant stated that inelastic analysis is also applied to ESBWR components, but only to demonstrate the acceptability of two types of postulated events—a postulated gross piping failure and a postulated blowout of CRD housing caused by a weld failure.

Ruptures are postulated in certain piping systems in accordance with guidelines in SRP Section 3.6.2. For some full-diameter ruptures, pipe whip restraints may be required to protect safety-related components or equipment from a whipping pipe. Inelastic analysis is used in the design of such restraints to ensure that they will withstand the pipe loading. DCD, Tier 2, Revision 7, Section 3.6.2, provides the loading combinations and design criteria for pipe whip restraints used to mitigate the effects of postulated piping failures.

3.9.1.3 *Staff Evaluation*

3.9.1.3.1 Regulatory Criteria

The applicant indicated that the ESBWR plant design meets the regulations listed in SRP Section 3.9.1. DCD, Tier 2, Revision 7, Section 3.9.1, referenced Appendix A to 10 CFR Part 100. However, for design certification or COL applications pursuant to 10 CFR Part 52, the applicable criteria appear in Appendix S to 10 CFR Part 50.

In RAI 3.9-3, the staff requested justification for not listing Appendix S to 10 CFR Part 50 in lieu of Appendix A to 10 CFR Part 100. In its response to RAI 3.9-3, the applicant stated that it will replace references to Appendix A to 10 CFR Part 100 with Appendix S to 10 CFR Part 50 throughout the DCD. In Revision 3, the applicant has revised the appropriate sections of DCD Tier 2 to reflect this change. The staff found this response acceptable, and RAI 3.9-3 was closed.

3.9.1.3.2 Design Transients

In accordance with the guidance in SRP Section 3.9.1.III, the staff reviewed the design transients listed in DCD, Tier 2, Revision 7, Table 3.9-1. To complete its review, the staff requested discussion and justification of various transients listed in this table.

In RAI 3.9-4, the staff asked the applicant to clarify whether the term “No. of Events” is synonymous with “cycles.” In its response to RAI 3.9-4, the applicant stated that the cycles are the number of anticipated operational events during the 60-year life of the reactor. It will revise Table 3.9-1 by changing the table column heading “No. of Events” to “No. of Cycles.” The staff found this response acceptable, and RAI 3.9-4 was closed.

In RAI 3.9-5, the staff requested the basis for the plant operating events and the corresponding number of events listed in the table. In its response to RAI 3.9-5, the applicant stated that the ESBWR events are basically the same as the events specified for all earlier BWRs, including the ABWR. The number of cycles specified over the 60-year life of the reactor is based on earlier BWR experience. The staff agreed that it is reasonable to use previous experience as a basis for specifying design transients and considered RAI 3.9-5 closed.

In RAI 3.9-6, the staff requested that the applicant discuss the difference between the specified cycles (180) for Event 3, “Start Up,” and the specified cycles (172) for Event 9, “Shutdown.” In its response to RAI 3.9-6, the applicant stated that the 180 startup cycles correspond to 172 shutdown cycles, specified for Event 9, plus 8 safety/relief valve (SRV) or single depressurization valve (DPV) actuation cycles, specified for Event 15, after which the reactor is also shut down. The staff found this response reasonable and acceptable and considered RAI 3.9-6 closed.

In RAI 3.9-7, the staff requested that the applicant discuss the basis of the "Dynamic Loading Events" in DCD, Tier 2, Table 3.9-1. In its response to RAI 3.9-7, the applicant stated that these events are based on seismic and hydrodynamic analyses and result in cyclic loads that are applied in component fatigue analyses. In RAI 3.9-7 S01, the staff requested further clarification of the basis. In response, the applicant stated that the dynamic loading events specified in Table 3.9-1 are consistent with events specified for earlier BWRs and that, based on previous experience and analysis, these events cover all conceivable dynamic conditions that the plant would experience in its lifetime. The staff found this response reasonable and acceptable and considered RAI 3.9-7 closed.

In RAI 3.9-8, the staff requested that the applicant discuss the basis of the statement regarding 2 events with 10 cycles per event for Event 13 in Table 3.9-1. In its response, the applicant stated that the number of earthquake cycles as defined for Event 13 is applicable to plants without an explicit operating-basis earthquake (OBE) design consideration, and that it is based on similar earthquake event/cycle postulations in the NRC-certified ABWR design and in Section 3.12.5.14 of the NRC final safety evaluation report (FSER) for the AP1000, NUREG- - 1793, "Final Safety Evaluation Report Related to Certification of the AP1000 Standard Design," issued September 2004. The applicant specifically quoted the following from Section 3.12.5.14:

> An acceptable cyclic load basis for fatigue evaluations consists of two SSE events with 10 maximum stress cycles per event (20 full cycles of the maximum SSE stress range). Alternately, a number of fractional vibratory cycles equivalent to that of 20 full SSE vibratory cycles may be used (but with an amplitude not less than one-third of the maximum SSE amplitude) when derived in accordance with Appendix D to IEEE Std 344-1987.

The staff has reviewed this response and concurs that the reference to Section 3.12.5.14 of the NRC FSER for the AP1000 is applicable to the ESBWR. The staff found this response reasonable and acceptable and considered RAI 3.9-8 closed.

In RAIs 3.9-9 and 3.9-10, the staff requested that the applicant discuss the basis for selecting one cycle for Events 14 and 16 in Table 3.9-1. In its response, the applicant stated that single Level D SSE and LOCA events are of very low probability, and each is therefore postulated to occur only once during the life of the plant. The staff found this response acceptable because it conformed to previously accepted nuclear power plant design practice. The staff considered RAIs 3.9-9 and 3.9-10 closed.

In RAI 3.9-11, the staff requested that the applicant provide confirmation that the transients in Table 3.9-1 are valid for 60-year operation. In its response, the applicant stated that it will add a footnote to the table indicating that plant events are for 60 years. The staff found this response reasonable and acceptable and considered RAI 3.9-11 closed.

On the basis of this evaluation and the evaluation of the responses to RAIs 3.9-2 through RAI 3.9-11, the staff finds that the information pertaining to the ESBWR design transients in DCD, Tier 2, Revision 7, Section 3.9.1.1, is consistent with the applicable guidelines in SRP Section 3.9.1 and is, therefore, acceptable. Sections 3.9.3 and 3.12 of this report provide additional staff evaluation of the design transients.

3.9.1.3.3 Computer Programs

In accordance with the guidance in SRP Section 3.9.1.III, the staff reviewed DCD, Tier 2, Revision 7, Section 3.9.1, for computer programs. Appendix 3D to DCD, Tier 2, Revision 7, describes these programs. To complete its review, the staff requested additional information.

In RAI 3.9-12, the staff asked that the applicant provide the following information for each program listed in Appendix 3D:

(1) the author, source, dated version, and facility
(2) the extent and limitation of its application
(3) the method used to demonstrate its applicability and validity

In its response to RAI 3.9-12, the applicant addressed item (1) of the RAI by providing a table showing the version and facility for the programs listed in Appendix 3D. The applicant also included Revision 3 of Appendix 3D to DCD Tier 2, which included responses to items 2 and 3 of the RAI. The staff reviewed the response to this RAI and found it acceptable because it conformed to current industry practice for verifying computer programs used in nuclear industry structural analysis. The staff considered RAI 3.9-12 closed.

In RAI 3.9-13, the staff requested that the applicant confirm that all computer programs used for calculating stresses and cumulative usage factors for Class 1 components include staff-endorsed environmental effects on the fatigue curves. In its response, the applicant listed the computer programs ANSYS, EVAST, and ANS17 as having the capability of performing ASME Code, Section III, fatigue calculations and cumulative usage factors. Of these programs, only ANS17 includes environmental effects on the fatigue curves in accordance with DG-1144, “Guidelines for Evaluating Fatigue Analyses Incorporating the Life Reduction of Metal Components Due to the Effects of the Light-Water Reactor Environment for New Reactors,” and NUREG/CR-6909, “Effect of LWR Coolant Environments on the Fatigue Life of Reactor Materials,” issued February 2007. The applicant stated that for the other two programs, the environmental effects on fatigue are determined externally to the program. The applicant did not state the basis for accounting for the environmental effects. The staff has therefore requested additional information on this item. RAI 3.9-13 was being tracked as an open item in the SER with open items.

In RAI 3.9-13 S01, the staff requested the applicant to provide clarification regarding how the environmental effects are accounted for in the calculation of the cumulative usage factor. In its response, the applicant stated that the ANSYS and EVAST computer programs do not specifically address environmental effects on fatigue curves. The calculations are performed outside the program; however, the calculations will be made in accordance with DG-1144 and NUREG/CR-6909. In Revision 5 of Tier 2 DCD, the applicant revised Appendix D to include the above statement in Sections 3D.3.1.3 and 3D.3.3.3. This conformed to the staff position associated with the environmental effects on fatigue evaluation. Therefore, RAI 3.9-13 and its associated open item were closed.

In DCD, Tier 2, Revision 7, Appendix 3D, Section 3D.4.1, PISYS was listed as a computer code for the static and dynamic analyses of the piping systems. The PISYS program was validated against benchmark problems in NUREG/CR-1677 and documented in Reference 3D-1 (NEDE-24210, “PISYS Analysis of NRC Benchmark Problems,” issued August 1979). However, Section 3D.4.1.2 noted that PISYS07 was used for the ESBWR piping analysis. PISYS07 was validated against benchmark problems in NUREG/CR-6049, “Piping Benchmark Problems for the General Electric Advanced Boiling Water Reactor,” issued August 1993. In RAI 3.9-254, the staff asked GEH to (1) clarify the listing of PISYS in Appendix D as the applied computer code in lieu of PISYS07 which is actually used for ESBWR piping analysis, (2) discuss the differences between PISYS and PISYS07, (3) clarify whether the PISYS07 program is documented as part of the documentation for PISYS in Reference 3D-1 or elsewhere, (4) confirm that PISYS and PISYS07 were both updated to incorporate methods and guides for response spectrum analysis and time-history analysis in accordance with RG 1.92, Revision 2, for ESBWR piping analysis (Ref. Section 3.7.3), (5) confirm that the results of PISYS07 (similar to those of PISYS) can be passed on to the ANSI7 runs via the EZPYP computer program for performing the fatigue analysis of piping, (6) clarify whether the PISYS described in Section 3D.4.1 is the computer program in Reference 3D-1, which documents a 1979 version of PISYS, and (7) confirm whether the validation package for PISYS07 is available for staff review. The information should include the author, source code, dated version, and facility; the program user's manual and theoretical description; the extent and limits of the program application; the benchmarking problems; and the QA control and maintenance of the program in accordance with 10 CFR Part 50 Appendix B to 10 CFR Part 50 and ASME NQA-1, "Quality Assurance Requirements for Nuclear Facility Applications."

The applicant responded to RAI 3.9-254 and its supplements. The applicant stated that PISYS is the name of the GEH pipe stress analysis program's name. The number 07 is a specific version of the program. Any change or improvement to the program will advance the number to a new version. Brookhaven National Library (BNL) benchmarked PISYS07 for the ABWR certification. GEH later corrected its statement to indicate that PISYS06 was actually used for the ABWR certification. PISYS07 has been benchmarked using NUREG/CR-6049 for closed space modes and rigid mode effects. In its response, GEH noted that PISYS07 has been validated using RG 1.92, Revision 1. The staff finds this to be acceptable since RG 1.92, Revision 2, acknowledges that RG 1.92, Revision 1, can still be used for new plant design work. GEH stated that it will revise DCD Appendix 3D to identify the applicability of RG 1.92, Revision 1, for the PISYS piping analysis computer code. In its response to question (5) in RAI 3.9-254, GEH clarified the documentation of PISYS 07 as it referred to Reference 3D-1 (NEDE-24210), which was published in 1979. Each new version of the PISYS program documents any program modifications in electronic design record files (eDRFs). The eDRF is used to document program changes, improvements, verifications, design reviews, and the results of program benchmarks. The eDRFs on the PISYS program maintain all documentation in accordance with GEH Engineering Operating Procedure Number 40.300 for computer programs. Each new version of PISYS is an improvement of the previous version. The new version must be benchmarked with the previous version for all defined test cases. Regarding the documentation and validation for PISYS07, GEH referred to the NRC Audit Trip Report issued May 3, 2007 for the results of the audit. Therefore, the staff concluded that RAI 3.9-254 was closed.

ESBWR DCD, Tier 2, Revision 7, Appendix 3D, Section 3D.4.2, states that the ANSI7 computer program performs the fatigue analysis, including the environmental effects for piping and components, in accordance with RG 1.207, "Guidelines for Evaluating Fatigue Analyses Incorporating the Life Reduction of Metal Components Due to the Effects of the Light-Water Reactor Environment for New Reactors," and NUREG/CR-6909. In RAI 3.9-255, the staff asked GEH to provide a summary description of the calculation of how the maximum stress intensity differences between two load sets were determined for the fatigue evaluation and of how the maximum strain rate was calculated for determining the environmental correction factor Fen in accordance with RG 1.207.

In its May 19, 2009, response to RAI 3.9-255, supplemented with information in letters dated August 15, 2009, and September 28, 2009, GEH indicated that the calculation of the alternating stress intensity between two load sets determined for the fatigue evaluation was performed in accordance with the ASME Code, Section NB-3650, Equations 10, 11, and 14. The environmental correction factor, Fen, is calculated in accordance with RG 1.207. For the strain rate effect, the maximum strain rate effect outlined in NUREG/CR-6909, Appendix A, is used. For ESBWR evaluations, the most conservative strain rate effect is assumed for all the load set ranges with the exception of dynamic cycles. The most conservative strain rate effect is the strain rate less than (0.0004 percent/second). Therefore, it is confirmed that ANSI7 assumes the maximum strain rate effect in calculating the Fen factor.

On October 26, 2009, the staff conducted an audit of the ANSI7 computer code for fatigue analysis of ESBWR safety-related Class 1 piping. The purpose of the audit was to review the ANSI7, Revision 13, verification and validation (V&V) benchmark documentation as GEH stated in the ESBWR DCD that the fatigue analysis, including the environmental effects, is performed in accordance with RG 1.207 and NUREG/CR-6909. The staff reviewed the ANSI7 Revision 13, DRF-A12-0166-00, issued July 2000, and the user's manual (both provided by GE). The staff discussed with GEH personnel the ANSI7 methodology, calculation, QA procedure, and computer code configuration control and maintenance. The staff found that ANSI7, Revision 13, as documented in the DRF, does not incorporate the environmental effects as stated in DCD Tier 2, Appendix 3D.4. During the discussion with GEH, the staff learned that the ANSI7 program was modified in March 2007 to incorporate environmental effects on the fatigue design based on the guidelines in RG 1.207 and NUREG/CR-6909. The modified version of ANSI7 was designated "Revision 14" (documented in GEH eDRF Section 0000-066-3117). Revision 14 DRF is preliminary and incomplete. The staff indicated that DCD Appendix 3D.4 should be revised to reflect that the program ANSI713D does not have the capability to calculate the environmental fatigue effects, and that the completion of the documentation and validation of ANSI714 is a followup issue affecting the use of ANSI7 to perform the fatigue analysis and account for the environmental fatigue effects for the ESBWR design certification.

As a result of the October 26, 2009, audit, the staff identified the following RAIs:

<u>RAI 3.9-255A</u>: The staff asked GEH to confirm whether the computer code ANSI713D is used for ESBWR design certification for the fatigue usage factors and to discuss how the environmental effects on fatigue usage of Class 1 piping and components were considered for the ESBWR design when using ANSI713D. If the DCD references ANSI713D, then GEH is requested to update the DCD to specify the requirement for additional analysis to account for the environmental effects on fatigue and the method that will be used for this analysis. Alternatively, GEH may update the DCD to reference a validated version of the ANSI7 code that includes the effects of environmental fatigue.

<u>RAI 3.9-255B</u>: During the October 26, 2009, audit, the staff found that both the program verification document and the ANSI 714 user's manual were preliminary and incomplete. Appendix B to 10 CFR Part 50 requires design control measures to verify the adequacy of the design of safety-related components and piping. On the basis of its review, the staff concluded that ANSI 714 was preliminary and had not been validated and was, therefore, not adequate for use in analysis of the design of Class 1 piping. The staff asked GEH to confirm whether the computer code ANSI 714 was used for ESBWR design certification, and, if necessary, discuss how and when it will complete the ANSI 714 documentation, including the V&V package and the user's instruction manual, for use in the design certification and for COL applicants.

RAI 3.9-255C: During the October 26, 2009, audit, the staff found that PISYS08 was used in lieu of PISYS07 for generation of loads and stresses for input to ANSI714 to perform resulting stresses for various load combinations and fatigue usage factors. The staff asked GEH to confirm whether the PISYS08 has been used or will be used for ESBWR design certification. If the program was used, GEH should confirm that the PISYS08 has been reviewed and approved by the NRC staff and provide V&V packages for staff review, as necessary.

In its response, and a supplemental response, GEH indicated that, as identified previously, this computer program has been updated as Version 13D to include the effects of environmental fatigue as specified in RG 1.207;; however, complete documentation was not in place to fully qualify this program to perform production work for ESBWR. GEH planned to use a two-step process to complete the qualification of this program. The first step was to document and verify all the software procedural documents, including the validation test report, an executable file, and the user's manual, in a DRF. This step was completed, and documented in DRF 0000 0109-2927. At this stage in the GEH quality program, the use of the program would have required that an alternate calculation be performed to complete the verification of a calculation that uses the program; this process would comply with 10 CFR Part 50, Appendix B. However, the applicant did not intend to use the program for production use until the second step was completed. The second step involved full qualification of the program to Level 2 status in the GEH quality program, so that the program could be used without alternate calculations. This step was completed by March 15, 2010, and will be documented in DCD Revision 8. The final version of ANSI 7 for ESBWR is Version 14 (ANSI 714). Since Table 3D.1-1 in DCD Revision 6 was premature in specifying Version 14, Corrective Action Request (CAR) 50082 was written to document the correction of this problem.

In its response, GEH confirmed that PISYS Version 08 was used for ESBWR, but similar to the response provided for ANSI 7, the Level 2 documentation was not yet complete. Version 07 contained ASME code data that were consistent with the 1989 edition of Section III of the ASME code, and PISYS needed to be updated in Version 08 to include data pertaining to ASME codes that were applicable for the ESBWR licensing basis. Using the same process as for ANSI7, GEH completed the first step for PISYS, and the documentation appeared in DRF 0000-0110-7837. The second step for the Level 2 program qualification was completed by March 15, 2010, and will be documented in DCD Revision 8.

GEH indicated that it will revise DCD Tier 2, Sections 3.7.2.7, 3D.4.1.1, 3D.4.1.2, and 3D.7 and Table 3D.1-1 as shown in markups attached to the response to clarify that all users of ANSI7 will use Version 14 and all users of PISYS will use Version 8, to provide additional details on the PISYS08 computer program, and to delete Reference 3D-1. **This is Confirmatory Item CI-SRP3.9-255-1**.

On March 19, 2010, the NRC staff performed an on-site review at the GEH office in Washington, DC, of the ESBWR V&V package for the computer codes PISYS and ANSI7, as documented in the "Summary of Follow-up Audit Conducted March 19, 2010 on Documentation of ESBWR Section 3.9.1 Computer Codes PISYS08 & ANSI714 related to RAI-3.9-254 and RAI 3.9-255," issued March 29, 2010. The intent of the review was to resolve RAIs 3.9-254 and 3.9-255. The staff reviewed the applicant's software design documents for PISYS08 and ANSI714: (1) hardware/software, (2) system specification, (3) software management plan, (4) software test plan, and (5) user's manual.

During its review of the ANSI714 V&V package, the staff noted that the temperature used in the calculation for Fen is not consistent with the procedure in NUREG/CR-6909, which states that an average temperature for the transient may be used to estimate Fen during a load cycle. GEH used the greater of either the (1) average temperature of the down-temperature transient or (2) the beginning temperature of the up-temperature transient. During the follow-up audit conducted March 19, 2010, the staff asked GEH to explain why it used a temperature different than that discussed in NUREG/CR-6909. GEH responded that fatigue consideration is for tension side; the up-temperature transient (heatup) causes compression stress. On this basis, GEH does not consider the average temperature of the up-temperature transient. The staff noted that the fatigue usage accounts for cyclic loadings of compression and tension. As a result of this discussion, the staff asked GEH either to provide technical justification or to revise the computer code to be consistent with NUREG/CR-6909. By its “Supplemental Response to Action Items from the Summary of the Follow-up Audit on documentation of ESBWR Section 3.9.1 Computer Codes PISYS08 & ANSI714 related to RAI-3.9-254 and RAI 3.9-255,” issued June 4, 2010, GEH indicated that it will revise the ANSI714 source code to use the average of the average up-transient temperature and the average down-transient temperature in the calculation of Fen. This issue was closed.

During the review of the PISYS08 user’s manual (Reference 5 of Appendix A), the staff noted that the user’s manual was not updated to incorporate the material properties revision. For instance, page 2-23 of the manual shows that the 1979 edition was noted, while page 3-1 in the test report indicates that the 2004 edition was used. In addition, GEH stated in the PISYS08 revision notes that PISYS08 has the built-in material properties for thermal expansion and modulus of elasticity based on the 2001 edition through the 2003 addenda, in lieu of the 1989 edition for PISYS07. During the follow-up audit conducted March 19, 2010, the staff asked GEH to clarify the differences in the Code edition and addenda between PISYS08 and the test report and to clarify the material properties input into PISYS, as documented in GEH’s supplemental response to the follow-up audit issued June 4, 2010. As a result, this issue was closed.

During the review, the staff noted that documents such as the PISYS08 user’s manual shows the preparer and the approver to be the same person. The staff asked GEH to discuss the QA status of this program. GEH explained that the design review team reviewed and approved the PISYS08 and ANSI714 computer codes, which are considered to be Level 2R programs. The documentation of these two programs is complete, pending the conclusion of the review and approval process by the GEH Software Control Component for a Level 2 status. The staff requested that GEH discuss the condition subject to the Level 2R program regarding its application to the design of ASME Class 1 piping and components for the ESBWR. The staff also asked GEH to commit to a date by which it would bring PISYS08 and ANSI714 to Level 2 status. In its response dated June 4, 2010, GEH indicated its commitment to attaining Level 2 status for the PISYS08 and ANSI714 programs by May 20, 2010. This issue was closed.

During the review, the staff also noted that in Section 2.1.2.3 of the PISYS08 test report, the results for pipe support should be the results for the pipe support loads. The staff asked GEH to revise the test report to address the pipe support loads. Regarding the verification of multiple support time-history analyses performed by PISYS08, the staff requested that GEH include the validation results for this method in Section 2, of the test report. In its response dated June 4, 2010, GEH indicated that it will revise the PISYS08 software test report to correct “piping supports” to “piping support loads” and will add material to Section 2.2 of the test report as shown in the mark-up pages attached to the response, which. This issue was closed.

Based on the review of the information in this section and the responses to the RAIs, the staff concludes that the computer code qualification methods described in this section are consistent with the requirements of SRP Section 3.9.1 and are therefore acceptable.

3.9.1.3.4 Experimental Stress Analysis

In accordance with the guidance in SRP Section 3.9.1.III, the staff found that the experimental stress analysis methods used in the design of ESBWR components comply with the provisions of Appendix II to the ASME Code, Section III, and were therefore acceptable.

3.9.1.3.5 Considerations for the Evaluation of Faulted Conditions—Inelastic Analyses

In accordance with the guidance in SRP Section 3.9.1.III, the staff reviewed the evaluation of components under the faulted loading conditions identified in DCD Tables 3.9-1 and 3.9-2. To complete its review, the staff requested in RAI 3.9-14 that, in accordance with SRP Section 3.9.1, for each of the components listed in DCD, Tier 2, Section 3.9.1.4, the applicant identify the computer program that it used to evaluate the stresses for determining that the limits in Appendix F to the ASME Code, Section III, have been met. In its response, the applicant stated that it will use the computer programs ASHSD2, FEMFL, and ABAQUS for determining ASME Code, Section III, Service Level D stresses, based on the elastic analysis requirements stated in paragraph F1321.3 of Appendix F to the ASME Code, Section III. The applicant also listed the program ANSYS for this purpose but stated that hand calculations are used to evaluate the stresses for determining if the Appendix F limits have been met. In supplements to this RAI, the staff requested clarification of the hand calculations and procedures used to evaluate the stresses to determine whether the Appendix F limits have been met. RAI 3.9-14 was being tracked as an open item in the SER with open items.

In its response to Supplements 2 and 3, GEH clarified how the hand calculations were performed to verify the Service Level D ANSYS stress to meet the acceptable limits in Appendix F to the ASME Code, Section III. GEH also indicated that the computer code supplied by the vendors will be qualified through the QA program described in ESBWR DCD, Tier 2, Revision 7, Chapter 17. The staff found GEH's response in accordance with requirements of appendix F to ASME Section III and the SRP, and therefore, RAI 3.9-14 and its associated open item were closed.

In RAI 3.9-15, the staff also requested that GEH describe the application of inelastic analysis to demonstrate the acceptability of a blowout of a CRD housing caused by a postulated weld failure. In its response dated May 16, 2007, the applicant submitted the requested description. The applicant stated that it performed an analysis to demonstrate the adequacy of the control rod guide tube (CRGT) to restrain a hypothetical blowout of the FMCRD and the attached control rod under a postulated failure in the weld attaching the FMCRD housing to the reactor vessel stub tube, or a postulated break in the CRD housing wall just below the weld. The applicant described these failure scenarios in DCD, Tier 2, Section 4.6.1.2.2. Under these postulated scenarios, the weight plus vessel pressure load acting on the drive and housing would tend to eject the drive. The analysis consisted of determining the elastic-plastic deformation of a model of the stainless steel CRGT base, the internal components, and the housing of the CRD, using the elastic-plastic analysis capability of the computer program ANSYS. The model was subjected to the dead weight of the FMCRD and the control rod, and the internal pressure load. Using ANSYS, the calculation determined the limiting load-carrying capability of the CRGT base and internal components under the two postulated failure scenarios. The actual loads acting on the FMCRD were then compared to the limiting loads for acceptability. The staff has evaluated the description of the analysis and found the analysis acceptable because it conformed to current industry practice; therefore, the staff considered RAI 3.9-15 closed.

In RAI 3.9-16, the staff also requested that the applicant identify the components where the inelastic Service Level D limits were met under the postulated faulted condition events. In its response, the applicant listed the CRGT, the CRD housing, and the CRD outer tube components as the components where the design is based on inelastic methods of analysis and where the inelastic Service Level D limits have been met. The staff found this response reasonable and in accordance with requirements of Appendix F in ASME Section III, and therefore considered RAI 3.9-16 closed.

Based on its review and the responses to the RAIs, the staff found that the application of elastic and inelastic analyses met the requirements stated in ASME Section III, Appendix F, and was therefore acceptable.

3.9.1.4 *Conclusions*

Based on its review of information provided by the applicant, the staff concluded that the applicant had demonstrated that PISYS08 and ANSI714 were in compliance with Appendix B to 10 CFR Part 50 and the ASME NQA-1-1994 regarding QA review for software and therefore were acceptable for ESBWR application, pending satisfactory resolution of **Confirmatory Item CI-SRP3.9-255-1**. In addition, on the basis of the evaluations in Sections 3.9.1.1 through 3.9.1.3 of this report, the staff concluded that the design transients and resulting loads and load combinations with appropriate specified design and service limits for mechanical components and met the relevant requirements of GDC 1, 2, 14, and 15; 10 CFR Part 50, Appendix B; and 10 CFR Part 50, Appendix S, and therefore, were acceptable.

3.9.2 Dynamic Testing and Analysis of Systems, Components, and Equipment

3.9.2.1 *Piping Vibration, Thermal Expansion, and Dynamic Effects*

3.9.2.1.1 Regulatory Criteria

The following regulatory requirements and guidelines provide the basis for the acceptance criteria for the staff's review:

- GDC 14, as it relates to systems and components of the RCPB being designed so as to have an extremely low probability of rapidly propagating failure or gross rupture

- GDC 15, as it relates to the RCS being designed with sufficient margin to ensure that the RCPB will not be breached during normal operating conditions, including anticipated operational occurrences

- RG 1.124, "Service Limits and Loading Combinations for Class 1 Linear-Type Component Supports"

- ASME Code, Section III, 2001 Edition including Addenda through 2003

- RG 1.68, "Initial Test Programs for Water-Cooled Nuclear Power Plants"

- ASME OM S/G-2003 Standard, Part 3, "Requirements for Pre-operational and Initial Startup Testing of Nuclear Plant Piping Systems"

- ASME OM S/G-2003 Standard, Part 7, “Requirements for Thermal Expansion Testing of Nuclear Plant Piping Systems”

3.9.2.1.2 Summary of Technical Information

In DCD, Tier 2, Revision 7, Section 3.9.2.1, the applicant discussed the vibration and dynamic effects testing, which included measurement techniques, monitoring requirements, test evaluation, acceptance criteria and reconciliation, and corrective actions. The applicant also discussed methods for determining the acceptability of steady-state and transient vibration for the affected systems (visual observation, local measurements, and remotely monitored and recorded measurements).

The applicant stated that the thermal expansion, preoperational, and startup testing program verifies that normal, unrestrained thermal movement occurs in specified safety-related high- and moderate-energy piping systems. The testing is performed through the use of visual observation and remote sensors. The purpose of this program is to ensure that the piping system is free to expand during system heatup and cooldown and to move without unplanned obstruction or restraint in the x, y, and z directions. The program also provides for measurement techniques, monitoring requirements, test evaluation, acceptance criteria and reconciliation, and corrective actions.

3.9.2.1.3 Staff Evaluation

The staff performed its review of the piping vibration, thermal expansion, and dynamic effects testing in accordance with SRP Section 3.9.2, Revision 3. This review consisted of an evaluation of DCD, Tier 2, Section 3.9.2.1, Section 14.2.8.1.42, Section 14.2.8.2.9, and Section 14.2.8.2.10. Areas reviewed encompassed the criteria, testing procedures, and dynamic analyses employed to ensure the structural and functional integrity of piping systems and their supports (including supports for conduit and cable trays and ventilation ducts) under vibratory loadings, including those caused by fluid flow and postulated seismic events, to confirm conformance with GDC 1, 2, 4, 14, and 15.

Piping vibration, thermal expansion, and dynamic effects testing should be conducted during startup testing. The staff’s review covers the following specific areas:

- all ASME Code Class 1, 2, and 3 systems

- other high-energy piping systems inside seismic Category I structures

- high-energy portions of systems whose failure could reduce the functioning of any seismic Category I plant feature to an unacceptable safety level

- seismic Category I portions of moderate-energy piping systems located inside containment

In DCD, Tier 2, Section 3.9.2.1, the applicant stated that, because one of the goals of the dynamic effects testing is to verify the adequacy of the piping support system, such components are addressed in this section and more specific requirements are provided in DCD, Tier 2, Section 3.9.3 7. Section 3.9.3.7 of this report presents a detailed staff review of these requirements.

In DCD, Tier 2, Section 14.2.8.1.42, the applicant provided classifications of systems to be monitored which conform generally with system classifications required by SRP Section 3.9.2, as stated above, with one exception. While SRP Section 3.9.2 requires all ASME Code Class 1, 2, and 3 systems to be monitored, the applicant simply stated ASME Code Class 1, 2, and 3 systems. Section 14.2.9 in DCD Tier 2 states that, to be exempt from such license conditions, the COL applicant must provide the final list of tests proposed, including adoption or augmentation of the above list, as appropriate. However, the applicant does not discuss the limitations on the changes that the COL applicant can make. Therefore, the staff was unable to assess which specific systems are covered under the vibration and dynamic effects testing program, described in DCD, Tier 2, Section 3.9.2.1.1 or whether the applicant intends to monitor all ASME Code Class 1, 2, and 3 systems. In RAI 3.9-17, the staff requested that the applicant provide a listing of the high- and moderate-energy piping systems covered by the vibration and dynamic effects testing program, described in DCD, Tier 2, Section 3.9.2.1.1, and those that are exempt. The staff also asked the applicant to provide the bases for these exemptions and verify that the program will include all ASME Code Class 1, 2, and 3 systems.

In its response to RAI 3.9-17, the applicant provided the requested information as follows:

> In accordance with RG 1.68, Appendix A, the following systems or portion of systems are covered by the vibration and dynamic effects testing program:
>
> - ASME Code Class 1, 2, and 3 Systems,
> - other High-Energy piping inside seismic Category I structures,
> - high-energy portions of systems whose failure could reduce the functioning of any seismic Category I plant feature to an unacceptable level, and
> - Seismic Category I portions of moderate-energy piping systems located outside Containment.
>
> The systems to be considered [in the ESBWR] are the following:
>
> - Nuclear Boiler System (B21)
> - ICS (B32)
> - CRD System (C12)
> - Standby Liquid Control System (C41)
> - Gravity Driven Cooling System (E50)
> - FAPCS (G21)
> - RWCU/SCS (G31)
> - FPS (U43)
> - Equipment and Floor Drain System (U50)
> - CWS (P25)

The staff finds the applicant's response reasonable and satisfactory because it provides a listing of the high- and moderate-energy piping systems, as requested. Therefore, RAI 3.9-17 was closed.

Essentially, three methods are available for determining the acceptability of steady-state and transient vibration for the affected systems. These include visual observation, local measurements, and remotely monitored and recorded measurements. The technique used depends on such factors as the safety significance of the particular system; the expected mode or magnitude, or both, of the vibration; the accessibility of the system during designated testing conditions; or the need for a time-history recording of the vibratory behavior. The applicant described general criteria based on the measurement technique selected. However, the applicant did not provide sufficient information to allow the staff to determine the specific technique used for a particular system. Therefore, in RAI 3.9-18, the staff requested that the applicant provide a listing of the systems to identify which measurement technique (visual observation, local measurements, or remotely monitored and recorded measurements) will be used on each piping system covered by the vibration and dynamic effects testing program.

In its response to RAI 3.9-18, the applicant stated the following:

> Within each applicable vibration category (steady-state and transient), the piping will be classified into one of the three vibration monitoring groups according the criteria presented in Paragraphs 3.1.1 and 3.1.2 of ASME OM S/G Standard, Part 3:
>
> (1) Vibration Monitoring Group 1 (VMG1) (Remote sophisticated monitoring devices and extensive data collection): Systems that exhibit a response not characterized by simple piping modes. The locations of the measurement points will be selected taking into account the maximum deformation in the modes of greatest mass participation. The following systems are VMG1.
>
> – MS piping and SRV discharging piping in the drywell
> – Feedwater piping inside the containment
>
> (2) Vibration Monitoring Group 2 (VMG2) (Local measurements): Systems that may exhibit significant vibration response based on past experience with similar systems or similar system operating conditions. As a general rule vibration measurement points will be located at:
>
> – Pump intakes and discharges
>
> – Devices that cause pressure drops, like flow restrictors, control valves, etc.
>
> – Quick-acting valves
>
> – Check valves
>
> (3) Vibration Monitoring Group 3 (VMG3) (Visual methods): Systems that are not expected to exhibit significant vibrational response based on past

experience with similar systems or similar system operating conditions. The following measurement points fall within this group:

- Drains and vents
- Instrumentation pipings—Pumps in parallel
- Weld junctions
- Sensitive equipment (valves, heat exchangers, pumps, etc.)

The staff finds the applicant's response reasonable and acceptable because it provides a listing of the systems to identify which measurement technique (visual observation, local measurements, or remotely monitored and recorded measurements) will be used on each piping system. Therefore, RAI 3.9-18 was closed.

Section 3.9.2.1.1 in DCD Tier 2 states that, for steady-state vibration, the Level 1 criteria are based on 68.95 megapascal (MPa) (10,000 pounds per square inch (psi)) maximum stress to ensure that failure from fatigue over the life of the plant will not occur. The corresponding Level 2 criteria are based on one-half of 68.95 MPa (10,000 psi) or 34.5 MPa (5,000 psi). However, the applicant did not provide a basis for using these limits for all piping configurations, environments, and materials. Therefore, in RAI 3.9-19, the staff requested that the applicant explain how these stress levels envelop all of the piping systems, configurations, environments, and materials. Alternately, the staff asked the applicant to provide a reference document that describes the vibration monitoring program.

In its response to RAI 3.9-19, the applicant provided the requested information as follows:

> The vibration criteria are based on ASME OM-S/G Standard, paragraph 3.2.1.2. For SS, the Level 1 criteria are 10,880 psi (75 MPa) and 5440 psi (37.5 MPa) for Level 2. For carbon steel and low alloy steel, the Level 1 criteria is 7692 psi (53 MPa) and 3846 psi (27.5 MPa) for Level 2. These are the applicable piping materials as defined in DCD, Tier 2, Tables 5.2-4 and 6.1-1.

Based on its review of the applicable piping materials defined in DCD, Tier 2, Revision 7, Tables 5.2-4 and 6.1-1, the staff finds that the stress levels envelop all of the piping systems. Therefore, RAI 3.9-19 was closed.

The applicant stated the following in DCD, Tier 2, Section 3.9.2.1.1:

> During the course of the tests, the remote measurements are regularly checked to verify compliance with acceptance criteria. If trends indicate that criteria may be violated, the measurements are monitored at more frequent intervals. The test is held for Level 2 criteria violations and terminated as soon as Level 1 criteria are violated.

The staff needed more information to determine how remote measurements are regularly checked during tests to verify compliance with the acceptance criteria, as stated in DCD, Tier 2, Section 3.9.2.1.1. In DCD Tier 2, the applicant stated that the piping response to test conditions is considered acceptable if the review of the test results indicates that the piping responds in a manner consistent with predictions of the stress report and/or that piping stresses are within the ASME Code, Subsections NB, NC, or ND-3600, limits. Acceptable limits will be determined after the completion of a piping system's stress analysis and will be provided in the piping test specifications. The applicant provided no discussion relative to the analytical methodology.

Therefore, in RAI 3.9-20, the staff requested that the applicant discuss in greater detail how remote measurements are regularly checked during tests to verify compliance with acceptance criteria. The staff requested that the discussion cover the vibration measurement and analysis methodology, including the approximate number of locations monitored, the specific systems covered by this monitoring, the basis for selection of systems and locations, and the instrumentation and analyzers used for such monitoring. Alternately, the staff asked the applicant to provide a reference document that describes the vibration monitoring program.

In its response, the applicant stated the following:

> Refer to Attachment B "ESBWR Startup Acceptance Criteria For Piping" which explains how remote measurements during testing ensure compliance with the acceptance criteria, how remote measurements are regularly checked during tests to verify compliance with acceptance criteria, the vibration measurement and analysis methodology including the approximate number of locations monitored, the specific systems covered by this monitoring, the basis for selection of systems and locations as well as the instrumentation/analyzers used for such monitoring.

Based on its review of the referenced document, the staff finds that it contains a satisfactory explanation of how remote measurements during testing ensure compliance with the acceptance criteria and how remote measurements are regularly checked during tests to verify compliance with acceptance criteria. In addition, the applicant satisfactorily addressed other staff concerns related to the vibration measurement and analysis methodology. Therefore, RAI 3.9-20 was closed.

The applicant further stated that, to ensure test data integrity and test safety, criteria have been established to facilitate assessment of the test while it is in progress. For steady-state and transient vibration, the pertinent acceptance criteria are usually expressed in terms of maximum allowable displacement and deflection. Visual observation is only used to confirm the absence of significant levels of vibration and not to determine the acceptability of any potentially excessive vibration. Therefore, in some cases, other measurement techniques will be required with appropriate quantitative acceptance criteria. The staff found that this description is too general and does not meet the acceptance requirement set forth in SRP Section 3.9.2.1. Therefore, in RAI 3.9-21, the staff requested that the applicant discuss methods used to anticipate piping movements and deflections. The staff also asked the applicant to identify and discuss any computer codes used in the analysis and to indicate whether or not they had been benchmarked or approved by the NRC. Alternately, the staff asked the applicant to provide a reference document that describes the piping system stress analysis methodology.

In its response to RAI 3.9-21, the applicant provided the following information:

> On May 12, 1979, the NRC sent a letter to the General Electric Company requesting that a set of five NRC generated benchmarks problems be solved with the PISYS Code. In August 1979, all benchmark problem results were compared and documented in NEDO-24210, which has about 1000 pages. Excellent agreements for all five cases were found and all the NRC requirements were met. Attachment A shows the cover page, introduction and conclusion of NEDO-24210 for reference.
>
> The NRC published the benchmark problems in NUREG-1677 in August 1985.

NUREG/CR-6409, BNL-NUREG-52377 (Attachment B)

This NUREG describes the piping benchmark problems for General Electric ABWR. The benchmark problems were performed by BNL to compare with PISYS analysis results. The piping systems selected for the analyses are ABWR feedwater piping and safety relief discharge piping. BNL completed their analysis using their computer program. The results of comparisons showed that PISYS analysis results were very close to the BNL results. Because PISYS program was used for the analysis of FOAKE project for the NRC, they were satisfied with BNL benchmark comparisons.

Testing Specifications

- For test specification, there are two Level of Limits, Limits on the pipe motion are established as "Level 1" and "Level 2" criteria to facilitate evaluation of the tests results. The limits are described in the following paragraphs.

Level 1: "Level 1" is that specified level of pipe motion which, if exceeded, mandates that the test be placed either on hold or terminated.

Level 2: "Level 2" is that specified level of pipe motion, which, if exceeded, requires that the responsible Piping Design Engineer, be advised. If a Level 2 limit is not satisfied, plant operating and startup testing plans will not necessarily be altered. However, an investigation of the measurements and of the criteria and calculations used to generate the pipe motion limits should be initiated. All appropriate and involved parties must reach an acceptable resolution to complete the evaluation of this test condition. Depending upon the nature of such resolution, the applicable tests may or may not have to be repeated.

Level 2 thermal displacement limits are the same as the calculated displacements for the test mode. Level 1 displacement limits are in accordance with the ASME Code. The expansion stresses resulting from pipe displacement are equal to or less than the 3 S_m limit for the mode tested.

Based on a review of the information provided by the applicant relating to benchmarking the computer codes used in the analyses and testing specifications, the staff finds that GEH has provided adequate information to resolve the staff's concerns in RAI 3.9-21. Therefore, RAI 3.9-21 was closed.

Section 14.2.8.2.10 in DCD Tier 2 states that vibration testing during the power ascension phase is limited to those systems that cannot be adequately tested during the preoperational phase. Systems within the scope of this testing are therefore the same as those mentioned in Section 14.2.8.1.42. This safety evaluation report discussed the staff's concerns with these systems in previous sections. The applicant stated that the systems that remain to be tested are primarily those exposed to and affected by steam flow and high rates of core flow. Because of the potentially high levels of radiation present during power operation, the testing is performed using remote monitoring instrumentation. Displacement, acceleration, and strain data are collected at various, critical steady-state operating conditions and during significant anticipated operational occurrences, such as turbine or generator trip, MSL isolation, and SRV actuation. The staff determined that SRP Section 3.9.2.1 requires a complete listing of the transients. Therefore, in RAI 3.9-22, the staff requested that the applicant provide a listing of the different flow modes of operation and transients, such as pump trips and valve closures, to which the components will be subjected during the tests.

In its response to RAI 3.9-22, the applicant referred the staff to DCD, Tier 2, Table 14.2-1, which identifies the power ascension test matrix, for the additional testing information requested. Based on its review of the information in the power ascension test matrix in DCD, Tier 2, Revision 7, Table 14.2-1, the staff finds that the applicant provided sufficient information concerning the different flow modes of operation and transients to which the components will be subjected during the test to resolve the staff's concerns in RAI 3.9-22. Therefore, RAI 3.9-22 was closed.

However, DCD, Tier 2, Revision 7, Section 3.9.2.1.1, lacks information relative to visual inspections and measurements. Therefore, in RAI 3.9-23, the staff requested that the applicant provide a list of selected locations in the piping system at which visual inspections and measurements will be performed during the tests. The staff asked the applicant to provide for each of these selected locations the deflection (peak-to-peak) or other appropriate criteria to be used to demonstrate that the stress and fatigue limits are within the design levels.

In its response to RAI 3.9-23, the applicant stated the following:

> Visual inspections are performed on systems that are not expected to exhibit significant vibration response based on past experience with similar systems or similar system operating conditions. All drain, vent systems, instrumentation piping 1" and under, are not expected to have significant vibration. These systems can use visual inspections. Any system using visual inspection should have vibration so low, that it will meet the ASME OM-S/G standard, Part 3 Appendix D velocity screen criteria, 0.5 in/sec. The above criteria and the other criteria specified in Subsection 3.9.2.1.1 are used to establish the visual inspection and measurement plan when the system piping details and analysis have been completed. See also response to RAI 3.9-18.

The locations selected for visual inspection are provided in the response to RAI 3.9-18. The staff finds the applicant's response reasonable and acceptable because it provides the basis for selecting locations in the piping system at which visual inspections and measurements will be performed during the tests. The applicant also provided appropriate criteria to be used to demonstrate that the stress and fatigue limits are not exceeded. Therefore, the concerns related to RAI 3.9-23 were resolved.

In DCD, Tier 2, Section 3.9.2.1.2, the applicant stated that the thermal expansion testing program includes all safety-related piping. Thermal expansion of specified piping systems is measured at both the cold and hot extremes of their expected operating conditions. Walkdowns and recording of hanger and snubber positions are conducted where possible, considering accessibility and local environmental and radiological conditions in the hot and cold states. Displacements and appropriate piping and process temperatures are recorded for those systems and conditions specified. Sufficient time must have passed before taking such measurements to ensure that the piping system is at a steady-state condition. In selecting locations for monitoring piping response, consideration should be given to the maximum responses predicted by the piping analysis. Specific consideration should also be given to the first run of pipe attached to component nozzles and pipe adjacent to structures requiring a controlled gap. The staff requires that the testing program provide a list of snubbers on systems that experience sufficient thermal movement to measure snubber travel from the cold to hot position, once the piping analysis is completed. The applicant should identify this item as an action item for the COL applicant and include it in the list of action items to be completed by the COL applicant in the ESBWR DCD Tier 2 document. Therefore, in RAI 3.9-24, the staff asked the applicant to provide this information. In its response to RAI 3.9-24, the applicant stated that it will revise DCD, Tier 2, Section 3.9.3.7.1(3), to acknowledge that this is an action item for the COL applicant. The applicant has since revised DCD, Tier 2, Section 3.9.3.7.1(3)f to include COL Information Item 3.9.9-4-A for the snubber testing program. Therefore, RAI 3.9-24 was closed.

In RAI 3.9-25, the staff asked the applicant to provide a more detailed description of the thermal motion monitoring program for verification of snubber movement; adequate clearances and gaps, including acceptance criteria; and measurement of snubber motion. Alternately, the staff requested that the applicant provide a reference document that describes the thermal motion monitoring program.

Based on the applicant's response to RAI 3.9-10 and the information in DCD, Tier 2, Revision 7, Section 3.9.2.1.2, as discussed below, the staff determined that the applicant provided adequate information relative to the thermal motion monitoring program to satisfactorily address the staff's concerns in RAI 3.9-25. Therefore, RAI 3.9-25 was closed.

Test Evaluation and Acceptance Criteria

To ensure test data integrity and test safety, the applicant has established criteria to facilitate assessment of the test while it is in progress. Limits of thermal expansion displacements are established before the start of piping testing; the actual measured displacements are then compared to these limits to determine the acceptability of the actual motion. If the measured displacement does not vary from the acceptance limits by more than the specified tolerance, the applicant considers the piping system to be responding in a manner consistent with the predictions and is therefore acceptable. The piping response to test conditions is considered acceptable if (1) the test results indicate that the piping responds in a manner consistent with the predictions of the stress report and/or (2) the piping stresses are within the ASME Code, Subsections NB, NC, or ND-3600, limits. Acceptable thermal expansion limits are determined after the completion of a piping system stress analysis and are provided in the piping test specifications. Level 1 criteria are bounding based on the ASME Code, Section III, stress limits. Level 2 criteria are stricter based on the predicted movements using the calculated deflections plus a selected tolerance.

Reconciliation and Corrective Actions

During the course of the tests, the applicant has committed to regularly check and verify compliance with the acceptance criteria via remote measurements. If trends indicate that the criteria may be violated, the measurements are monitored at more frequent intervals. The test is held for Level 2 criteria violations and terminated as soon as Level 1 criteria are violated. As soon as possible after the test hold or termination, investigative and corrective actions are taken. If practicable, a walkdown of the affected piping and suspension system is made to identify potential obstruction to free piping movement. Hangers and snubbers should be positioned within their expected cold and hot settings. All signs of damage to piping or supports are investigated.

The applicant will check for proper operation and calibration of instrumentation, including comparison with other instrumentation located in the proximity of the out-of-bounds movement. Assumptions, such as piping temperature, used in the calculations that generated the applicable limits are compared with actual test conditions. The criteria account for noted discrepancies, including possible reanalysis. The staff determined that the applicant did not provide sufficient information relative to the corrective actions. Therefore, in RAI 3.9-26, the staff requested that the applicant provide detailed information relative to the use of corrective restraints if vibration is noted beyond acceptable levels or no motion is observed at stations where large motion is predicted.

In its response to RAI 3.9-26, the applicant stated the following:

> Corrective restraints are added if the existing restraints are determined inadequate or damaged, depending on the vibration frequency range (low or high frequency). Low frequency vibration can be adequately restrained through the addition of supports, preferably located near bends, heavy concentrated masses and piping discontinuities. Vibration of vents, drains, bypass and instrument piping can be corrected by bracing the masses to the main pipe eliminating relative vibrations.

The staff finds these corrective measures acceptable because they will reduce the piping system vibration.

The applicant further stated the following:

> Spring Sway Struts can be used for controlling low frequency vibration problems. Straps with elastomeric elements and no gap can be also used for high frequency, located at points with high dynamic vibration susceptibility. The snubber piston travel should not be affected by the vibration displacements. This is because the snubber travel is significantly larger than the vibration amplitude, which is normally less than 0.020 inches.

The staff finds the applicant’s response reasonable and acceptable because it describes the identified discrepancies in snubber motion, as requested. Therefore, RAI 3.9-26 was closed.

3.9.2.1.4 Conclusion

The staff concludes that the applicant has met the relevant requirements of GDC 14 and 15 with respect to the design and testing of the RCPB to ensure that design conditions are not exceeded during normal operation, including anticipated operational occurrences. The applicant will conduct an acceptable vibration, thermal expansion, and dynamic effects test program during startup and initial operation on specified high- and moderate-energy piping and all associated systems, restraints, and supports.

The tests will provide adequate assurance that the piping and piping restraints of the system have been designed to withstand vibrational dynamic effects resulting from valve closures, pump trips, and other operating modes associated with the design-basis flow conditions. In addition, the tests provide assurance that adequate clearances and free movement of snubbers exist for unrestrained thermal movement of piping and supports during normal system heatup and cooldown operations.

3.9.2.2 *Seismic Analysis and Qualification of Mechanical Equipment*

3.9.2.2.1 Regulatory Criteria

The following regulatory requirements provide the basis for the acceptance criteria for the staff's review:

- GDC 2, as it relates to systems, components, and equipment important to safety being designed to withstand appropriate combinations of the effects of natural phenomena such as earthquakes

- Appendix S to 10 CFR Part 50, as it relates to the suitability of the plant design bases for mechanical components established in consideration of site seismic characteristics

- RG 1.92, Revision 2

3.9.2.2.2 Summary of Technical Information

DCD, Tier 2, Section 3.9.2.2, describes the criteria for dynamic qualification of safety-related mechanical equipment and associated supports, as well as the qualification testing and analysis applicable to the major components on a component-by-component basis. Seismic and other events that may induce reactor building vibration (RBV) are considered.

3.9.2.2.3 Staff Evaluation

The staff performed its review of the seismic analysis and qualification of mechanical equipment in accordance with SRP Section 3.9.2, Revision 3. The review consisted of an evaluation of DCD, Tier 2, Section 3.9.2.2, and portions of Sections 3.7.2, 3.7.3, and 3.10. It applied to all seismic Category I systems, components, and equipment and their supports (including supports for conduit, cable trays, and ventilation ducts). Areas reviewed included seismic analysis methods, determination of the number of earthquake cycles, basis for the selection of frequencies, combination of modal responses and spatial components of an earthquake, criteria used for damping, torsional effects of eccentric masses, interaction of other piping with seismic Category I piping, and buried seismic Category I piping.

In DCD, Tier 2, Section 3.7.3.2, the applicant stated that SSE is the only design earthquake considered for the ESBWR standard plant. To account for the cyclic effects of the more frequent occurrences of lesser earthquakes and their aftershocks, the fatigue evaluation for ASME Code Class 1, 2, and 3 components and CS structures considers two SSE events with 10 peak stress cycles per event for a total of 20 full cycles of the peak SSE stresses. This is equivalent to the cyclic load basis of one SSE and five OBE events, as recommended in SRP Section 3.7.3, which is consistent with the guidance provided in the July 21, 1993, SRM for SECY-93-087. Alternatively, a number of fractional vibratory cycles equivalent to 20 full SSE vibratory cycles may be used (with amplitude not less than one-third of the maximum SSE amplitude) when derived in accordance with Appendix D to IEEE 344-1987.

The staff also found the above proposed earthquake events and number of peak stress cycles to be consistent with the requirements of RG 1.100, "Seismic Qualification of Electric and Mechanical Equipment for Nuclear Power Plants," which endorses IEEE 344-1987 for both the fatigue evaluation of ASME Code Class 1, 2, and 3 components and CS structures and the seismic qualification of safety-related mechanical equipment. The applicant's proposed approach is, therefore, acceptable.

For generic sites, the design response spectra are developed in accordance with the response spectrum of RG 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants," which is anchored to a peak ground acceleration (PGA) of 0.3 acceleration due to gravity (g), both in the horizontal and vertical directions. In DCD Tier 2, Section 3.7.5.1, the applicant stated that, to confirm the seismic design adequacy, COL applicants referencing the ESBWR design must demonstrate that the site-specific, free-field SSE ground response spectra of 5-percent damping, defined as outcrop spectra at the foundation level (bottom of the base slab), are enveloped by the ESBWR design response spectra, as shown in DCD, Tier 2, Figures 2.5-1 and 2.5-2, for the horizontal and vertical direction, respectively. Section 3.7.1 of this report provides the staff's evaluation of the development of the enveloping design spectra.

Input motions for the qualification of equipment and piping are usually in the form of FRS and displacements obtained from the primary system dynamic analysis. Dynamic qualification can be performed by analysis, testing, or a combination of both, or by the use of experience data. Selection of testing, analysis, or a combination of the two is determined by the type, size, shape, and complexity of the equipment being considered. When practical, operability is determined by testing. Otherwise, operability is demonstrated by mathematical analysis or by a combination of test and analysis. It is noted that equipment that is large, simple, or consumes large amounts of power is usually qualified by analysis or static bend tests to show that the loads, stresses, and deflections are less than the allowable maximum. Analysis or static bend testing, or both, is also used to show that there are no natural frequencies below the zero period acceleration (ZPA) defined in DCD, Tier 2, Section 3.7.2.7. When the equipment is qualified by dynamic test, the response spectrum or time history of the attachment point is used in determining input motion.

Natural frequency may be determined by running a continuous sweep frequency search using a sinusoidal steady-state input of low magnitude. Dynamic load conditions are simulated by testing, using random vibration input or single frequency input within equipment capability over the frequency range of interest. Whichever method is used, the input amplitude during testing envelops the actual input amplitude expected during the dynamic loading condition.

The equipment being dynamically tested is mounted on a fixture, which simulates the intended service mounting and causes no dynamic coupling to the equipment. Other interface loads (e.g., nozzle loads, weights of internal and external components attached) are simulated. Equipment having an extended structure, such as a valve operator, is analyzed by applying static equivalent dynamic loads at the center of gravity of the extended structure. In cases in which the equipment's structural complexity makes mathematical analysis impractical, a static bend test is used to determine spring constant and operational capability at maximum equivalent dynamic load conditions.

The staff found the tests and analysis criteria and methods, as provided in DCD, Tier 2, Section 3.9.2.2.1, for equipment seismic and dynamic qualification, to be generally consistent with industry practice. Therefore, they are acceptable. The staff also found that qualification of safety-related major mechanical equipment, as presented in DCD, Tier 2, Section 3.9.2.2.2, generally follows the guidelines provided.

For other ASME Code, Section III, equipment, the methodology and criteria of testing, including natural frequency search, generally follow those described above for the safety-related major mechanical equipment. The equipment, including associated supports, is qualified for seismic and other RBV loads to ensure its functional integrity during and after the event. The equipment is tested, if necessary, to ensure its ability to perform its specified function before, during, and following a test. For this equipment, the critical damping values for welded steel structures from DCD, Tier 2, Table 3.7-1, are employed.

For devices that are housed inside a large piece of equipment or component, such as consoles or racks, the individual devices may be tested separately, when necessary, in their operating condition. The component to which the device is assembled is vibration tested with a similar but inoperative device installed on it. The component should be mounted on the vibration generator in a manner that simulates the final service mounting. The goal of the testing is to determine that, at the specified vibratory accelerations, the support structure does not amplify the forces beyond the level to which the devices have been qualified.

Equipment for which continued function is not required after a seismic or other RBV loads event, but whose postulated failure could produce an unacceptable influence on the performance of systems having a primary safety function, is also evaluated. Such equipment is qualified to the extent necessary to ensure that an SSE including other RBV loads, in combination with normal operating conditions, will not cause unacceptable failure. Qualification requirements are satisfied by ensuring that the equipment in its functional configuration, complete with attached appurtenances, remains structurally intact and affixed to the surface. In this case, the structural integrity of internal components is not required; however, adequate enclosure of such components is required to ensure their confinement. Where applicable, fluid or pressure boundary integrity will be demonstrated.

Section 3.10 of this report provides a more detailed discussion of the methodology and criteria used for the mechanical equipment seismic and dynamic qualification by testing or the use of experience data.

In accordance with SRP Section 3.9.2, conduit and cable trays and ventilation ducts and their supports should be designed for postulated seismic loadings. The staff review of DCD, Tier 2, Sections 3.7.3 and 3.9.2, noted that the applicant did not provide sufficient information for the qualification of seismic Category I cable tray and conduit supports. DCD, Tier 2, Section 3.10.3.2, provides only limited information for loadings that are used for their design and analysis. In RAI 3.9-27, the staff requested that the applicant provide a detailed discussion on the methods and criteria used for the design of the seismic Category I electrical raceways (cable trays, conduits, and HVAC) and their supports, including the applicable codes, standards, and specifications used for the design. The staff also requested that the applicant explain how the design would conform to the guidance of SRP Section 3.9.2.

In its response to RAI 3.9-27, the applicant stated that it will revise DCD, Tier 2, Sections 3.8.4.1.6, 3.8.4.1.7, 3.9.2, 3.10.3.2, 9.4.1.3, 9.4.2.3, and 9.4.6.3, to incorporate all pertinent information regarding the design of the seismic Category I electrical raceways (cable trays, conduits, and HVAC) and their supports. In DCD, Tier 2, Sections 3.8.4.1.6 and 3.8.4.1.7, the applicant stated that cable tray, conduit, and HVAC duct locations are based on the requirements of the electrical cable network and HVAC system, respectively. They are supported at intervals by supports made of hot- or cold-rolled steel sections. The supports are attached to the walls, floor, and ceilings of structures as required by the arrangement. The type of support and spacing is determined by allowable tray or conduit spans, which are governed by rigidity and stress. Bracing is provided where required. The loads, loading combinations, and allowable stresses are in accordance with applicable codes, standards, and regulations, consistent with Tables 3.8-6 and 3.8-9 of DCD Tier 2. In addition, DCD, Tier 2, Sections 3.9.2 and 3.10.3.2, specify the design and location requirements for conduit and cable tray supports, whereas Sections 3.9.2, 9.4.1.3, 9.4.2.3, and 9.4.6.3 also specify the design and location requirements for HVAC ducts and their supports.

In Section 3.9.2 of DCD Tier 2, the applicant stated that conduit and cable trays and ventilation ducts and their supports are designed to ensure their structural and functional integrity under vibratory loadings, including those caused by fluid flow and postulated seismic events, as discussed in SRP Section 3.9.2. In Section 3.10.3.2 of DCD Tier 2, the applicant stated that seismic Category I cable trays and conduit supports are designed by the response spectrum method. Analysis and dynamic load restraint measures are based on combined limiting values for static load, span length, and response to excitation at the natural frequency. The structural capacity of the tray is used in configuring restraints against excessive lateral and longitudinal movement and in determining the spacing of the fixed support points. Provisions for differential motion between buildings are made by breaks in the trays and by flexible connections in the conduit. The applicant stated that, regardless of cable tray function, all tray supports are designed to meet seismic Category I requirements. In addition, the floor response spectra (FRS) used are those generated for the supporting floor. For the cases in which supports are attached to the walls or to two different locations, the upper bound enveloped spectra are used. In many cases, to facilitate the design, several FRS are combined to form an upper bound envelope.

Based on the additional information provided by the applicant, the staff determined that the design methodologies and criteria will provide reasonable assurance that the seismic Category I cable trays and conduits and HVAC ducts, and their supports will perform their safety function. Therefore, RAI 3.9-27 was closed.

Seismic FRS are developed from the primary structural dynamic analysis using the time-history method. A direct spectra generation without resorting to time history is also acceptable if adequately justified. Seismic FRS for various damping values are generated in three orthogonal directions (two horizontal and one vertical) at various elevations and locations of interest to the design of equipment and piping. When the dynamic analyses are performed separately for each of the three components of the input motion, the resulting codirectional response spectra are combined according to the square root of the sum of the squares (SRSS) method to obtain the combined response spectrum in that direction. An alternative approach to obtaining the codirectional FRS is to perform dynamic analysis with simultaneous input of the three excitation components, if those components can be justified to be statistically independent of one another. The FRS so calculated are peak broadened by ±15 percent to account for uncertainties in the structural frequencies resulting from uncertainties in the material properties of the structure and soil and from approximations in the modeling techniques used in the analysis. When the calculated floor acceleration time history is used in the time-history analysis for piping and equipment, the uncertainties in the time history are accounted for by expanding and shrinking the time history within $1/(1\pm0.15)$ so as to change the frequency content of the time history within ±15 percent. Alternatively, a synthetic time history that is compatible with the broadened FRS may be used.

The staff found the applicant's proposed approach for the FRS generation and its peak broadening to be adequate. Section 3.7.2 of this report provides further discussion and the staff's evaluation of the method proposed for generating the amplified building response spectra.

The applicant performed the subsystem analyses on an elastic basis. Multiple degree of freedom (DOF) modal response spectrum and time-history methods formed the basis for the analyses of all major seismic Category I systems and components. When the response spectrum method was used, modal responses, up to the ZPA frequency of 100 hertz (Hz), were considered. Sections 3.12.4.2 and 3.12.4.3 of this report discuss the modal combination methods used for either uniform support motion (USM) or independent support motion of analysis, respectively.

The applicant stated that the mathematical modeling of primary piping systems is generally developed according to the finite element model (FEM) procedures described in DCD, Tier 2, Section 3.7.2.3. The models are constructed to reflect the dynamic characteristics of the system. The continuous system is modeled as an assemblage of piping elements (straight sections, elbows, and bends), supported by hangers and anchors, and restrained by pipe guides, struts, and snubbers. Pipe sections and hydrodynamic fluid masses are lumped at the nodes and connected by massless elastic elements, which reflect the physical properties of the corresponding piping segment. In general, six DOFs are assigned to each mass nodal point (i.e., three translational and three rotational). The mass nodal points are selected to coincide with the locations of large masses, such as valves, pumps, and motors, and with areas of significant geometry change. All concentrated weights on the piping system, such as the valves, pumps, and motors, are modeled as lump mass rigid systems if their fundamental frequencies are greater than the cutoff frequency. On straight runs, mass points are located at spacing no greater than the span that would have a fundamental frequency equal to or less than the cutoff frequency when calculated as a simply supported beam with uniformly distributed mass. The analytical model includes the torsional effects of valve operators and other equipment with an offset center of gravity with respect to the piping center line. The number of dynamic DOFs is considered adequate when additional DOFs do not result in more than a 10-percent increase in response. Alternatively, the number of dynamic DOFs is no less than twice the number of modes below the ZPA frequency. The staff considered the above FEM approach of piping segments to be consistent with the general industry practice. Therefore, it is acceptable.

The applicant stated that all pipe guides and snubbers are modeled so as to produce representative stiffness. The equivalent linear stiffness of the snubbers is based on actual dynamic tests performed on prototype snubber assemblies or on data provided by the vendor. Pipe supports will be designed and qualified to satisfy stiffness values used in the piping analysis. For struts and snubbers, the stiffness to consider is the combined stiffness of strut, snubber, pipe clamp, and piping support steel. In RAI 3.9-28, the staff asked the applicant to further discuss the process used to calculate the representative snubber stiffness for each different size, type, and design of snubbers. By letter dated February 16, 2007, the applicant stated that the vendor's standard procedures for stiffness measurement typically provide equivalent linear stiffness of snubber assemblies. The vendor's data are based on certified test results, which would not typically require separate independent verification by the applicant. The applicant revised DCD, Tier 2, Section 3.7.3.3.1, to incorporate this information. This is acceptable to the staff, and RAI 3.9-28 was closed.

In DCD, Tier 2, Section 3.7.3.3.1, the applicant stated that, in general, the piping analysis considers pipe support component weights, which are directly attached to a pipe such as a clamp, strut, snubber, and trapeze. Frame-type supports will be designed to carry their own mass and will be subjected to deflection requirements. A maximum deflection of 1/16-inch is used for normal operating conditions, and 1/8-inch (in.) is used for abnormal conditions. The applicant stated that for other types of supports, it would either demonstrate that the support is dynamically rigid or that one-half of the support mass is less than 10 percent of the mass of the straight pipe segment of the span at the support location to preclude amplification. Otherwise, the contribution of the amplification attributable to support weight is added into the piping analysis. The applicant stated that piping supports will be evaluated to include the impact of self-weight excitation on the support structure and anchorage in detail, along with piping loads analyzed where this effect may be significant. Section 3.9.3.3 of this report provides further evaluation of the adequacy of the applicant's frame-type support design.

The applicant stated that the stiffness of the building steel and structure (i.e., beyond the natural frequency jurisdictional boundary) is not considered in pipe support overall stiffness. Response spectra input to the piping system includes flexibility of the building structure. When attachment to a major building structure is not possible, the analysis of the pipe support includes any intermediate structures.

Based on the above information, the staff determined that the applicant properly considered the dynamic effects of pipe support self-weight in its pipe support design by incorporating the overall effects of the mass and stiffness of the support structural components in the piping seismic analysis. This is acceptable to the staff.

In DCD, Tier 2, Section 3.7.3.3.2, the applicant stated that equipment is represented for dynamic analysis by a lumped-mass system, which consists of discrete masses connected by massless elements. The criteria used to lump masses for an accurate equipment dynamic modeling are, in general, similar to those discussed above for piping systems. Specifically, masses are lumped at points at which significant concentrated weights are located. Examples are the motor in the analysis of a pump stand and the impeller in the analysis of a pump shaft. In addition, if the equipment has a free-end overhang span with significant flexibility when compared to the center span, a mass is lumped at the overhang span. As in the modeling of piping systems, efforts are made to ensure that the equipment modeling will be performed so as to yield conservative dynamic responses. The staff finds this acceptable because the staff considered this lumped-mass FEM approach to be consistent with the general industry practice.

In DCD, Tier 2, Section 3.7.2.3, the applicant stated that the RPV is analyzed together with the primary structure using a coupled RPV and supporting structural model. The RPV model includes major internal components, such as the fuel assemblies, control rod guide tubes (CRGTs), CRD housings, shroud, chimney, standpipes, and steam separators. The model does not include the stiffness of light components, such as in-core guide tubes (ICGTs) and housings, spargers, and their supply heaters, but their masses are considered. To ensure that the coupled dynamic analysis properly models the RPV and its internals, the staff requested, in RAI 3.9-30, that the applicant provide the following additional information concerning the adequacy of the modeling for the RPV and its internal components: (1) detailed modeling consideration for each floor and nodal point of the RPV and its major components and sample calculations of lumped masses and stiffness properties; (2) justification that the mathematical models are detailed enough (i.e., they have sufficient dynamic DOFs) to amplify high-frequency inputs at 33 Hz to as high as 100 Hz, considering that projected SSE ground motion estimates in several future U.S. sites will likely possess high-frequency accelerations, as depicted in the ESBWR ground spectra; (3) discussion of the concern in item (2) above considering the effects of suppression pool hydrodynamic loads; (4) the natural frequencies and mode shapes for the RPV and its major internal components generated from the seismic analysis, including the graphic representation of the mode shapes; (5) discussion of the natural frequencies and mode shapes generated, and, based on that, justification of the adequacy of the modeling; and

(6) discussion of any differences in the dynamic analysis modeling for the RPV and its internal components between the ESBWR application and the earlier ABWR design.

In its response to RAI 3.9-30, the applicant provided the following additional information:

(1) For the seismic analysis, the RPV, its internals, and supporting structures are modeled as three-dimensional beams with six DOFs at each of the two beam defining nodes.

The beam model is completely characterized by nodes with due consideration to their spacing; material properties such as the temperature-dependent values of Young's Modulus, Poisson's ratio, and mass density; and section properties such as the cross-sectional area of the beam and the second moment of the section area.

Nodal spacing is determined by the highest natural frequency that needs to be predicted accurately for obtaining reliable analysis results, as will be further addressed in item (2) below.

The mass and stiffness matrices of the structural system are computed internally by the computer program used for the analysis. The inputs required for this computation are the geometric and material properties described above. As an example, the RPV is modeled as a series of connected vertical beams with horizontal cross-section properties, together with the material properties, completely defining the associated mass and stiffness matrix.

The distributed masses of a beam element are computed and lumped at each of the three translational DOFs of the end nodes. Rotational inertias are neglected. Hydrodynamic masses are included, along with the off-diagonal mass terms that define the fluid coupling between the RPV and its internals, as well as between the various internals components such as the shroud and fuel.

(2) For time-domain solutions obtained by either time-history or response spectrum analytical methodologies, the nodal refinement of the primary structure analytical models must be sufficiently small for the finite element analysis (FEA) to accurately capture all significant response amplification implicit to the frequency content of the seismic/dynamic input motion. Inadequate nodal refinement in the analytical models can lead to significant distortion of the calculated responses in the form of either period elongation or amplitude decay or both. This is also true for the numerical integration time step if the value selected is not sufficiently small, as discussed in DCD, Tier 2, Section 3.7.2.1.1.

The discussion in Section 3.7.2.1.1 of DCD, Tier 2, Revision 2, points out that limiting the integration time step to no more than one-tenth of the shortest period of interest minimizes the distortion in the calculated response. Consistent with that concept, the distortions in the FEM responses are also minimized if the primary structure model beam element maximum length is limited to less than one-tenth of the wavelength of the highest significant characteristic frequency in the seismic/dynamic input motion. This means that the highest frequency response wavelength associated with the model will contain at least 10 beam elements and at least 11 model node points. This is more than sufficient to minimize period elongation and amplitude decay distortions in the calculated responses.

If the one-tenth-wavelength criterion is satisfied in the generation of the primary structure seismic/dynamic models, it follows that the high-frequency capability of the models is at the very least equal to the highest significant characteristic frequency in the seismic/dynamic input motion. Based on this one-tenth-wavelength criterion, it follows that, if the required highest frequency capability of the RPV model is 100 Hz, the beam element maximum length will be equal to 11.31 feet (3.45 meters). However, because the beam element maximum length in the actual ESBWR RPV and internals mathematical, beam-element, centerline model is only 7.35 feet (2.26 meters), the actual high-frequency capability is at least 149 Hz.

(3) The highest significant characteristic frequency associated with the suppression pool hydrodynamic loads is less than 100 Hz. It then follows from item (2) that the ESBWR RPV model is adequate for analyzing the suppression pool hydrodynamic loads.

(4) The applicant's response provided the first four natural frequencies of the RPV and internals model, along with the associated mode shapes. These represent the horizontal modal displacements of the separator mode at 3.78 Hz, the fuel mode at 6.04 Hz, the chimney/shroud mode at 10.82 Hz, and the RPV mode at 16.17 Hz. The vertical vibration frequencies are higher.

(5) Judging from the cross-sectional areas and lengths, the separator/standpipes component is the most flexible component. The lowest frequency is thus associated with this component. The nodal discretization (discussed under item (2) above) is sufficiently detailed to allow accuracy of the model beyond 100 Hz. The lowest modes are predicted with higher accuracy.

The applicant stated that the adequacy of the model is justified by the refinement of discretization and expected behavior under seismic excitation. On earlier BWR models, the accuracy of models based on these considerations is confirmed by agreement of analytically predicted frequencies with those obtained from test results. As an example, in the ABWR model, the high-pressure core flooder coupling and sparger's first frequency was predicted to be 62.1 Hz, while the test results showed the frequency to be 60 Hz.

(6) The dynamic modeling procedures adopted in the ESBWR are identical to those adopted for the ABWR. The differences in the design of the two have no impact on the modeling procedures.

Based on the above information, the staff determined that the applicant adequately addressed the staff's concerns regarding the dynamic modeling of the RPV and its internals. The staff determined that the applicant's proposed modeling approach will adequately analyze the dynamic response of the RPV, its internals, and supporting structures, along with the primary structure, using the combined RPV and supporting structural model according to the SRP guidance. RAI 3.9-30 was, therefore, closed.

In DCD, Tier 2, Section 3.7.3.3.3, the applicant originally stated that, when the special engineered supports, described in DCD, Tier 2, Section 3.9.3.7.1(6), are employed, modifications to the linear-elastic piping analysis methodology used with conventional pipe supports are needed to account for greater damping of the energy absorbers and the nonlinear behavior of the limit stops. In RAI 3.9-31, the staff requested that the applicant discuss the modifications that will be involved if these special devices are used. The staff also asked the applicant to confirm that the modeling and analytical methodology will be consistent with the methodology accepted by the NRC at the time of certification or at the time of COL application. In its response to RAI 3.9-31, the applicant stated that special engineered pipe supports, as noted in DCD, Tier 2, Revision 2, Sections 3.7.3.3.3 and 3.9.3.7.1(6), will not be used. The staff confirmed that the applicant revised these two sections in later DCD revisions by noting that "special engineered pipe supports shall not be used." The staff finds this acceptable, and RAI 3.9-31 was closed.

In DCD, Tier 2, Section 3.7.3.8, the applicant stated that, in simulating the dynamic effects of non-Category I systems attached to seismic Category I systems, the non-Category I systems, up to the first anchor beyond the interface, are also designed in such a manner that during an earthquake of SSE intensity they do not cause a failure of the seismic Category I systems. In RAI 3.9-32, the staff asked the applicant to clarify that this designated first anchor is designed as a six-way restraint for the specific non-Category I system. In its response to RAI 3.9-32, the applicant stated that, to simulate the dynamic effects of the non-Category I systems attached to seismic Category I systems, either this anchor in the non-Category I system is a six-way restraint anchor or the extent of the non-Category I system covers a sufficient distance such that there are at least two seismic restraints in each of the three orthogonal directions. The staff found the response provided by the applicant to be acceptable because the isolation of the non-Category I system provided by two seismic restraints in each of the three orthogonal directions is equivalent to that provided by an anchor, and RAI 3.9-32 was closed.

For multiple-supported systems (pipe and equipment) analyzed by the response spectrum method for the determination of inertial responses, enveloped response spectrum with USM is applied at all support points for each orthogonal direction of excitation.

In DCD, Tier 2, Section 3.9.2.2.2, the applicant stated that, for the case of equipment having supports with different dynamic motions, the most severe FRS is applied to all of the supports. This is not consistent with the general guidance provided in SRP Section 3.9.2.II.2.G, where an upper bound envelope (instead of the "most severe" of all the individual response spectra) is required to calculate the maximum inertial response of multiple-supported equipment or components. In RAI 3.9-45, the staff requested that the applicant revise the statement regarding the use of the most severe FRS for all supports. In its response to RAI 3.9-45, the applicant clarified that, for the case of equipment having multiple supports with different dynamic motions, an upper bound envelope, instead of the most severe of all the individual response spectra for these locations, is used to calculate maximum inertia responses of the equipment items. This is consistent with the guidance of SRP Section 3.9.2.II.2.G, and RAI 3.9-45 was closed.

In addition to the inertial response discussed above, the effects of relative support displacements are considered. The maximum relative support displacements are obtained from the dynamic analysis of the building, or as a conservative approximation, by using the FRS. For the latter option, the maximum displacement of each support is predicted by $Sd = Sag/\omega^2$, where Sa is the spectral acceleration in "g's" at the high-frequency end of the spectrum curve (which, in turn, is equal to the maximum floor acceleration), "g" is the gravity constant, and ω is the fundamental frequency of the primary support structure in radians per second. The applicant stated that the support displacements are imposed on the supported systems in a conservative manner, and static analysis is performed for each orthogonal direction. In RAI 3.9-33, the staff requested that the applicant clarify the meaning of the phrase, "conservative manner," when used to describe the imposition of support displacements on the supported systems, given the criteria of SRP Section 3.7.3.II.9, which state that the support displacements be imposed on the supported item in the "most unfavorable combination" using static analysis procedures. In its response to RAI 3.9-33, the applicant clarified that by "conservative" it meant the "most unfavorable combination." This is consistent with the guidance of SRP Section 3.7.3.II.9. RAI 3.9-33 was therefore closed.

The applicant stated that the resulting responses from the support displacements are then combined with the inertial effects by the SRSS method. This is not consistent with the current staff position as provided in SRP Section 3.9.2, which states that for the USM method of analysis the responses attributable to the inertial effect and relative support displacements should be combined by the absolute sum (ABS) method. Section 3.12.6.13 of this report provides further discussion and resolution of this issue.

In place of the response spectrum method using USM, as discussed above, an independent support motion (ISM) time-history method of analysis may be used for multiple-supported systems in a building subjected to distinct support motions, in which case both inertial and relative support displacement effects are automatically included. Alternatively, an ISM response spectrum can be applied at each support for each orthogonal direction of excitation.

When the ISM response spectrum method of analysis, as explained in DCD, Tier 2, Section 3.7.2.1.2, is used, a support group is defined by supports that have the same time-history input. This usually means all supports located on the same floor, or portions of a floor, of a structure. The responses caused by motions of supports in two or more different groups are combined by the SRSS procedure. This is not consistent with the current staff position for group combinations in the ISM response spectrum method of analysis, as presented in Volume 4, Section 2, of NUREG-1061, "Report of the U.S. Nuclear Regulatory Commission Piping Review Committee: Evaluation of Other Loads and Load Combinations," issued December 1984. The reference states that group responses are to be combined by the ABS method. Section 3.12.4.3 of this report provides further discussion and resolution of this issue.

The staff found that the applicant's general approach to analyzing multiple-supported systems or components (using a response spectrum method or a time-history method of analysis) adequately takes into account both the inertial effects and the effects resulting from support differential motions. This approach is consistent with the guidelines provided in SRP Section 3.9.2 for both the USM and ISM methods of analyses. Sections 3.12.6.13 and 3.12.4.3 of this report discuss further this issue of the response calculation of multiple-supported piping systems in a building.

With regard to the effect of differential building movements, DCD, Tier 2, Section 3.7.3.12, discusses the case of a piping system that is anchored and restrained to floors and walls of buildings that may have differential movements during a seismic event. The concern is specifically focused on relatively large displacements between separate buildings at a high seismic activity site. The applicant stated that differential endpoint or restraint deflections cause forces and moments to be induced into the system. The resulting stress can be placed in the secondary-stress category because the stresses are self-limiting. When these stresses exceed yield strength, minor distortions or deformations within the system satisfy the condition that caused the stress to occur. In RAI 3.9-34, the staff requested that the applicant further clarify how such a piping system will be analyzed for both inertial response and the response caused by differential anchor movements. In its response to RAI 3.9-34, the applicant stated that displacements corresponding to the maximum differential building displacements that could occur are applied to the anchors and restraints. The stress thus produced is a secondary stress. The static analysis is made three times: twice for the two horizontal differential displacements and once for the vertical differential displacement.

The applicant stated that the inertial (primary) and displacement (secondary) responses are dynamic in nature and their peak values are not expected to occur at the same time. Hence, the combination of the peak values of inertial response and the anchor displacement response is quite conservative. The applicant stated that, in addition, anchor movement effects are computed from static analyses in which the displacements are applied to produce the most conservative loads on the components. Therefore, the primary and secondary responses are combined by the SRSS method. The staff acknowledges that this combination method may not affect the piping design since the ASME Code load combination equations evaluate inertial and seismic anchor movement (SAM) loads separately. However, this will affect the pipe support design where the inertial loads and SAM loads are combined in the evaluation. RAI 3.12-27 also raised this same issue, and the staff requested that the applicant provide a technical justification for using SRSS combination of the inertial and SAM responses for the USM method of analysis. The applicant updated DCD, Tier 2, Section 3.7.3.12, to state that, when the piping analysis is performed using USM analysis, in accordance with SRP Section 3.9.2, the ABS method is used to combine the inertia results and the seismic anchor motion results for both piping and piping support design. The staff finds the response to RAI 3.12-27 acceptable in Section 3.12 of this report and RAI 3.12-27 was closed. Hence, RAI 3.9-34 was also closed.

As stated in DCD, Tier 2, Section 3.7.2.3, for seismic analysis modeling, the amplified response spectra are generally specified at discrete building node points. The applicant did not discuss incorporating any additional flexibility between these points and the pipe support (e.g., supplementary steel) in the piping analysis model. In RAI 3.9-35, the staff requested that the applicant discuss the effects of this additional flexibility on the amplified response spectra, considering different varieties of pipe supports. In its response to RAI 3.9-25, the applicant stated that pipe supports are designed and qualified to satisfy stiffness values that are used in the piping analysis. For struts and snubbers, the stiffness to consider is the combined stiffness of strut, snubber, pipe clamp, and pipe support steel. For other type of supports, it is demonstrated that the support is dynamically rigid to preclude amplification. Though reflecting a common industry practice of assuming a support stiffness between the seismic subsystems (i.e., equipment and piping) and the supporting seismic systems (i.e., structures), this approach may allow the influence of the anchorage system stiffness on the dynamic response to be neglected, as stated in SRP Section 3.9.2.III.2.A. Therefore, in RAI 3.9-35 S01, the staff requested that the applicant provide supplemental information to address the following issues:

(1) Discuss the effects of the dynamic characteristics of the support anchorages to the building structure, including anchor base plate and anchor bolts or through-bolts, on the seismic and dynamic response of piping, equipment, and components, especially heavy equipment. Verify that appropriate assumptions have been made with regard to the stiffness of the subsystem anchorage in the seismic and dynamic analyses. In light of IE Bulletin (BL) 79-02 requirements, discuss how base plate flexibility may cause the anchorage system stiffness to be different from the assumed rigid condition. Discuss how the reduction of natural frequencies, as a result, would potentially affect the seismic and dynamic response calculations for the piping, equipment, and components.

(2) Certain degree of anchor bolt torque relaxation may occur after years of operation causing reduction in the natural frequencies of piping, equipment, and components. This, in turn, may lead to higher seismic responses of the piping, equipment, and components than originally analyzed. Provide the plant-specific compensatory measures or quality control/QA programs to be relied on prior to, during, and after the installation of the anchorage systems, in order to alleviate the effects of anchor bolt torque relaxation.

(3) Discuss the statement made in the response to RAI 3.12-31(1), where it is stated that expansion anchor bolts shall not be used for any safety-related system components. Provide a sample list of such safety-related system components, and their associated loading environments.

RAI 3.9-35 S01 was tracked as an open item in the SER with open items. In its response to RAI 3.9-35 S01, the applicant stated that the surface-mounted anchor base plate with drilled in anchor bolts or through bolts will not be considered as a rigid attachment for the supports of piping, equipment, and component. The base plate's flexibility and stiffness will be evaluated based on plate thickness and anchor bolt type and size. The anchor base plate's stiffness and flexibility will be used to determine the overall frequency, stiffness, and deflection of the support frame. The combined stiffness and frequency will be used for seismic and dynamic response calculation for piping, equipment, and components. The staff found the applicant's response to be adequate in addressing the concerns regarding the potential effects of the stiffness of the anchorage systems to the seismic and dynamic response of piping, equipment, and components.

The applicant stated that all anchor bolts, which require a specific installation torque, will be provided with a locking device, such as double lock nut, to prevent relaxation of torque. The installation and inspection guidelines for anchor bolts will include this provision. The staff found this plant-specific compensatory measure to be acceptable in alleviating the effects of anchor bolt torque relaxation.

The applicant also confirmed that the supporting frame for piping component systems identified as either seismic Category I or safety related, or both, shall not use expansion bolts as an anchoring device. The staff found this response to be satisfactory because not using expansion bolts will eliminate the performance concerns raised in RG 1.199.

Based on the above additional information provided by the applicant, the staff concluded that RAI 3.9-35 S01 was resolved. Therefore, RAI 3.9-35 and its associated open item were closed. The staff also concluded that the applicant adequately addressed the issues identified in Generic Issue (GI) 146, "Support Flexibility of Equipment and Components," regarding the potential effects on the seismic and dynamic responses of piping, equipment, and components caused by the stiffness and relaxation of anchorage systems. Therefore, Generic Issue 146 was resolved for ESBWR.

For the cases in which piping terminates at nonrigid equipment (e.g., tanks, pumps, or heat exchangers), the applicant did not provide sufficient information regarding consideration of the flexibility and mass effects of the equipment by piping analytical models. In RAI 3.9-36, the staff asked the applicant to discuss how the analytical model will incorporate the flexibility and masses of equipment attached to the piping. In its response to RAI 3.9-36, the applicant stated that, when piping terminates at nonrigid equipment (e.g., tanks, pumps, or heat exchangers), the piping analysis must include the 6-degree restraint stiffness at the attached point. Normally, the tanks, pumps, and heat exchangers are anchored on floors. The analysis must also include thermal displacements at the pipe terminal ends. The applicant stated that the piping analysis is not significantly affected when the dynamic displacements at the pipe terminal ends are sufficiently small. In this case, the piping analysis need not consider the equipment mass. The applicant stated that there are very few cases in which tanks, pumps, or heat exchangers are not rigidly supported. If that is the case, the piping model includes the mass and stiffness of the equipment. The applicant provided one example of a nonrigid component, the ABWR reactor internal pump (RIP). In this case, the piping model included the RIP-to-RPV vessel wall attachment, and the analysis included the RIP mass and RPV nozzle stiffness.

Based on the above information, the staff determined that the applicant adequately addressed its concern regarding the case of piping terminating at nonrigid equipment. This ensures that the piping analysis model will consider and take into account the dynamic characteristics of the equipment that serves as the termination of the piping. This is acceptable to the staff, and RAI 3.9-36 was therefore closed.

When analyzing piping systems, it is generally practical to decouple the small-bore branch lines from the large-bore main piping. In DCD, Tier 2, Section 3.7.3.16, the applicant provided the criteria for the decoupling of the piping systems in the analysis model. The applicant stated that branch lines can be decoupled when the ratio of run to branch pipe moment of inertia is 25 to 1 or greater. In addition, these small branch lines must be designed with no concentrated masses, such as valves, in the first one-half span length from the main run pipe and with sufficient flexibility to prevent restraint of movement of the main run pipe. The applicant stated that the small branch line is considered to have adequate flexibility if its first anchor or restraint to movement is at least one-half pipe span in a direction perpendicular to the direction of relative movement between the pipe run and the first anchor or restraint of the branch piping. A pipe span is defined as the length tabulated in ASME Code, Table NF-3611-1, “Suggested Piping Support Spacing.” For branches that cannot meet the preceding criteria for sufficient flexibility, the applicant must demonstrate acceptability by using alternative criteria for sufficient flexibility or by accounting for the effects of the branch piping in the analysis of the main run piping.

In RAI 3.9-37, the staff asked the applicant to address several issues regarding the approach used to ensure branch pipe flexibility. Since the issuance of this RAI, the staff has eliminated three of the seven items contained in the original RAI. The four remaining items ask the applicant to (1) explain the basis of using the ratio of run to branch pipe moment of inertia of 25 to 1 as part of the decoupling criteria, (2) confirm that the small branch pipes in question are indeed all laid out horizontally, since the suggested piping support spacing as tabulated in ASME Code, Table NF-3611-1, is for horizontal straight runs of standard and heavier piping, (3) explain how the suggested support span will ensure an adequate measure of branch line flexibility since the suggested pipe span is derived based on the assumption that there are no concentrated loads (e.g., flanges, valves, specialties) existing between supports and is aimed to ensure that the pipe stress and deflection remain within allowable limits, and (4) explain how the small branch pipe will still have adequate flexibility if its first anchor or restraint is at one-half pipe span from the main run pipe, as stated in the DCD.

In its response to RAI 3.9-37, the applicant stated the following:

(1) The ratio of run to branch pipe moment of inertia of 25 to 1 is established based on a common industrial practice. The intersectional point of run/branch pipes from the stiffness distribution (using the ratio of run to

branch pipe moment of inertia of 25 to 1) is considered to be a fixed point for small branch pipe.

(2) The basis used to generate the “suggested piping support spacing” considers pipe weight under 1.0 g and the limited allowable stress in compliance with the applicable code. ASME Code, Table NF-3611-1, also conservatively applies to the vertical branch pipes.

(3) When the concentrated load, such as flange, valve, or pipe riser, exists in the pipe system, a two-way restraint (e.g., U-bolts for the sway brace) must be immediately installed adjacent to this concentrated load. The support load is calculated based on its concentrated load and the associated seismic/dynamic “g” values, unless otherwise justified.

(4) Because of branch decoupling, the thermal displacements at the run pipe are combined with associated pressures and temperatures for the flexibility analyses of the branch pipe. All stresses must meet ASME Code requirements. The branch pipe analysis results will also ensure adequate flexibility and proper design of all restraints on the branch pipe. Since there is no need to specify the additional restraint requirements, DCD, Tier 2, Section 3.7.3.16, will be revised to remove references to the “one-half span length” of ASME Code, Table NF-3611-1.

The staff found the applicant’s responses to be adequate in resolving all of the identified concerns related to the use of the ASME Code, Table NF-3611-1, pipe span length as part of the branch line decoupling criteria. Instead of referencing the “one-half span length” of Table NF-3611-1 as the criteria for branch pipe flexibility, the applicant elected to perform branch pipe analyses to ensure proper design of all restraints and branch pipe flexibility. The piping decoupling criteria of is acceptable because the branch pipe can be decoupled without affecting the response of the run pipe if the ratio of run to branch pipe moment of inertia is 25 to 1 or greater. Therefore, RAI 3.9-37 was closed.

In DCD Tier 2, Section 3.7.3.16, the applicant provided an alternative method for analyzing small-bore piping and small branch lines that are 50 millimeters (mm) or less nominal pipe size. The applicant proposed to use small-bore piping handbooks in lieu of performing a static and dynamic stress evaluation, in accordance with equations in ASME Code, Section III, Subsections NB, NC, and ND, as well as ASME/ANSI Standard B31.1, “Power Piping,” if the following three conditions are met:

(1) The small-bore piping handbook is currently accepted by the regulatory agency for use on equivalent piping at other nuclear power plants.

(2) When the small-bore piping handbook is serving the purpose of the design report, it meets all of the ASME requirements for a piping design report for the piping and its supports.

(3) Formal documentation exists showing that piping designed and installed to the small bore piping handbook (a) is conservative in comparison to results from a detailed stress analysis for all applied loads and load combinations using static and dynamic analysis methods defined in DCD, Tier 2, Section 3.7.3; (b) does not result in piping that is less

reliable because of a loss of flexibility or because of excessive number of supports; and (c) satisfies required clearances around sensitive components.

The staff found the applicant's alternative methodology for small-bore piping design to be acceptable provided that the relevant documentation stated in item (3) above will be made available for staff audit, if required.

The staff agreed with the applicant that the small-bore piping handbook methodology will not be applicable when specific information is needed on the (1) magnitude of pipe and fittings stresses, (2) pipe and fitting cumulative usage factors (CUFs), and (3) accelerations of pipe-mounted equipment or locations of postulated breaks and leaks. The applicant stated that the small-bore piping handbook methodology is not applied to piping systems that are fully engineered and installed in accordance with the engineering drawings.

In DCD, Tier 2, Section 3.7.3.17, the applicant stated that small, seismic Category II piping directly attached to seismic Category I piping can be decoupled from seismic Category I piping. However, the applicant did not provide specific decoupling criteria. In RAI 3.9-38, the staff requested that the applicant provide the decoupling criteria for seismic Category II piping directly attached to seismic Category I piping. In its response to RAI 3.9-38, the applicant stated that the criteria for decoupling small branch lines from the main run of seismic Category I piping is that the ratio of run to branch pipe moment of inertia is 25 to 1 or greater. As discussed above in the staff's evaluation of the applicant's response to RAI 3.9-37, the staff finds the criteria for decoupling small, seismic Category II piping from its attached seismic Category I main run to be acceptable. RAI 3.9-38 was closed.

The applicant stated that Table 3.7.1-1 of DCD, Tier 2, Revision 1, includes the damping values for equipment and piping, which are consistent with RG 1.61, "Damping Values for Seismic Design of Nuclear Power Plants." The staff finds the above proposed damping values to be consistent with the RG 1.61 damping values. They are, therefore, acceptable.

When the modal superposition method of analysis (either time history or response spectrum) is used for models that consist of elements with different damping properties, the composite modal damping ratio can be obtained either as stiffness weighted or mass weighted, as described in DCD, Tier 2, Section 3.7.2.13. Section 3.7.2 of this report provides the staff's evaluation of the method of analysis for damping.

DCD, Tier 2, Table 3.7-1 and Figure 3.7-36, propose a damping value of 20 percent for the cable tray system (including supports), which is 50 percent to fully loaded. This is not consistent with the damping values acceptable to the staff. In RAI 3.9-40, the staff requested that the applicant revise the table and DCD, Tier 2, Section 3.7.1.2, regarding the acceptable damping value for the cable tray system. In its response to RAI 3.9-40, the applicant stated that, as described in its responses to RAIs 3.7-13 and 3.7-13 S01, it has deleted DCD, Tier 2, Revision 2, Figure 3.7-36, and revised Table 3.7-1. In DCD, Tier 2, Section 3.7.1.2, the applicant stated that the damping values shown in Table 3.7-1 for cable trays and conduits are based on the results of over 2,000 individual dynamic tests conducted by Bechtel/ANCO for a variety of raceway configurations. The maximum damping on welded steel tray systems must be 10 percent. However, if the cables were to be restrained by spray-on fire protection materials, the damping would be limited to 7 percent for cable trays on welded or bolted steel supports. The damping value of the conduit system (including supports) is a constant 7 percent. For HVAC ducts and supports, the damping value is 7 percent for companion angle or pocket lock construction and 4 percent for welded construction. The staff has reviewed the applicant's responses and finds the revised damping values for the cable tray and HVAC ducts and supports to be acceptable. RAI 3.9-40 was closed.

DCD, Tier 2, Section 3.7.3.13, outlines information for the analysis of buried seismic Category I or Category II buried piping, conduits, tunnels, and auxiliary systems. In RAI 3.9-41, the staff asked the applicant to provide the analytical methodologies and criteria used for the design of the buried piping and components, including applicable references, codes, and standards. The staff also requested that the applicant clarify whether the buried piping within the scope of design certification will be in contact with the soil or routed in tunnels. In responding to RAI 3.12-9, the applicant stated that it had revised DCD, Tier 2, Section 3.7.3.13, to delete Category II from the paragraph scope and to indicate that the ESBWR design does not include buried seismic Category I piping. Based on the information provided, RAI 3.9-41 was closed.

DCD, Tier 2, Section 3.9.2.2.1, states that equipment that is large, simple, or consumes large amounts of power is usually qualified by analysis or static bend test to show that the loads, stresses, and deflections are less than the allowable maximum for seismic and other RBV loads. The applicant did not discuss the codes and standards used for the seismic and dynamic qualification of mechanical equipment. In RAI 3.9-42, the staff asked the applicant to identify all relevant codes and standards, including their editions, and discuss their applicability to the seismic and dynamic qualification of all major mechanical equipment covered under DCD, Tier 2, Section 3.9.2.2.2. The staff also requested that the applicant identify the equipment that it will seismically qualify and make it available for staff audit.

In its response to RAI 3.9-42, the applicant stated that DCD, Tier 2, Table 3.2-1, specifies the codes and standards that are applicable to equipment identified in Section 3.9.2.2.2, and Table 1.9-22 identifies the applicable ASME Code edition and addenda. The applicant also stated that the testing and analysis records for all ASME mechanical equipment that is required to meet seismic Category I equipment qualification requirements will be available for staff review when the equipment is ready for delivery. The staff found the applicant’s commitment to make available the testing and analysis records of equipment qualification for staff audit acceptable.

The staff found that the applicant’s response on the question of codes and standards did not provide sufficient information. It should be noted that, although some mechanical equipment items are qualified solely by design or analysis, in accordance with industry standards such as ASME Code, Section III, others are qualified by tests or a combination of testing and analysis. In RAI 3.9-42 S01, the staff asked the applicant to identify all relevant mechanical equipment items for which testing is involved in their qualification. In addition, for such equipment items, the staff requested that the applicant identify the qualification standards (such as IEEE 344), with editions, that are acceptable to the NRC for the equipment seismic and dynamic qualification. Furthermore, the staff asked the applicant to provide a summary description of how the qualification will be performed for each of these equipment items.

In its response to RAI 3.9-42 S01, the applicant provided a supplemental response which stated that seismic qualification testing is required for active mechanical equipment necessary to perform a required safety function. Seismic qualification is performed in accordance with IEEE-344-1987. The applicant stated that for the ESBWR, active valves are the only active mechanical equipment. In DCD, Tier 2, Table 3.9-8, any valve listed with a function of active or isolation is subject to testing under the seismic and dynamic equipment qualification program discussed in DCD, Tier 2, Section 3.10.2.1. However, in lieu of testing, these components can also be qualified by a combined testing and analysis method when applicable. The applicant stated that DCD Tier 2, Section 3.10, contains the criteria for seismic qualification testing of seismic Category I mechanical equipment. Section 3.10.2.1 specifies the requirements for qualification by testing, and Section 3.10.2.3 discusses the requirements for qualification by combined testing and analysis. The applicant also stated that DCD Tier 1 already covered the commitment to make available the testing and analysis records of equipment qualification for staff audit. In DCD, Tier 1, Section 1, the scope of the system configuration includes equipment qualification. Each system has a requirement for ITAAC to validate the basic configuration, which includes making the equipment qualification records available. The staff found the applicant's response to be adequate in clarifying the specific codes and standards, including editions, used to qualify mechanical equipment by means of testing or a combined testing and analysis method. Since IEEE-344-1987 is acceptable to the staff for performing such equipment qualification, RAI 3.9-42 S01 was closed.

In DCD, Tier 2, Section 3.9.2.2.2, the application stated that the qualification of the CRD housing (with enclosed CRD) is done analytically, and the stress results of the analysis establish the structural integrity of these components. In RAI 3.9-43, the staff requested that the applicant discuss the mathematical model of the CRD housing (including CRD) and the computer code used for the analysis. The staff also asked the applicant to discuss the codes and standards used, the stress limits, and the input loading considered. To verify the CRD during a dynamic event, the staff requested that the applicant describe the dynamic test model used for the verification. RAI 3.9-43 was tracked as an open item in the SER with open items.

In its response to RAI 3.9-43, the applicant stated that the input loads required for the seismic/dynamic qualification of the CRD assembly are obtained from corresponding analyses of the ESBWR primary structure analytical model. The input loads include seismic/dynamic required response spectra (RRS), member end loads (e.g., axial, shear, and moment load components) and relative displacements. The input loads are obtained at the appropriate interface locations of the CRD assembly in the primary structure analytical model.

In the primary structure model, the CRD assembly is represented as an assemblage of standard beam elements with six DOFs, three translational and three rotational, at the two end nodes of each beam element. "Lumped" masses are concentrated along the assemblage node points, consistent with the inertia support locations of the CRD internal fine motion drive assembly. The structural section properties (e.g., cross-sectional area, shear area, moments of inertia) of the CRD beam elements in the primary structure model are the result of the external CRD housing only. The distributed and concentrated mass of the CRD beam element portion of the primary structure model represents both the external CRD housing and the internal CRD drive mechanism. Some of the computer codes used for generating the inputs loads are ANSYS, SASSI, and DAC3N. The inputs loads are applied to the mechanical components to calculate the stress. The computer code used for stress analysis is ANSYS.

The stress limit acceptance criteria are derived from the ASME Code, Section III, requirements for ASME Code components. For those components that are not ASME Code components, the ASME Code, Section III, requirements are used as guidelines. DCD, Tier 2, Tables 3.9.1 and 3.9.2, detail the input load and load combinations. Functional testing or analysis using load/load combinations and the stress criteria in Tables 3.9.1 and 3.9.2 are used to demonstrate component acceptance. In addition, the "number of cycles" in Table 3.9.1 refers to the number of cycles associated with plant operating events and dynamic loading events used for the design and analysis for the plant life. The applicant also stated that the "dynamic test model" is a preproduction prototypical FMCRD that will be dynamically tested to validate performance and operability.

The staff found the applicant's responses to have adequately addressed its concerns regarding various aspects of the qualification testing and analysis of CRD housing, including the enclosed CRD mechanism. RAI 3.9-43 and its associated open item were closed.

3.9.2.2.4 Conclusions

Based on the above evaluation, the staff determined that the applicant has met the relevant requirements of GDC 2 by adequately demonstrating the design adequacy of all safety-related mechanical equipment and supports to withstand the appropriate combinations of the effects of normal and accident conditions with the effects of an SSE.

3.9.2.3 *Dynamic Response of Reactor Internals under Operational Flow Transients and Steady-State Conditions*

3.9.2.3.1 Regulatory Criteria

- GDC 1, as it relates to structures and components being designed, fabricated, erected, constructed, tested, and inspected to quality standards commensurate with the importance of the safety function to be performed

- GDC 4, as it relates to systems and components important to safety being appropriately protected against the dynamic effects of discharging fluids

- RG 1.20, Revision 3, "Comprehensive Vibration Assessment Program for Reactor Internals During Preoperational and Initial Startup Testing"

3.9.2.3.2 Summary of Technical Information

The applicant considered the ESBWR as a non-prototype Category II through Revision 6 of DCD Tier 2, but revised its classification to prototype in Revision 7. For further information, see the discussion of RAI 3.92-75 S02 at the end of Section 3.9.2.4.3 in this safety evaluation. Thus, both classifications of prototype and non-prototype Category II appear in the descriptions and discussions that follow.

The applicant stated in DCD, Tier 2, Section 3.9.2.3, that major reactor internal components within the vessel are subjected to extensive testing, coupled with dynamic system analyses, to properly evaluate the resulting flow-induced vibration (FIV) phenomena during normal reactor operation and anticipated operational transients.

The applicant stated that, in general, the vibration-forcing functions for operational flow transients and steady-state conditions are not predetermined by detailed analysis. Special analysis of the response signals measured for reactor internals of many similar designs is performed to obtain the parameters that determine the amplitude and modal contributions in the vibration responses. This study, according to the applicant, provides useful predictive information for extrapolating the results from tests of components with similar designs to components of different designs. The applicant believes this vibration prediction method is appropriate when standard hydrodynamic theory cannot be applied because of the complexity of the structure and flow conditions. DCD, Tier 2, Section 3.9.2.3, outlines elements of the vibration prediction method.

In Section 3.9.2.3 of DCD Tier 2, the applicant stated that the major reactor internal components will be tested and analyzed for FIV. The applicant outlined the general procedures for the analyses, but provided no specific procedures.

If forcing functions for a component can be defined, then dynamic analysis will be used to obtain responses, preceded by modal analyses to identify vibration frequencies and mode shapes. But most often, the forcing functions are not expected to be definable and an alternate analysis procedure will be followed, which also is preceded by modal characterization of the structure. In the alternate analysis, vibration data from previous plants will be assembled and examined for component similarity, from which modal and response information might be extrapolated; operating parameters will be identified that influence FIV; normalized correlation functions will be developed for each component and response mode under analysis; and a prediction of the amplitude will be made for each dominant response mode, including estimates of the prediction uncertainty.

In addition, modal characterization forms the basis for the interpretation of the initial startup test results. Modal stresses will be calculated, from which the maximum stresses are extrapolated knowing the test sensor location and response amplitude. Acceptance is based on peak stress amplitudes less than the allowable fatigue stress of 68.95 MPa (10,000 psi).

DCD, Tier 2, Appendix 3L, Section 3L.5.5.1, supplements this section of the DCD by providing information on how specific components will be modeled to characterize their modal response. However, the applicant provides neither the details of the FEMs nor the mode shapes and natural frequencies.

DCD, Tier 2, Appendix 3L, Section 3L.3, presents more complete details on the dynamic analysis of the chimney partition assembly. The staff has already discussed and commented on Section 3L.3 in the review of DCD, Tier 2, Section 3.9.5.

DCD, Tier 2, Appendix 3L, Section 3L.4, describes the process by which the dynamic analysis of the steam dryer will be performed, but no analyses are made. The staff has discussed and commented on Section 3L.4 in the review of DCD, Tier 2, Section 3.9.5, in Section 3.9.5 of this report.

3.9.2.3.3 Staff Evaluation

The staff evaluated the information provided by the applicant in DCD, Tier 2, Section 3.9.2.3, to determine whether GEH provided adequate information to satisfy the guidance of SRP Section 3.9.2.3, Revision 3, and the relevant requirements of GDC 1 and 4, in particular, as well as the applicable portions of the other regulatory criteria listed in Section 3.9.2.3.1 of this report.

The staff requires analysis of the dynamic responses of structural components within the reactor vessel caused by steady-state and operational flow transient conditions. The purpose of this analysis is to predict the vibration behavior of the components so that the input-forcing functions and the level of response can be estimated. Before conducting the analyses, the specific locations for calculated responses, the considerations in defining the mathematical models, the interpretation of analytical results, the acceptance criteria, and the methods of verifying predictions by means of tests should be determined.

DCD, Tier 2, Section 3.9.2.3, states that the major reactor internal components within the vessel are subjected to extensive testing, coupled with dynamic system analyses, to properly evaluate the resulting FIV phenomena during normal reactor operation and anticipated operational transients. However, the applicant did not provide a complete listing of the major components. Therefore, in RAI 3.9-46, the staff requested that the applicant provide a list of the major reactor internal components within the vessel that would be subjected to FIV testing.

In its response to RAI 3.9-46, the applicant stated the following:

> DCD, Tier 2, Appendix 3L.2, Subsection 1 "Evaluation Process—Part 1" identifies the reactor internal components for evaluation and potential FIV testing.

The staff finds the applicant's response acceptable because it identifies the relevant information, as requested. Therefore, RAI 3.9-46 was closed.

DCD, Tier 2, Section 3.9.2.3, states that, in general, detailed analysis does not predetermine the vibration-forcing functions for operational flow transients and steady-state conditions. This is acceptable according to the SRP Section 3.9.2 guidance. However, the applicant did not discuss the analytical methodology in sufficient detail to determine the vibration-forcing functions for operational flow transients and steady-state conditions. Therefore, in RAI 3.9-47, the staff asked the applicant to discuss its methodology for determining the vibration-forcing functions for operational flow transients and steady-state conditions.

In its response to RAI 3.9-47, the applicant stated the following:

> The vibration forcing functions for operational flow transients and steady state conditions are determined by first postulating the source of the forcing function, such as forces due to flow turbulence, symmetric and asymmetric vortex shedding, pressure waves from steady state and transient operations. Based on these postulates, prior startup and other test data from similar or identical components are examined for the evidence of the existence of such forcing functions. Based on these examinations, the magnitudes of the forcing functions and/or response amplitudes are derived. These magnitudes are then used to calculate the expected ESBWR responses for each component of interest during steady state and transient conditions.

The staff found the applicant's response to RAI 3.9-47 acceptable because it provides the relevant information regarding the forcing functions, as requested. However, in RAI 3.9-47 S01, the staff requested that the applicant include this information in the ESBWR DCD.

In its response to RAI 3.9-47 S01, the applicant proposed modifications to DCD, Tier 2, Section 3.9.2.3, to reflect its answer to RAI 3.9-47. RAI 3.9-47 was tracked as a confirmatory item in the SER with open items. The staff found the proposed modifications of the DCD acceptable. The staff confirmed that the applicant incorporated the proposed modifications into DCD, Tier 2, Section 3.9.2.3, Revision 6. Therefore, RAI 3.9-47 and its associated confirmatory item were closed.

DCD, Tier 2, Section 3.9.2.3, states that special analysis of the response signals measured from the reactor internals of many similar designs is performed to obtain the parameters that determine the amplitude and modal contributions in the vibration responses. However, the applicant did not identify the specific parameters that are used to determine amplitude and modal contributions and did not explain with typical diagrams how the special analysis used these parameters. Therefore, in RAI 3.9-48, the staff requested that the applicant identify these specific parameters.

In its response to RAI 3.9-48, the applicant stated the following:

> The test data from sensors (accelerometers, strain gages, and pressure sensors) installed on reactor internal components is first analyzed through signal processing equipment to determine the spectral characteristics of these signals. The spectral peak magnitudes and the frequencies at the spectral peaks are then determined. These spectral peak frequencies are then classified as natural frequencies or forced frequencies. If a spectral peak is classified as being from a natural frequency, its amplitude is then determined using a band-pass filter if deemed necessary. The resultant amplitude is then identified as the modal response at that frequency. This process is used for all frequencies of interest. Thus the modal amplitudes at all frequencies of interest are determined. If a spectral peak identified is being from a forced frequency, the source [such as a vane passing frequency (VPF) of a pump] is identified. Again, its magnitude is determined using a band-pass filter if deemed necessary.
>
> The modal amplitudes and the forced response amplitudes are then used to calculate the expected ESBWR amplitudes for the same component. These ESBWR expected amplitudes are determined by calculating the expected changes in the forcing function magnitudes from the test component to the ESBWR component. For example, for flow turbulence excited components, the magnitudes are determined by ratioing with the flow velocity squared.

The staff found the applicant’s response to RAI 3.9-48 acceptable because it explains how the various parameters are used in the special analysis, as requested. However, in a supplemental RAI, the staff asked the applicant to include this information in the ESBWR DCD. In its response to RAI 3.9-48 S01, the applicant proposed revisions to the DCD that were acceptable to the staff. RAI 3.9-48 was tracked as a confirmatory item in the SER with open items. The staff has confirmed that the applicant incorporated the proposed modifications into DCD, Tier 2, Section 3.9.2.3, Revision 6. Therefore, RAI 3.9-48 and its associated confirmatory item were resolved.

DCD, Tier 2, Section 3.9.2.3, states that response signals measured from the reactor internals of many similar designs are used to predict the vibration responses for the ESBWR reactor internals. However, the applicant did not identify the specific plants that it considers to be similar to the ESBWR design. Therefore, in RAI 3.9-49, the staff requested that the applicant provide a listing of the plants that it considers to have reactor internals similar to the ESBWR design and explain the bases for its decision. In addition, the staff asked the applicant to discuss the dissimilarities and explain what impact they could have on the predicted results.In its response to RAI 3.9-49, the applicant stated the following:

> The plants considered as being similar to the ESBWR depend on the component being investigated. For example, the incore monitor guide tube (ICMGT), and incore monitor housing, and control rod guide tube (CRGT) in the ABWR, and all BWR5/6’s are considered as being similar to the ESBWR. Except for shorter lengths due to a shorter core of the ESBWR, the designs for these components in these plants are essentially identical from a structural and FIV viewpoint. A shorter length will result in higher natural frequencies and lower responses for

> the ESBWR. For the shroud/separator structure, the ABWR design, except for the inclusion of the chimney in the ESBWR, is considered similar to the ESBWR. Inclusion of the chimney is expected to result in a different shroud/separator, chimney response for the ESBWR. Thus startup testing for this structure is planned.
>
> The dissimilarities between the ABWR and the ESBWR are detailed in Table 2 of NEDE-33259P, January 2006, as well as in later Revisions 1 (December 2007) and 2 (June 2009).

Based on its review of the referenced documents and the applicant's commitment to perform startup testing on components, the staff finds the applicant's response to perform testing to be reasonable and acceptable. However, as discussed below, the staff raised several questions regarding the identification for FIV evaluation of the similarities and dissimilarities between the components and flow conditions of the ESBWR and other reactors.

The FIV response of a component depends on its structural characteristics (geometry, mass distribution, including added fluid mass, and boundary conditions) and the character of the pressures exerted on the component by the local flow field (as represented by pressure amplitudes, frequencies, spatial and time distributions, and their correlations). In turn, the structural characteristics determine the modal characteristics (modal frequencies, mode shapes, modal masses, and modal damping) used in FIV evaluations. As the flow moves past the component and upstream flow obstructions and other components, the character of the flow (including the velocity vector field, the density, the viscosity, and the flow regimes) determines the pressures, FIV-forcing functions, and FIV excitation mechanisms. The applicant should discuss all of these variables for each reactor component when identifying similar components in other reactors that will be used for FIV evaluation. Using the applicant's examples of the ICMGT, the in-core monitor housings (ICMHs), and the CRGT, outstanding structural information that requires further discussion includes the similarity of their boundary conditions, the similarity of their interconnections, whether the components respond individually or in a group, and the similarity of the structural modal frequencies, mode shapes, modal masses, and modal damping. Outstanding fluid flow information that requires further discussion includes an explanation as to why the pressures exerted on these components by the natural convection flow in the ESBWR is expected to be similar to the near-field flow from the jet pumps in other reactors.

When FIV response results from other reactors are used to predict ESBWR component responses, the applicant should provide complete justifications for the structural and flow similarities between the ESBWR and the other reactors for each ESBWR reactor component. The structural justifications should discuss geometry, mass distribution, and boundary conditions; modal frequencies; mode shapes; modal masses; and modal damping. The fluid flow justifications should discuss pressure amplitudes, frequencies, spatial and time distributions and their correlations, the flow properties, the flow velocity vector fields, the flow regimes and the turbulent characteristics of the flow, and the potential FIV-forcing functions and mechanisms.

Based on the statements above, the staff requested, in RAI 3.9-49 S01, that the applicant provide additional information comparing the components and flow conditions of the ESBWR and other reactors so as to reliably evaluate the FIV.

In its response to RAI 3.9-49 S01, the applicant detailed the dynamic structural analysis method used to calculate the ESBWR response. The response provided the forced response equation, based on modal analysis; tables from which the structural parameters of the ABWR and ESBWR components could be determined; and selected measured responses of the ABWR. The applicant assumed the fluid forcing function F(t,x) to be the same in the ESBWR as in the ABWR, except that differences in local flow velocities must be taken into account.

After evaluating the response to RAI 3.9-49 S01, the staff agrees that the forced response equation is applicable, that the definition of the structural parameters can be conservatively estimated for both the ABWR and the ESBWR, and the fluid forcing function will depend on the flow velocity. The flow velocity and turbulence intensity is higher in the ABWR because jet pumps drive the flow below the core rather than the natural circulation of the ESBWR. Further, the staff agrees that the response of the ABWR to turbulence excitation can be used to conservatively estimate the response of the ESBWR to turbulent flow using the forced response equation. However, different FIV excitation mechanisms may occur in the ESBWR, which do not occur in previous reactors, because the flow below the core is less turbulent and shroud support brackets, or support legs in the latest design, are present at the entrance to the flow region below the core. Thus, self-generated vortex shedding may be more intense and shedding from nearby shroud support brackets or support legs, which are not present in the ABWR, could excite components below the core, especially those on the periphery. ESBWR response to these potential excitations mechanisms could not be determined using the forced response equation and measured ABWR response, as outlined by the applicant's response to RAI 3.9-49 S01, but the applicant did address the potentials in NEDE-33259P, Revisions 1 and 2, and in the applicant's response to RAI 3.9-79 S01. Self-generated vortex shedding frequencies and those from the shroud support brackets were determined to be much lower than any of the components below the core, and thus found to be incapable of causing significant excitation.

For purpose of FIV structural response analysis and predictions, the staff found the response acceptable because the applicant has provided a list of the specific plants that it considers to have reactor internals and excitation mechanisms similar to the ESBWR, justified the choice of the plants, compared component by component and excitation mechanism by excitation mechanism, and discussed the dissimilarities in FIV information, including the impact of the dissimilarities could have on the predicted results. Therefore, RAI 3.9-49 was closed.

DCD, Tier 2, Section 3.9.2.3, states that dynamic modal analysis of major reactor internals components and subassemblies is performed to identify vibration modes and frequencies. The analysis models used for this purpose are similar to the analysis models for seismic Category I structures outlined in DCD, Tier 2, Section 3.7.2. Based on its review, the staff determined that differences exist between the two models. Therefore, in RAI 3.9-50, the staff requested that the applicant discuss the differences between the analytical models being used in the dynamic modal analysis of major components and subassemblies and the models used for seismic Category 1 structures discussed in DCD, Tier 2, Section 3.7.2.

In its response to RAI 3.9-50, the applicant stated the following:

> The models for reactor internals, as well as seismic Category I structures (DCD, Tier 2, Subsection 3.7.2), are similar as far as the characterization of structural finite elements—mass, stiffness and damping—is concerned. However, their characterizations may take special forms more appropriate to the particular models. For example, damping of seismic Category I structures may be better

specified through composite material damping because of the widely different damping properties of structural materials in such structures, whereas the use of a simpler constant modal damping is realistic in the case of reactor internals. The nature of the forcing functions, which in the two cases is different, lends to mathematical simplicity in the case of seismic excitation, but is much more complex and random for pressure excitations in the ESBWR. Similarly, for Category I structures, a diagonal mass matrix is a standard representation of structural mass in the model, whereas for the analysis of RPV internals the inclusion of hydrodynamic masses coupling the degrees-of-freedom of internal components necessitate a non-diagonal representation of model mass matrix. The essential modeling procedures are, however, the same in both the cases.

The staff finds the applicant's response acceptable because it satisfactorily explains the analytical models and procedures being used in the dynamic modal analysis of major components and subassemblies and the models used for seismic Category 1 structures, as requested. Therefore, RAI 3.9-50 was closed.

DCD, Tier 2, Section 3.9.2.3, states that data from previous plant vibration measurements are assembled and examined to identify predominant vibration response modes of major components. In general, response modes are similar, but response amplitudes vary among BWRs of differing size and design. The discussion provided in DCD Tier 2, is insufficient and does not discuss the extent of the variation in the response amplitudes for major components in BWRs of differing size and design. Therefore, in RAI 3.9-51, the staff requested that the applicant provide this information.

In its response to RAI 3.9-51, the applicant stated the following:

> Since the shroud/separator structure is of special interest to the ESBWR, the variations in the measured shroud/separator responses during startup testing at full power for seven older reactors are provided below.

Plant Name	RPV ID (in.)	Shroud Displacement Amplitude (p-p mils)
Dresden 2	251	1.5
Dresden 3	251	1.5
Fukushima 1	188	0.5
Millstone	213	1.5
Monticello	205	1.0
Quad Cities 1	251	0.5
KKM	158	2.5

> The mean value of these displacements is 1.29 and the standard deviation is 0.699.

The applicant provided in its response to RAI 3.9-51 the extent of the variation in the response amplitudes for the shroud separator in BWRs of differing size and design, as requested. However, the applicant did not provide response amplitudes for other major components. In RAI 3.9-51 S01, the staff requested that the applicant provide a more complete list of predominant vibration response amplitudes of major ESBWR components in other BWRs of differing size and design. RAI 3.9-51 was tracked as an open item in the SER with open items. Since issuance of RAI 3.9-51 S01, GEH has issued NEDE-33259P, Revision 2. This report discusses the testing of specific reactor internal components. The review of this report and the resulting RAIs supersede RAI 3.9-51 S01. In the review of NEDE-33259P, the staff found that the issue of RAI 3.9-51 had been adequately addressed. Therefore, RAI 3.9-51 and its associated open item were closed.

DCD, Tier 2, Section 3.9.2.3, states that parameters are identified that are expected to influence vibration response amplitudes among the several reference plants. These include hydraulic parameters, such as velocity and steamflow rates, and structural parameters, such as natural frequency and significant dimensions. In RAI 3.9-52, the staff asked the applicant to identify all of the parameters that are expected to influence vibration response amplitudes among the reference plants. The staff also asked the applicant to discuss the relative significance of each parameter. In its response to RAI 3.9-52, the applicant stated the following:

> The following process parameters have the potential to impact component vibration amplitudes: power, re-circulation flow rates and velocities, feedwater flow rates and velocities, and steam mass flow rates and velocities. Plant transients are affected by main steam isolation valve (MSIV) and turbine stop valve (TSV) closure rates. The following structural and fluid parameters have the potential to impact component vibration amplitudes: Structural and fluid damping, structural natural frequencies, and mode shapes. Other parameters that may impact vibration amplitudes are: frequency of the forcing function, amplitudes and spatial distribution of forcing functions.
>
> In general, the vibration amplitudes are linearly related to the fluid mass and proportional to the square of fluid flow velocities. Transient response amplitudes are generally inversely proportional to the closure rates of MSIVs and TSVs. In general, the vibration amplitudes are inversely proportional to the frequency squared. Also, the lower natural modes generally have higher responses because the generalized forces are normally higher for the lower mode shapes. This is because generalized force is a measure of the energy input into the vibrating system by the applied force. The frequency of the forcing function becomes critical if it is near a natural frequency. This is because resonance or near resonance could occur. At or near resonance, the vibration amplitudes increase exponentially.

The staff found that the applicant’s response to RAI 3.9-52 provided parameters that are expected to influence vibration response amplitudes among the reference plants with one exception—the relative phases of the forcing functions. The staff requested, in RAI 3.9-52 S01, that the applicant discuss the importance of the relative phases of the forcing functions and identify any components for which relative phase could affect the response significantly.

In its response to RAI 3.9-52 S01, the applicant stated that, during normal steady-state operation, the ESBWR reactor internal components may be subjected to pressure fluctuations resulting from flow turbulence. These pressure fluctuations do not have an identifiable phase. Turbulent pressure fluctuations cause the reactor internal components to respond in their natural modes. Each natural mode response vibrates with a broadband frequency peaking at the natural frequency. The vibration phases of each mode differ from one another. Thus, the phases of the peak responses of the modes are such that the peaks do not coincide in time or structural location. This results in lower actual responses when compared to the ABS of the peak responses of each mode. On rare occasions, it is possible for the peak of two modes to coincide. Because such occurrences occur infrequently, they do not significantly affect the fatigue usage factor. The SRSS method is used to combine these modal responses.

The applicant also indicated that, besides turbulence-induced excitation, reactor internals may also be subjected to pressure fluctuations from active pumping actions from various fluid systems. The ESBWR design does not include recirculation pumps, which are significant sources of pressure fluctuations at the VPF in other reactor designs. Thus, only minor pressure fluctuations with definite frequency and phase influence reactor internal responses. If these responses are not negligible, they are considered simultaneously with the responses from turbulent flow for fatigue usage calculations, in accordance with the ASME Code.

In addition, the applicant indicated that plant transients, such as MSIV and TSV closure, result in forcing functions with definite but indeterminate phases. The phase depends on the time of actuation of these valves. Because of this indeterminacy, the stresses are considered simultaneously with the responses from turbulent flow for fatigue usage calculations, in accordance with the ASME Code.

The staff found the applicant's identification, interpretation, and evaluation of the phasing of turbulence-induced excitation, pump pressure fluctuations, and plant transients acceptable. However, other forms of excitation not discussed by the applicant are possible. Other forms not discussed have been responsible for several past component failures. In a supplement to RAI 3.9-52, the staff issued RAI 3.9-59 S02 and requested that the applicant discuss how its FIV analysis and testing programs considered deterministic excitation mechanisms, like acoustic and vortex shedding excitation, as well as the importance of the phasing of the forcing functions. In its response to this RAI and to RAI -3.9-59 S02 and to RAI 3.9-79, the applicant provided additional information, which the staff found acceptable. The staff's evaluation of this information is discussed under RAI 3.9-79 later in this section. RAI 3.9-52 was tracked as a confirmatory item in the SER with open items, and it has been closed.

DCD, Tier 2, Section 3.9.2.3, states that correlation functions of the variable parameters are developed which, when multiplied by response amplitudes, tend to minimize the statistical variability between plants. A correlation function is obtained for each major component and response. The staff requested, in RAI 3.9-53, that the applicant discuss the development of the correlation functions for the major components and response modes with typical, specific examples to demonstrate how multiplication by the response amplitude tends to minimize the statistical variability.In its response to RAI 3.9-53, the applicant stated the following:

> Since all BWRs are geometrically similar, the BWRs that have been vibration tested represent very good models of other reactor internals to be tested. Therefore, a prediction based on prior test results can be made based on engineering evaluation of the parameters that are known to affect vibration response.

The applicant has defined relationships for internals components and provided a methodology, using a set of correlation parameters and appropriate coefficients, which tends to reduce the statistical dispersion of the nondimensional amplitudes among plants.

The staff determined that the applicant's response to RAI 3.9-53 did not fully justify the applicability of the data from other reactors to the ESBWR components. In particular, the statement, "Since all BWRs are geometrically similar, the BWRs that have been vibration tested represent very good models of other reactor internals to be tested," may not necessarily be true. Geometric similarity is only one consideration in determining whether a component is a good model for the ESBWR components. Therefore, in RAI 3.9-53 S01, the staff requested that the applicant justify the similarity of each component using all parameters relevant to FIV excitation before using any data from other reactor components to develop correlations. In its response to RAI 3.9-53 S01, the applicant referred to its response to RAI 3.9-49 S01 and NEDE-33259P, Revision 1. Based on its review of the applicable portions of NEDE-33259P, Revision 1, and RAI 3.9-49 S01, the staff finds that the applicant has discussed a methodology that justifies the similarity of each component based on data obtained from other reactors, as requested. Revision 2 of NEDE-33259P retains the applicable portions. Therefore, RAI 3.9-53 was closed.

DCD, Tier 2, Section 3.9.2.3, states that the predicted amplitude for each dominant response mode is stated in terms of a range, taking into account the degree of statistical variability in each of the correlations. The predicted mode and frequency are obtained from the dynamic modal analyses. The staff requested, in RAI 3.9-54, that the applicant use typical analytical data to demonstrate that the predicted amplitude takes into account the degree of statistical variability. In its response to RAI 3.9-54, the applicant stated the following:

> Please refer to the response to NRC RAI 3.9-53. FEMs of reactor internal components that have been tested are made to determine the natural frequencies and mode shapes of these reactor internal components. The results are compared to the measured values in the reactor. Where deemed appropriate, the FEMs are refined so that the calculated values are closer to the measured values. For a component requiring new tests, their FEMs are developed following the methodology used for the components already tested. Using the FEMs thus developed, the responses are calculated. The calculated response values are taken to be the mean value of the response. The correlation functions, consisting of the correlation factors and correlation coefficients, are calculated as described in the response to RAI 3.9-53. The calculated mean values and standard deviation are used, in conjunction with other variable data (e.g. fatigue strength) to assess the structural adequacy from an FIV viewpoint.

The staff found the applicant’s response acceptable because it demonstrates with typical analytical data that the predicted amplitude takes into account the degree of statistical variability, as requested. Therefore, RAI 3.9-54 was closed.

DCD, Tier 2, Section 3.9.2.3, states that the dynamic loads caused by FIV from the feedwater (FW) jet impingement have no significant effect on the steam separator assembly. Analysis is performed to show that the impingement FW jet velocity is below the critical velocity. However, the applicant provided no analytical methodology or quantitative data. In RAI 3.9-55, the staff requested that the applicant provide quantitative analytical or test data to demonstrate that dynamic loads caused by FIV from the FW jet impingement do not have a significant impact on the steam separator assembly.

In its response to RAI 3.9-55, the applicant stated the following:

> The shroud head and steam separator assembly in GE BWR/6 plants is clamped in place by 28, 32 or 36 shroud head studs and nuts. Together, the stud, nut, shroud head bolt, locking collar and certain other components comprise the shroud head stud assembly. The shroud head bolt is an in-reactor tool used to torque and un-torque the stud. The bolt also provides a locking function to prevent rotation of the stud. Shroud head stud bolt wear has been found at all GE BWR/6 plants. Wear has been observed on the bolt splines, on the guide

pins of the locking collar assembly and on the bolt shaft where it passes through the lower support ring. This is the only flow induced issue that has occurred in the steam separator assembly, and the problem was unique to BWR/6 plants due to its different design where the shroud head bolt was unloaded and free to vibrate during plant operation. Mockup testing by GE has confirmed that the wear was caused from vibration of the shroud head bolts as a result of feedwater flow impinging on the bolt shafts. The shroud head bolts in the ESBWR design are quite different from the BWR/6 design, and are the same fundamental design that all other BWRs have successfully operated with, and have not experienced any vibration problems. In this design, the components that are opposite the feedwater flow are fully loaded during plant operation.

The staff found the applicant’s response acceptable because it provides test data to demonstrate that dynamic loads caused by FIV from the FW jet impingement have no significant impact on the steam separator assembly, as requested. Therefore, RAI 3.9-55 was closed.

DCD, Tier 2, Section 3.9.2.3, states that it can be shown that the excitation frequency of the steam separator (dryer) skirt is very different from the natural frequency of the skirt. The applicant provided no additional rationale or analysis to demonstrate the validity of this statement. In RAI 3.9-56, the staff requested that the applicant provide the analysis or test data to show that the excitation frequency of the steam separator (dryer) skirt is substantially different from the natural frequency of the skirt. In its response to RAI 3.9-56, the applicant provided the requested test data that showed that the natural frequency of steam separator (dryer) skirt is very different from that natural frequency of the skirt alone, and proposed modifications to the DCD, which the staff found acceptable. The applicant included these changes in the formal revision of the DCD. Therefore, RAI 3.9-56 was closed.

DCD, Tier 2, Section 3.9.2.3, does not discuss the acoustic and computational fluid dynamic analyses to predict stresses at the locations to be monitored in the steam dryer. In RAI 3.9-58, the staff requested that the applicant discuss the acoustic and computational fluid dynamic analyses to predict stresses at the locations to be monitored in the steam dryer.

In its response to RAI 3.9-58, the applicant stated the following:

> The steam dryer acoustic load definition process is described in Subsection 3L.4.4 of DCD, Tier 2, Appendix 3L. A more detailed discussion of the source of the load definition and validation of the load definition methodology will be provided in a future reference report: Reference 3L-5: NEDE-33312P and NEDO-33312.
>
> The steam dryer structural evaluation is described in Subsection 3L.4.5 of DCD, Tier 2, Appendix 3L. The steam dryer stress analysis and comparison to acceptance criteria will be provided in a future reference report: and NEDO-33313.
>
> The steam dryer instrumentation and startup testing process is described in Subsection 3L.4.6 and validation of the load definition methodology in Subsection 3L.4.6 of DCD, Tier 2, Appendix 3L. Details regarding the validation of the steam dryer load definition methodology are provided in the GEH Reports, NEDE-33312P and NEDC-33408P. The steam dryer structural evaluation is described in Subsection 3L.4.5 of DCD, Tier 2, Appendix 3L. The steam dryer

stress analysis and acceptance criteria are provided in the GEH Report, NEDC-33313P. The steam dryer instrumentation and startup testing process is described in Subsection 3L.4.6 of DCD, Tier 2, Appendix 3L.

Based on its review, the staff finds that the applicant deferred the submission of information related to the steam dryer load definition and stress analysis requested by the staff to a future date. RAI 3.9-58 was tracked as an open item in the SER with open items. The applicant has submitted NEDE-33312P and NEDC-33313P, as mentioned above. In addition, the applicant has submitted NEDC-33408P and its Supplement 1. The staff has evaluated this additional information and submitted several RAIs. The staff evaluated the responses to these additional RAIs in two separate SERs: one for NEDC-33312, NEDC-33408P, and their supplements, and another for NEDC-33313P. Therefore, RAI 3.9-58 is superseded by these additional RAIs. RAI 3.9-58 and its associated open item were therefore closed.

Vibration predictions should be verified by test results. If the test results differ substantially from the predicted response behavior, the vibration analysis should be appropriately modified to improve the agreement with test results and to validate the analytical method as appropriate for predicting responses of the prototype unit, as well as of other units, where confirmatory tests are to be conducted.

FIV evaluation analyses are required for all components with significantly different features and loading conditions, in accordance with RG 1.20, “Comprehensive Vibration Assessment Program for Reactor Internals During Preoperational and Initial Startup Testing,” and SRP Section 3.9.2. In RAI 3.9-59, the staff requested that the applicant provide detailed descriptions of each of the components, their structural boundary conditions and FEM (including assumed damping), the flow conditions, the FIV load definitions, the modal characteristics, and the results of the response analyses, including acceptance criteria.

In its response to RAI 3.9-59, the applicant stated the following:

> The following ESBWR Internals components will be instrumented and analytically evaluated for FIV since they are new components that are being used in the ESBWR design:
>
> <u>Shroud and Chimney</u>
>
> Due to the addition of a chimney, the ESBWR shroud, top guide, chimney, and chimney head/steam separator assembly are considered to be new or sufficiently different to require testing and analysis. The shroud/chimney/steam separator assembly is a freestanding structure; however, there are eight lateral restraints at the top of the chimney that transmit loads to the RPV. The 12 shroud support brackets also provide a load path from the shroud to the RPV. There are bolted connections at the shroud to top guide, top guide to chimney, and chimney to chimney head.
>
> In order to determine the shroud vibration frequencies and mode shapes, an axisymmetric shell model, with each node having four degrees-of-freedom, is developed using the ANSYS computer code or an equivalent qualified program. The detailed shell model consists of the RPV, chimney, chimney support, and shroud, such that the hydrodynamic interaction effects between the components are accounted for. This shell model is applicable only to the axisymmetric FEM

of the shroud and vessel. Responses calculated from this model, other than that of the shroud, shall not be construed as being representative of other reactor components. The following assumptions are made in generating the axisymmetric shell model:

(1) Discrete components move in unison for guide tubes, steam separators, standpipes, and CRD housings and guide tubes.

(2) Masses are lumped at the nodal points. Rotational inertias of the masses are neglected.

(3) Stiffnesses of control rods, CRDs, steam dryers, and incore housings are neglected.

(4) Top guide beam and core plate are assumed to have zero rotational stiffness.

(5) Masses of CRD housings below the vessel are lumped to the bottom head.

Equivalent shells are used to model the mass and stiffness characteristics of the guide tubes, steam separators, and standpipes such that they match the frequencies obtained from a horizontal beam model. Diagonal hydrodynamic mass terms are selected such that the beam mode frequencies of the shell model agree with those from the beam model.

The RPV, chimney and shroud are modeled as thin shell elements. Discrete components such as guide tubes are modeled as equivalent thin shell elements. The shell element data are defined in terms of thickness, mass density, modulus of elasticity, and Poisson's ratio for the appropriate material and temperature.

The natural frequencies and mode shapes of the shroud shell model are given in terms of two parameters, termed "n" and "m." The "n" parameter refers to the number of circumferential waves, while the "m" parameter refers to the number of axial half-waves. Thus, for beam types of vibration, n = 1.

The fluid velocity of the water in the annulus between the chimney and the RPV is approximately the same as that in the annulus between the shroud and the RPV for the ABWR; and therefore, the corresponding fluid induced forces are similar. In the ESBWR annulus between the shroud and the RPV, the fluid velocities are higher than those at the ABWR, and so are the fluid forces, because of a narrower annulus width.

The calculation of maximum FIV stresses in the shroud and the chimney requires, as a first step, the identification of modes that are excited by fluid forces. This information is obtained from strain gages and displacement transducers during testing. Using analytically determined mode shapes for the vibrating modes, the test data is then converted into maximum modal stress anywhere on the shroud and the chimney. The process is repeated for each vibration mode identified from the analysis of test data. The stresses for all vibrating modes are then appropriately combined to obtain total maximum stress.

In the case when test data is not available, test data from the ABWR, suitably modified to account for differences in responses between the ABWR and ESBWR, is used.

The preceding analysis does not require the specification of damping since the effect of damping is implicit in test measurements. However, any supplementary analysis that may require the use of time histories of forcing functions, a 2 percent damping will be used for FIV evaluation. The applicant's acceptance criteria require that this maximum stress is below a threshold value of 68.9 MPa (10,000 psi).

Standby Liquid Control Lines:

In the ESBWR prototype plant reactor, there are two standby liquid control pipes that enter the reactor vessel and are routed to the shroud. To predict the vibration characteristic of the standby liquid control line, a dynamic FEM of the entire line is developed. In the model the ends of the line are fixed anchor points since the lines are welded at the vessel nozzle and the shroud attachment points. The Standby Liquid Control System (SLC) pipe is modeled by beam elements with each node having six degrees-of-freedom. Pipe masses along with added fluid masses are lumped at nodes. The spacing of the nodes is determined by the expected stress gradient and the maximum frequency required to be predicted with accuracy.

The lower part of the SLC is subject to higher fluid forces than the upper part because the fluid velocity in the shroud-RPV annulus is higher than that in the chimney-RPV annulus.

The procedure for determining maximum stress is similar to that described above for the shroud/chimney FIV analysis; namely, identification of vibration modes from test data, analytical mode shape determination for thus identified modes, using test data and mode shape information to obtain maximum modal stress anywhere on the SLC lines, and combination of modal stresses to obtain the total maximum stress. Prior to the availability of test data, SLC piping responses are calculated by applying fluid forces based on ABWR measurements. Vortex shedding frequencies (lowest frequency = 5.5 Hz) are also calculated and compared to the calculated natural frequencies (lowest frequency = 25.2 Hz). As before, no damping is required in this analysis. However, a damping of 1 percent will be used where required. The applicant's acceptance criteria require that this maximum stress be below a threshold value of 68.9 MPa (10,000 psi).

In response to RAI 3.9-59, the applicant provided descriptions of two components (shroud and chimney, and standby liquid control line), their structural boundary conditions and FEM (including assumed damping), the flow conditions, the FIV load definitions, the modal characteristics, and the results of the response analyses, including acceptance criteria, as requested. The staff found that the applicant did provide, as requested, detailed descriptions of two components, their structural boundary conditions and FEM (including assumed damping), their flow conditions, the FIV load definitions, the modal characteristics, and the results of the response analyses, including acceptance. However, other components were not addressed and the staff had questions on the assumptions of the analysis for the shroud/chimney. Therefore, in RAI 3.9-59 S01, the staff requested the following information:

(1) The applicant should justify similarity for FIV evaluations on a component-by-component basis when the test data for response analysis of an ESBWR component are obtained on components in other reactor tests.

(2) The axisymmetric analysis of the freestanding shroud/chimney/steam separator structure does not allow investigation of torsion modes. The applicant should justify why the excitation of torsion modes is not significant and discuss any torsion constraint between the chimney and the RPV at the lateral constraint, as well as potential FIV excitation sources that could excite torsion modes.

(3) RAI 3.9-59 requested a response for all components with significantly different features and loading conditions, in accordance with RG 1.20 and SRP Section 3.9.2. The applicant should confirm whether the two items reported upon are the only components considered to have significantly different features and justify the exclusion of others.

In response to RAI 3.9-59 S01 (1), the applicant has identified the components that are sufficiently different from the earlier BWRs and the ABWR and stated they will be instrumented and analytically evaluated for FIV. This is acceptable because the applicant will be instrumenting the components that are sufficiently different from the earlier BWRs and ABWR components. In response to RAI 3.9-59 (2), the applicant provided information that showed only small torsional fluid forces would be active on shroud/chimney/steam separator structure and the torsional restraint at the top of the chimney will result in an ESBWR torsional response that is less than the comparable ABWR response. Therefore, the staff found the response acceptable because the response to torsional forces is bounded by the corresponding ABWR response. In response to RAI 3.9-59 (3), the applicant provided sufficient information, on a component-by-component basis, for the staff to agree that the remaining components in the ESBWR have characteristics sufficiently similar to the ABWR so that detailed FIV testing and analyses are unnecessary. For these reasons the staff concluded that RAI 3.9-59 S01 was resolved.

The applicant's FIV evaluation program for the reactor internals is incomplete and difficult to comprehend because the FIV program information is spread across DCD, Tier 2, Sections 3.9.5 and 3.9.2, and two supplemental reports. In addition, the different documents are not cross-referenced and, clearly, additional reports are planned. Based on the information made available to date, the staff concludes that proper design of the reactor internals can minimize any FIV excitation that is present. However, the staff could not make a final evaluation of the FIV program for the ESBWR internals without further information, as identified in the RAIs that follow and those provided in the evaluation of DCD, Tier 2, Section 3.9.5. Therefore, in RAI 3.9-72, the staff requested that the applicant provide a revised and comprehensive DCD on the FIV evaluation of reactor internals.

In its response to RAI 3.9-72, the applicant stated the following:

> The ESBWR LTR for Vibration (NEDE-33259P) identified several components requiring additional analyses. These components are: shroud/chimney assembly, chimney head/steam separator assembly, and SLC piping. The LTR will be updated upon completion of these additional analyses. Appendix 3L will be changed as necessary to be consistent with the LTR. In addition to the above

> components, the steam dryer and chimney partitions have their own separate programs.

After reviewing the applicant's response to RAI 3.9-72, the staff requested that the applicant provide the revised NEDE-33259P, with the completed analyses for staff review. NEDE-33259P, Revisions 1 and 2, submitted by the applicant, contain the information requested by the staff.

Based on its review of the applicant's response, in NEDE-33259P, as well as the applicant's response to RAI 3.9-59 S01, the staff finds the response acceptable because NEDE-33259P, Revision 2, includes the completed analyses of the components that differ from the ABWR, and the revised Appendix 3L is consistent with the revised report. Therefore, RAI 3.9-72 was closed.

The applicant considers the ESBWR a non-prototype Category II, in accordance with RG 1.20, because of the similarity of the ABWR and the ESBWR designs, but arguments can be made that the ESBWR is a prototype. The applicant has already identified 50 percent of the major internal components for new evaluations and startup testing instrumentation. In addition, as indicated in the RAIs below, questions exist regarding the need for further evaluation of the other components. As far as an FIV evaluation is concerned, it is most important to understand the flow fields, loading functions, structural analyses, and benchmark testing to be performed. A more justifiable classification of the reactor internals according to RG 1.20 can be made after all the information is provided.

For the ESBWR FW sparger and the chimney head and steam dryer guide rods, the applicant implied that valid prototype structures and flow conditions provide evidence that those differences between the prototype and the ESBWR will not have a significant effect on the vibratory response of any of the ESBWR components, as discussed in RG 1.20 and SRP Section 3.9.2. In RAI 3.9-76, the staff asked the applicant to identify and describe the structures and flow conditions in the valid prototype that correspond to the ESBWR FW sparger and the chimney head and steam dryer guide rods and to provide additional evaluation and evidence to show that the differences, if any, will have no significant effect on the vibratory response.

In its response to RAI 3.9-76, the applicant stated the following:

> The ESBWR feedwater sparger and the steam dryer guide rod are the same in design as the ESBWR prototype ABWR. BWR steam dryer guide rods, including those for the ABWR have had satisfactory operation for many decades and no FIV issues are anticipated. The feedwater spargers in older BWRs had encountered self-excited vibration problems due to leakage flow at the thermal sleeve. Subsequent to those occurrences, BWR feedwater spargers have been redesigned to eliminate or minimize leakage flow. Tests conducted on the re-designed spargers show negligible flow induced vibration (FIV) response. Thus, even though the ESBWR feedwater flow is about 10 percent higher, no unacceptable vibration amplitudes are anticipated. There have not been any vibration issues with the re-designed feedwater spargers. The chimney head is a newly designed component. The applicant has completed additional analysis work on this component. The NEDE-33259P will be revised to include the information on the analysis. This revision will be completed and submitted to the NRC by March 2007.

The staff found that the applicant's response regarding the sparger needed clarification and information on the chimney head incomplete. Therefore, in RAI 3.9-76 S01, the staff asked the applicant to identify and describe the structures and flow conditions in the valid prototype that correspond to the chimney head and to provide additional evaluation and evidence to show that the differences, if any, have no significant effects on the vibratory response. In addition, the staff requested clarification of the uncertainty in the term anticipated in the phrase, "even though the ESBWR feed-water flow is about 10 percent higher, no unacceptable vibration amplitudes are anticipated."

In its response to RAI 3.9-76 S01, the applicant stated the following:

> The chimney head structure is unique to the ESBWR. As such, it is a newly designed structure requiring extensive analysis. A comprehensive finite element model has been used for the detailed evaluation. The analytical methodology and results are presented in NEDE-33259P, Revision 1, which was transmitted to the staff. As in the ABWR, the ESBWR FW sparger is of the "welded-in" design. In the welded-in design, flow leakage is eliminated by welding the thermal sleeve to the nozzle safe end. Since there is no leakage, there are no leakage-flow induced instabilities. Thus, even though the FW flow in the ESBWR is about 10 percent higher than that in the ABWR, there is no possibility of leakage flow induced instabilities.

After reviewing the pertinent sections of NEDE-33259P, the staff found it acceptable that an FIV analysis of the chimney head/steam separator assembly due to flow in the annuli had been completed and instrumentation is to be included during startup testing to verify the analysis. Also based on the review of NEDE-33259P, the staff found that the reported welded-in design does eliminate the possibility of leakage flow instabilities in the FW sparger. Therefore, the staff considers concerns related to RAI 3.9-76 were resolved.
The RG 1.20 and SRP Section 3.9.2 guidelines state that the differences between the valid prototype and the non-prototype reactors should not significantly affect the vibratory response of any of the components. In RAI 3.9-77, the staff requested that the applicant describe the modifications made to the vibration analysis of the ABWR top guide assembly, which was used to predict the response of the ESBWR top guide, to demonstrate that the FIV response of the top guide of the ESBWR is not significantly modified because of the structural differences between the ESBWR and the ABWR. In particular, the staff asked the applicant to discuss the modifications made to account for the differences in any cutout patterns in the guide plates, their diameters, and their attachments to the shroud and the chimney or shroud head.

In its response to RAI 3.9-77, the applicant stated the following:

> This component has proven trouble free in past BWR designs, with various size cores, including the ABWR. The design of the ESBWR top guide is made from a solid forging that is the same as the ABWR design in the arrangement and size of the cells. In addition, the overall thickness of the top guide is the same as the ABWR design. The ESBWR top guide does have a modestly larger overall diameter to accommodate the increased quantity of fuel assemblies, and as a result, the ESBWR has a larger number of cells. The top guide in both the ABWR and ESBWR is bolted into a larger structure. For the ABWR, the top guide is bolted to the shroud. For the ESBWR, the top guide is bolted between the shroud and chimney. The flow across the Top Guide is limited to the by-pass flow between fuel assemblies. For the ESBWR, the fluid velocities are lower

than the ABWR, further reducing any potential for FIV. DCD Table 3L-4 identifies instrumentation that will be placed on the top guide to measure its lateral motion. This instrumentation will be the same as instrumentation placed on the top guide for the ABWR, as identified in DCD Reference 3L-1.

In its response to RAI 3.9-77, the applicant did not provide the engineering analysis or experimental evidence requested and discussed in RG 1.20. In particular, the description of the ESBWR guide plate only mentions that the ABWR and ESBWR plates are connected to different components and that the ESBWR plate has more cutouts and a larger diameter than the ABWR plate. The ESBWR guide plate supports, in a cantilevered fashion, a very long chimney on which the steam separators are attached. The ABWR does not include a long chimney (i.e., longer than either the shroud or separator components) between the guide plate and the separators. In addition, the ESBWR has more of the guide plate cut out than the ABWR, which may create greater stress concentration factors. Furthermore, the fluid dynamic forces transmitted to the guide plate will be different for the ESBWR because the fluid forces on the chimney do not exist in the ABWR and the steam separator unit is of a different design. The lateral motion of the guide plate is not of main interest; instead, the staff is concerned about the dynamic stresses induced by dynamic deformation. Based on its review, the staff determined that further information was necessary.

Therefore, in accordance with RG 1.20, Revision 3, and SRP Section 3.9.2, Revision 3, the staff asked the applicant, in RAI 3.9-77 S01, to demonstrate that the differences between the ABWR and the ESBWR top guide plates will have no significant effect on the vibratory response. The staff also asked the applicant to describe the modifications made to the analytical or experimental vibration analysis of the ABWR top guide assembly used to predict the response of the ESBWR top guide plate and to demonstrate that the FIV response of the ESBWR top guide plate is not significantly modified by the structural and FIV loading differences between the ESBWR and ABWR designs. RAI 3.9-77 was tracked as an open item in the SER with open items.

The applicant provided the following response to RAI 3.9-77 S01. To calculate the FIV response of the ESBWR shroud/chimney/separator structure, measured pressure time histories in the ABWR RPV-shroud annulus were suitably scaled to define pressure time histories in the ESBWR RPV-shroud/chimney annulus. The scale factors were computed as the square of the ratio of ESBWR annulus fluid velocity to the corresponding value for the ABWR. Both ABWR shroud and ESBWR shroud/chimney structures were then analyzed under fluid forces resulting from the corresponding annulus pressure time histories to determine comparative responses of the shroud/chimney/separator structure. During the prototype ABWR FIV test, the movement of the top guide was measured together with the shroud. The pressure time history was therefore further normalized such that the calculated ABWR response was equal to the measured ABWR response. The highest zero-to-peak stress intensity calculated on the basis of these measurements was 10.8 MPa(1,566 psi)

The ESBWR top guide is made from a solid forging that is the same as the ABWR design in the arrangement and size of the cells. Because the ESBWR is a forging, the stress concentration factors are smaller than those in the ABWR. Since the calculated ESBWR lateral load at the top guide is two times higher than that of the ABWR, the highest zero-to-peak stress intensity is 21.6 MPa and is well below the allowable value of 68.9 MPa.

In evaluating the applicant's response to RAI 3.9-77 S01, the staff formulated RAI 3.9-77 S02 to clarify that the applicant analyzed the geometry of the ESBWR directly and did not extrapolate it from the ABWR stress analysis. In RAI 3.9-77 S02, the staff asked the applicant to provide justification for extrapolating the stresses in the ESBWR top guide from the stresses calculated in the ABWR, based on the guide plate lateral load results from the beam model analyses. In particular, the staff asked the applicant to comment on any differences in stress concentrations and stress patterns in the ABWR and ESBWR top guides, all of which would have to be the same or very similar in the ABWR and the ESBWR for the extrapolation to provide a reasonable estimate of the stress in the ESBWR top guide.

The applicant provided the following response to RAI 3.9-77 S02:

The scaled FIV Loads are now applied to the ESBWR specific geometry; as such there is no need to scale the stresses. The ESBWR zero to peak stress intensity is below 5.0 MPa (726 psi) as compared with 10.8 MPa (1,566 psi) for the ABWR and still well below the allowable value of 68.9 MPa (10,000 psi). The scaling of the FIV Loads is based on the dynamic pressure ratios. The staff found that the applicant had made clear in its response to RAIs 3.9-77, 3.9-77 S01, and 3.9-77 S02 that the actual geometry was analyzed subject to the scaled loads from the ABWR and that the stresses are well below the allowable value of 68.9 MPa (10,000 psi). Therefore, RAI 3.9-77 and its associated open item were closed.

NEDE-33259P, Revision 0, states that the ESBWR core plate does not require further FIV evaluation because it is similar to the ABWR core plate, which the applicant contends is a valid prototype of the ESBWR design. In RAI 3.9-78, the staff requested that the applicant explain how it modified the vibration analysis of the ABWR core plate to account for the structural differences in the ESBWR plate. The staff also asked the applicant to demonstrate that the ESBWR FIV response is not significantly modified from that of the ABWR, and, in particular, to discuss the modifications made to account for any differences in the cutout patterns in the core plates, their diameters, and their attachments to the shroud. NEDE-33259P, Revision 1, includes the above-requested information. However, the applicant changed the ESBWR core plate design from a welded and reinforced plate to a solid plate after the issuance of NEDE 33259P, Revision 1. NEDE-33259P, Revision 2, includes the analysis of the solid core plate. Based on a review of this information, the staff finds that the concerns related to the core plate were resolved. RAI 3.9-78 was closed because the ESBWR core plate stresses are well below the allowable stresses.

Comparing Figure 3.9-3 in the ESBWR DCD Tier 2 to Figure 3.9-2 in the ABWR DCD Tier 2, the character and distribution of the flow below the core can be expected to differ because of the lack of jet pumps and the presence of 12 separate shroud supports in the ESBWR. In RAI 3.9-79, the staff requested that the applicant explain these flow differences and how they will not significantly affect the FIV response of these ESBWR safety-related components, as discussed in RG 1.20 and SRP Section 3.9.2. In particular, the staff requested that the applicant discuss the potential effects of organized wake flows downstream of the shroud supports.

In its response to RAI 3.9-79, the applicant stated the following:

> The flow within an ESBWR reactor vessel is driven by the hydraulic head within the reactor vessel. The absence of a recirculation pump to drive flow eliminates pressure pulses and turbulence from the pumps in prior BWR designs. In a forced circulation reactor with jet pumps, the high velocity jets cause additional disturbances in flow exiting from the jet pump diffuser. The flow exiting from the diffuser enters the lower plenum and excites the lower plenum components such

> as the CRGT and incore guide tube (ICGT)/housing. On the other hand, the flow in the ESBWR, in the absence of pumping action, will have a much smoother lower velocity. Thus, the ESBWR flow entering the lower plenum has a lower velocity and flow disturbance lower than the flow in the ABWR. In addition to the above, the flow paths within the reactor vessel have better distribution and fewer flow disturbances due to the absence of jet pumps or RIPs, and have fewer changes in cross sectional area that cause flow variations. In the ESBWR, there are twelve shroud support brackets, each with a frontal area of 0.065 m^2. For the ABWR, there are 10 shroud support legs with a frontal area of 0.33 m^2 each. Thus wake turbulence in the ESBWR is much weaker. All the above factors, lower velocity and lower flow turbulence, combine to lower the FIV response of the lower plenum components.

The applicant's response is acceptable, with one exception, because it discusses the turbulent flow differences and explains how they will not significantly affect the FIV response. However, the applicant did not discuss the potential effects of organized wake flows downstream of the shroud supports. According to the applicant's response, the ESBWR core flow has lower flow turbulence than the flow from past reactors that use jet pumps. But lower flow turbulence promotes the shedding of more organized shear layers from the 12 smaller shroud support brackets upstream of the lower plenum components, such as the CRGT and the ICGT/housing. Therefore, in RAI 3.9-79 S01, the staff asked the applicant to discuss the potential effects of wake flows from the shroud supports shedding and impinging on downstream lower plenum components. In particular, the staff requested that the applicant include the assessment of the coincidence of the frequencies of organized wakes with the natural frequencies of the lower plenum components.

In response to RAI 3.9-79 S01, the applicant provided information which addressed the staff's concerns and was therefore acceptable. The staff also evaluated relevant portions of NEDE-33259P, Revision 1. This report discussed the effects of the self-generated vortex shedding on the core components, which were found to be insignificant and therefore acceptable. Subsequent to the issuance of NEDE-33259P, Revision 1, the core supports were changed back to the support legs employed in the ABWRs. The vortex shedding issues were readdressed and resolved in the audit of August 25, 2009, and the review of NEDE-33259P, Revision 1. Thus, RAI 3.9-79 was resolved.

The staff found discrepancy between NEDE-33259P and DCD Appendix 3L, as to the need for additional evaluations of the ICMHs and the ICMGTs of the ESBWR, both of which are safety-related components. The appendix recommends modeling the components as a continuously connected structure to accurately predict the vibration characteristics. NEDE-33259P treats the components as individual tubes, both for determining vibration characteristics as well as for fluid loading (a single tube in crossflow). In RAI 3.9-80, the staff requested that the applicant clarify the vibration characteristics and fluid loading on the ICMHs, the ICMGTs, and the stabilizer bar network. The staff also asked the applicant to explain how the FIV response of the ESBWR components will not differ significantly from those of the ABWR.

In its response to RAI 3.9-80, the applicant stated the following:

> To determine the natural frequencies and mode shapes, the ICMGTs and incore monitor housings are modeled by using beam elements interconnected by structural ties. On the other hand, individual cylinders of the ICMGTs and incore monitor housings are used for calculating the vortex shedding frequencies.

Since the fundamental natural frequency of the incore guide tube forest is far removed from the vortex shedding frequency, the response excited by vortex shedding is small. Thus the dominant excitation is from flow turbulence. This is confirmed by the startup measurements made at the prototype ABWR plant. As pointed out in Section 5.6 of NEDE-33259P, the ESBWR ICMGTs and housings are shorter than those in the ABWR. Thus the ESBWR structure has a higher fundamental frequency than that of the ABWR. The ESBWR velocity will be lower, and the vortex shedding frequency will be lower. Thus, the vortex shedding frequency will be even further removed from the natural frequency. Thus, no FIV issues are anticipated.

The staff found the response of the applicant to be acceptable for the postulated excitation mechanisms of flow turbulence and vortex shedding from the core tubes because the structural dynamic modes of the forest of tubes were found to be far higher than the vortex shedding frequencies. Furthermore, flow turbulence excitation has not been a problem in other reactors. Therefore, RAI 3.9-80 was closed.

3.9.2.3.4 Conclusions

As far as steam dryer is concerned, the SERs for NEDE-33312P ,, NEDC-33313P, and NEDC-33408Psupersede this SER and evaluate the dynamic response of the steam dryer separately, as stated in closure statement of RAI 3.9-58.

The staff concludes that the applicant's evaluation of the dynamic responses of the reactor internals (excluding the steam dryer) under operational conditions is acceptable and meets the requirements of GDC 1 and 4. This conclusion is based on the following two findings:

(1) The applicant has met the requirements of GDC 1 by designing the reactor internals to quality standards commensurate with the importance of the safety functions performed. The design procedures and criteria for the reactor internals comply with the requirements of Subsection NG of ASME Code, Section III. The applicant has adequately evaluated the potential adverse flow effects on the reactor internals, excluding the steam dryer in a BWR, up to full licensed power conditions.

(2) The applicant has met the requirements of GDC 4 by designing components important to safety to withstand the dynamic effects of normal operation, maintenance, testing, and postulated accidents (including LOCAs) to maintain their capability to perform safety functions.

The specified design transients, design and service loadings, and combination of loadings, as applied to the design of the reactor internals structures and components, provide reasonable assurance that in an earthquake or a system transient during normal plant operation the consequent deflections and stresses imposed on these structures and components would not exceed allowable stresses and deformation limits for the materials of construction. Limitation of stresses and deformations under such loading combinations is an acceptable basis for the design of these structures and components to withstand the most adverse loading events postulated to occur during service lifetime without loss of structural integrity or impairment of function.

As an integral part of satisfying the requirements of GDC 1 and 4, there is a commitment for the COL applicant to classify the reactor internals in accordance with the regulatory guidance of

RG 1.20, Revision 3 and to provide milestones for submitting the measurements, analysis, correlation, and inspection procedures and reports. DCD Section 3.9.9-1 lists this commitment as COL Information Item 3.9.9-1-A.

3.9.2.4 *Initial Startup Flow-Induced Vibration Testing*

3.9.2.4.1 Regulatory Criteria

- GDC 1, as it relates to designing reactor internals to appropriate quality standards commensurate with the importance of the safety functions to be performed

- GDC 4, as it relates to reactor internals appropriately protected against the dynamic effects of discharging fluids

- RG 1.20, Revision 3, "Comprehensive Vibration Assessment Program for Reactor Internals During Preoperational and Initial Startup Testing"

3.9.2.4.2 Summary of Technical Information

DCD, Tier 2, Section 3.9.2.4, states that initial startup testing will be planned so as to meet the guidelines of RG 1.20, except for the requirements related to preoperational testing that cannot be performed for a natural circulation reactor. Vibration measurements will be made up to 100-percent rated flow. The test will verify the anticipated effects of the flow on the component vibration responses.

The applicant provided a listing of sensors and components to be instrumented, but did not offer any specifics relating a particular sensor to a component or location. The data will be recorded and online analyses performed, followed by a comparison of measured vibrations with the predictable and allowable stresses. These comparisons will be made for the dominant vibration modes.

The applicant will conduct inspections before and following startup testing to identify any damage, excessive wear, or loose parts. Post testing inspections will be performed on a selected basis on the chimney, chimney head, CS structures, the peripheral CRDs, and in-core housings.

DCD, Tier 2, Section 3.9.9.1, identifies the information to be provided to the NRC regarding the startup FIV program. Section 3L.5, of Appendix 3L to DCD Tier 2 provides additional general information on the purpose of the typical sensors (Table 3L-3) to be used and potential sensor locations (Table 3L-4), but does not identify specific sensors and locations. Furthermore, Section 3L.5 presents a general description of, and the reasons for, testing with startup transient and steady-state flow conditions, but does not provide detailed flow parameters. However, the applicant did outline in some detail the type of data reductions to be made and the general process by which peak-to-peak amplitudes will be obtained from time-history and spectral analysis. Section 3L.5 details three methods for evaluating the maximum component stresses from the sensor data. Each method is tailored for structures with different modal response characteristics (Table 3L-7), such as (1) structures with many closely spaced vibration frequencies or modes distributed over a narrow frequency band or over several narrow frequency bands, and (2) structures with widely spaced, distinct natural vibration frequencies.

3.9.2.4.3 Staff Evaluation

The staff evaluated DCD, Tier 2, Section 3.9.2.4, in accordance with SRP Section 3.9.2, Revision 3. DCD, Tier 2, Section 3.9.2.4, states that vibration measurements will be made during reactor startup at conditions up to 100-percent rated flow and power. The initial startup testing will evaluate the steady-state and transient conditions of natural circulation flow operation. However, the applicant did not provide the steady-state and transient conditions of the natural circulation flow operation. Therefore, in RAI 3.9-60, the staff requested that the applicant provide a complete list of the steady-state and transient conditions of the natural circulation flow operation that are to be evaluated.

In its response to RAI 3.9-60, the applicant stated the following:

> ESBWR is subjected to vibration testing during steady state at rated volumetric flow as well as transient conditions. Transients outside of steady state include measurement during power ascension, also low, mid and high core power flow conditions. Vibrations are measured during anticipated operational events such as turbine or generator trip, MS line isolation, and SRV actuation.
>
> The internals vibration is measured during individual component or system startup testing where operation may result in significant vibration excitation of reactor internals, such as isolation condenser testing. The duration of the startup testing at the various flow configurations shall ensure that each critical component vibration is within design limitations.

The staff found the applicant's response reasonable and acceptable because it provides the steady-state and transient conditions that are to be evaluated, as requested. Therefore, RAI 3.9-60 was closed.

DCD, Tier 2, Section 3.9.2.4, states that accelerometers are provided with double integration signal conditioning to give a displacement output. This section provides a partial list of the sensor locations. The staff could not determine from the list whether instrumentation is mounted directly on the steam dryer at all significant locations, including the outer hood, skirt, and all potential high-stress areas. In RAI 3.9-61, the staff asked the applicant to clarify whether instrumentation is mounted directly on the steam dryer at significant locations, including the outer hood, skirt, and all potential high-stress locations. In its response to RAI 3.9-61, the applicant referred to the steam dryer instrumentation and startup test procedure described in DCD, Tier 2, Appendix 3L, Section 3L.4.6. However, this information does not adequately address the staff's concerns. RAI 3.9-61 was tracked as an open item in the SER with open items.

RAI 3.9-61 is superseded by RAI 3.9-212 S01. The SER prepared for NEDC-33313P presents the response to RAI 3.9-212 S01 and its evaluation. Therefore, RAI 3.9-61 and its associated open item were closed.

The discussion provided in DCD, Tier 2, Section 3.9.2.4, does not specifically address the steam dryer instrumentation and its capabilities. It also does not discuss the data that would be obtained from these sensors for a stress analysis of the steam dryer and MS system components. In RAI 3.9-62, the staff requested that the applicant demonstrate that the instrumentation mounted directly on the steam dryers will (1) provide sufficient information to perform an accurate stress analysis of all steam dryer and MS system components, and (2) include appropriate pressure sensors, strain gauges, and accelerometers. In its revised response to RAI 3.9-62, the applicant stated that the steam dryer will be instrumented with strain gauges and accelerometers to provide vibration measurements during startup testing and to check whether the stress acceptance criteria are exceeded. In addition, the steam dryer will be instrumented with pressure sensors to confirm the acoustic load definition used in the structural analysis. Section 3L.4.6 of Appendix 3L to DCD Tier 2 describes the steam dryer instrumentation and startup test procedure. The staff finds the instrumentation and test procedures acceptable because the applicant will be installing sufficient instrumentation on the steam dryer for estimating the stresses and defining the acoustic loads. Therefore, RAI 3.9-62 was closed.

The discussion provided in DCD, Tier 2, Section 3.9.2.4, does not specifically address how the MSLs in the ESBWR will be instrumented to identify the presence of acoustic resonances. In RAI 3.9-63, the staff requested that the applicant demonstrate how the MSLs in the ESBWR will be instrumented to determine steam pressure fluctuations to identify the presence of acoustic resonances. The staff also asked the applicant to discuss how the pressure fluctuations will be analyzed to determine steam dryer loading and stresses. In its revised response to RAI 3.9-63, the applicant referred to the steam dryer instrumentation and startup test procedure described in DCD, Tier 2, Appendix 3L, Section 3L.4.6, and in the response to RAI 3.9-144A(e) S01. Therefore, RAI 3.9-144 S01 supersedes RAI 3.9-63. Section 3.9.5 of this report discusses the evaluation of RAI 3.9-144A(e) S01. RAI 3.9-63 and its associated open item, as described in the SER with open items, were closed.

The discussion provided in DCD, Tier 2, Section 3.9.2.4, does not specifically address how the steam dryer data will be used to calibrate the MSL instrumentation and data analysis before the removal or failure of the steam dryer instrumentation. In RAI 3.9-64, the staff requested that the applicant demonstrate how the steam dryer data will be used to calibrate the MSL instrumentation. In its response to RAI 3.9-64, the applicant referred to the steam dryer instrumentation and startup test procedure described in Section 3L.4.6 of Appendix 3L to DCD Tier 2, in which the applicant submitted additional information on April 7, 2008. The staff's evaluation of this additional information is discussed in detail under RAI 3.9-79. The staff finds that the additional information above, addresses the staff's concern and thus the staff finds the applicant's responses acceptable. Therefore, RAI 3.9-64 was closed.

The discussion provided in DCD, Tier 2, Section 3.9.2.4, does not specifically state that the steam, FW, and condensate lines and associated components will be instrumented during the initial startup testing. In RAI 3.9-65, the staff requested that the applicant verify that these lines and associated components, including SRVs and power-operated valves (POVs) and their actuators, will be instrumented to measure vibration during testing. The staff also asked the applicant to discuss how these data will be used to demonstrate that short- and long-term limits will not be exceeded for the piping and individual components.

In its response to RAI 3.9-65, the applicant stated the following:

> Refer to Attachment B "ESBWR Startup Acceptance Criteria For Piping" which describes that the steam, feedwater, and condensate lines and associated components shall be instrumented during the initial startup testing, how these lines and associated components, including safety relief valves and power operated valves and their actuators will be instrumented to measure vibration during testing and how this data would be used to demonstrate that short term and long term limits would not be exceeded for the piping and individual components. For example, Paragraph 7.0, Gages required, of the Attachment specifies accelerometers on SRVs and MSIVs, Paragraph 5, Steady State

> Vibration Criteria discusses long term limits and Paragraph 3.0, Transient Dynamic Loads discusses short-term limits.

Based on its review of the referenced document, the staff finds that the applicant provided a satisfactory discussion on how data obtained from the steam, FW, and condensate lines and associated components will be used to demonstrate that short- and long-term limits will not be exceeded for the piping and individual components. Therefore, RAI 3.9-65 was closed.

The discussion provided in DCD, Tier 2, Section 3.9.2.4, does not specifically state that the startup test procedure will include the stress limit curve to be applied for evaluating steam dryer performance. In RAI 3.9-66, the staff requested that the applicant confirm that the startup test procedure will include the stress limit curve. The staff also asked the applicant to provide the details of the stress limit curve that will be used for the ESBWR steam dryer components. In its revised response to RAI 3.9-66, the applicant referred to the steam dryer instrumentation and startup test procedure described in Section 3L.4.6 of Appendix 3L to DCD Tier 2. The applicant also provided acceptance criteria for the measured strains in Section 3L.5.5.3 of DCD, Tier 2, Appendix 3L. RAI 3.9-66 was tracked as an open item in the SER with open items.

The response is acceptable for the first ESBWR plant in which the steam dryer will be instrumented with strain gauges and accelerometers and, therefore, would not require stress limit curve. However, this response does not address the subsequent ESBWR plants in which only MSLs will be instrumented with strain gauges and the steam dryers will not be instrumented. In the NRC, “Report of the August 25, 2009 NRC Staff Audit on ESBWR RPV Internals,” issued September 15, 2009, audit report comment 5, the staff requested the applicant to address this issue. Section 9.0 of NEDE-33313P, Revision 2, discusses the startup test, including instrumentation, monitoring, and acceptance criteria, for the steam dryers in the ESBWR plants in which only MSLs will be instrumented for estimating acoustic pressures on dryers. The SER for NEDE-33313P, Revision 2, evaluates this information. Therefore, RAI 3.9-66 and its associated open item were closed, based on the staff’s evaluation of NEDE-33313P.

The discussion provided in DCD, Tier 2, Section 3.9.2.4, does not specifically state that the startup test procedure will include specific holdpoints for interaction with the NRC staff. Therefore, in RAI 3.9-67, the staff requested that the applicant verify that the procedures for the ESBWR startup tests will include specific holdpoints for interaction with the NRC staff. The staff also asked the applicant to specify the activities to be accomplished during the power ascension and confirm that the holdpoints will be of sufficient duration to accomplish those activities.

In its response to RAI 3.9-67, the applicant stated the following:

> Specific hold points for interaction with NRC staff will be included in the ESBWR startup procedures for FIV. DCD, Tier 2, Subsection 3.9.9.1 commits to providing information on startup testing to the NRC at the time of COL application, and this commitment will be included.

The staff finds the applicant’s response reasonable and acceptable because COL Information Item 3.9.9-1-A ensures that the COL applicant will provide the requested information on startup testing to the NRC at the time of the COL application.

The discussion provided in DCD, Tier 2, Section 3.9.2.4, does not identify the plant parameters that will be monitored during the holdpoints on the steam, FW, and condensate systems and components. Therefore, in RAI 3.9-68, the staff requested that the applicant discuss the plant parameters that would be monitored during the holdpoints with respect to the steam, FW, and condensate systems and components.

In its response to RAI 3.9-68, the applicant stated the following:

> The plant parameters which would be monitored during the hold points (test conditions) with respect to the steam, feedwater and condensate systems and components are discussed in DCD, Tier 2, Subsection 14.2.8.2, General Discussion of Startup Tests, and shown in Attachment A, REQUIRED TESTS AND ASSOCIATED SYSTEM CONDITIONS, tables. It is noted that detailed test specifications will be prepared separately prior to the pre-operation and start-up tests.

Based on its review of the information in DCD, Tier 2, Section 14.2.8.2, the staff found that GEH adequately identified the plant parameters that will be monitored during the holdpoints with respect to the steam, FW, and condensate systems and components, as requested. Therefore, RAI 3.9-68 was closed.

The discussion provided in DCD, Tier 2, Section 3.9.2.4, does not specifically state how the ESBWR plant parameters will be trended. With respect to the steam, FW, and condensate systems and components, the staff requested, in RAI 3.9-69, that the applicant discuss the methods that will be used to trend the plant parameters during the ESBWR startup tests. In its response to RAI 3.9-69, the applicant identified DCD, Tier 2, Section 3.9.2.1.1, and specifically, the subsection entitled, "Reconciliation and Corrective Actions," that describes the trended prediction and action requirements for system piping and components. Based on its review, the staff finds that the applicant provided adequate information related to the trending of the plant parameters. Therefore, RAI 3.9-69 was closed.

The discussion provided in DCD, Tier 2, Section 3.9.2.4, does not provide specific information on the acceptance criteria for monitoring, trending, and inspection of the steam, FW, and condensate systems during the ESBWR startup tests. The staff considers this information highly pertinent in evaluating the potential adverse flow effects, particularly on steam dryers and MS system components. Therefore, in RAI 3.9-70, the staff requested that the applicant discuss the acceptance criteria for monitoring, trending, and conducting walkdowns and inspections relating to the steam, FW, and condensate systems during ESBWR startup tests. The staff also asked the applicant to discuss the actions that it would take should the acceptance criteria not be satisfied. In its response to RAI 3.9-70, the applicant stated the following:

> Refer to Attachment B "ESBWR Startup Acceptance Criteria For Piping" which provides information on the acceptance criteria for monitoring, trending and inspection of the steam, feedwater, and condensate systems during ESBWR startup testing, including the acceptance criteria for monitoring, trending, and conducting the walkdowns and inspections relating to the steam, feedwater, and condensate systems during ESBWR startup tests, and the actions to be taken if acceptance criteria are not satisfied.

Based on its review of the information in Attachment B to the applicant's response, the staff finds that GEH adequately discussed the acceptance criteria for monitoring, trending, and conducting walkdowns and inspections relating to the steam, FW, and condensate systems during the ESBWR startup tests. Therefore, RAI 3.9-70 was closed.

The discussion provided in DCD, Tier 2, Section 3.9.2.4, does not specifically state how the predicted and allowable amplitudes are obtained for the steam dryer components at significant locations. Therefore, in RAI 3.9-71, the staff requested that the applicant clearly explain how the predicted and allowable amplitudes are obtained for the steam dryer at significant locations, including the outer hood, skirt, and all potential high-stress areas. In its response to RAI 3.9-71, the applicant referred to the steam dryer instrumentation and startup test procedure described in Section 3L.4.6 of Appendix 3L to DCD Tier 2. RAI 3.9-71 was tracked as an open item in the SER with open items. Section 3L.4.6 states the following:

Section 3L.4.6 states:

The steam dryer startup test and monitoring power ascension limits are developed on a similar basis as the monitoring limits used for recent extended power uprate replacement steam dryers. The power ascension limits are based on the final FIV analysis performed for the as-built steam dryer. The strain gauge and accelerometer instruments are mounted in locations that provide measurements that are strongly coupled with projected high stress locations. Additional strain gauges and accelerometers are used as needed to provide an overall validation of the structural finite element model.

The staff finds the technical basis for developing power ascension limits on measured strains (or stresses) acceptable because it ensures that the maximum stresses in the steam dryer components would be less than the fatigue limit of 93.8 MPa (13,600 psi). Therefore, RAI 3.9-71 and its associated open item were closed.

The staff reviewed the specifics of the instrumentation, the expected response, and the flow conditions required for all components that will be instrumented during startup FIV testing, in accordance with RG 1.20, Revision 3, and SRP Section 3.9.2, Revision 3. The applicant did not provide sufficient information in this area. For each component that will be instrumented, the staff requested, in RAI 3.9-73, that the applicant (a) identify the component and explain why it is being instrumented, (b) provide the modal response characteristics and the specific locations and orientation of the sensors, (c) describe the sensors, including their sensitivities and frequency responses, (d) provide the expected response of the sensor for the flow conditions to be tested, as well as the test acceptance criteria for each sensor, and (e) justify the use of the sensor and its placement.

In its response to RAI 3.9-73, the applicant stated the following:

(a) The selection of the components to be instrumented is based on the following considerations:

Is the component a significantly different or new design compared to the one in earlier BWRs?

Does the component have a history of FIV-related problems?

Is the component subjected to significantly different or new flow conditions?

Based on these criteria, the following reactor internal components have been selected to be instrumented in the ESBWR startup FIV test program:

Steam Dryer Bank Hoods and End Plates based on history of past FIV related problems (fatigue cracking between hood and endplate).

Steam Dryer Skirt based on history of past FIV-related problems (fatigue cracking between skirt and drain channels).

Steam Dryer Drain Channels based on history of FIV-related problems (fatigue cracking between skirt and drain channels).

Steam Dryer Support Ring based on history of FIV-related problems (dryer rocking) and the resulting new design features for replacement dryer designs (e.g., strengthened weld joints, castings).

Chimney partition assembly based on new design features (elongated chimney shell, partition assembly, chimney restraint), and potential new flow conditions.

Chimney Head/Steam Separator assembly based on new design (flat head with beam reinforcement and elongated standpipes).

Shroud/Chimney assembly based on new design features (discrete shroud support members and the chimney connection), potential new flow conditions and difficulty of repair in event of failure.

SLC internal piping based on new design.

(b) DCD, Tier 2, Subsection 3.9.9.1 commits to providing information on startup testing to the NRC at the time of COL application. Subsection 3.9.9.1 will be modified at that time to provide the modal response characteristics and the specific locations and orientation of the sensors.

(c) Sensors to be used for ESBWR FIV test are:

Strain gages

Accelerometers

Displacement Sensors—LVDT (Linear Variable Differential Transformer)

Dynamic Pressure Sensors

All of the above sensors are designed for nuclear reactor environment. The selection and placement of the sensors will be based on past experience with other BWRs startup testing and analysis. The sensors will be pressure tested, and the ones that meet the requirements will be used for installation into the reactor.

The strain gages are welded on the components and will have a typical gage factor of 1.6, and they are capable of measuring up to 5000 microstrains. These strain gages can be used for a frequency range between 0 to 2500 Hz. However, for ESBWR testing, the usable range will be limited to 2-Hz to 300-Hz bandwidth. The strain gage output sensitivity is typically set for 1 Volt to represent 100 microstrains.

The LVDTs will have typical measurement range of -200 to +200 mils with an overall frequency response from 2 Hz to 150 Hz. The transducer along with the signal conditioning would be field calibrated such that 1 volt output represents 10 mils displacement (typical).

The accelerometers are of piezoelectric type. The accelerometers have a typical sensitivity of 10 pC/G and have a range greater than 100 Gs. The usable measurement range for ESBWR testing will be limited to 10 Gs and will have overall frequency response of 3 Hz to 500 Hz. Accelerometer signals will also be double integrated for selected sensors to obtain displacement. The frequency response in displacement mode will be from 5 Hz to 500 Hz. The typical overall output of the accelerometer together with remote charge converter and the amplifier would be set such that 1 Volt equals 2 G and 1 Volt equals 20 mils in the displacement mode, which are typical.

The pressure transducers are of piezoelectric type and will have typical sensitivity of 190 pC/bar for one type of transducer and 25 pC/bar for the less sensitive type. These dynamic pressure transducers are capable of measuring 20 bars or greater and have frequency response from 2 Hz to 1000 Hz. For ESBWR testing, the usable frequency bandwidth will be limited to 3 Hz to 500 Hz. The typical pressure range is expected to be less than 5 psi. The typical overall output of the pressure transducer together with remote charge converter and the amplifier would be set such that 1 volt equal to 1 psi.

(d) DCD, Tier 2, Subsection 3.9.9.1 commits to providing information on startup testing to the NRC at the time of COL application. Subsection 3.9.9.1 will be modified at that time to provide the expected response of the sensor for the flow conditions to be tested, as well as the test acceptance criteria for each sensor.

(e) See answers to (a) and (b) above.

The applicant's response to RAI 3.9-73 is acceptable for the components identified for instrumentation during startup testing because it provides the reasons for testing and describes the instrumentation and pertinent specifications. COL Information Item 3.9.9-1-A will ensure that the COL applicant will provide at the time of COL application the component's modal responses, a justification for each sensor and its placement, the expected responses of the sensors during testing, and the test acceptance criteria. The staff asked the applicant, in RAI 3.9-73 S01, to justify why the components below the core (i.e., CRGTs, ICGTs and stabilizers, and the nonpressure boundary portion of control rod housing and in-core housings) are not being instrumented for testing. In particular, the staff asked the applicant to discuss potential FIV excitation mechanisms associated with the upstream core support structures, which were also identified in RAI 3.9-79. In its response to RAI 3.9-79 S01, GEH explained why the components below the core do not need to be tested. The staff found the response to RAI 3.9-79 S01 acceptable, as discussed in RAI 3.9-79 in Section 3.9.2.3 of this report. Therefore, RAI 3.9-73 was resolved.

The use of the terms "prototype" and "non-prototype" in DCD, Tier 2, Section 3.9.9.1, and NEDE-33259P are contradictory. In RAI 3.9-75, the staff asked the applicant to revise Section 3.9.9.1 using RG 1.20, including the information on startup testing that will be provided to the NRC.

In its response to RAI 3.9-75, the applicant stated the following:

> The term "prototype" in NEDE-33259P applies only to the shroud/chimney and SLC structures. The ESBWR as a whole is classified as Non-Prototype Category II. DCD, Tier 2, Subsection 3.9.9.1 commits to providing information on startup testing to the NRC at the time of COL application. Subsection 3.9.9.1 will be modified at that time.

The applicant's response is acceptable because it clarifies the use of terms and identifies a schedule for providing startup information at the time of the COL application. This commitment is a COL item. However, in RAI 3.9-75 S01, the staff informed the applicant that it will not classify the whole of the ESBWR as non-prototype Category II until the applicant submits responses to all open items. In its response to RAI 3.9-75 S01, the applicant generally agreed with the staff. RAI 3.9-75 was tracked as an open item in the SER with open items.

Revision 1 to NEDE-33259P provided further clarification and responded to the remaining open items. The staff reviewed this topical report revision and formulated RAIs 3.9-233, 3.9-234, 3.9-235, 3.9-236, 3.9-237, 3.9-238, 3.9-239, 3.9-240, 3.9-241, and 3.9-242. In turn, GEH answered these RAIs and, after further review, the staff subsequently closed them. This completed the staff's inquiry into FIV excitation of the reactor internals.

In its revised response to RAI 3.9-75, GEH stated the following:

> NRC Regulatory Guide 1.20, Revision 3 requires detailed information on a comprehensive vibration assessment program for reactor internals during startup testing. The information requested includes descriptions of an analytical program, and an extensive measurement and inspection program. The required information for the ESBWR was provided in Licensing Topical Report (LTR) Reactor Internals Flow Induced Vibration Program, NEDE-33259P, Revision 1 dated December 2007. With the submittal of the revised LTR and changes to DCD Tier 2, subsections, as noted below, GEH is providing information to support closure of open items associated with classifying ESBWR as a Non-Prototype Category II plant.

GEH has revised the following sections of DCD, Tier 2, Revision 5: Sections 3.9.2.3, 3.9.2.6, 3L.1, 3L.5.3, 3L.5.5.1.3, and 3L.5.5.1.4.

The staff finds that GEH has provided detailed information on a comprehensive vibration assessment program for reactor internals during startup testing in the revised sections of DCD Tier 2. The revisions describe an impressive analytical program and an extensive measurement and inspection program. The applicant has provided many of the analysis results and a description of the transducers and their general location in NEDE-33259P, Revision 1. As discussed above in the staff's review of the original response to RAI 3.9-75 S01, this report provided sufficient information to enable the staff to close most open RAIs.

Based on further discussions with the staff, the applicant agreed to reclassify the ESBWR as a prototype, in accordance with Revision 3 of RG 1.20, for the reactor internals vibration program. The applicant informed the staff that it would revise applicable sections of the DCD and NEDE-33259P to reflect this change in classification.

The staff agreed with the applicant's reclassification of the ESBWR as a prototype, in accordance with Revision 3 of RG 1.20, and closed this issue. The staff also found that the changes to the DCD were appropriate and acceptable. This closed the RAI 3.9-75 S01 issues.

3.9.2.4.4 Conclusions

The SER for NEDC-33313P, Revision 1, Class III (Proprietary), evaluates the plans for the startup testing of the steam dryer. The plans for operational steady-state testing are given in DCD, Section 3.9.2, Appendix 3L, and NEDE-33259P.

The staff concludes that the applicant's plans for initial startup FIV testing of reactor internals (excluding the steam dryer) under operational conditions is acceptable and meets the requirements of GDC 1 and 4 for testing of reactor internals with the potential to generate loose parts to quality standards commensurate with the importance of the safety functions performed with appropriate protection against dynamic effects. The applicant has met the regulatory guidance of RG 1.20 for the conduct of preoperational vibration tests by a preoperational vibration program planned for the reactor internals. This program will provide an acceptable basis for design adequacy of these internals under test loading conditions comparable to those experienced during operation. The combination of tests, predictive analysis, and posttest inspection will provide adequate assurance that the reactor internals will, during their service lifetime, withstand the FIVs of reactor operation without loss of structural integrity.

As an integral part of satisfying the requirements of GDC 2 and 4, the applicant has committed to classify the reactor internals in accordance with the guidance of RG 1.20 and to provide milestones for submitting the measurements, analysis, correlation, and inspection procedures and reports to the NRC. DCD Section 3.9.9-1 lists this commitment as COL Information Item 3.9.9-1-A.

3.9.2.5 *Dynamic System Analysis of Reactor Internals under Faulted Conditions*

3.9.2.5.1 Regulatory Criteria

The following regulatory requirements and guidelines provide the basis for the acceptance criteria for the staff's review:

- GDC 2, as it relates to systems, components, and equipment important to safety being designed to withstand appropriate combinations of the effects of normal and accident conditions with the effects of natural phenomena SSE

- GDC 4, as it relates to systems and components important to safety being appropriately protected against the dynamic effects of discharging fluids

3.9.2.5.2 Summary of Technical Information

DCD, Tier 2, Section 3.9.5.3, defines the faulted events that are evaluated. This section also discusses the loads that occur as a result of these events and the analysis performed to determine the response of the reactor internals.

Dynamic analysis is performed by coupling the lumped-mass model of the reactor vessel and internals with the building model to determine the system's natural frequencies and mode shapes. The relative displacement, acceleration, and load response is then determined by either the time-history method or the response spectrum method. This analysis yields the loads on the reactor internals resulting from the faulted event SSE. The applicant stated that the reactor internals satisfy the stress deformation and fatigue limits, as defined in DCD, Tier 2, Section 3.9.5.4.

3.9.2.5.3 Staff Evaluation

The staff evaluated the information provided by the applicant in DCD, Tier 2, Section 3.9.2.5, to determine whether the applicant satisfied the requirement of SRP Section 3.9.2.5, Revision 3, and the relevant requirements of GDC 2 and 4.

The staff requires that the dynamic system analyses should be performed to confirm the structural design adequacy and ability of the reactor internals and unbroken loops of the reactor coolant piping to withstand, with no loss of function, the loads from a LOCA in combination with the SSE. The staff review covers the methods of analysis, the considerations in defining the mathematical models, the descriptions of the forcing functions, the calculation schemes, the acceptance criteria, and the interpretation of analytical results.

DCD, Tier 2, Section 3.9.2.5, states that the analysis described in DCD, Tier 2, Section 3.9.5.3, will determine the reactor internals pressure differentials resulting from an assumed break in the MSL or FW line. To ensure that no significant dynamic amplification of load occurs as a result of the oscillatory nature of the blowdown forces during an accident, the periods of the applied forces are compared to the natural periods of the CS structures being acted upon by the applied forces. A comprehensive vertical dynamic model of the RPV and internals is used to determine these periods. Therefore, in RAI 3.9-81, the staff requested that the applicant provide the analytical results to demonstrate that there is no significant dynamic amplification of the loads on the reactor internals CS structures as a result of the postulated break in the MSL or FW line. In its response dated July 29, 2008, the applicant stated the following:

> The only reactor internals vertical core support structure, in the GEH ESBWR nuclear reactor, is the control rod guide tubes/control rod drive housings (CRGTs/CRDHs). An assemblage of axial beam elements is employed to represent the CRGTs/CRDHs fuel vertical inertia load path in the vertical primary structure model. No vertical natural frequency, below 105.4 Hz, was obtained for the CRGTs/CRDHs load path in the vertical primary structure model eigen analysis. Furthermore, the blowdown loads associated with the main steam and feedwater line breaks do not excite the CRGTs/CRDHs fuel core vertical inertia

> load path. Consequently, there can be no dynamic amplification of the blowdown loads through the CRGTs/CRDHs load path.

The applicant has revised DCD Tier 2, Section 3.9.2.5, Revision 5, to address this issue. DCD, Tier 2, Revision 5, Section 3.9.5.3, describes loading conditions for RPV internals.

Based on its review of the applicant's response to RAI 3.9-81, the staff has determined that GEH has provided a satisfactory explanation of the absence of dynamic amplification of the blowdown loads through the CRGTs/CRD housings load path. Therefore, the staff's concerns related to RAI 3.9-81 were resolved.

DCD, Tier 2, Section 3.9.2.5, states that the response of the RPV internals and CS structures to applied loads is determined from a comprehensive dynamic model of the RPV and internals. Besides the real masses of the RPV and CS structures, the model takes into account the water inside the RPV. However, the applicant did not discuss how the analytical model accounts for the mass of the water. Therefore, in RAI 3.9-82, the staff requested that the applicant explain how the modeling of the RPV and internals accounts for the presence of water. In its response, the applicant stated that it provided this information in response to RAI 3.7-28, items (b), (c), and (d). Based on its review of the applicant's response to RAI 3.7-28, the staff finds that GEH has satisfactorily explained how the modeling of the RPV and internals accounts for the presence of water. Therefore, RAI 3.9-82 was closed.

DCD, Tier 2, Section 3.9.2.5, states that, except for the nature and locations of the forcing functions, the dynamic model and the dynamic analysis method are identical to those for seismic analysis. DCD, Tier 2, Table 3.9-1, identifies the resulting loads on the reactor internals. However, DCD Tier 2 does not discuss the basis for the development of the dynamic reactor internals model. Therefore, in RAI 3.9-83, the staff asked the applicant to explain how the model accounted for the fluid-structure interaction effects between the reactor internals and dynamically related piping, pipe supports, and components. The staff also asked the applicant to describe with typical diagrams the basis for the model development.

In its response to RAI 3.9-83, the applicant stated the following:

> Discussion pertaining to how the fluid-structure interaction effects are accounted for in the dynamic modeling of the RPV and internals is provided in the applicant's response to NRC RAI 3.9-82. The technical details of the hydrodynamic mass derivation are given in Reference 3.7-6 of the DCD. Fluid-structure interaction effects between the reactor internals and dynamically related piping, pipe support components external to the reactor vessel are small and can be neglected. This is true because of two conditions. First, the reactor vessel wall is so thick and stiff that the piping penetration through the vessel wall are assumed to be fixed anchor points for all "dynamically related" internal and external piping. Second, the decoupling criteria described in the ESBWR DCD Subsection 3.7.2.3 are satisfied. Therefore, the vessel internal and external "dynamically related" piping can be decoupled when analyzed. Consequently, any dynamic interaction effects between the two are small and can be neglected.

The staff finds the applicant's explanation reasonable and acceptable.

In addition the applicant stated the following:

> All horizontal, cross-coupling effects in the reactor and internals are assumed to be small and can therefore be neglected. This follows from the fact that the physical geometry of the ESBWR RPV and internals is very approximately axisymmetrical. Consequently, any vertical plane, which contains the RPV vertical centerline axis, is a plane of symmetry. It then follows that there can be no cross coupling between any two orthogonal, spatial, horizontal directions. Finally, because the RPV and internals model is essentially axisymmetrical and because it is also a mathematical centerline model, there is no dynamic interaction or cross coupling between the model horizontal and vertical spatial directions.

The staff concurs with the applicant's explanation for the absence of horizontal and vertical cross-coupling in the model. Based on its review of the applicant's response as stated above, the staff finds that GEH has satisfactorily explained how the model accounts for the fluid-structure interaction effects between the reactor internals and dynamically related piping, pipe supports, and components. Therefore, RAI 3.9-83 was closed.

DCD, Tier 2, Section 3.9.2.5, states that the dynamic model and the dynamic analysis methods are identical to those for seismic analysis. Dynamic analysis is performed by coupling the lumped-mass model of the reactor vessel and internals with the building seismic model to determine the system's natural frequencies and mode shapes. The analysis yields the loads on the reactor internals caused by the faulted SSE event. However, the applicant did not discuss the reactor internals system characteristics, such as mass inertia effect and damping. Therefore, in RAI 3.9-84, the staff asked the applicant to justify that the dynamic reactor internals model is representative of system structural characteristics, such as flexibility, mass inertia effect, geometric configuration, and damping (including possible coexistence of viscous and Coulomb damping).

In its response to RAI 3.9-84, the applicant stated the following:

> The requested discussion that corroborates the adequacy of the ESBWR RPV and internals mathematical, centerline, beam element model for purposes of seismic/dynamic analysis is based on both qualitative and quantitative technical considerations, as well as a combination of the two. From a quantitative perspective with regard to the mass matrix of the analytical model, essentially all equipment concentrated masses associated with the reactor internals subassemblies were weighted by load cells in the lifting equipment used to assemble the subassemblies. Furthermore, the physical geometry corresponding to the subassemblies for which the weights are calculated, are simple and uniform (e.g., core shroud, CRGTs, chimney, etc.). The result is the actual distributed and concentrated mass characteristics of the RPV and internals are very accurately reflected in the assembled mass matrix of the corresponding analytical models. Next, because the actual physical geometries of most of the RPV and the vessel sub assemblies are representative of prismatic beams; it follows that the beam element representation of the local geometry is both representative and accurate. Consequently, the analytical model assembled stiffness matrix is also quite representative of the overall stiffness characteristics of the actual RPV and internals physical geometry. These latter considerations are mostly qualitative in nature.

The staff found the applicant's qualitative justification of the adequacy of the ESBWR RPV and internals mathematical, centerline, and beam element model reasonable and acceptable.

In addition, the applicant stated the following:

> The model assembled mass and stiffness matrices are combined into the governing, coupled, second order, ordinary differential equations of motion with constant coefficients. The eigen analyses performed on the coupled equations of motion yield natural frequencies of the reactor subassembly components that very nearly match the corresponding values obtained from in-situ instrumentation and testing of the same reactor internals subassemblies. The excellent correlation between the reactor and internals eigen characteristics, measured by instrumentation and testing and the corresponding values calculated by dynamic modeling and analysis, provides very strong qualitative and quantitative evidence that the ESBWR RPV and internal analytical model is both representative and adequate for ESBWR seismic/dynamic analysis.

Based on its review of the applicant's response as discussed above, the staff finds that GEH satisfactorily explained both qualitatively and quantitatively that the reactor internals analytical model is both representative and adequate for ESBWR seismic and dynamic analysis. Therefore, RAI 3.9-84 was closed.

DCD, Tier 2, Section 3.9.2.5, states that the dynamic model and the dynamic analysis methods for the reactor internals are similar to those described in DCD, Tier 2, Sections 3.9.1.2 and 3.7. Dynamic analysis is performed by coupling the lumped-mass model of the reactor vessel and internals with the building seismic model to determine the system's natural frequencies and mode shapes. However, the applicant did not discuss the structural partitioning and directional decoupling that may have been employed. Therefore, in RAI 3.9-85, the staff requested that GEH discuss and justify any system structural partitioning and directional decoupling employed in the dynamic system modeling of the RPV and the reactor internals.

The applicant's response to RAI 3.9-82 resolved the staff's concerns with regard to directional decoupling. With regard to any system structural partitioning, the applicant stated in its response to RAI 3.9-85 that it did not employ any significant system structural partitioning in the generation of the ESBWR mathematical, centerline, beam, and concentrated mass model of the RPV and internals. Therefore, RAI 3.9-85 was closed.

DCD, Tier 2, Section 3.9.2.5, states that the dynamic model and the dynamic analysis methods for the reactor internals are similar to those described in DCD, Tier 2, Sections 3.9.1.2 and 3.7. Dynamic analysis is performed by coupling the lumped-mass model of the reactor vessel and internals with the building seismic model to determine the system's natural frequencies and mode shapes. However, the applicant did not discuss any effects of flow upon the mass and flexibility properties of the system. Therefore, in RAI 3.9-86, the staff asked the applicant to explain how the lumped-mass model of the reactor vessel and internals incorporates the effects of flow upon the mass and flexibility properties of the system.

In its response to RAI 3.9-86, the applicant stated the following:

> The fluid flow effects of the flow of the reactor coolant through the ESBWR NSSS piping and reactor internals and nuclear core has no effect on the RPV and internal model mass and stiffness characteristics. The system overall mass

characteristics are unaffected because there is no fluid inventory buildup in the overall NSSS reactor and piping systems during normal plant operation. Even during NSSS pipe rupture LOCA faulted conditions, the change in the reactor coolant inventory in the NSSS systems would be negligible. Next, the reactor coolant fluid flow through the reactor core does not contribute to any structural, inertia load path in the reactor and internal assembly. Consequently, the reactor coolant flow also has no affect on the stiffness characteristics of the RPV and internals analytical models. However, the reactor coolant flow through the reactor internals does engender FIV loads in the form of distributed pressure transients which act on the surfaces of the reactor internals subassemblies which channel the flow, or are in the flow path, of the reactor coolant as it passes through the RPV internals.

Based on its review of the applicant's response to RAI 3.9-86, the staff finds the GEH explanation reasonable and acceptable and concurs that the reactor coolant fluid flow through the reactor internals does not affect the mass and stiffness characteristics of the RPV and internals. However, the fluid flow does engender the FIV load cases. Therefore, RAI 3.9-86 was closed.

DCD, Tier 2, Section 3.9.2.5, states that an assumed break of the MSL, the FW line, or the RWCU/SDC line at the reactor vessel nozzle results in jet reaction and impingement forces on the vessel and asymmetrical pressurization of the annulus between the reactor vessel and the shield wall. These time-varying pressures are applied to the dynamic model of the reactor vessel system. However, the applicant did not adequately explain the basis for developing the forcing function. Therefore, in RAI 3.9-87, the staff requested that the applicant provide the following information:

(a) Typical diagrams and the basis for postulating the pipe break-induced forcing function, including a description of the governing hydrodynamic equations and the assumptions used for flow path geometries.

(b) Tests for determining flow coefficients, and any semi-empirical formulations and scaled model flow testing for determining pressure differentials or velocity distributions.

In its response to RAI 3.9-87, the applicant stated the following:

(a) For jet reaction and jet impingement forces, diagrams and the basis for postulating break induced forcing functions are based on Appendix B, C, and D of ANSI/ANS-58.2.

(b) For determining pressure differentials or velocity distribution, analytically established values may be used instead of performing a scale model test (SMT). The development of forcing functions is based solely upon analytical techniques. Sample calculations that demonstrate the analytical method were previously submitted in the applicant's response to RAI 3.6-6. These sample calculations are based on hydrodynamic equations developed in F.J. Moody, "Thermal-Hydraulics of a Boiling Water Nuclear Reactor," ANS 1993, and additionally utilize the methodologies outlined by ANSI/ANS 58.2.

RAI 3.9-87 was tracked as an open item in the SER with open items. Section 6.2.1.2 of this report evaluates the asymmetrical pressurization of the annulus between the reactor vessel and the shield wall, and Section 3.6.2 of this report evaluates the jet impingement forces. Therefore RAI 3.9-87 and its associated open item were closed.

DCD, Tier 2, Section 3.9.2.5, states that the relative displacement, acceleration, and load response is determined by either the time-history method or the response spectrum method. The loads on the reactor internals resulting from the faulted event SSE are considered in combination with various LOCA loads. However, the applicant did not discuss the methods and procedures used in the dynamic system analysis in sufficient detail. Therefore, in RAI 3.9-88, the staff requested that GEH discuss the methods and procedures used for dynamic system analyses, including the governing equations of motion and the computational scheme used to derive results.

In its response to RAI 3.9-88, the applicant stated the following:

> The reactor and internals dynamic system analyses, for the faulted load cases, are performed by both the time history and response spectrum analytical methodologies. The seismic and non-seismic loads, as well as the faulted load combination cases for ESBWR, are defined in DCD, Tier 2, Table 3.9-2. The seismic/dynamic analysis methodology is presented in DCD, Tier 2, Subsection 3.7.2.1. In particular, the details of the time history and response spectrum methodologies, including governing equations, are provided in DCD, Tier 2, Subsections 3.7.2.1.1 and 3.7.2.1.2, respectively. The methodology for combining the peak collinear contributions due to the three, orthogonal spatial components of seismic excitation is presented in detail, including governing equations, in Subsection 3.7.2.6 and the corresponding methodology for combining collinear peak modal response contributions in Subsection 3.7.2.7. Independent analyses are performed for each seismic and non-seismic dynamic load case and the resulting peak dynamic responses are combined for each faulted load case as defined in Table 3.9-2.

Based on its review of the discussion in the above-referenced sections of the DCD, the staff has determined that the applicant explained the methods and procedures used for dynamic system analyses in sufficient detail. Furthermore, as discussed in the review and evaluation of the above-mentioned sections, the staff finds these methods and procedures acceptable. Therefore, RAI 3.9-88 was closed.

It is not clear from the discussion in DCD, Tier 2, Section 3.9.2.5, which subassemblies of the reactor internals experience the highest stress, deformation, or fatigue under the faulted condition loadings. Therefore, in RAI 3.9-89, the staff asked the applicant to identify the locations in the reactor internals where the stress deformation and fatigue are determined to be the highest. The staff also requested that the applicant identify the corresponding loading combination.

In its response to RAI 3.9-89, the applicant stated the following:

> The magnitude and locations of the highest stresses, deformations and fatigue usage in the Reactor Internal Structures will be determined in the detailed design analysis. The Certified Design Specification for the Core Support Structures requires the components be analyzed in detail to meet the requirements of the

> ASME Code, Section III, Subsection NG using the loads and loading combinations described in Section 3.9.2.5 of the DCD Tier 2. As for the deformations of the Core Structure Components due to faulted condition loads, the Certified Design Specification will specify the maximum permissible displacements of the Top Guide, Core Plate, Shroud and CRD Guide Tubes to ensure safe insertion of the control rods.

Based on its review of the applicant's response, the staff finds that GEH has committed to meet the appropriate ASME Code requirements. The staff, therefore, finds the applicant's response acceptable. Thus, RAI 3.9-89 was closed.

DCD, Tier 2, Section 3.9.2.5, does not discuss the stability of elements in compression under faulted condition loads. Therefore, in RAI 3.9-90, the staff requested that the applicant describe how it investigated the stability of the elements in compression, such as the core shroud and CRGTs, under pipe rupture loadings.

In its response to RAI 3.9-90, the applicant stated the following:

> The input loads for the seismic/dynamic evaluation of reactor internals subassemblies such, as CRGTs and the core shroud (i.e., core barrel), under faulted conditions are generated from the horizontal and vertical ESBWR primary structure models. The CRGTs and the core shroud are represented as separate beam element sub assemblages in the primary structure analytical models.

The applicant further stated the following:

> The faulted load case member end loads (axial, shear, torsion and moments) are taken directly from the primary structure model faulted response for the critical beam element in each reactor internals subassembly. Simple hand calculations, based on the member end loads and classical beam theory, are then performed to demonstrate that the maximum stresses in each critical beam element are within the corresponding Euler buckling stress allowable. Historically, the GE BWR design for reactor internals subassembly compression members (e.g., CRGTs and the core shroud), which are part of the fuel core inertia load path, has a very conservative buckling margin.

Based on its review of the above discussion, the staff finds that the applicant has reasonably and satisfactorily explained how it investigated the stability of the elements in compression, such as the core shroud and CRGTs, under pipe rupture loadings. Therefore, RAI 3.9-90 was closed.3.9.2.5.4

Conclusions

Based on its evaluation, the staff concludes that the applicant has met the relevant provisions of GDC 2 and 4, which require that the design of systems and components important to safety have the ability to withstand the effects of earthquakes, as well as appropriate combinations of the effects of normal and postulated accident conditions with the effects of the SSE, as determined by a dynamic system analysis. This analysis provides an acceptable basis for the structural design adequacy of the reactor internals and unbroken piping loops to withstand the combined dynamic loads of a postulated LOCA and SSE and the combined loads of a postulated MSL rupture and SSE. The analysis also provides adequate assurance that the combined stresses and strains in the components of the RCS and reactor internals will not exceed the allowable design stress and strain limits for the materials of construction and that the consequent deflections or displacements at any structural elements of the reactor internals will not distort the reactor internals geometry to the extent that core cooling may be impaired.

3.9.2.6 *Correlation of Reactor Internals Vibration Tests with the Analytical Results*

3.9.2.6.1 Regulatory Criteria

The following regulatory requirement provides the basis for the acceptance criteria for the staff's review:

- GDC 1, as it relates to structures and components being designed, fabricated, erected, constructed, tested, and inspected to quality standards commensurate with the importance of the safety function to be performed

3.9.2.6.2 Summary of Technical Information

Before initiation of the instrumented vibration measurement program for the prototype plant, extensive dynamic analyses of the reactor and internals are performed. The results of these analyses are used to generate the allowable vibration levels during the vibration test. The vibration data obtained during the test are to be analyzed in detail. The results of the data analyses, vibration amplitudes, natural frequencies, and mode shapes are then compared to those obtained from the theoretical analysis. Such comparisons provide the analysts with added insight into the dynamic behavior of the reactor internals. The applicant has used the additional knowledge gained from previous vibration tests in the generation of the dynamic models for seismic and LOCA analyses for the ESBWR plant.

3.9.2.6.3 Staff Evaluation

The staff reviewed the methods to be used to correlate results from the reactor internals vibration test with the analytical results from dynamic analyses of the reactor internals under steady-state and operational flow transient conditions, in accordance with SRP Section 3.9.2, Revision 3.

In addition, the staff reviewed test results from previous plants of similar characteristics which may have been employed to verify the mathematical models used for the loading condition of a LOCA in combination with the SSE by comparing such dynamic characteristics as the natural frequencies. The staff review also covered the methods to be used for comparing test and analytical results and for verifying the analytical models.

DCD, Tier 2, Section 3.9.2, states that GEH used the knowledge gained from previous vibration tests in the generation of the dynamic models for the ESBWR plant to predict vibration amplitudes, natural frequencies, and mode shapes. The applicant did not discuss this statement in sufficient detail. Therefore, in RAI 3.9-91, the staff requested that GEH compare the measured response frequencies to the analytically obtained natural frequencies of those reactor internals of the plant that the applicant considers to be similar to the ESBWR design for possible verification of the mathematical model used in the analysis.

In its response to RAI 3.9-91, the applicant stated the following:

> The following comparisons for ABWR demonstrate the adequacy of reactor internals models in predicting responses under operating conditions.
>
> | Component | First Mode Frequency | |
> |---|---|---|
> | | Analytical Prediction | Measurement |
> | HPCF Coupling/Sparger | 62.1 | 60.0 |
> | ICMGT | 54–70 | 55–64.5 |
> | CRDGT/CRDH | 18.7–20 | 16–20 |
>
> In addition, the shroud, which was modeled as a shell structure, shows a number of closely spaced modes with the lowest natural frequency of 6.8 Hz. The test spectra of strain gages and displacement transducers on the shroud show dominant frequencies of 6 Hz and 9.5 Hz from the transducers, and 34 Hz and 41.5 Hz from the strain gages. These were identified as corresponding to analytically predicted frequencies of 6.8 Hz (n = 2 harmonic, mode 1), 9.2 Hz (n = 1 harmonic, mode 1), 34.1 Hz (n = 1 harmonic, mode 3) and 40.6 Hz (n = 2 harmonic, mode 3).

The staff finds this response acceptable because it demonstrates that the applicant's methods of dynamic modeling and analysis of the ABWR, which it considers to be similar to the ESBWR, adequately predict the natural frequencies that were measured during vibration testing for many of the reactor internals components. Therefore, RAI 3.9-91 was closed.

DCD, Tier 2, Section 3.9.2, states that the knowledge gained from previous vibration tests has been used in the generation of the dynamic models for the ESBWR plant to predict vibration amplitudes, natural frequencies, and mode shapes. Therefore, in RAI 3.9-92, the staff requested that the applicant compare the analytically obtained mode shapes to the shape of measured motion from the plant that the applicant considers to be similar to the ESBWR design for possible identification of the modal combination or verification of a specific mode.

In its response to RAI 3.9-92, the applicant stated the following:

> An analysis of the vibration test data from sensors identifies the dominant vibration frequencies that correspond to either the component natural frequencies or forcing function frequencies. Unless each reactor internals component is extensively instrumented, it is not possible to determine mode shapes corresponding to dominant vibration modes exclusively from the test data. The recourse that is taken is to use analytical models that are validated by demonstrating agreement of predicted natural frequencies with those obtained from the test data. Once the test vibration natural frequency of a reactor internal is identified by the analytical model, the corresponding mode shape predicted by the analytical model is used to establish response characteristics of that internals component in that vibration mode. The relative magnitudes and phase relationships among the sensors on a particular component are used to help identify the correspondence between the analytic and test modes.

The staff finds this response acceptable because it explains that the methods of vibration testing in past reactors alone do not provide enough information to determine mode shapes for comparison to analytical predictions. However, once an analytical natural frequency has been identified with a measured frequency, then the correspondence between the analytic and test modes are evaluated by comparing the relative magnitudes and phase relationships among the sensors on a particular component. RAI 3.9-92 was closed.

DCD, Tier 2, Section 3.9.2, states that the knowledge gained from previous vibration tests has been used in the generation of the dynamic models for the ESBWR plant to predict vibration amplitudes, natural frequencies, and mode shapes. Therefore, in RAI 3.9-93, the staff requested that the applicant compare the response amplitude time variation to the frequency content obtained from testing and analysis conducted on a plant that GEH considers to be similar to the ESBWR design for possible verification of the postulated forcing function.

In its response to RAI 3.9-93, the applicant stated the following:

> As stated in the applicant's response to RAI 3.9-92, the analytical model is validated by demonstrating agreement of predicted natural frequencies with those obtained from test. The analytical models cannot predict response amplitude time variation unless the forcing function time and spatial variation is known a priori. The quantitative assessment of this forcing function can only be made from the test data. The response time history and its spectral decomposition are obtained directly from the test sensor data at the sensor location. At other locations on the component, the analytically derived mode shapes enable the determination of responses, from those recorded at the sensor location.

The staff finds the response acceptable because it explains that a comparison of the response amplitude time variation to the frequency content obtained from testing and analysis cannot be done unless the time and spatial variation is known a priori. Furthermore, the applicant explained that a quantitative assessment of the forcing function relies on the test data. Therefore, RAI 3.9-93 was closed.

DCD, Tier 2, Section 3.9.2, states that the knowledge gained from previous vibration tests has been used in the generation of the dynamic models for the ESBWR plant to predict vibration amplitudes, natural frequencies, and mode shapes. Therefore, in RAI 3.9-94, the staff requested that the applicant provide a comparison of the maximum responses obtained from the testing and analysis conducted on the plant that GEH considers to be similar to the ESBWR design for possible verification of stress levels.

In its response to RAI 3.9-94, the applicant stated the following:

> As stated in the applicant's response to RAI 3.9-92 and RAI 3.9-93, the analytical model is validated by demonstrating agreement of predicted natural frequencies with those obtained from test. The test sensor data from a reactor internals component, together with the analytically derived mode shapes, are employed to determine modal responses at locations other than the sensor location of the component. The modal responses are then appropriately combined to obtain maximum response anywhere in the component. The tests response is available only at the sensor location but provides a basis for the analytical determination of response elsewhere. In an ABWR FIV study conducted in 1992, the analytical models for CRDGT/CRDH and ICMH were used to predict the maximum stress values. The first ABWR startup test data later confirmed the analytically predicted values to be realistic. The following table, comparing maximum stress responses obtained from analytical methods and those from startup test

measurements, demonstrates the validity of analysis models, the methodology, and the reliability of results predicted by such models and methods.

Component	Maximum Stress Analytical Results	Maximum Stress Startup Test Results
CRDGT/CRDH	2.74 MPa (398 psi)	2.74 MPa (398 psi)
ICMH	11.77 MPa (1706 psi)	9.81 PMa (1422 psi)

The staff finds the applicant’s response acceptable because it provides examples of the reliability of the models and methods in predicting maximum stress levels in selected components of the ABWR which GEH considers to be similar to the ESBWR design. RAI 3.9-94 was closed.

DCD Tier 2, states that GEH used the knowledge gained from previous vibration tests in the generation of the dynamic models for the ESBWR plant to predict vibration amplitudes, natural frequencies, and mode shapes. Therefore, in RAI 3.9-95, the staff requested that the applicant provide a comparison of the mathematical model used for dynamic system analysis under operational flow transients and under the combined LOCA and SSE loadings for a plant similar to the ESBWR plant and note such similarities.

In its response to RAI 3.9-95, the applicant stated the following:

> FEM are generated for reactor internal subassemblies that have been instrumented and tested. The generated FEMs are used to compute the reactor internals subassembly eigen-data set, which includes natural frequencies and corresponding mode shapes. Computer programs are utilized to perform the FEM eigen-analyses. Calculated results are compared to corresponding values recorded in the reactor during testing. Once the test vibration natural frequency of a reactor internal is identified by the analytical model, the corresponding mode shape predicted by the analytical model is used to establish response characteristics of that internals component in that vibration mode. The relative magnitudes and phase relationships among the sensors on a particular component are used to help identify the correspondence between the analytical and test modes. Where deemed appropriate, the FEMs are refined so that the calculated values are closer to the measured values.
>
> The ESBWR primary structure, analytical model, which is subjected to the LOCA and seismic loadings, is a mathematical, centerline, beam element model comprised of beam and spring elements. Each beam element has six degrees of freedom (DOFs), three translational and three rotational, at each end node. The massless beam elements connect the model nodes. The model mass is appropriately distributed to the model nodes as concentrated masses. The reactor vessel shell and the reactor internal subassemblies are represented by separate beam element assemblages in the primary structure model.
>
> This same primary structure, mathematical centerline analytical model, used for the SSE and LOCA loadings, is also used for dynamic system analyses associated with operational flow transients; i.e., associated with FIVs loads. The interface loads generated at the reactor internals subassembly attachments locations in the primary structure FIV analyses are then applied to more detailed,

subsystem three dimensional FEMs of the subassemblies for dynamic qualification and stress analysis purposes.

The staff found the applicant's response reasonable and acceptable because the analytical model described by GEH in its above response conforms to the SRP guidelines and accepted industry practice. Therefore, RAI 3.9-95 was closed.

DCD, Tier 2, Section 3.9.2.4, states that the first ESBWR plant will be instrumented for testing. However, the applicant did not fully discuss the extent of the startup tests, their basis, and compliance with RG 1.20, Revision 3, guidance. Therefore, in RAI 3.9-96, the staff asked the applicant to explain why the testing for the first ESBWR plant is restricted to only those aspects that are perceived to demonstrate that the FIVs expected during operation do not cause damage. The staff requested that GEH identify the differences in the tests that were conducted on the plant that the applicant considered to be prototypical of the ESBWR reactor internals design and those tests that the applicant proposes to conduct on the reactor internals of the first ESBWR plant. The staff understands that the applicant contends that the ESBWR reactor internals fall under the classification of non-prototype Category II. Therefore, the staff requests that the applicant discuss how its testing program is consistent with the vibration assessment program delineated in Regulatory Position C.2.2 of RG 1.20, Revision 3, which is associated with the testing program for non-prototype Category II reactor internals.

In its response to RAI 3.9-96, the applicant stated the following:

> The ABWR was considered to be a prototype plant due to the introduction of RIPs and other new components. Also, higher power and higher core flows contributed to the ABWR being classified as a prototype plant. In accordance with NRC RG 1.20, Revision 3 for a prototype design, extensive analysis, testing and full inspection was conducted during the first plant startup. A total of 46 sensors of different types were used to obtain vibration data on 11 different reactor internals component structures. The ABWR components monitored during startup included the steam dryer, high pressure core flooder, control rod guide tube, the ICMGT and housing, the top guide, and the shroud. In addition, pressure sensors were installed at various locations. The pressure sensors are used to obtain data for potential diagnosis purposes.
>
> For the ESBWR, extensive instrumentation of the chimney and standby liquid control lines, both non-prototypical components, is planned. Prior to the startup testing, extensive analyses of these two components are made to establish the acceptance criteria. The acceptance criteria are set such that the maximum stresses anywhere on the structure are less than 68.9 MPa (10,000 psi). If the FIV response amplitudes are less than the acceptance criteria, damage to the component will not occur. Thus, the startup vibration program will ensure that these non-prototype components will not be subjected to unacceptable FIV stresses during operation.

The staff determined that it needed more information because the applicant's response only identified the differences between the tests that were conducted on the ABWR, which GEH considers to be prototypical of the ESBWR reactor internals design, and those tests that GEH proposes to conduct on the reactor internals of the first ESBWR plant. The applicant did not explain why the testing for the first ESBWR plant is restricted to only those aspects that are perceived to demonstrate that the FIVs expected during operation do not cause damage.

Furthermore, the applicant did not discuss how its testing program is consistent with the vibration assessment program delineated in Regulatory Position C.2.2 of RG 1.20, Revision 3, which is associated with the testing program for non-prototype Category II reactor internals. The applicant should justify the non-prototype Category II classification of the ESBWR on a component-by-component basis. In addition, the applicant should explain why the testing for the first ESBWR plant is restricted to only those aspects that are perceived to demonstrate that the FIVs expected during operation do not cause damage. In RAI 3.9-96 S01, the staff asked the applicant to provide the above information.

In its response to RAI 3.9-96 S01, the applicant provided the following information:

> In NEDE-33259P, Revision 0, ESBWR Reactor Internals Flow Induced Vibration Program—Part 1, the ESBWR components requiring additional evaluations and tests for FIV, and components considered acceptable are delineated. The plant that is used for comparison purposes that is closest to the ESBWR configuration is the Advance Boiling Water Reactor (ABWR). The first ABWR plant completed an FIV program that included analysis, testing and inspection as outlined in Regulatory Guide 1.20. Since the steam dryer and the chimney partition assemblies FIV programs were discussed in Appendix 3L of the DCD, the LTR, Rev. 0, focused on the following components:
>
> Chimney Head/Steam Separator Assembly
> Shroud/Chimney Assembly
> Top Guide
> Core Plate
> Standby Liquid Control (SLC) piping
> Control Rod Drive Housings (CRDH)
> Control Rod Guide Tubes (CRGT)
> In-Core Monitor Guide Tubes (ICMGT)
> In-Core Monitor Housings (ICMH)
>
> The remaining reactor internals components that are not specifically identified in Appendix 3L of the DCD, or in the LTR are basically proven by past trouble-free BWR experience,and have designs and flow conditions that are similar to prior operating BWR plants, e.g., the feedwater spargers and guide rods (guides chimney head and steam dryer in place during installation).
>
> An item by item discussion of why each component was considered to be prototypical and selected for further analysis and testing or why it was considered adequate without further detailed analysis or testing has been provided in Revision 1 (and Revision 2) of NEDE-33259P, ESBWR Reactor Internals Flow Induced Vibration Program. The revised LTR contains detailed analytic methods used to determine the FIV response of each item requiring further evaluation, the results of the evaluation and comparison to allowable stresses. Where testing is determined to be required for a particular component, the revised LTR also includes the types and locations of sensors.

The staff found the applicant’s response acceptable with respect to how its testing program is consistent with the vibration assessment program delineated in Regulatory Position C.2.2 of RG 1.20, Revision 3, and why the testing for the first ESBWR plant is restricted to only those aspects that are perceived to demonstrate that the FIVs expected during operation do not cause damage. However, the applicant's item by item discussion of why each component was considered to be prototypical and selected for further analysis and testing or why it was considered adequate without further detailed analysis or testing in NEDE-33259P, Revision 1, raised other concerns related to RAI 3.9-96 S01. RAI 3.9-96 was tracked as an open item in the SER with open items.

After its review of Revision 1 to NEDE-33259P, the staff formulated RAIs 3.9-233, 3.9-234, 3.9-235, 3.9-236, 3.9-237, 3.9-238, 3.9-239, 3.9-240, 3.9-241, and 3.9-242. (See the safety evaluation of NEDE-33259P). In turn, the applicant responded to these RAIs, which the staff, after further review, subsequently closed. This completed the staff's enquiry into FIV excitation of the reactor internals. Thus, RAI 3.9-96 and its associated open item were closed.

After RAI 3.9-96 was closed, GEH revised its classification of the ESBWR to a prototype in DCD, Tier 2, Revision 7, but considered the ESBWR as a non-prototype Category II through Revision 6 of DCD Tier 2. See the discussion of RAI 3.92-75 S01 at the end of Section 3.9.2.4.3 of this report for further information.

3.9.2.6.4 Conclusions

The SER for NEDC-33313P, Revision 1, Class III (Proprietary), provides the plans for correlating the reactor internals vibration startup test results with the analytical predictions for the steam dryer. DCD 3.9.2, Appendix 3L, and NEDE-33259P provide the SER for NEDC-33313P, Revision 1, Class III (Proprietary). The plans for correlating reactor internals vibration startup test results with analytical predictions.

The staff concluded that the applicant has met the relevant requirements of GDC 1 for the reactor internal components (excluding the steam dryer) designed and tested to quality standards commensurate with the importance of the safety functions performed by the proposed program to correlate the test measurements with the analysis results. The program provides an acceptable basis for demonstrating the compatibility of the results from tests and analyses, the consistency between mathematical models used for different loadings, and the validity of the interpretation of the test and analysis results. As an integral part of satisfying the requirements of GDC 1, there is a commitment for the COL applicant to classify the reactor internals in accordance with the guidance of RG 1.20 and to provide milestones for submitting the measurements, analysis, correlation, and inspection procedures and reports to the NRC. DCD Section 3.9.9-1 lists this commitment as COL Information Item 3.9.9-1-A.

3.9.3 ASME Code Class 1, 2, and 3 Components, Component Supports, and Core Support Structures

The structural integrity and functional capability of pressure-retaining components, their supports, and CS structures are ensured by designing them in accordance with ASME Code, Section III, or other industrial standards. This section addresses the loading combinations and their respective stress limits, the design and installation of pressure-relief devices, and the design and structural integrity of ASME Code Class 1, 2, and 3 components and component supports.

The criteria for the SSC design include the following considerations:

- loading combinations, design transients, and stress limits

- pump and valve operability assurance

- design and installation criteria of ASME Code Class 1, 2, and 3 pressure-relieving devices

- component and piping supports

3.9.3.1 *Regulatory Criteria*

The following regulatory requirements provide the basis for the acceptance criteria for the staff's review:

- 10 CFR 50.55a and GDC 1, as they relate to the design, fabrication, erection, construction, testing, and inspection of structures and components to quality standards commensurate with the importance of the safety functions to be performed

- GDC 2, as it relates to the design of structures and components important to safety to withstand the effects of earthquakes combined with the effects of normal or accident conditions

- GDC 4, as it relates to the design of structures and components important to safety to accommodate the effects of, and to be compatible with, the environmental conditions of normal and accident conditions

- GDC 14, as it relates to the design, fabrication, erection, and testing of the RCPB to have an extremely low probability of abnormal leakage, rapidly propagating failure, and gross rupture

- GDC 15, as it relates to the design of the RCS with sufficient margin to ensure that the design conditions are not exceeded

- 10 CFR 52.47, as it relates to the level of design completeness required for design certification

3.9.3.2 *Summary of Technical Information*

3.9.3.2.1 Loading Combinations, Design Transients, and Stress Limits

DCD, Tier 2, Section 3.9.3.1, and Table 3.9-1 discuss the design and service loading combinations specified for the ASME Code, Section III, components designated as ASME Code Class 1, 2, 3, and CS, structures. In accordance with SRP Section 3.9.3, Revision 2, this review determines whether appropriate design and service limits have been designated for all loading combinations and whether the stress limits and deformation criteria comply with the applicable limits specified in ASME Code, Section III. This section also identifies the applicable loadings, calculation methods, and allowable stresses for ASME Code, Section III, Class 1, 2 and 3 equipment and associated pressure-retaining parts.

DCD, Tier 2, Table 3.9-1, specifies the design transients and dynamic loading for ASME Code, Section III, Class 1, 2, and 3 components and component supports and CS structures and equipment. DCD, Tier 2, Section 3.9.1.1, covers design transients for ASME Code Class 1, 2, and 3 equipment. Table 3.9-1 defines the transient loading conditions applicable to ASME Code, Section III, system and component design, including the definition for design-basis pipe break (DBPB) loading that includes both LOCA and non-LOCA transient loads. DCD, Tier 2, Section 3.7, discusses seismic-related loads and dynamic analyses, and Appendix 3B discusses the suppression pool-related RBV loads. Loading combinations that are considered for the evaluation of specific equipment are derived from DCD, Tier 2, Table 3.9-2, and specified in the design specifications or design reports, or both, of the respective equipment. For ASME Code, Section III, Class 1 piping, DCD, Tier 2, Table 3.9-9, shows specific loading combinations and acceptance criteria.

The applicant stated that the design life for the ESBWR standard plant is 60 years. A 60-year design life is a requirement for all major plant components with a reasonable expectation of meeting this design life. However, the applicant also stated that all plant operational components and equipment, except the reactor vessel, are designed to be replaceable, design life not withstanding. The design life requirement allows for refurbishment and repair, as appropriate, to ensure that the design life of the overall plant is achieved. In effect, essentially all piping systems, components, and equipment are designed for a 60-year life. Many of these components are classified as ASME Code Class 2, 3, or QG D.

For any non-Class 1 components that are subjected to cyclic loadings of a magnitude or duration so severe that the 60-year design life cannot be ensured by required ASME Code calculations, GEH stated that applicants referencing the ESBWR design must identify these components and either provide an appropriate analysis to demonstrate the required design life or provide designs to mitigate the magnitude or duration of the cyclic loads. Thermal sleeves are an example of such components and may be required to protect the pressure boundary from severe cyclic thermal stress at points where mixing of hot and cold fluids occurs. For the ESBWR, these locations include the SRV discharge line going into the quencher and the FW pipe within the steam tunnel at the RWCU junction. (See DCD, Tier 2, Revision 7, Section 3.9.9-2-A, which requires that the COL holder provide the analyses, as required by ASME Code, Section III, Subsection NB.)

3.9.3.2.1.1 Plant Conditions

In DCD, Tier 2, Section 3.9.3.1.1, the applicant identified four plant loading conditions that were defined to establish the design basis for plant equipment. These plant conditions are based on all events that the plant might credibly experience during a reactor year. The plant conditions are based on event probability (i.e., frequency of occurrence) and correlated to the service levels and design limits defined in ASME Code, Section III, as shown in DCD, Tier 2, Tables 3.9-1 and 3.9-2. For the ESBWR, the applicant defined these service loading conditions as follows:

- Normal conditions are conditions in the course of system startup, operation in the design power range, normal hot standby (with condenser available), and system shutdown other than for upset, emergency, faulted, or testing conditions.

- Upset conditions are any deviations from normal conditions anticipated to occur often enough that the design should include the capability to withstand the conditions without operational impairment. Upset conditions include system operational transients (SOTs) (i.e., anticipated operational occurrences), as defined in Appendix A to 10 CFR Part 50. Hot standby with the main condenser isolated is also an upset condition.

- Emergency conditions are any deviations from normal conditions that require shutdown for correction of the conditions or repair of damage in the RCPB. Such conditions have a low probability of occurrence, but are included to provide assurance that no gross loss of structural integrity results as a concomitant effect of any damage developed in the system. Emergency condition events include but are not limited to infrequent operational transients (IOTs) (e.g., infrequent events), as defined in DCD, Tier 2, Section 15.0.12. An anticipated transient without scram (ATWS) or reactor overpressure with delayed scram (DCD, Tier 2, Tables 3.9-1 and 3.9-2) is a special event, as defined in DCD, Tier 2, Section 15.0.1.2, that is classified as an emergency condition.

- Faulted conditions are any of those combinations of conditions associated with extremely low-probability postulated events whose consequences are such that the integrity and operability of the system may be impaired to the extent that considerations of public health and safety are involved.

The applicant also presented a correlation between the probability of an event occurring per reactor year and these plant conditions. This correlation also included the appropriate ASME Code, Section III, service levels for the plant conditions and probabilities, as follows:

- normal condition (planned) A 1.0
- upset condition (moderate probability) B $1.0 > P > 10^{-2}$
- emergency condition (low probability) C $10^{-2} > P > 10^{-4}$
- faulted condition (extremely low probability) D $10^{-4} > P > 10^{-5}$

The applicant specified the following two DCD Tier 2 safety-related functional criteria:

(1) For any normal or upset design condition event, safety-related equipment and piping (DCD, Tier 2, Section 3.2.1) shall be capable of accomplishing their safety function as required by the event and shall incur no permanent changes that could deteriorate their ability to accomplish their safety function as required by any subsequent design condition event.

(2) For any emergency or faulted design event, safety-related equipment and piping shall be capable of accomplishing their safety function as required by the event, but repairs could be necessary to ensure their ability to accomplish their safety function as required by any subsequent design condition event.

3.9.3.2.2 Reactor Pressure Vessel Assembly

In DCD, Tier 2, Section 3.9.3.2, the applicant described the RPV assembly as including (1) the reactor vessel boundary out to and including the nozzles and housings for the FMCRD and in-core instrumentations, (2) vessel sliding support, and (3) shroud support. The applicant stated that the reactor vessel components are classified as ASME Code, Section III, Class 1, and the analysis of these components is performed on an elastic basis. DCD, Tier 2, Section 3.9.5, discusses the relevant loading conditions, design stress limits, and methods for stress analysis for the CS structures and other reactor internals.

3.9.3.2.3 Main Steam System Piping

In DCD, Tier 2, Section 3.9.3.3, the applicant also described the MS system piping as extending from the RPV to and including the outboard MSIV. The applicant stated that the piping is designed and constructed in accordance with the ASME Code, Section III, Class 1 criteria. The MS system piping extending from the outboard MSIV valve to the TSV is constructed in accordance with the ASME Code, Section III, Class 2 criteria. Section 3.12 of this report addresses the evaluation of MS system piping.

3.9.3.2.4 Other Components

In DCD, Tier 2, Section 3.9.3.4, the applicant stated the following design requirements for the following safety-related components:

- The SLC accumulator is designed and constructed in accordance with the requirements for ASME Code, Section III, Class 2 components.

- The SLC injection valve is designed and constructed in accordance with the requirements for ASME Code, Section III, Class 1 components.

- The GDCS piping and valves connected with the RPV, including squib valves, and up to and including the biased-open check valve (CV), are designed and constructed in accordance with the requirements for ASME Code, Section III, Class 1 components. Other valves in the system are ASME Code, Section III, Class 2 components.

- The MSIVs, SRVs, and DPVs are designed and constructed in accordance with the ASME Code, Section III, Subsection NB-3500, requirements for ASME Code, Section III, Class 1 components.

- The SRV discharge piping extending from the relief valve discharge flange to the VW penetration is designed and constructed in accordance with the requirements for ASME Code, Section III, Class 3 components. The relief valve discharge piping extending from the DF penetration to the quenchers is also designed and constructed in accordance with the requirements for ASME Code, Section III, Class 3 components.

- The primary component cooling (PCC) heat exchangers and associated piping are designed and constructed in accordance with the requirements for ASME Code, Section III, Class 2 components and piping.

- The isolation condenser system (ICS) condenser and piping inside the primary containment between the RPV and the condenser isolation valve are designed and constructed in accordance with the requirements for ASME Code, Section III, Class 1 components. The isolation condenser (IC) and piping outside containment are designed and constructed in accordance with the requirements for ASME Code, Section III, Class 2 components.

- The applicant stated that the RWCU/SDC system pump and heat exchangers (regenerative and nonregenerative) are not part of a safety system. However, the pumps and heat exchanger are seismic Category I equipment. The design and construction of the RWCU system pump and heat exchanger components conform to the ASME Code, Section III, requirements for Class 3 components.

- All ASME Code, Section III, Class 2 and 3 vessels not previously discussed are constructed in accordance with ASME Code, Section III, Class 2 and 3 requirements, respectively. The stress analysis of these vessels is performed using elastic methods.

- All ASME Code, Section III, Class 1, 2, and 3 valves not previously discussed are constructed in accordance with the ASME Code, Section III, Class 1, 2, and 3 criteria, respectively. All valves and their extended structures are designed to withstand the accelerations caused by seismic and other RBV loads. The attached piping is supported so that these accelerations are not exceeded. The stress analysis of these valves is performed using elastic methods.

- All ASME Code Class 1, 2, and 3 piping not previously discussed is constructed in accordance with the ASME Code, Section III, requirements for Class 1, 2, and 3 piping, respectively. In the event that a Section NB-3600 analysis is performed for Class 2 or 3 pipe, all the analysis requirements for Class 1 pipe, as specified in the DCD and the ASME Code, will be performed. DCD, Tier 2, Table 3.9-9, shows the specified load combinations and acceptance criteria for Class 1 piping systems. In addition, if ASME Code Case N-122-2 is used for analysis of a Class 1 pipe, the design report for the piping system will include the analysis complying with this case. For submerged piping and associated supports, the analysis shall include the applicable direct external loads (e.g., hydrodynamic loads) applied to the submerged components.

3.9.3.2.5 Valve Operability Assurance

In DCD, Tier 2, Section 3.9.3.5, the applicant discussed operability assurance of active ASME Code valves, including actuators. The operability of active valves is ensured by meeting the requirements of the programs defined in DCD, Tier 2, Sections 3.9.2.2, 3.10, and 3.11, in addition to this section. The applicant also stated that Section 4.4 of the applicant's environmental qualification program (DCD, Tier 2, Reference 3.9-3) applies to this subsection, and the seismic qualification methodology presented in this reference is applicable to mechanical as well as electrical equipment.

The applicant listed the following five tests that are performed before installation of the SRVs:

(1) shell hydrostatic test to ASME Code, Section III requirements

(2) back seat and main seat leakage tests

(3) disk hydrostatic test

(4) functional tests to verify that the valve opens and closes within the specified time limits when subject to the design differential pressure

(5) operability qualification of valve actuators for the environmental conditions over the installed life

Environmental qualification procedures for operation follow those specified in DCD, Tier 2, Section 3.11. The results of all required tests are properly documented and included as a part of the operability acceptance documentation package.

The applicant stated that the functionality of active valves during and after a seismic and other RBV event is demonstrated by an analysis or by a combination of analysis and test. The valves are designed using either stress analyses or the pressure-temperature rating requirements based on design conditions. An analysis of the extended structure is performed for static equivalent dynamic loads applied at the center of gravity of the extended structure. The maximum stress limits allowed in these analyses confirm structural integrity and are the limits developed and accepted by ASME for the particular ASME Code class of valve analyzed. Safety-related valves that do not have an overhanging structure, such as CVs and pressure-relief valves, are qualified as described below.

Active CVs are qualified by a combination of stress analysis, including the dynamic loads where applicable, in-shop hydrostatic tests, in-shop seat leakage tests, and periodic in situ valve exercising and inspection to ensure the functional capability of the valve.

Active pressure-relief valves are qualified by test and analysis, similar to that for CVs, stress analyses (which include the dynamic loads), and in-shop hydrostatic seat leakage and performance tests. Functional capability of these valves is ensured by periodic in situ valve inspection, as applicable, and periodic removal, refurbishment, performance testing, and reinstallation. Tests of the relief valve under dynamic loading include pressurizing the valve with nitrogen, subjecting the valve to accelerations equal to or greater than the dynamic event (SSE plus other RBV), and demonstrating that valve actuation can occur during application of the loads.

The applicant stated that all of the preceding requirements that demonstrate the functionality of active valves are documented in a format that clearly shows that each consideration has been properly evaluated and a designated QA representative has validated the tests. The certified stress report for the assembly includes the analysis.

3.9.3.2.6 Design and Installation of Pressure-Relief Devices

An SRV is identified as a pressure-relief valve or vacuum breaker (VB). DCD, Tier 2, Section 5.4.13, identifies and describes SRVs in the reactor components and subsystems.

In DCD, Tier 2, Section 3.9.3.6, the applicant summarized the dynamic analysis of MS and SRV discharge piping systems subjected to fluid transients resulting from SRV discharge. Section 3.12 of this report addresses the evaluation of MS and SRV discharge piping.

The operability assurance program discussed in DCD, Tier 2, Section 3.9.3.5, applies to SRVs. ESBWR SRVs and VBs are designed and manufactured in accordance with ASME Code, Section III, requirements.

The design of ESBWR SRVs incorporates SRV opening and pipe reaction load considerations required by Appendix O to ASME Code, Section III, and includes the additional criteria of SRP Section 3.9.3.II.2 for pressure and structural integrity. SRV and vacuum relief valve operability is demonstrated either by dynamic testing or analysis of similarly tested valves or a combination of both in compliance with the requirements of SRP Section 3.9.3.

3.9.3.2.7 Component Supports

DCD, Tier 2, Section 3.9.3.7, indicates that all ASME Code, Section III, component supports, including those used to support piping and RCPB components, should be designed, manufactured, installed, and tested in accordance with all applicable codes and standards. Supports include hangers, snubbers, struts, spring hangers, frames, energy absorbers, and limit stops. Pipe whip restraints are not considered as pipe supports. Section 3.9.3.7 also covers the design of bolts for component supports.

3.9.3.3 *Staff Evaluation*

3.9.3.3.1 Loading Combinations, Design Transients, and Stress Limits

In accordance with SRP Section 3.9.3, the staff reviewed the DCD Tier 2 loading combinations, the design transients, and the stress limits that are used for the design of ESBWR safety-related ASME Code, Section III, Class 1, 2, and 3 components and component supports and CS structures. These appear in DCD, Tier 2, Table 3.9-2. To complete its review, the staff requested additional information as described below.

In RAI 3.9-97, the staff requested confirmation that the requirements of 10 CFR 50.55a(b) will be satisfied without exception for the ASME Code, Section III edition identified in Table 1.9-22, as applicable to the design of components, component supports, and CS structures. In its response, the applicant stated that the response to RAI 3.12-1 is also applicable to this RAI. The staff reviewed the response to RAI 3.12-1 and concurs that this response, described in SER Section 3.12, is an acceptable response to RAI 3.9-97. Therefore, RAI 3.9-97 was closed.

In RAI 3.9-98, the staff requested justification for excluding seismic inertia loading from the stress calculation of ASME Code, Section III, Subsections NC/ND-3600, using equations 9, 10, and 11, for Service Levels A and B, as stated in footnote 12 of Table 3.9-2. In its response, the applicant stated that SSE inertia loading is included only in fatigue calculations for ASME Code, Section III, Class 1, Service Levels A and B. For Class 2 and 3 components, SSE inertia loading is included in Service Level D primary stress calculations using equation 9. The staff finds this response acceptable, since OBE loading is not specified for the ESBWR. Therefore, RAI 3.9-98 was closed.

In accordance with SRP Section 3.9.3, the objectives in reviewing the loading combinations and stress limits employed by the applicant in the design of ASME Code, Class 1, 2, and 3 components, component supports, and core support structures are to confirm that the appropriate postulated events have been included and that the loading combinations (including system operating transients) and the designation of design and service stress limits are appropriate. For the reviews of design certification and COL applications under 10 CFR Part 52, the reviewer verifies that the objectives have been implemented in the design by checking selected design documents required by the ASME Code, such as design specifications and design reports, to confirm that the design criteria have been utilized and that components have been designed to meet the objectives. DCD, Tier 2, Revision 3, originally included a COL information item in Section 3.9.9.4, which requires that COL holders make design specifications and design reports required by the ASME Code for piping and mechanical components available for NRC audit. Later revisions of the DCD no longer list this COL item under Section 3.9.9.

In RAI 3.9-177, the staff requested that the applicant reinstate the COL information item originally listed in DCD Section 3.9.9.4 (Revision 3) in DCD Section 3.9.9 or address the information item through an ITAAC. In its response, the applicant stated that this item is addressed through ITAAC, as described in its earlier response to RAI 14.3-131 S01. The staff reviewed the response to RAI 14.3-131 S01 and found that it partially resolved RAI 3.9-177.

Based on the addition of component ITAAC identified in DCD, Tier 1, Revision 5, Section 2, the staff believes that the portion of the COL information item regarding verification of component ASME Code design reports has been addressed. However, the staff also requires that the design specifications for all risk-significant mechanical components (not just a representative sample) be available for staff review before the approval of the ESBWR design certification application. Subsequently, the applicant provided the list of risk-significant component design specifications available for staff audit.

During July 20–24, 2009, the staff conducted an audit of risk-significant component design specifications at the applicant's office in Wilmington, NC. The purpose of the audit was to verify that the applicant was performing the ESBWR component design and qualification in accordance with the methodology and criteria described in the DCD in support of the ESBWR design certification application and the North Anna Unit 3 COL application. This included verifying that the design information described in the ESBWR DCD was adequately translated into documentation for the components designed to ASME Code, Section III, Class 1, 2, and 3, requirements.

During the audit, the staff found in the RPV system design specification (Specification Number 26A6631) that the fatigue evaluation of all ASME Code, Class 1 components will be performed in accordance with RG 1.207 and NUREG/CR-6909 guidance for including environmental effects. However, DCD Revision 5, Section 3.9.3, does not indicate that this is applicable for component design, although, for Class 1 piping design, the applicant commits in the DCD to include the environmental effects using RG 1.207 and NUREG/CR-6909 guidance. The staff discusses this item in NRC's, "Summary of the July 20 to 24, 2009, Regulatory Audit of Design Specification of Risk Significant ESBWR Components at General Electric Hitachi (GEH) Office in Wilmington, NC, issued September 1, 2009 as audit Follow-Up Item No. 1.

The staff requested that the applicant revise DCD Revision 5, Section 3.9.3.1, to indicate that the fatigue evaluation of ASME Code Class 1 components will be performed using RG 1.207 and NUREG/CR 6909 guidance for including the environmental effects.

In its response to the audit summary followup items, the applicant stated that it added the following sentence to the end of the second paragraph of DCD Revision 6, Section 3.9.3.1:

> For Class I components where analysis for cyclic operation is evaluated in accordance with ASME B&PV Code, Section III, Subarticle NB-3222.4, the fatigue usage evaluation shall include the use of environmental fatigue curves in accordance with RG 1.207 and NUREG/CR-6909.

The staff reviewed DCD Revision 6, Section 3.9.3.1, and confirmed that the applicant had made the change. The staff found that the applicant's response of this audit followup item is acceptable. The staff found that all audited components are designed in accordance with the ASME Code subsections and are appropriately documented in design and purchase specifications. Therefore, RAI 3.9-177 was closed.

In reviewing DCD, Tier 1, Revision 5, Section 2, which provides component ITAAC on a system basis, the staff identified a number of errors, both in the text and in the associated ITAAC tables. In RAI 14.3-414, the staff requested that the applicant correct the errors listed below and others that may exist in the Tier 1 ITAAC:

(a) Table 2.2.2-7, for Control Rod Drive System, the description of Inspections, Tests, and Analyses (ITA) for as-built ITAAC in Item 2.a2 is not consistent with the intended revision. And the description of the entire fabrication and installation ITAAC is missing in Item 2.a3.

(b) Section 2.4.1, for Isolation Condenser System, the description of as-built ITAAC in item (2)a2 is not consistent with the intended revision.

(c) Table 2.6.2-2, for Fuel and Auxiliary Pools Cooling Cleanup System, the description of the entire fabrication and installation portion of the ITAAC is missing in Item 2.a3.

(d) Section 2.11.1, for Turbine Main Steam System, no description of component ITAAC is provided.

(e) Table 2.11.1-1, for Turbine Main Steam System, no component ITAAC is included in the table.

(f) Table 2.15.1-2, for Containment System, the descriptions of ITA and Acceptance Criteria for the fabrication and installation portion of the ITAAC in Item 2.c.1 are not consistent with the intended revisions.

By letter dated December 12, 2008, the applicant stated that it will revise DCD Tier 1, Section 2, to incorporate the suggested changes. The staff has reviewed the markups provided by the applicant, confirmed that the changes were made in Revision 6 of the DCD. The staff found the revisions to be acceptable. RAI 14.3-414 was, therefore, closed.

3.9.3.3.1.1 Plant Conditions

In DCD, Tier 2, Section 3.9.3.1.1, the applicant identified four plant loading conditions that were defined to establish the design basis for plant equipment. These plant conditions are based on all events that the plant might credibly experience during a reactor year. The plant conditions, discussed in detail in Section 3.9.3.2.1.1 of this SER, are correlated to the service levels and design limits defined in ASME Code, Section III.

In RAI 3.9-99, the staff asked the applicant to provide the basis for the correlation between the plant conditions and the associated probability ranges. The staff also requested that the applicant provide these probabilities for the plant events listed. In its response, the applicant indicated that all events classified as ASME Code, Section III, Service Level A, are postulated to have a probability of occurrence of 1.0, since these events are assumed to occur during every plant operating cycle. Events classified as ASME Code, Section III, Service Level B, are postulated to occur infrequently and therefore have a moderate probability of occurrence. Events classified as ASME Code, Section III, Service Level C, are postulated to occur very infrequently and therefore have a low probability of occurrence. Events classified as ASME Code, Section III, Service Level D, such as an SSE or large-break LOCAs, are postulated to have an extremely low probability of occurrence, with no known instance of ever having occurred. The frequency of occurrence of the various events is based on industry operating experience and engineering judgment. The applicant’s response is satisfactory, and the staff concurs with the response to this RAI. Therefore, RAI 3.9-99 was closed.

The staff reviewed the list of events that comprise the individual plant conditions and finds them acceptable, since they conform to the plant events shown in DCD, Tier 2, Tables 3.9-1 and 3.9-2, and are consistent with the guidelines in SRP Section 3.9.3.

3.9.3.3.2 Reactor Pressure Vessel Assembly

The staff reviewed the applicant's description in DCD, Tier 2, Section 3.9.3.2, of the analysis of the RPV assembly. In RAI 3.9-100, the staff asked the applicant to provide a listing and description of the computer programs and calculation procedures used for the analysis of the RPV and the RPV internals, including the CS structures. In its response, the applicant referenced Appendix 3D to DCD Tier 2 for a list of the computer programs used for the analysis of the RPV and RPV internals, except for the computer programs for the fuel, which appear in DCD, Tier 2, Section 4.1.4.1. The applicant's response is acceptable. Therefore, RAI 3.9-100 was closed.

3.9.3.3.3 Main Steam System Piping

The staff reviewed the applicant's description in DCD, Tier 2, Section 3.9.3.3, of the analysis of the MS system piping. In RAI 3.9-101, the staff requested that the applicant confirm that the stresses in the MS Class 1 piping meet the acceptance criteria for Service Levels A and B (listed in DCD, Tier 2, Section 3.9.3.4, Table 3.9-9, Revision 1, as equations 12 and 13 of ASME Code, Section III, Subsection NB-3600) of less than or equal to 3.0 Sm. In its response, the applicant stated that Revision 2 of DCD, Tier 2, Section 3.9, changed the acceptance criterion in Table 3.9-9 for equations 12 and 13 to 2.4 Sm, in accordance with the requirements in SRP Section 3.6.2, BTP MEB-3.1, to avoid postulating pipe breaks in these lines. The staff reviewed the changes and concurs with the applicant's response because the stresses meet the acceptance criterion called out in ASME Code and NRC guidance. Therefore, RAI 3.9-101 was closed. The staff performed an audit of the MSL design calculations and verified that the stresses meet the stated acceptance criteria. Section 3.12 of this report describes the results of this audit.

3.9.3.3.4 Other Components

The staff reviewed the design requirements of other safety-related plant components listed in DCD, Tier 2, Section 3.9.3.4. In RAI 3.9-102, the staff asked the applicant to verify that Sections 3.9.3 and 3.9.4 of DCD Tier 2 include all ESBWR pressure boundary safety-related components and component supports. In its response, the applicant stated that it compared the pressure boundary components and related component supports listed in DCD, Tier 2, Table 3.2-1, to those listed in Sections 3.9.3 and 3.9.4. Based on this comparison, the applicant included in-core instrumentation in the RPV assembly definition in DCD, Tier 2, Revision 3, Section 3.9.3.2, which will also be consistent with DCD, Tier 2, Section 3.9.1.4. The staff finds that the applicant has provided the necessary verification in its response to the RAI. The staff also finds the design requirements of other safety-related plant components acceptable because they are consistent with the requirements stated in SRP Section 3.9.3 for ASME Code, Section III, Class 1, 2, and 3 components. Therefore, RAI 3.9-102 was closed.

3.9.3.3.5 Valve Operability Assurance

The staff reviewed DCD, Tier 2, Section 3.9.3.5, with regard to the design, installation, and testing criteria applicable to ASME Code Class 1, 2, and 3 active valves. This review, conducted in accordance with SRP Section 3.9.3, included evaluating the applicable loading combinations and stress criteria. The staff also reviewed the dynamic qualification procedures of active valves, as described in DCD, Tier 2, Section 3.9.3.5.1 and Section 3.9.3.5.2.

In RAI 3.9-103, the staff requested that the applicant provide a table showing the load combinations and acceptance criteria for safety-related active valves and pressure-relief devices, similar to Table 3.9-9 in DCD, Tier 2, Section 3.9.3. The staff also requested that the applicant confirm that safety-related components and component supports required to remain operational and to perform a safety function after a specified plant condition event are designed to lower ASME Code, Section III, service level stress criteria. In its response, the applicant stated that information similar to that in Table 3.9-9 appears in DCD, Tier 2, Table 3.9-2, for safety-related active valves and pressure-relief devices. The staff finds this part of the response acceptable. The applicant also stated that safety-related components and component supports required to remain operational and to perform a safety function after a specified plant condition event are designed to the appropriate ASME Code, Section III, service level stress criteria. By letter dated May 14, 2007, the applicant confirmed that the stress criteria for active components and their supports that experience a design-basis event are lower than the stress criteria allowed by the corresponding ASME Code service condition to which the event is classified. The applicant stated that analysis, testing, or a combination of analysis and testing, is used to confirm that an active component will not incur damage that inhibits a safety-related function because of the loads imposed for a specified service condition. This includes components and their supports expected to perform active safety functions during and after experiencing Service Level D loads. The staff finds this response acceptable because the stress criteria allowed by the DCD are more conservative than those allowed by ASME Code. Therefore, RAI 3.9-103 was closed.

In RAI 3.9-104, the staff asked the applicant to describe Section 4.4 of its environmental qualification program and to indicate whether the NRC has reviewed and approved this program. In its response, the applicant stated that this information appears in NEDE-24326-1-P, “General Electric Environmental Qualification Program,” issued January 1993, which the NRC approved and which is referenced in Section 3.11.4 of NUREG-1503, “Final Safety Evaluation Report Related to the Certification of the Advanced Boiling Water Reactor Design,” issued July 1994. The staff finds this response acceptable. Therefore, RAI 3.9-104 was closed.

In RAI 3.9-105, the staff asked the applicant to confirm that the stresses in active valve bodies and pump casings loading conform to the requirements in SRP Section 3.10, draft Revision 3, issued April 1996, for faulted conditions. In its response, the applicant confirmed that the stresses in active valve bodies conform to the requirements in SRP Section 3.10, draft Revision 3, as identified in DCD, Tier 2, Table 1.9-20. DCD Section 3.9.3.5 specifically identifies that the requirements of SRP Section 3.10 are applicable, and this section identifies that testing and analysis is in compliance with SRP Section 3.10. Table 1.9-20 and Reference 3.10-1 specifically identify the SRP draft Revision 3 requirements. However, compliance with SRP Section 3.10 for safety-related pumps is not required for the ESBWR since the ESBWR design contains no such components. The staff finds this response acceptable. Therefore, RAI 3.9-105 was closed.

The staff confirmed that the stresses in active valve bodies conform to the requirements in SRP Section 3.10, draft Revision 3. DCD Section 3.9.3.5 specifically identifies that the requirements of Section 3.10 are applicable, and this section identifies that testing and analysis is in compliance with SRP Section 3.10. Table 1.9-20 and Reference 3.10-1 specifically identify

SRP draft Revision 3. Because there are no safety-related pumps in the ESBWR design, compliance with SRP Section 3.10 is not required for these components.

In RAI 3.9-106, the staff requested that the applicant provide a detailed description of the dynamic load qualification that demonstrates the functionality and operability of a representative active valve. In its response, the applicant provided clarification in Revision 3 of DCD, Tier 2, Section 3.9.3.5.2, which included additional details of the dynamic qualification testing procedure for valve operability, and referenced Section 3.9.2.2 and portions of Sections 3.10.1 and 3.10.2 applicable to active valve assemblies. The staff finds this response acceptable because it provides the requested information. Therefore, RAI 3.9-106 was closed.

The applicant stated that the certified stress report for the assembly documents all of the preceding requirements that demonstrate the functionality of active valves. The format of the documentation clearly shows that each consideration has been properly evaluated. Furthermore, a designated QA representative has validated the tests.

In RAI 3.9-107, the staff asked the applicant to list the design reports documenting the qualification of the safety-related valves and to confirm that the design reports meet the requirements stated in ASME Code, Section III, Subsection NCA-3550. In its response, the applicant stated that ASME Code, Section III, Subsection NCA-3200, outlines the owner's responsibilities for reviewing design reports. The requested list of design reports provides a record of the plant's construction that conforms to the requirements in ASME Code, Section III, Subsection NCA-3260. The design reports are available and maintained on file at the site of the nuclear plant in accordance with the requirements in Appendix B to 10 CFR Part 50. The staff concurs with the applicant's response because the licensee will meet ASME Code requirements. Therefore, RAI 3.9-107 was closed.

Section 3.9.6 of this report provides additional discussion of the operability assurance and functional qualification of safety-related valves.

3.9.3.3.6 Design and Installation of Pressure-Relief Devices

The staff reviewed DCD, Tier 2, Section 3.9.3.6, with regard to the design, installation, and testing criteria applicable to the mounting of pressure-relief devices used for the overpressure protection of ASME Code Class 1, 2, and 3 components. This review, conducted in accordance with SRP Section 3.9.3, included evaluation of the applicable loading combinations and stress criteria.

In RAI 3.9-108, the staff asked the applicant to verify that the design and installation of pressure-relief devices are consistent with the provisions stated in SRP Section 3.9.3.II.2. In its response, the applicant confirmed that the ESBWR design meets all applicable provisions of SRP Section 3.9.3.II.2, as shown in DCD, Tier 2, Table I-9-20. This table indicates that the design does not deviate from the guidelines in SRP Section 3.9.3. The staff reviewed the changes and finds this response acceptable. Therefore, RAI 3.9-108 was closed.

In accordance with 10 CFR 50.34(f)(2)(x), pressurized-water reactor (PWR) and BWR licensees and applicants must conduct testing to qualify the RCS SRVs and associated piping and supports under expected operating conditions for design-basis transients and accidents (Three Mile Island (TMI) Action Item II.D.1 of NUREG-0737, "Clarification of TMI Action Plan Requirements," issued November 1980).

In RAI 3.9-109, the staff asked the applicant to provide a detailed description of the tests that are conducted to address the testing requirements in TMI Action Item II.D.1 or to provide a reference to the section in DCD Tier 2 that discusses this issue. In its response, the applicant stated that the design of the ESBWR RCS SRVs meets the recommendations of TMI Action Item II.D.1 regarding a test program and associated model development and qualification testing, in accordance with DCD, Tier 2, Revision 2, Section 5.2.2, and the response to RAI 5.2-7. The applicant also stated that DCD, Tier 2, Revision 2, Chapter 1, Table A-1, provides additional description and details of the tests that are conducted to meet the requirements of TMI Action Item II.D.1. The staff finds this response acceptable because it addresses the RAI regarding testing requirements in the referenced TMI action item. Therefore, RAI 3.9-109 was closed.

In RAI 3.9-110, the staff asked the applicant to list the design reports documenting the qualification of the pressure-relief devices and to confirm that the design reports meet the requirements stated in ASME Code, Section III, Subsection NCA-3550. In its response, the applicant stated that the design reports, as required by ASME Code, Section III, Subsection NCA-3550, are provided as part of the delivery of completed N-stamp components. As such, these reports are not yet available but, in accordance with ASME Code, Section III, Subsection NCA-3557, must be made available for audit by NRC inspectors at the plant site. These reports will show that the SRVs provided for the ESBWR fully comply with the applicable ASME Code requirements. The staff has reviewed this response and finds it acceptable because it conforms to the requirements of ASME Code, Section III. Therefore, RAI 3.9-110 was closed.

The staff has reviewed the DCD Tier 2 sections on valve operability assurance and pressure-relief devices for conformance with the requirements of SRP Section 3.9.3 regarding loading conditions and stress limits for active valves and pressure-relief devices. The staff finds them acceptable because they conform to the requirements of this SRP section.

3.9.3.3.7 Component Supports

The staff reviewed the design and analysis of component supports in accordance with SRP Section 3.9.3. The staff reviewed all information provided in DCD Tier 2, Section 3.9.3.7, to ensure that ASME Code Class 1, 2, and 3 component supports are designed to meet the pertinent requirements of the regulations discussed in Section 3.9.3.1 of this report. The review included an assessment of the design criteria, analysis methods, and loading combinations used in establishing a basis for structural integrity of the supports. It addressed plate and shell, linear, and component standard types of supports.

The applicant stated that ASME Code, Subsection NF, specifies the design of bolts for component supports. Subsection NF-3324.6 gives the stress limits for bolts multiplied by the appropriate stress limit factor for the particular service loading level and stress category specified in Table NF-3225.2-1. For equipment mounted on a concrete support, sufficient holes for anchor bolts are provided to limit the anchor bolt stress to less than 68.95 MPa (10,000 psi) on the nominal bolt area in shear or tension. In addition, with regard to safety factor and base plate flexibility, concrete expansion anchor bolts will follow all aspects of Inspection and Enforcement (IE) BL 79-02, “Pipe Support Base Plate Design Using Concrete Expansion Anchor Bolts,” Revision 2, dated November 8, 1979. The design and installation of all anchor bolts will be performed in accordance with Appendix B to American Concrete Institute (ACI) 349-01, “Anchoring to Concrete,” subject to the conditions and limitations specified in RG 1.199, “Anchoring Components and Structural Supports in Concrete,” and all applicable requirements of IE BL 79-02, Revision 2. The staff finds the above anchor bolt design as provided in DCD, Tier 2, Section 3.9.3.7, to be consistent with general industry practice and NRC guidelines. Therefore, it is acceptable.

DCD, Tier 2, Section 3.9.3.7.1, states that supports and their attachments for essential ASME Code Class 1, 2, and 3 piping are designed in accordance with ASME Code, Section III, Subsection NF, up to the interface of the building structure, with jurisdictional boundaries as defined by Subsection NF. The applicable loading combinations and allowable used for the design of supports appear in DCD, Tier 2, Revision 3, Table 3.9-10 for snubbers, Table 3.9-11 for struts, and Table 3.9-12 for anchors and guides. Section 3.12.7.1 of this SER reviews the adequacy of the loads and load combinations presented in these tables. All piping supports are designed, fabricated, and assembled so that they cannot become disengaged by the movement of the supported pipe after they have been installed. The stress limits are consistent with ASME Code, Section III, Subsection NF and Appendix F. The applicant stated that supports are generally designed either by the load rating method, in accordance with Subsection NF-3280, or by stress limits in accordance with Subsection NF-3143.

DCD, Tier 2, Section 3.9.3.7, mentioned seismic Category IIA pipe supports without providing a definition. In RAI 3.9-111, the staff asked the applicant to clarify and discuss how it has addressed the provisions of RG 1.29 with regard to this category of pipe supports. By letter dated February 16, 2007, the applicant stated that seismic Category IIA pipe supports will be designed so that the SSE would not cause unacceptable structural interaction or failure. Support design will follow the intent and general requirement specified in Appendix F to ASME Code, Section III, to ensure that the structural integrity of the pipe supports is maintained under the SSE design loading condition. The applicant has revised DCD, Tier 2, Section 3.9.3.7.1, to incorporate the changes. The staff determined the applicant's response to be acceptable because seismic Category IIA pipe supports will be designed so that the SSE would not cause unacceptable structural interaction or failure. The staff confirmed the changes were made. Therefore, RAI 3.9-111 was closed.

DCD, Tier 2, Section 3.9.3.7.1, states that the building structure component supports designed in accordance with American National Standards Institute/American Institute of Steel Construction (ANSI/AISC) N690, "Nuclear Facilities-Steel Safety-Related Structures for Design, Fabrication and Erection," or the AISC Specification for the Design, Fabrication, and Erection of Structural Steel, correspond to those used for design of the supported pipe. In RAI 3.9-112, the staff asked the applicant to discuss the types of component supports that are being designed in accordance with ANSI/AISC N690 or the AISC specification and to explain how these component supports correspond to those used for design of the supported pipe.

In its response to RAI 3.9-112, the applicant stated that it will revise DCD, Tier 2, Section 3.9.3.7.1, to state that the building structure component supports (connecting the NF support boundary component to the existing building structure) are designed in accordance with ANSI/AISC N690 (1994 Edition) or the AISC Specification for the Design, Fabrication, and Erection of Structural Steel. The staff found the applicant's response to be acceptable in clarifying which component supports are being designed in accordance with ANSI/AISC N690 or the AISC specification. In addition, Section 3.8.3 (Table 3.8-7) and Section 3.8.4 (Table 3.8-16) of DCD Tier 2 properly indicate the use of ANSI/AISC N690, including S02 (issued 2004). This is consistent with the requirements of SRP Sections 3.8.3 and 3.8.4 and is acceptable. Therefore, RAI 3.9-112 was closed.

The applicant stated that maximum calculated static and dynamic deflections of the piping at support locations do not exceed the allowable limits specified in the piping design specification. The purpose of the allowable limits is to preclude failure of the pipe supports because of piping deflections. The staff determined that the applicant did not provide sufficient information for the pertinent service level stress limits of component supports, as well as their deformation limits under both static and dynamic loadings. In RAI 3.9-113, the staff asked the applicant to respond to the following three requests:

(1) For each loading combination considered for each component support, the applicant should describe the designation of the appropriate service level stress limit and discuss its conformance to the criteria provided in SRP Section 3.9.3.II.3 and Appendix A, and RG 1.124 and RG 1.130, "Service Limits and Loading Combinations for Class 1 Plate-and-Shell-Type Component Supports."

(2) The applicant should discuss how the support deformation limits are incorporated into the operability assurance determination and seismic qualification program of the components.

(3) The applicant should provide examples of the deformation limits considered for the supports, accounting for the types of supports, their characteristics (such as stiffness), and the components or structures to which they are attached.

In its response to RAI 3.9-113, the applicant further stated that the revision of Section 3.9.3.7 (Revision 3) clarifies the design of the pipe support structure with respect to design limits. The applicant clarified that the design and service loadings and limits will be established in accordance with ASME Code, Section III, Division 1, Subsections NCA-2000 and NF. These loadings and stress limits apply to the structural integrity of components and supports when subjected to combinations of loadings derived from plant and system operating conditions and postulated plant events. The design specification of each component and support includes the combination of loadings and stress limits. When the design and service stress limits specified in the ASME Code do not necessarily provide direction for the proper consideration of operability requirements for conditions that warrant consideration, SRP Section 3.9.3, Section 3.9.3.II.3 and Appendix A, as well as RGs 1.124 and 1.130, will be used for guidance. The applicant stated that, where these stress limits apply, the treatment of functional capability, including collapse, deformation, and deflection limits, will be evaluated and appropriate information will be developed for inclusion in the design specification. The staff concluded that the component support design, including service level stress limits, deflection limits, and operability considerations, will be in accordance with ASME Code and NRC guidance.

In its response, the applicant stated that the load caused by deadweight is the operating load on spring hangers being used as pipe supports. The hangers are calibrated to ensure that they support the operating load at both their hot and cold load settings. Spring hangers provide a specified down travel and up travel in excess of the specified thermal movement. This is in accordance with general industry practice and, therefore, is acceptable for spring hanger design.

In the RAI 3.9-113 response, the applicant stated that the friction loads are caused by unrestricted motion of the piping because the thermal displacements are considered to act on the support with a friction coefficient of 0.3 in the case of steel-to-steel friction. For SS, Teflon, and other materials, the friction coefficient could be less. The seismic or dynamic loading evaluation of pipe support structures does not consider the friction loads. The staff finds this to be acceptable because the practice ensures friction loads are considered in the pipe support design.

The staff verified the changes were made in the DCD and found this response addressed RAI 3.9-113 Question (1) and is acceptable

In its response to the related RAI 3.12-37, the applicant stated that it will revise DCD, Tier 2, Revision 2, Section 3.9.3.7.1, to state that a deflection limit of 1.6 mm (1/16 in.) for erection and operation loading is used for the design of piping supports, based on Welding Research Council (WRC)-353, "Position Paper on Nuclear Pipe Supports," paragraph 2.3.2. For the consideration of loads from the SSE and in the cases involving springs, the deflection limit is increased to 3.2 mm (1/8 in.). The staff found the response addressed RAI 3.9-113 Question (2) how the support deformation limits are incorporated into the operability assurance determination.

In its response to RAI 3.12-37, the applicant also stated that snubbers are chosen in lieu of rigid supports where restricting thermal growth would induce excessive stresses in the piping or nozzle loads on equipment. The operating loads on snubbers are the loads caused by dynamic events (e.g., seismic, RBV because of LOCA, SRV and DPV discharge, discharge through a relief valve line, or valve closure) during various operating conditions. Snubbers restrain piping against responses to the dynamic excitation and to the associated differential movement of the piping system anchor points. During the initial plant layout stage, the snubber locations and support directions are first decided by estimation so that the stresses in the piping system have acceptable values. The snubber locations and support directions are then refined by performing the dynamic analysis of the piping and support system so that the piping stresses and support loads meet ASME Code requirements. The staff found the response addressed RAI 3.9-113 Question (2) how the support deformation limits are incorporated into the seismic qualification program.

Based on the above evaluation, the staff finds that the applicant addressed RAI 3.9-113 Question (2) and is acceptable.

In the RAI 3.9-113 response, the applicant stated that the small-bore lines (e.g., small branch and instrumentation lines) are supported, taking into account the flexibility and thermal and dynamic motion requirements of the pipe to which they connect. DCD, Tier 2, Section 3.7.3.16, provides details for the support design and criteria for instrumentation lines 50 mm (2 in.) and less where it may be acceptable to use piping handbook methodology. Section 3.9.2.2 of this report provides the staff's evaluation of small-bore piping using handbook methodology. The staff found the response addressed RAI 3.9-113 Question (3) and is acceptable.

Based on the above evaluation, the applicant responses to RAI 3.9-113 were acceptable, therefore, RAI 3.9-113 was closed.

The staff found that DCD, Tier 2, Section 3.9.3.7.1(3), did not provide sufficient information for potential snubber end-fitting clearance and lost motion. In RAI 3.9-114, the staff asked the applicant to discuss how it accounted for snubber end-fitting clearance and lost motion and how these would affect the calculations of snubber reaction loads and stresses using a linear analysis methodology. In multiple snubber applications where mismatch of end-fitting clearance and lost motion exists, the staff also asked the applicant to discuss the potential impact on the synchronism of activation level or release rate and, consequently, on the assumption of the load sharing of multiple snubber supports. By letter dated February 16, 2007, the applicant stated that, in multiple snubber applications where mismatch of end-fitting clearance and lost motion could possibly exist, the piping analysis model will evaluate the synchronism of activation level or release rate, if deemed necessary, when this application could be considered critical to the functionality of the system, such as a multiple snubber application located near rotating equipment. Equal load sharing of multiple snubber supports will not be assumed if a mismatch in end-fitting clearances exists and will be evaluated as a part of this assessment. The staff found the applicant's response to be insufficient in explaining how the effects of snubber end-fitting clearance and lost motion would be calculated and, as a result, how the piping analysis model will account for unequal load sharing of multiple snubber supports. RAI 3.9-114 was tracked as an open item in the SER with open items.

In its RAI 3.9-114 response, the applicant stated that each end connection consists of a spherical ball bushing with one or more spacer bars that permit controlled angular rotation in any plane. Snubbers are not permitted to be skewed at severe angles from their connecting points and are not allowed to be binding in the pipe clamp. By design, end connection clearance is not considered a critical element of the support function as long as the manufacturer specifications and installation instructions are strictly followed. The applicant stated that total lost movement, excluding that due to compressibility of fluid and major structural parts, is expected to be less (in the range of 0.05 in.) than the normal gap seen at other types of rigid supports because of construction tolerances and fit-up. This minimal gap is not expected to warrant any "specialty" type of analyses because of this extremely small magnitude of movement.

The applicant also stated that the effects of snubber end-fitting clearance and lost motion are not considered to be significant and have no bearing on the safety of the piping system to which the snubbers are attached. Typically, snubbers are modeled in a linear analysis as rigid restraints, which means that their design load is 1.52 times the product of the distributed mass and the seismic acceleration (F = DLFma) at the lowest fundamental frequency in the seismic spectrum. If end-fitting clearance and snubber engagement motion should cause any movement, the net result will be a reduction in dynamic load factor (DLF) and an increase in system damping, resulting in a reduced dynamic force on the snubber during the earthquake. Therefore, it is conservative to ignore end-fitting clearances and snubber engagement displacements.

The applicant further stated that, in a snubber pair where one snubber engages before the other, each snubber is typically capable of carrying the entire seismic restraint load by itself without failure. The resulting snubber stress may exceed the design limit, but the other snubber, with its delayed engagement, will pick up load before failure of the snubber that engages first.

The staff found the above additional information provided by the applicant to be adequate in explaining how the effects of snubber end-fitting clearance and lost motion would be evaluated,and, as a result, how the piping analysis model will account for nonequal load sharing of multiple snubber supports. This was acceptable; therefore, RAI 3.9-114 and its associated open item were closed.

The applicant stated that the pipe support design specification requires that snubbers be provided with position indicators to identify the rod position. This indicator facilitates the checking of hot and cold settings of the snubber, as specified in the installation manual, during plant preoperational and startup testing. The staff finds that the applicant's use of position indicators for facilitating the checking of snubber settings represents a good industry practice and, therefore, is acceptable.

The applicant stated that the pipe support design specification requires that the snubber supplier prepare an installation instruction manual. This manual is required to contain complete instructions for the testing, maintenance, and repair of the snubber. It also contains inspection points and the period of inspection. The pipe support design specification requires that hydraulic snubbers be equipped with a fluid level indicator so that the level of fluid in the snubber can be ascertained easily. The staff found the provisions provided by the specification acceptable.

An important aspect of the structural analysis is the realistic characterization of snubber mechanical properties (i.e., spring constant) in a piping system model. As stated previously, the snubber supplier initially provides the effective stiffness of the snubber for a specific load capacity, which is compared against that used in the piping system model. If the spring constants are the same, then the snubber location and support direction become confirmed. If the spring constant used in the analysis is not in agreement with the one supplied, they are brought into agreement, and the system analysis is redone to confirm the snubber loads. This iteration is continued until all snubber load capacities and spring constants are reconciled. The staff finds that DCD, Tier 2, Section 3.9.3.7.1(3), did not provide sufficient information for the characterization of snubber mechanical properties in the analytical model. In RAI 3.9-115, the staff asked the applicant to provide a detailed discussion on the characterization of effective stiffness for the snubber support assembly (e.g., the snubber plus clamp, transition tube extension, backup support structure) used in the refined piping analysis. In its response, the applicant stated that the piping analysis includes snubber stiffness, as supplied by the snubber vendor. Other support components, such as the pipe clamp/extension piece/transition tube and structural auxiliary steel stiffness values, are incorporated into the final determination of the stiffness value used in the analysis. The staff found the applicant’s response to be acceptable because the piping analysis includes support stiffness values. Therefore, RAI 3.9-115 was closed.

In addition, the applicant stated that the pipe support design specification requires snubbers to be designed in accordance with ASME Code, Section III, Subsection NF. This design requirement includes analysis for normal, upset, emergency, and faulted loads. The applicant also stated that these calculated loads are then compared against the allowable loads to ensure that the stresses are below the ASME Code’s allowable limits. The staff, however, found no specific design requirements provided for snubbers. In RAI 3.9-116, the staff requested that the applicant provide a detailed discussion on the specific design rules of Subsection NF applied to snubbers. The staff also asked the applicant to provide a detailed discussion on how the load capacity for design, normal, upset, emergency, and faulted conditions is derived and compared against the vendor’s allowables, for both mechanical and hydraulic snubbers.

In its response, the applicant stated that snubber designs are based on the requirements set forth in ASME Code, Section III, Subsection NF. The design requirements include analysis for normal, upset, emergency, and faulted loads. Calculated loads are then compared against allowables as established by the snubber vendor. The rules and sections of Subsection NF that are established for these designs are at the discretion of the snubber vendor. The selection of the vendor will be based on an approved vendor list for which snubber suppliers are required to provide sufficient documentation that their in-house programs comply with all ASME Code and QA/quality control requirements. The applicant further stated that the vendor’s snubber design and load ratings are based on certified analysis and test results, which would not typically require a separate independent verification by the COL applicant. Based on these responses and the responses provided for RAI 3.9-117 S01, the staff considers the applicant to have adequately resolved this RAI because the snubber designs are based on ASME Code requirements. Therefore, RAI 3.9-116 was closed.

In DCD, Tier 2, Section 3.9.3.7.1(3)c(ii), the applicant stated that snubbers are tested to ensure that they can perform as required during the SSE and other RBV events, as well as under anticipated operational transient loads or other mechanical loads associated with the design requirements for the plant. However, the applicant did not provide a detailed, delineated description of snubber qualification and production tests. In RAI 3.9-117, the staff requested that the applicant (1) discuss the procedure and scope of production and qualification test programs, separately, for both the mechanical and hydraulic snubbers of different sizes and manufacturers, (2) discuss how the criteria for each pertinent snubber functional parameter are met in the testing, and (3) provide the codes and standards used for the test programs. In its response, the applicant noted that it will revise DCD, Tier 2, Section 3.9.3.7.1(3)c, in Revision 3 to add the following statement:

> Production and qualification test programs for both hydraulic and mechanical snubbers are carried out by the snubber vendors in accordance with the snubber installation instruction manual required to be furnished by the snubber supplier. Acceptance criteria to assure compliance with ASME Section III Subsection NF are cited in this manual, and applicable codes and standards are referenced.

The staff found that this response did not address all questions in RAI 3.9-117 and asked the applicant to supplement its response to the RAI on the snubber production and qualification test programs. For a more specific delineation, the staff asked, in RAI 3.9-117 S01, that the applicant address, for mechanical and hydraulic snubbers of all makes and sizes, the following:

(1) how the snubber production and qualification test programs are carried out in accordance with the snubber installation instruction manual, as stated in the February 16, 2007, response

(2) confirmation that the production tests consider all snubbers in the population or justification if not so

(3) how the samples are selected for the qualification tests

(4) the procedures taken to obtain the required snubber load ratings demonstrated

(5) the acceptance criteria cited in the installation instruction manual that would ensure compliance with ASME Code, Section III, Subsection NF, and the referenced Subsection NF requirements

(6) the specific functional parameters (e.g., activation level, release rate, drag, dead band) considered for all snubber production and qualification testing and the bases of their acceptance

(7) the acceptable codes and standards (including editions) used for snubber qualification and production testing

(8) verification that the production operability tests for the large-bore hydraulic snubbers (greater than 50 kips load rating) include the following:

(a) a full Service Level D load test to verify sufficient load capacity

(b) testing at the full load capacity to verify proper bleed with the control valve closed

(c) testing to verify that the control valve closes within the specified velocity range

(d) testing to demonstrate that breakaway and drag forces are within the acceptable design limits

RAI 3.9-117 was tracked as an open item in the SER with open items.

By letter dated November 15, 2007, the applicant stated that, in response to the above specific questions with regard to snubbers, it had revised DCD, Tier 2, Section 3.9.3.7.1(3)c(iii), as shown in the DCD markup attached to the letter. Specifically, the applicant stated that the acceptance criteria to ensure compliance with ASME Section III, Subsection NF, and other applicable codes, standards and requirements are as follows:

- Snubber production and qualification test programs are carried out by strict adherence to the manufacturer's snubber installation and instruction manual, which is prepared by the snubber manufacturer and subjected to review by the applicant for compliance with the applicable provisions of the ASME Pressure Vessel and Piping Code of record. The test program is periodically audited during implementation by the applicant for compliance.

- All snubbers will be inspected and tested for compliance with the design drawings and functional requirements of the procurement specifications.

- All snubbers are inspected and tested. No sampling methods may be used in the qualification tests.

- All snubbers are load rated by testing in accordance with the snubber manufacturer's testing program and in compliance with the applicable sections of ASME QME-1, Subsection QDR, and ASME Operations and Maintenance (OM) Code, Subsection ISTD.

- Design compliance of the snubbers will be in accordance with ASME Code, Section III, Subsections NF-3128, NF-3411.3, and NF-3412.4.

- The snubbers are tested for various abnormal environmental conditions. Upon completion of the abnormal environmental transient test, the snubber is tested dynamically at a frequency within a specified frequency range. The snubber must operate normally during the dynamic test. The functional parameters cited in ASME Code, Subsection NF-3412.4, are included in the snubber qualification and testing program. Other parameters in accordance with applicable ASME QME-1 and the ASME OM Code will be incorporated.

- The codes and standards used for snubber qualification and production testing are as follows:

  – ASME Code, Section III (Code of Record date) and Subsection NF

- ASME QME-1, Subsection QDR, and ASME OM Code, Subsection ISTD (latest applicable edition)

- All large-bore hydraulic snubbers (LBHSs) that include full Service Level D load testing, including verifying bleed rates, control valve closure within the specified velocity ranges, and drag forces/breakaway forces, are acceptable in accordance with ASME QME-1 and the ASME OM

Based on the additional information provided above, the staff determined that the applicant adequately addressed all of the issues identified in RAI 3.9-117 S01 and provided an adequate description of snubber test requirements. The staff verified that the applicant revised the pertinent portions of DCD, Tier 2, Section 3.9.3.7.1(3)c(iii), to incorporate the changes as stated. Therefore, RAI 3.9-117 and its associated open item were closed. In addition, in the above responses, the applicant also adequately addressed the issues identified in Generic Safety Issue 113 for LBHSs. The staff, therefore, determined that the generic issue was closed for the ESBWR design certification.

In DCD, Tier 2, Section 3.9.3.7.1(3)c(ii), which appears as Section 3.9.3.7.1(3)c(iii) in Revision 3 and later revisions, the applicant stated that, as part of test requirements, snubbers are subjected to force or displacement versus time loading at frequencies within the range of significant modes of the piping system. In RAI 3.9-118, the staff requested that the applicant explain how the force or displacement versus time loading as stated are related to the velocity and acceleration parameters measured during snubber testing. By letter dated February 16, 2007, the applicant referred to its response to RAI 3.9-117. RAI 3.9-118 was tracked as an open item in the SER with open items. Since the applicant's response to RAI 3.9-117, which was related to snubber test requirements, also was a satisfactory response to RAI 3.9-118, the staff considered RAI 3.9-118 and its associated open item to be closed.

The applicant stated in DCD, Tier 2, Section 3.9.3.7.1(3)d, that the installation instruction manual, as required by the pipe support design specification, also contains instructions for storage, handling, erection, and adjustments (if necessary) of snubbers. Each snubber has an installation location drawing that contains the installation location of the snubber on the pipe and structure, the hot and cold settings, and additional information needed to install the particular snubber. To ensure proper installation of snubbers and their readiness for power operation, the staff requested, in RAI 3.9-119, that the applicant commit to demonstrate the operational readiness of essential snubbers by verifying the proper installation of the snubber and by performing visual inspections and measurements of the cold and hot positions of the snubbers as required during plant heatup to verify that the snubbers are performing as intended.

In its response to RAI 3.9-119, the applicant noted that existing Sections 3.9.3.7.1(3)b and 3.9.3.7.1(3)e of DCD Tier 2 state that the snubber supplier will provide a snubber installation instruction manual as required by the pipe support design specification. This manual contains instructions for the erection, testing, maintenance, repair, and adjustment of each individual snubber. This includes procedures for compliance with the specified hot and cold settings. The applicant stated that a thermal motion monitoring program is established for verification of snubber movement and adequate clearance and gaps, including motion measurement and acceptance criteria to ensure compliance with ASME Code, Section III, Subsection NF. This is acceptable to the staff since it addresses the staff's questions regarding the procedures and requirements provided in the snubber installation instruction manual. The staff also verified that the applicant revised the pertinent portions of DCD, Tier 2, Section 3.9.3.7.1(3), to incorporate the changes as stated. Therefore, RAI 3.9-119 was closed.

In DCD, Tier 2, Section 3.9.3.7.1(3)e, the applicant provided the specific preservice examination plan for all snubbers covered by the plant-specific technical specifications. This examination is made after snubber installation, but not more than 6 months before initial system preoperational testing. If the period between the initial preservice examination and initial system preoperational tests exceeds 6 months, reexaminations will be performed as required. Snubbers that are installed incorrectly or otherwise fail to meet the above requirements are repaired or replaced and reexamined in accordance with the above criteria.

Although the staff found the above preservice examination requirements for snubbers to be generally acceptable, the applicant provided no specific reference to the codes and standards used and no regulatory basis. In RAI 3.9-120, the staff asked the applicant to confirm that the snubber preservice examination requirements meet the intent of the design code of record incorporated by reference in 10 CFR 50.55a. The staff also requested that the applicant clarify that, during initial system heatup and cooldown, snubber thermal movements will be verified according to an acceptable ASME Code requirement. In its response to RAI 3.9-120, the applicant stated that it will revise DCD, Tier 2, Section 3.9.3.7.1(3)e, to specifically reference the ASME OM Code, which is referenced in 10 CFR 50.55a and which provides in Subsection ISTD-4000 the requirements for preservice examination during initial system heatup and cooldown. The staff found that the applicant adequately addressed the concern regarding snubber preservice examination requirements. The staff also verified that the applicant revised the pertinent portion of Section 3.9.3.7.1(3)e to incorporate the changes as stated. Therefore, RAI 3.9-120 was closed.

In its review of DCD, Tier 2, Section 3.9.3.7.1, the staff found that the applicant did not provide sufficient information regarding snubber preservice testing. In RAI 3.9-121, the staff asked the applicant to provide a detailed discussion on snubber preservice testing requirements, including the codes and standards used. In its response to RAI 3.9-121, the applicant stated that it will revise DCD, Tier 2, Section 3.9.3.7.1(3)e, to specifically reference the ASME OM Code, which provides the requirements for the preservice testing in Subsection ISTD-5000. The applicant stated that it will prepare the specification for preservice examination and testing of snubbers, in accordance with the ASME OM Code, after performance of the detailed plant design, including piping system stress analysis, so that the number and type of snubbers to be tested are known. The previously mentioned pipe support installation instruction manual prepared by the snubber supplier provides additional detailed information for preservice testing. The staff found that the applicant adequately addressed its concern regarding the snubber preservice testing requirements. The staff also verified that the applicant revised the DCD as required. Therefore, RAI 3.9-121 was closed.

In connection with the required inservice examination and testing requirements, the staff requested, in RAI 3.9-122, that, as part of the COL information items listed in DCD, Tier 2, Section 3.9.9, COL applicants provide (1) the scope of the snubber inservice examination program, including the codes and standards used, (2) the scope of the snubber inservice testing (IST) program, including the codes and standards used, and (3) a detailed discussion on the accessibility provisions for maintenance, inservice examination and testing, and possible repair or replacement of snubbers consistent with the requirements of SRP Section 3.9.3.

In its response, the applicant stated that it will revise DCD, Tier 2, Section 3.9.9, to require that COL applicants provide a plan for the detailed snubber IST and inspection program in accordance with the ASME OM Code. This plan includes baseline preservice testing to support the periodic IST of all snubbers covered by the plant-specific technical specifications. The staff found the applicant's response to be consistent with the requirements of 10 CFR 50.55a and the applicable guidelines of SRP Section 3.9.3. Therefore, it is acceptable. In addition, commitments to ISI and testing found in DCD, Tier 2, Section 6.6, are consistent with ASME Code, Section XI, and further ensure snubber operability during plant operation. The ISI and testing plan, which the COL applicant referencing the ESBWR design will provide, reports details of the inservice examination and testing program, including test schedules and frequencies. This is COL Information Item 3.9.9-4-A. The staff has verified that DCD, Tier 2, Section 3.9.9, includes the above-stated snubber IST and inspection program as COL Information Item 3.9.9-4-A. Items (1) and (2) of RAI 3.9-122 were, therefore, closed. The applicant, however, did not address the staff's concern identified in item (3) of the RAI regarding the accessibility provisions for maintenance, inservice examination and testing, and possible repair or replacement of snubbers.

By letter dated April 16, 2007, the applicant provided a supplemental response stating that, with regard to the accessibility requirements for testing and inservice examination of snubber supports and other plant features, DCD, Tier 2, Revision 3, Section 3.8.3.7, describes the space controls needed in the ESBWR plants to allow unobstructed access. The applicant stated that the ESBWR plant layout design includes the appropriate considerations of space availability for maintaining and performing the required testing and ISI of components. The staff reviewed DCD, Tier 2, Section 3.8.3.7, and confirmed that the applicant incorporated the above provisions as stated. The response is acceptable because Section 3.8.3.7 fully describes space controls to be used which should ensure accessibility for servicing snubbers. Therefore, RAI 3.9-122 was closed.

To ensure that a documented snubber program will be in place for a plant site audit, the staff requested in RAI 3.9-123 that the applicant discuss in detail the content of the snubber information items, as required by SRP Section 3.9.3.II.3.B(iii), and confirm that they are included as part of the COL information items listed in DCD, Tier 2, Section 3.9.9. In addition, the staff asked the applicant to confirm that the procurement program include provisions for the snubber manufacturer to submit its QA and assembly quality control procedures for review and acceptance by the purchaser. In its response, the applicant stated that it will add, in DCD, Tier 2, Section 3.9.3.7.1(3), a new paragraph f as follows:

f. Snubber audit support data

To ensure that the plant-specific snubber programs will be readily available for a site audit, the plant-specific design specification provided by the COL applicant will include the following specific snubber information:

(i) the general functional requirement,

(ii) operating environment,

(iii) applicable codes and standards,

(iv) materials of construction and standards for hydraulic fluids and lubricants,

(v) environmental, structural, and performance design verification tests,

(vi) production unit functional functional verification tests and certification,

(vii) packaging, shipping, handling, and storage requirements,

(viii) description of provisions for attachments and installation, and

(ix) QA and assembly quality control procedures for review and acceptance by the purchaser.

The staff verified that the applicant included the above additional information under a new paragraph f in Section 3.9.3.7.1(3). The staff further verified that, in DCD, Tier 2, Section 3.9.9, the applicant included COL Information Item 3.9.9-4-A to commit to provide a full description of the snubber preservice and ISI and testing programs, as well as a milestone for program implementation, including development of a data table identified in Section 3.9.3.7.1(3)f. Based on the above, the staff found the applicant's responses to be acceptable. Therefore, RAI 3.9-123 was closed.

DCD, Tier 2, Section 3.9.3.7.1, did not identify all safety-related components that use snubbers in their support systems, as required by SRP Section 3.9.3.II.4.C. In RAI 3.9-124, the staff requested that the applicant identify and tabulate all such safety-related components that use snubbers in their support systems. In its response, the applicant stated that it will revise DCD, Tier 2, Section 3.9.3.7.1(3)c, to state that all safety-related components that use snubbers in their support systems will be identified and inserted into the FSAR in table format and will include the following:

- identification of systems and components
- number of snubbers used in each system and on what component
- snubber types, hydraulic or mechanical, and name of supplier
- verification of construction to ASME Code, Section III, Subsection NF, or other
- use of snubber for shock, vibration, or dual purpose
- for those snubbers identified as the dual-purpose or vibration-arrestor type, an indication of whether both snubber and component were evaluated for fatigue strength

The staff verified that the applicant added the above additional information as DCD, Tier 2, Section 3.9.3.7.1(3)c(iv). Therefore, RAI 3.9-124 was closed because the DCD was revised to include identification of safety-related components that use snubbers as suggested in NRC guidance.

ASME Code, Section III, Subsection NF, defines struts as component standard supports. They consist of rigid rods pinned to a pipe clamp or lug at the pipe and pinned to clevis attached to the building structure or supplemental steel at the other end. Struts are normally used instead of snubbers where dynamic supports are required and the movement of the pipe as a result of thermal expansion or anchor motions, or both, is small. Struts are not used at locations where restraint of pipe movement to thermal expansion significantly increases the secondary piping stress ranges or equipment nozzle loads.

Because of the pinned connections at the pipe and the structure, struts carry axial loads only. The design loads on struts may include those loads caused by thermal expansion, deadweight, and the inertia and anchor motion effects of all dynamic loads. As in the case of other supports, the forces on struts are obtained from an analysis and are confirmed not to exceed the design loads for various operating conditions. The staff finds that the applicant's design for struts follows general industry practice and, therefore, is acceptable.

ASME Code, Section III, Subsection NF, defines frame-type (linear) pipe supports as component standard supports. As stated in DCD, Tier 2, Section 3.9.3.7.1, these supports consist of frames that are constructed of structural steel elements that are attached to the pipe. They act as guides to allow axial and rotational movement of the pipe, but serve as rigid restraints to lateral movement in either one or two directions. Similar to struts, frame-type supports are not used at locations where restraint of pipe movement to thermal expansion significantly increases the secondary piping stress ranges or equipment nozzle loads.

The design loads on frame-type pipe supports include those loads caused by thermal expansion, deadweight, and the inertia and anchor motion effects of all dynamic loads. The forces on frame-type supports are evaluated to ensure that they do not exceed the design loads for various operating conditions.

In RAI 3.9-125, the staff requested that the applicant provide the following information concerning the frame-type support:

(1) the hot and cold gaps to be used between the pipe and the frame-type support

(2) the coefficients of friction used for different pipe and support material combinations, and the calculation of friction forces induced by the pipe on the support

(3) how the seismic excitation of a large frame-type support structure itself is considered in the design of the support anchorage

In its response, the applicant stated that it will revise DCD, Tier 2, Section 3.9.3.7.1(5), to state that the design incorporates any hot or cold gaps required by the qualifying pipe stress analysis results. Where friction between the pipe and frame support occurs as a result of sliding, an appropriate coefficient of friction will be used to calculate friction loading on the support. In addition, the design of frame supports covered by ASME Code, Section III, Subsection NF, considers seismic inertia loads as well as static seismic loads. By letter dated December 11, 2006, in its responses to RAIs 3.12-32 through 3.12-35, the applicant stated that it revised DCD, Tier 2, Section 3.9.3.7.1, to state that the piping analysis generally considers pipe support component weights that are directly attached to a pipe, such as a clamp, strut, snubber, and trapeze. Frame-type supports will be designed to carry their own mass and will be subjected to deflection requirements. In addition, the larger and more massive type of supports will be evaluated in detail to include the impact of self-weight excitation on support structure and anchorage along with piping analyzed loads.

The staff verified that the applicant made appropriate changes in DCD, Tier 2, Section 3.9.3.7.1, including Section 3.9.3.7.1(5), to reflect the above responses for the frame supports. Therefore, RAI 3.9-125 was closed.

To minimize the use and application of snubbers, special engineered pipe supports may be used in some instances where neither struts nor frame-type supports can be applied. However, in response to RAI 3.9-31, the applicant stated that the ESBWR would not use special engineered supports. The staff verified that the applicant modified Section 3.9.3.7.1(6) to reflect this change. This is acceptable to the staff, and RAI 3.9-31 was closed.

In DCD, Tier 2, Section 3.9.3.7.2, the applicant stated that the ESBWR RPV sliding supports are defined in ASME Code, Section III, Subsection NF-3124, and are designed as an ASME Code Class 1 component support in accordance with the requirements of ASME Code, Section III, Subsection NF. DCD, Tier 2, Tables 3.9-1 and 3.9-2, give the loading conditions and stress criteria, and the calculated stresses shall meet the ASME Code allowable stresses at all locations for various plant operating conditions. The stress level margins ensure the adequacy of the RPV sliding supports. This discussion in the DCD is acceptable because the calculated stresses meet the ASME Code allowable stresses at all locations for various plant operating conditions.

In DCD, Tier 2, Section 3.9.3.7.3, the applicant stated that the RPV stabilizer is designed as a safety-related linear-type component support in accordance with the requirements of ASME Code, Section III, Subsection NF. The stabilizer provides a reaction point near the upper end of the RPV to resist horizontal loads caused by effects such as earthquake, pipe rupture, and RBV. DCD, Tier 2, Table 3.9-2, gives the design loading conditions and stress criteria, and the calculated stresses meet the ASME Code allowable stresses in the critical support areas for various plant operating conditions. The staff finds this discussion in the DCD to be acceptable because the RPV stabilizer design meets ASME Code.

In DCD, Tier 2, Section 3.9.3.7.4, the applicant stated that the IC heat exchangers are analyzed to verify the adequacy of their support structures under various plant operating conditions. In all cases, the calculated stresses in the critical support areas are within ASME Code allowable stresses. The staff found this discussion acceptable.

In the above discussion of the design adequacy for component supports, the applicant stated that the supports associated with all major ASME Code Section III equipment are designed to meet the required ASME Code allowable loads and stresses. However, the DCD did not provide sufficient details for the analytical models and the methods of analysis used for designing the component supports that support the major ASME Code Class 1 equipment. In RAI 3.9-126, the staff asked the applicant to discuss the analytical models and the methods of analysis used for all major ASME Code Class 1 component supports.

In its response, the applicant stated that analytical models and methods of analysis for all major ASME Code Class 1 component supports, including snubbers, are fully defined in the user manuals for the pipe stress computer programs that are selected and approved for qualifying the Class 1 piping systems to the applicable ASME Code requirements. The staff considered the applicant’s generic response to the RAI to be acceptable, since the design report associated with each component support will contain a more detailed description of the analytical model and the method of analysis. Therefore, RAI 3.9-126 was closed.

In DCD, Tier 2, Sections 3.9.2.2 and 3.9.3.7, the applicant described the analysis and qualification of safety-related major mechanical equipment and its supports, including the dynamic loadings involved. However, the submerged effects of the heat exchangers in an elevated water pool are not discussed. For the analysis of heat exchangers, such as the passive reactor IC and containment cooling system heat exchangers, which are immersed in large elevated water pools, the staff requested, in RAI 3.9-247, that the applicant address the following:

(1) Discuss whether the hydrodynamic effects of the water pools are included in the building seismic analysis and in the generation of in-structure response spectra at the floor elevations to which the heat exchangers are mounted.

(2) Discuss in detail how the pertinent dynamic and seismic forces are applied to heat exchangers in their analysis, including the dynamic forces that are due to hydrodynamic sloshing effects. Discuss the methods of deriving the equivalent dynamic characteristics related to the surrounding water pool, if applicable, such as mass, stiffness, and damping, which are considered in the analysis.

In its response to RAI 3.9-247, the applicant provided the following information:

(1) The hydrodynamic effects of the water pools are included in the building seismic analysis in the form of added water mass, in which the entire water mass is conservatively considered as impulsive mass rigidly attached to the wall/slab nodes (RAI 3.7-23 response). The building seismic analysis directly generates in-structure response spectra including those at the floor elevations to which the heat exchangers are mounted.

(2) The structural dynamic response analysis of the PCCS heat exchanger is carried out by means of a 3D finite element model using the response spectrum method. The input dynamic loads are in-structure response spectra at the heat exchanger mounting location calculated from the building dynamic analyses. Additional dynamic forces due to hydrodynamic sloshing effects of the submerged PCCS heat exchangers are taken into account in the form of the hydrodynamic mass, which is equal to the displaced water mass. The displaced water mass for each component, which is surrounded by the pool water, of the heat exchanger assembly is added to the self-mass for the total component mass in the finite element model. Thus, the dynamic and seismic forces including hydrodynamic mass effect of the pool water are intrinsically calculated together in the analysis. No stiffness and damping considerations are given to the pool water. The same methods of analysis will be used for IC heat exchangers in detailed design.

In RAI 3.9-247 S01, the staff requested that the applicant provide the following information:

(1) Add a description in ESBWR DCD Section 3.9.3.7 addressing the methodology for the RAI 3.9-247 seismic analysis with sloshing effect and the commitment to apply it to the seismic analysis of ICS and PCCS.

(2) Develop and document an ITAAC to confirm the completion of ICS and PCCS submerged heat exchangers support structure design.

In response to RAI 3.9-247 S01, the applicant modified the description of the methodology of the seismic analysis with respect to the sloshing effect and the commitment to apply it to the seismic analysis of the ICS and PCCS in DCD Section 3.9.3.7.4. The applicant revised Table 2.4.1-3 in DCD, Tier 1, Section 2.4.1, and Section 2.15.4, Table 2.15.4-2, of the ITAAC to confirm the completion of the ICS and PCCS submerged heat exchangers support structure design. The staff found that the modifications more thoroughly defined the design and would allow verification that the design methodology was followed in the final design for the heat exchangers. The staff verified these changes in DCD Revision 6 and found that the changes were acceptable. Therefore, RAI 3.9-247 was closed.

In the ESBWR design, the generation of hydrogen and oxygen gas by radiolysis in the core occurs in a stoichiometric ratio at a rate proportional to the core decay heat. During a LOCA, these gases escape into the containment and become diluted with steam in the drywell area. Both the PCCS (six units) and ICS (four units) are designed to receive this mixture of steam and noncondensable gases (hydrogen and oxygen), condense the steam, and return the condensate back to the wetwell. As a result, the noncondensable gases may persistently linger in certain components of the PCCS and ICS at concentrations that may originate deflagrations or detonations in these components. The applicant identified these critical components to be the condenser tubes, the lower drums, the vent pipes, and the drain pipes.

Unlike the PCCS, the noncondensable gases accumulated in the ICS are not vented, and the condensation rate of the tubes is quickly reduced. The ICS vent lines do not open during LOCA conditions, and the lower drum and drainlines will be subjected to the same accumulation of the noncondensable gases as the PCCS. The applicant is committed to design both PCCS and ICS condensers to withstand detonation loads to satisfy their intended design functions. Current LOCA thermohydraulic analyses do not credit heat transfer for the ICS.

It is important to note that the PCCS condensers are part of the containment pressure boundary. In the response to RAI 6.2-202, the applicant stated that, should a combustible gas mixture accumulate in the PCCS, the PCCS is designed to withstand overpressure from possible deflagrations or detonations to prevent compromising the containment pressure boundary integrity and the long-term cooling (72 hours) of the containment. The resolution of this issue is discussed in Section 6.2 of this report.

3.9.3.4 *Conclusions*

Based on its review of the information provided in DCD Tier 2 (up to Revision 6) and the additional information provided by the applicant, the staff concludes that the ESBWR design of ASME Code Class 1, 2, and 3 components, component support, and core support structures meet the requirements of 10 CFR Part 50, specifically 10 CFR 50.55a and GDC 1, 2, 4, 14, and 15, as well as 10 CFR 52.47. Therefore, these designs are acceptable.

3.9.4 Control Rod Drive System

3.9.4.1 *Regulatory Criteria*

The following regulatory requirements provide the basis for the acceptance criteria for the staff's review:

- GDC 1, "Quality Standards and Records," and 10 CFR 50.55a, "Codes and Standards," require that the control rod drive (CRD) system be designed to quality standards commensurate with the importance of the safety functions to be performed.

- GDC 2, “Design Bases for Protection Against Natural Phenomena,” requires that the CRD system be designed to withstand the effects of an earthquake without loss of the capability to perform its safety functions.

- GDC 14, “Reactor Coolant Pressure Boundary,” requires that the RCPB portion of the CRD system be designed, constructed, and tested for the extremely low probability of leakage or gross rupture.

- GDC 26, “Reactivity Control System Redundancy and Capability,” requires that the CRD system be one of the independent reactivity control systems that is designed with appropriate margin to ensure reactivity control function under conditions of normal operation, including anticipated operational occurrences.

- GDC 27, “Combined Reactivity Control Systems Capability,” requires that the CRD system be designed with appropriate margin and, in conjunction with the emergency core cooling system (ECCS), be capable of controlling reactivity and cooling the core under postulated accident conditions.

- GDC 29, “Protection Against Anticipated Operational Occurrences,” requires that the CRD system, in conjunction with reactor protection systems, be designed to ensure an extremely high probability of accomplishing its safety functions in the event of anticipated operational occurrences.

3.9.4.2 *Summary of Technical Information*

DCD, Tier 2, Section 3.9.4, Revision 6, presents the technical information supporting the design basis for the CRD system. The primary functions of the CRD system are to insert or withdraw the control rods during startup, normal operation, and shutdown and to provide hydraulic-powered rapid insertion (scram) of control rods during abnormal operating conditions. The fine motion control rod drive (FMCRD) used for positioning the control rod in the reactor core is a mechanical/hydraulic-actuated mechanism. An electric motor driven ball-nut and ball-screw assembly is capable of positioning the drive during normal operation. A single HCU powers the scram function of two FMCRDs. Upon scram valve initiation, high-pressure nitrogen from the HCU raises the piston within the accumulator, forcing water through the scram piping. This water is directed to each FMCRD connected to the HCU. Inside each FMCRD, high-pressure water lifts the hollow piston off the ball-nut and drives the control rod into the core. A spring washer buffer assembly stops the hollow piston at the end of its stroke. Departure from the ball-nut releases spring-loaded latches in the hollow piston that engage slots in the guide tube. These latches support the control rod and hollow piston in the inserted position. The control rod cannot be withdrawn until the ball-nut is driven up and engaged with the hollow piston.

Stationary fingers on the ball-nut then cam the latches out of the slots and hold them in the retracted position, allowing rod withdrawal. A scram action is complete when every FMCRD has reached the fully inserted position.

Safety-related SSCs are classified as Quality Group (QG) A, B, C, or D. In DCD, Tier 2, Table 3.2-3, the applicant provided a correlation of the quality grouping with specific design codes and standards. The relationship between the QGs and the ASME Code, Section III, classes is shown below:

ESBWR Quality Group	ASME Code, Section III, Class
A	1
B	2
C	3
D	–

All pressure-retaining components and component supports designated as QG A, B, or C are constructed in accordance with ASME Code, Section III, Class 1, 2, or 3 rules, respectively. "Construction," as defined in ASME Code, Section III, Subsections NB/NC/ND-1110(a) and used here, is an all-inclusive term encompassing the design, materials, fabrication, examination, testing, inspection, and certification required in the manufacture and installation of components. Components classified as QG D are designed to the applicable standards identified in DCD, Tier 2, Table 3.2-3.

3.9.4.3 *Staff Evaluation*

The staff's review under SRP Section 3.9.4, draft Revision 3, included the CRD system up to its interface with the control rod blades. Those components of the CRD system that are part of the primary pressure boundary are designed according to ASME Code Class 1 requirements. The staff reviewed the information in DCD, Tier 2, Section 3.9.4, related to the criteria used to ensure structural integrity of the CRD system during normal operation and under postulated conditions. The staff reviewed the criteria for conformance with the acceptance criteria in SRP Section 3.9.4.

The staff compared the SRP version used during the review with the 2007 version of the SRP. The 2007 version did not include any requirements, generic issues, bulletins, GLs, or technically significant acceptance criteria beyond those identified in the version used by the staff. Therefore, the staff finds that the use of draft Revision 3 of SRP Section 3.9.4, issued in 1996, is acceptable for this review.

Section 3.9.3 of this report discusses loading combinations for the CRD system. Section 4.6 of this report includes additional evaluations related to the functional design and testing of the CRD system.

The staff based its review of the design and acceptance criteria for the CRD system on the guidance provided in GDC 1, 2, 14, 26, 27, and 29; 10 CFR 50.55a; and SRP Section 3.9.4.

The CRD system includes electrohydraulic FMCRD mechanisms, the HCU assemblies, the condensate supply system, and the power for the FMCRD motors. The system extends inside to the coupling interface with the control rod blades.

DCD, Tier, 2, Sections 3.9.4 present the technical information supporting the design basis for the CRD system. The primary functions of the CRD system are to insert or withdraw the control rods during startup, normal operation, and shutdown and to provide hydraulic-powered rapid insertion (scram) of control rods during abnormal operating conditions. The FMCRD used for positioning the control rod in the reactor core is a mechanical/hydraulic-actuated mechanism.

An electric motor driven ball-nut and ball-screw assembly is capable of positioning the drive during normal operation. A single HCU powers the scram function of two FMCRDs. Upon scram valve initiation, high-pressure nitrogen from the HCU raises the piston within the accumulator, forcing water through the scram piping.

This water is directed to each FMCRD connected to the HCU. Inside each FMCRD, high-pressure water lifts the hollow piston off the ball-nut and drives the control rod into the core. A spring washer buffer assembly stops the hollow piston at the end of its stroke. Departure from the ball-nut releases spring-loaded latches in the hollow piston that engage slots in the guide tube. These latches support the control rod and hollow piston in the inserted position. The control rod cannot be withdrawn until the ball-nut is driven up and engaged with the hollow piston. Stationary fingers on the ball-nut then cam the latches out of the slots and hold them in the retracted position, allowing rod withdrawal. A scram action is complete when every FMCRD has reached the fully inserted position.

In DCD, Tier 2, Section 3.2.2, the applicant described the QG classification designations. Safety-related SSCs are classified as QG A, B, C, or D. In DCD, Tier 2, Table 3.2-3, the applicant provided a correlation of the quality grouping with specific design codes and standards, which agrees with the guidance in SRP Section 3.2.2 and RG 1.26, “Quality Group Classifications and Standards for Water-, Steam-, and Radioactive-Waste-Containing Components of Nuclear Power Plants.” DCD, Tier 2, Section 3.9.4.2, shows the relationship between QGs and ASME Code, Section III, classes.

All pressure-retaining components and component supports designated as QG A, B, or C are constructed in accordance with ASME Code, Section III, Class 1, 2, or 3 rules, respectively. “Construction,” as defined in ASME Code, Section III, Subsections NB/NC/ND-1110(a) and used here, is an all-inclusive term encompassing the design, materials, fabrication, examination, testing, inspection, and certification required in the manufacture and installation of components. Components classified as QG D are designed to the applicable standards identified in DCD, Tier 2, Table 3.2-3.

The staff concludes that the design of the CRD system is acceptable for the ESBWR and meets GDC 1, 2, 14, 26, 27, and 29 and 10 CFR 50.55a. By designing the CRD system up to the interface with the control rods to acceptable loading combinations for normal operation and accident conditions using the requirements in ASME Code, Section III, and Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants,” to 10 CFR Part 50, the applicant has ensured the structural integrity of the CRDs. Therefore, the applicant meets GDC 1 and 10 CFR 50.55a with regard to designing components important to safety to quality standards commensurate with the importance of the safety function to be performed. The applicant meets GDC 2, 14, and 26 with regard to designing the CRD system to withstand the effects of earthquakes and anticipated normal operational occurrences, with adequate margins to ensure its structural integrity and functional capability and with an extremely low probability of leakage or gross rupture of the RCPB. Sections 3.9.1 and 3.9.3 of this report discuss the staff’s evaluation of the specific design transients, design and service loadings, and combinations of loads. By limiting the stresses and deformations under such loading combinations, the design conforms to the appropriate guidelines in SRP Sections 3.9.3 and 3.9.4. In addition, the applicant meets the requirements of GDC 27 and 29 with respect to designing the control rod system to ensure its capability of controlling reactivity and cooling the core with appropriate margin in conjunction with either the ECCS or reactor protection system. The operability assurance program is acceptable with respect to meeting system design requirements in observed performance as to wear, functioning times, latching, and overcoming a stuck rod.

3.9.4.4 *Conclusions*

Based on its review of the DCD and t clarifying information in RAI responses provided by the applicant, and for the reasons described above, the staff concludes that the design of the CRD system for the ESBWR meets GDC 1, 2, 14, 26, 27, and 29 and 10 CFR 50.55a and is thus acceptable. By designing the CRD system, up to its interface with the control rod blades, to acceptable loading combinations of normal operation and accident conditions using the ASME Code and the requirements of Appendix B to 10 CFR Part 50, the applicant has ensured the structural integrity of the CRD system.

3.9.5 Reactor Pressure Vessel Internals

3.9.5.1 *Regulatory Criteria*

The following regulatory requirements and guidelines provide the basis for the acceptance criteria for the staff's review:

- GDC 1, as it relates to designing RPV internals (reactor internals) to appropriate quality standards commensurate with the importance of the safety functions to be performed

- GDC 2 and Appendix S to 10 CFR Part 50, as they relate to designing reactor internals to withstand the effects of earthquakes without loss of capability to perform their safety functions

- GDC 4, as it relates to designing reactor internals to accommodate the effects of and to be compatible with the environmental conditions associated with normal operations, maintenance, testing, and postulated accidents, including LOCAs

- GDC 10, as it relates to designing reactor internals with appropriate margin to ensure that adequate structural support of the reactor core is provided such that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences

- 10 CFR 50.55a, as it relates to designing, fabricating, testing, and inspecting reactor internals to appropriate quality standards commensurate with the importance of the safety functions to be performed

- 10 CFR 52.47, as it relates to the application for design certification specifying design information sufficiently detailed to permit the preparation of procurement specifications and construction and installation specifications by an applicant

- RG 1.20, Revision 2, as it relates to verifying the structural integrity of reactor internals for steady-state and transient FIV loading

- ASME Code, Section III, Division 1, 2001 Edition and Addenda through 2003, consistent with ESBWR DCD, Tier 2, Table 1.9-22

3.9.5.2 ***Summary of Technical Information***

DCD, Tier 2, Revision 6, Section 3.9.5, addresses the RPV internals, as discussed in the SRP, 2007 (NUREG-0800) Section 3.9.5. RPV internals discussed in the context of DCD Section 3.9.5 consist of all structures and mechanical components inside the reactor vessel, with the exception of the fuel system design, including reactor fuel assemblies and reactivity control elements, which are addressed in DCD Section 4.2.

The staff used the 2007 version of the SRP (NUREG-0800) during the review.

Safety-related structures and components are constructed and tested to quality standards commensurate with the importance of the safety functions to be performed. They are designed with appropriate margins to withstand the effects of normal operation; anticipated operational occurrences; natural phenomena, such as earthquakes; and postulated accidents, including the design basis LOCA.

3.9.5.2.1 Identification and Discussion of Structural and Functional Integrity of the Major Reactor Pressure Vessel Internals, including Core Support Structures

3.9.5.2.1.1 Safety Classification of Reactor Pressure Vessel Internals

DCD, Tier 2, Section 3.9.5, identifies the following structures as CS structures:

- shroud support
- core plate, including its hardware
- top guide, including its hardware
- orifice and peripheral fuel supports
- nonpressure boundary portion of CRD housings

The RPV internals include the following safety-related components:

- SLC system header
- sparger and piping
- ICGT and stabilizers
- nonpressure boundary portion of in-core housings

In addition, the RPV internals include the following non-safety-related components:

- chimney and partition
- chimney head and steam separator assembly
- steam dryer assembly
- FW spargers
- RPV vent assembly
- surveillance sample holders

3.9.5.2.1.2 Functional Description of Reactor Pressure Vessel Internals

The floodable inner volume of the RPV includes the volume up to the level of the GDCS equalizing nozzles, which are the RPV nozzles having the lowest elevation. One end of the reactor internals, such as the shroud, chimney, steam separators, and guide tubes, is unrestricted and therefore free to expand.

The CS structures form partitions within the reactor vessel to sustain pressure differentials across the partitions, direct the flow of the coolant water, and laterally locate and support the fuel assemblies. The shroud and chimney make up a stainless steel (SS) cylindrical assembly that provides a partition to separate the upward flow of coolant through the core from the downward recirculation flow. The shroud support includes a series of horizontal brackets welded to the reactor vessel wall to provide support to the shroud and core. The core plate provides lateral support and guidance for the CRGTs in-core flux monitor guide tubes, peripheral fuel supports, and startup neutron sources. The entire assembly is bolted to a support ring with 12 support legs that are welded to the bottom of the RPV. The top guide consists of a circular plate with square openings for fuel assemblies. Each opening provides a lateral support and guidance for or in some cases fewer, fuel assemblies. The top guide is mechanically attached to the top of the shroud. The chimney is bolted to the top surface of the top guide. Each peripheral fuel support is located at the outer edge of the active core, supports one fuel assembly, and contains an orifice to ensure proper coolant flow to the supported fuel assembly. Each fuel support holds four fuel assemblies vertically and horizontally and has four orifices to provide proper coolant flow distribution to each of the four assemblies. Each orifice support rests on top of a CRGT, and a control rod passes through a cruciform opening in the center of the support. The CRGTs are located inside the vessel and extend from the top of the CRD housings up through holes in the core plate. The CRD housing supports the bottom of the guide and transmits the weight of the guide tube, fuel support, and fuel assemblies to the reactor vessel lower head.

The reactor vessel internals direct and control flow through the core and support both safety-related and non-safety-related functions. The chimney is a cylindrical structure, which is mounted on the top guide and supports the steam separator assembly. The chimney provides the driving head necessary to sustain the natural circulation flow. The chimney forms the annulus separating the upward flow of the steam/water mixture exiting the core from the FW and the subcooled recirculation flow returning downward from the steam separators. Inside the chimney are partitions that channel the flow of the steam/water mixture exiting the core into smaller chimney sections to limit crossflow and flow instabilities. The partitions do not extend to the top of the chimney, thereby forming a mixing chamber or a discharge plenum for the steam/water mixture before entering the steam separators. Individual SS axial-flow steam separators are supported on and attached to the top of standpipes that are welded into the chimney head. In each separator, the steam/water mixture rising through the standpipe passes vanes that impart a spin and establish a vortex separating the water from the steam. The separated water flows from the lower portion of the steam separator into the downcomer annulus.

The steam dryer assembly consists of multiple banks of dryer units mounted on a common structure, which is supported by brackets welded to the reactor vessel wall. The dryer assembly includes the dryer banks, drain collecting trough, drain duct, and a skirt that forms a water seal extending below the upper end of the separator. Reactor vessel internal stops limit the upward and radial movement of the dryer assembly under the action of blowdown and seismic loads. These stops are arranged to permit differential thermal expansion of the dryer assembly with respect to the RPV.

The FW spargers deliver makeup water to the reactor during plant startup, power generation, and shutdown modes of operation. The FW spargers are SS headers located in the mixing plenum above the downcomer annulus. A separate sparger in two halves is fitted to each FW nozzle by a tee and is shaped to conform to the curve of the vessel wall. FW enters the center of the spargers and is discharged radially inward to mix the cooler FW with the downcomer flow from the steam separators and steam dryer.

Each of the two SLC system nozzles supplies four injection lines via SLC header and distribution lines. The injection lines have nozzles penetrating the shroud at four different elevations. The injection lines enable the sodium pentaborate solution to be injected around the periphery of the core.

The RPV vent assembly passes steam and noncondensable gases from the reactor head to the steamlines during startup and operation. The ICGT protect the in-core instrumentation from the flow of water in the bottom head plenum and provide a means of positioning fixed detectors in the core. The ends of the guide tubes are supported by the core plate and the RPV bottom head, and a latticework of tie bars connected to the core support ring provides additional lateral support.

The surveillance sample holders are welded baskets hanging from the brackets attached to the inside of the reactor vessel wall and extend to the midheight of the active core. The radial positions of the basket are such that the impact and tensile specimens, which are carried in the baskets, are exposed to the same environment and maximum neutron fluxes experienced by the reactor vessel itself.

3.9.5.2.1.3 Flow Induced Vibration Assessment Program

Appendix 3L to DCD Tier 2 outlines a comprehensive vibration assessment program for evaluating and ensuring the integrity of reactor internal components subject to steady-state and transient flow conditions. This program includes an analytical evaluation phase, a startup test phase, and an inspection phase, consistent with the guidelines of RG 1.20, and is intended to verify that no FIV problems exist for the as-built condition of the RPV internals. The first part of the evaluation identifies components that are deemed susceptible to FIV and for which additional evaluation and potential instrumentation for startup testing may be necessary. The chimney partition and the steam dryer have been identified as components for additional FIV analysis and startup test instrumentation. The second part of the evaluation will establish finite element analyses and correlation functions based on prior data to determine stress levels for those components deemed to require additional work to demonstrate their adequacy and to confirm that the fatigue stress limits of 68.95 MPa (10 kips per square inch (ksi)) will not be exceeded. The analyses will include the determination of vibration frequencies and mode shapes, as necessary. The applicant has presented the second part of the evaluation for internal components other than the steam dryer in Appendix 3L to DCD Tier 2 and NEDE-33259P (Ref. 1). The applicant has presented the results of these evaluations for the steam dryer in NEDE-33312P (Ref. 2); NEDC-33408P (Ref. 3); NEDC-33408P, Supplement 1 (Ref. 4); and NEDE-33313P (Ref. 5). The review of DCD, Tier 2, Section 3.9.2.4, covers the startup test phase of this program.

As outlined in Appendix 3L to DCD Tier 2, the applicant conducted analyses for the chimney partition, as described in NEDE-33259P, because the chimney partition is a component that has never been subjected to preoperational or initial startup testing. Appendix 3L to DCD Tier 2 also outlines the steam dryer evaluation program. The steam dryer design is patterned after the replacement steam dryer design developed for BWR operating plants.

NEDE-33259P, Revision 2, further evaluates internal components, other than the chimney partition and steam dryer, to establish the need for further analysis and testing. Each of the other component designs and operating conditions are compared for similarity with those of the ABWR, three of which are operating. As a result of this comparison, in addition to the chimney partition and steam dryer, the shroud/chimney assembly, the chimney head/steam separator assembly, and the SLC lines were determined to require further analysis as part of the ESBWR FIV prototype test program. Because of their similarities to the operating ABWR reactors, further evaluation is not considered necessary for the remaining RPV internals components.

3.9.5.2.2 Design Criteria Used for Assessing the Adequacy of Core Support Structures

DCD, Tier 2, Section 3.9.5.4, provides the following criteria for assessing the adequacy of CS structures:

- The design and construction of the CS structures are in accordance with the requirements of the American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel Code, Section III, Subsection NG.

- The design criteria, loading conditions, and analyses that provide the basis for the design of reactor internals other than the CS structures meet the guidelines of ASME Code, Section III, Subsection NG-3000, and must be constructed so as not to adversely affect the integrity of the CS structures, as stipulated in ASME III, Subarticle NG-1122.

3.9.5.2.3 Criteria Used for Assessing the Adequacy of Steam Dryer and Chimney Assemblies, Including the Information from Appendix 3L to DCD Tier 2

Appendix 3L to DCD, Tier 2, Revision 6, describes potential FIV testing of reactor internals in an ESBWR prototype plant. The evaluation process identified both the chimney, a component new to the ESBWR design, and the steam dryer as structures that will be tested during power ascension in the ESBWR prototype. The steam dryer was chosen for testing based on recent industry experience; some steam dryers in operating BWR plants have experienced structural degradation as a result of fatigue failure under power uprate conditions over the past few years.

For normal operating conditions, Appendix 3L to DCD Tier 2 has identified FIV analysis and FIV test programs to demonstrate the adequacy of the components and to confirm that their stresses are bounded by fatigue limits of 68.95 MPa (10 ksi). Section 3.9.5.2.1 of this report discusses these programs.

3.9.5.2.4 Criteria Used for Assessing the Adequacy of Internal Structures Other Than Steam Dryer and Chimney Assemblies, Including the Information from NEDE-33259P

DCD, Tier 2, Tables 3.9-4 through 3.9-7, identify the stress, deformation, and fatigue limit criteria of safety-related components from which appropriate criteria are selected for a specific component and loading condition. The applicant stated that the criteria are based on applicable codes and standards for similar equipment, manufacturing standards, or empirical methods, based on field experience and testing, and meet the guidelines of ASME Code, Section III, Subsection NG3000. The stated construction philosophy is to provide adequate clearances for components that must move during emergency and faulted conditions and not adversely affect the integrity of the CS structure, in accordance with the guidelines in ASME Code, Section III, Paragraph NG1122. For the other components designated as non-safety-class internals, ASME

Code design requirements are followed where applicable. Otherwise, accepted industry or engineering practices are used.

As discussed in Section 3.9.5.2.1 of this report, Appendix 3L to DCD Tier 2 and NEDE33259P describe a method for establishing component adequacy for FIV under normal operating conditions, with the ultimate goal of showing that the fatigue stresses in the components are bounded by 68.95 MPa (10 ksi). The criterion used in NEDE-33259P to judge which components require additional work and which components are considered acceptable and require no additional work is to compare their design and operating conditions for similarity with those of the ABWR and operating BWRs. Resolution of RAI 3.9-75 S02 in Section 3.9.2 of this report provides further information, including a discussion of the classification of the ESBWR reactor internals as a prototype, in accordance with RG 1.20.

3.9.5.2.5 Design Basis Loading Events

DCD, Tier 2, Section 3.9.5.3, states that CS structures and safety-related internal components must satisfy the safety design basis (DCD, Tier 2, Section 3.9.5.4) for the following three load events:

(1) RPV line break accident, which is a break in any one line between the reactor vessel nozzle and the isolation valve resulting in significant pressure differential across some of the structures within the reactor and RBVs caused by suppression pool dynamics

(2) earthquakes which subject the CS structures and reactor internals to significant forces as a result of ground motion and consequent RBV

(3) SRV or DPV discharge resulting in RBV caused by suppression pool dynamics and structural feedback

3.9.5.2.5.1 Load Combinations and Stress Limits

DCD, Tier 2, Section 3.9.1.4, discusses the evaluation methods and stress limits used for the faulted conditions (RPV line break accident and earthquake). DCD, Tier 2, Table 3.9-2, presents load combinations and acceptance criteria for CS structures.

The applicant used the TRACG computer code to determine pressure differences for reactor internals during the events under normal, upset, emergency, and faulted conditions. The code analyzes the transient conditions within the reactor vessel following anticipated operational occurrences, infrequent events, and accidents (e.g., LOCAs). To determine the maximum pressure differences across the reactor internals, the applicant performed a statistical uncertainty study. To determine the upper bound pressure difference, two standard deviations of the uncertainty was added to the normal pressure differences.

In DCD, Tier 2, Section 3.7, the applicant described a dynamic analysis method used to determine the loads resulting from an earthquake and other building vibrations acting on the reactor vessel internals.

3.9.5.2.5.2 Flow Induced Vibrations

For FIV, the normal operating pressure differential drives the coolant flow that impinges on and loads the reactor internal components in different ways. Table 3 of NEDE-33259P presents flow velocities and vortex shedding frequencies for ESBWR and ABWR components deemed similar.

According to Appendix 3L to DCD Tier 2, the applicant has completed two-phase hydraulic flow testing simulating expected reactor flow conditions for the chimney partition, and the pressure loading function has been determined.

In addition, Appendix 3L to DCD Tier 2 outlines the evaluation program for the steam dryer. For FIV, extensive scale model and prototype BWR 3 testing have been performed to determine acoustic loading functions for normal operating conditions. The qualitative characteristics of the loads are described. The quantitative acoustic load definition for the ESBWR steam dryer, described in NEDE-33312P, Revision 1, will be determined by applying the applicant's plant-based load evaluation (PBLE) methodology, described in two LTRs: NEDC-33408P, Revision 1, and NEDC-33408P, Supplement 1, Revision 1. The PBLE steam dryer load definition approach has been extensively benchmarked against plant data, including Quad Cities and Susquehanna data. NRC's "SER for GEH LTRs NEDE-33312P, NEDC-33408P, and NEDC-33408P Supplement 1," issued **August 2010**, evaluates these three reports and confirms the conservatism and acceptability of applying the PBLE methodology to ESBWR steam dryer designs.

3.9.5.2.6 Design Bases

DCD, Tier 2, Section 3.9.5.4, states that the reactor internals, including CS structures, must meet the following safety design bases:

- The reactor nozzles and internals shall be so arranged as to provide a floodable volume in which the core can be adequately cooled in the event of a breach in the nuclear system process barrier external to the reactor vessel.

- Deformation of internals shall be limited to ensure that the control rods and core standby cooling system can perform their safety-related functions.

- Mechanical design of applicable structures shall ensure that the above safety design bases are satisfied so that the safe shutdown of the plant and removal of decay heat are not impaired.

The reactor internals, including CS structures, shall be designed to the following power generation design bases:

- The internals shall provide the proper coolant distribution during all anticipated normal operating conditions to full-power operation of the core without fuel damage.

- The internals shall be arranged to facilitate refueling operations.

- The internals shall be designed to facilitate inspection.

The applicant stated that the design loading categories for the CS structures and safety class internals stress limits are consistent with ASME Code, Section III, Subsection NG.

The stress and fatigue limits for the CS structures are also consistent with ASME Code, Section III, Subsection NG.

The applicant provided the stress, deformation, and fatigue criteria for safety-related reactor internals (except CS structures), which are based on the criteria established in applicable codes and standards for similar equipment, by manufacturers' standards, or by empirical methods based on field experience and testing. These criteria include the minimum safety factors provided for each of the four ASME Code, Section III, service conditions (i.e., normal, upset, emergency, and faulted).

The applicant stated that the design criteria, loading conditions, and analyses that provide the basis for the design of the safety class reactor internals, other than the CS structures, meet the guidelines of ASME Code, Article NG-3000, and are constructed so as not to adversely affect the integrity of the CS structures (ASME Code, Section III, paragraph NG-1122).

Appendix 3L to DCD Tier 2 states that the primary design basis is to maintain the dynamic (fatigue) stresses below the limit of 68.95 MPa (10 ksi). As discussed in Section 3.9.5.2.1 of this report, dynamic stress analysis using FEM analysis has been or will be performed for all of the reactor internal components, including the steam dryer, that will be instrumented during startup testing. NEDE-33295P includes these results for all of the vessel internals except the steam dryer; DCD Appendix 3L includes some of the results for the chimney partition. ITAAC 8b of DCD, Tier 1, Table 2.1.1-3, includes a commitment by the licensee for performing stress analysis for the as-built configuration of the steam dryer, chimney, chimney partitions, and related components to verify that the design limits of ASME Code, Section III, Article NG-3000 have been satisfied.

The applicant found the fundamental frequency of the chimney partition (54-56 Hz) to be much larger than the frequency of the maximum peak-to-peak pressure fluctuation (2 Hz). Therefore, the applicant performed an equivalent static analysis to show that the fatigue stress limits bounded the calculated stress.

3.9.5.3 *Staff Evaluation*

3.9.5.3.1 Identification and Discussion of the Structural and Functional Integrity of the Major Reactor Pressure Vessel Internals, Including Core Support Structures

As described in Section 3.9.5.2.1 of this report, the applicant identified the major safety-related reactor internal structures, including CS structures, for the ESBWR. In addition, the applicant identified the non-safety-related internal structures. DCD, Tier 2, Section 3.9.5, summarizes the functions of the internals. The staff found that the applicant has adequately discussed the physical arrangement of these components inside the vessel, which provides axial support and lateral retention of the internal assemblies and components. A general design rule employed is to free one end of certain reactor internals to accommodate dimensional changes because of differential thermal growth and other effects.

The applicant used the method described in Appendix 3L to DCD Tier 2 and NEDE-33259P for establishing component integrity for FIV under normal operating conditions to show that the fatigue stresses in the internal components are bounded by the limit of 68.95 MPa (10 ksi). This method is acceptable. However, Appendix 3L to DCD Tier 2 presented the results of the evaluation analysis for only one of the components: the chimney partition.

As discussed in Appendix 3L to DCD Tier 2, related to FIV, the applicant indicated that many of the reactor internal components require additional analysis to demonstrate their design adequacy. Furthermore, FIV evaluation analyses are required for components with significantly different features and loading conditions from valid prototype reactor internals, in accordance with RG 1.20 and SRP Section 3.9.5. Therefore, in RAI 3.9-132, the staff asked the applicant to provide detailed descriptions of the components, their boundary conditions, the load definitions, the design criteria, the bias errors and uncertainties, and the evaluation analyses for the ESBWR shroud/chimney assembly, the chimney head/steam separator assembly, the SLC lines, the CRGTs and CRD housings, the ICMGTs and housings, the chimney partition, and the steam dryer.

In its response, the applicant stated that it will submit a revision of NEDE-33259 to account for ongoing design changes of the reactor internals, including additional analysis work for most of the components identified in RAI 3.9-132. The applicant concluded that no analyses are necessary for the CRGTs and CRD housings and the ICMGTs and housings because of their similarity to current ABWR designs, as discussed in NEDE-33259P, Revision 2 (Ref. 1). RAI 3.9-132 was tracked as an open item in the SER with open items.

The staff's review of the revised NEDE-33259P discusses the resolution of several other RAIs related to the RPV internals FIV program, in addition to resolution of RAI 3.9-132, and is documented in the "SER for GEH LTR NEDE-33259P, Reactor Internals Flow Induced Vibration Program," issued **August 2010**. After its review of Revision 2 of the LTR, the staff held an audit meeting at the applicant's offices in Wilmington, NC, on August 25, 2009. During the technical discussions of FIV related issues, as documented in GEH's "Response to NRC Report of the August 25, 2009, and September 9, 2009, Regulatory Audit of Reactor Pressure Economic Simplified Boiling Water Reactor," issued October 8, 2009, the applicant indicated that, because design details of the chimney partition were still being evaluated, the design of the chimney partition is not complete. The applicant committed to complete the final design of the chimney partition and FIV stress analyses as part of ITAAC 8b (listed in Table 2.1.1-3 of DCD Tier 1) in order to verify this design commitment. The revised NEDE-33259P adequately addressed the staff's concerns and provided appropriate analysis. Therefore, RAI 3.9-132 and its associated open item were closed. The staff also concluded that the addition of ITAAC 8b in Revision 6 of the DCD was sufficient to resolve the associated staff audit comment.

3.9.5.3.2 Criteria Used for Assessing the Adequacy of Core Support Structures

The staff finds that the criteria proposed by the applicant for assessing the adequacy of CS structures are acceptable because they utilize the requirements of ASME Code, Section III, Division 1, Subsection NG. Section 3.9.5.3.6 of this report further evaluates this information.

3.9.5.3.3 Criteria Used for Assessing the Adequacy of Steam Dryer and Chimney Assemblies, Including the Information from Appendix 3L to DCD Tier 2

The staff finds the use of flow testing and structural dynamic analysis appropriate for assessing the adequacy of the chimney assembly and steam dryer because the chimney is a new component to the ESBWR design, and some steam dryers in operating reactors have experienced structural degradation resulting from fatigue failure under power uprate conditions over the past few years. The staff also finds the use of a fatigue limit of 68.95 MPa (10 ksi) acceptable because it satisfies the ASME Code requirement. However, the staff had several concerns, discussed below, regarding how the applicant attempted to satisfy these criteria.

The original submittal of DCD Appendix 3L (Reactor Internals Flow Induced Vibration Program, October 24, 2005) did not make it clear whether the applicant had committed to install instrumentation on the steam dryer in the prototype ESBWR plant for FIV response during power ascension. Although the report describes test and instrumentation plans for some components, and the applicant listed the differences between the ESBWR and past BWR dryers in Section 3L.5.5.1.5, stating that “these differences warrant a detailed vibration analysis and test monitoring,” Item 5 in Section 3L.2.1 (page 3L-4) of Appendix 3L to DCD Tier 2 implies that the applicant might submit a supplemental report asserting that “FIV will not be an issue” for various components, which might include the steam dryer. In addition, Table 3L-4 lists many sensors that might be installed on the prototype steam dryer and includes several caveats in the last column stating, “if problem occurs.” Therefore, in RAI 3.9-133, the staff asked the applicant to identify the instrumentation that will be installed on the steam dryer, the MSLs, and the steam system components in the ESBWR prototype plant for FIV response during the startup power ascension. The staff also asked the applicant to clarify whether it will acquire data for all equipment listed in Table 3L-4 during testing.

In response to RAI 3.9-133, the applicant committed to instrumenting (1) the prototype ESBWR steam dryer in accordance with DCD, Tier 2, Section 3.9.2.4, and DCD, Tier 2, Appendix 3L, Section 3L.4.6, and (2) the prototype ESBWR chimney partitions in accordance with DCD, Tier 2, Appendix 3L, Section 3L.5. The applicant clarified Item 5 in DCD, Tier 2, Section 3L.2.1 (page 3L-4), stating that it does not apply to the steam dryer or chimney partition assembly. The applicant also clarified that it will acquire vibration data for all of the equipment listed in DCD, Tier 2, Table 3L.4, during initial startup and power ascension testing. Pressure data, however, while recorded during startup testing, will not be evaluated in detail unless the primary vibration measurements indicate the need for further assessment. The staff found the applicant’s response acceptable, because it is consistent with guidance from RG 1.20, and confirmed the changes made in the DCD. Therefore, RAI 3.9-133 was closed.

3.9.5.3.3.1 Steam Dryer Acoustic Loading Effects from Safety-Relief Valve Standpipes and Main Steam Piping

The applicant stated that most recent BWR steam dryer fatigue failures resulted from “strong narrow-band pressure” at frequencies between 120 and 200 Hz that emanate from acoustic resonances in the SRV standpipes (Section 3L.4.4, pages 3L-7 through 3L-8), and that “the ESBWR SRV standpipe design is intended to reduce or eliminate acoustic resonances in these branch lines.” However, the applicant did not present the details of the ESBWR standpipe design. Therefore, in RAI 3.9-134, the staff asked the applicant to provide the following:

(a) The staff asked the applicant to describe the design of the ESBWR SRV standpipes, summarizing (1) dimensions of the SRVs, standpipes, and MSLs, (2) expected steam flow speeds near the SRV standpipes, (3) plant power levels at which acoustic resonances in the standpipes might be strongly excited, along with the frequencies of the resonances and their expected amplitudes, and (4) the proximity of various SRVs to each other on individual MSLs.

(b) The applicant planned to limit the data acquisition, signal processing, and data interpretation of all FIV testing during prototype ESBWR power ascension to frequencies below 200 Hz (and, in some cases, below 100 Hz), as shown in Tables 3L-5 and 3L-6 and described in Section 3L.5.4. The staff asked the applicant to justify this frequency limit based on submission of complete ESBWR SRV standpipe design criteria in part (a) of this RAI.

(c) In addition to the instrumentation for the steam dryer in the prototype ESBWR for FIV testing, the staff asked the applicant to submit a list of instrumentation planned for the SRVs and MSLs and to provide justification where such instrumentation will not be installed.

In its response to RAI 3.9-134, the applicant stated the following:

(a) The ESBWR SRV standpipe design is currently under evaluation. The entrance to the standpipe is being designed to minimize the resonant feedback effect on the shear layer instability, thus minimizing the amplitude of potential resonances in the standpipe. Scale model testing (SMT) will be performed on the individual MSLs in order to determine the optimum locations that minimize valve-to-valve interaction.

(b) The frequency ranges shown in DCD, Tier 2, Tables 3L-5 and 3L-6, and described in DCD, Tier 2, Section 3L.5.4, are approximate. The frequency ranges being monitored in the FIV test program will be adjusted to bound the range of frequencies determined in the FIV evaluations for the final ESBWR design.

(c) For MSL acoustic monitoring, at least two locations will be monitored on each MSL in the containment. The instruments at each location will include either a minimum of four strain gauges orientated in the hoop direction or one piezoelectric pressure transmitter mounted flush with the inside wall of the pipe. The data sampling rate will be high enough to resolve the frequencies associated with potential acoustic resonances in the SRV standpipes. The amplification and sensitivity and maximum sample rate of the data acquisition equipment will be sufficient to define temporal acoustic steamline data.

In accordance with responses (b) and (c) above, the applicant revised DCD, Tier 2, Sections 3L.4.4 and 3L.5.4, as well as Tables 3L-5 and 3L-6.

Since the applicant has removed the limitations placed on the frequency range that will be analyzed and has identified the instrumentation that will be used to monitor the SRVs and MSLs, the staff considered RAI 3.9-134(b) and RAI 3.9-134(c) to be closed. Since the ESBWR SRV standpipe and piping layout designs were under further evaluation, as indicated in the applicant's response, RAI 3.9-134(a) remained open until the designs are completed, the resonant conditions are characterized, and the results are communicated to the staff before pre-startup or startup testing. These concerns were addressed in RAI 3.9-134 S01. RAI 3.9-134(a) was tracked as an open item in the SER with open items.

In RAI 3.9-134 S01, the staff asked the applicant to provide the following information about the design of the ESBWR SRV standpipes after the ESBWR MSL layout and standpipe designs are completed and the acoustic resonance conditions are characterized: (1) dimensions of the SRVs, standpipes, and the MSLs; (2) expected steamflow speeds near the SRV standpipes; (3) plant power levels at which acoustic resonances in the standpipes might be strongly excited, along with the frequencies of the resonances and their expected amplitudes; and (4) the proximity of various SRVs to each other on individual MSLs.

In its revised response to RAI 3.9-134 S01, the applicant discussed its general design approach, stating that the MSLs and branch connection piping for the SRVs will be designed to avoid the possibility of any acoustic resonance. However, since the design of the SRV branch pipes was not submitted, the staff asked the applicant, in RAI 3.9-134 S02, to submit the actual design parameters of the MS piping and SRV branch piping, or to provide additional detail (design requirements, criteria, methods) to provide assurance that the possibility of acoustic resonance will be avoided. The staff also asked the applicant to provide associated ITAAC to verify this design commitment.

The applicant provided the following response to RAI 3.9-134 S02:

> The design of the main steam (MS), safety relief valve (SRV) and safety valve (SV) piping is not final at this time; therefore, an ITAAC will be added to DCD Tier 1 to verify that this piping is designed such that the structural integrity of the piping is not adversely affected by acoustic vibration. In addition, DCD, Tier 2, Sections 5.4.9.2, 5.4.13.2 and Appendix 3L.4.1 will be revised to describe this design commitment. The applicant has performed preliminary acoustic resonance calculations for the MS, SRV and SV piping based on preliminary design information. These calculations show that the calculated Strouhal numbers are outside the range for which adverse impacts due to acoustic resonances would occur. The calculations were performed at 100 percent and 102 percent power.

The staff reviewed the applicant's response, as well as the revised versions of DCD Tier 1, DCD, Tier 2, and Appendix 3L.4.1, and concludes that the applicant is committed to designing the MSLs to avoid acoustic resonance in the SRV standpipes at normal operating conditions. Additionally, Table 2.1.2-3 of DCD Tier 1 lists this commitment as ITAAC 36. The staff finds this response reasonable, but the focus of RAI 3.9-134 S02 was not on the structural integrity of piping, but rather on that of the steam dryer not being adversely affected by acoustic vibrations. Therefore, the applicant should revise the proposed ITAAC accordingly. Also, the applicant should explain whether it performed the preliminary acoustic resonance calculations at 100-percent power or at 100-percent power. The staff discussed this issue with GEH during the August 25, 2009, audit conducted at the applicant's main offices in Wilmington, NC, and identified this issue as NRC Audit Comment 4 in the NRC's, "Report of the August 25, 2009 NRC Staff Audit on ESBWR RPV Internals," issued September 15, 2009.

In its response to NRC Audit Comment 4, the applicant stated that it revised ITAAC 36, presented in Table 2.1.2-3 of DCD Tier 1, to state that the MSL and SRV/SV branch piping geometry precludes first and second shear layer wave acoustic resonance conditions from occurring and avoids the corresponding pressure loads on the steam dryer at plant normal operating conditions. The applicant also confirmed that it performed the preliminary acoustic resonance calculations at 100 percent power; however, to account for local MSL velocity changes, the calculation considers a 16 percent variation in velocities from the 100 percent normal power operating conditions. The staff found this response acceptable, because the revision to ITAAC 36 and the clarification of the power levels at which acoustic resonance calculations were performed satisfied the staffs' concerns. Therefore, RAI 3.9-134 and its associated open item were closed.

3.9.5.3.3.2 ESBWR Steam Dryer Load Definition

In RAI 3.9-135, the staff asked the applicant to describe in detail (1) the source of the load definition of the ESBWR steam dryer, (2) the validation of the methodology used in developing the load definition, (3) the stress analysis performed using the load definition, (4) the error and uncertainties associated with each aspect of the analysis, (5) the application of the error and uncertainties in the stress analysis, (6) the stress analysis results and comparison to acceptance criteria, and (7) the plans to confirm the steam dryer load definition and stress analysis using actual steam dryer data during plant operation. In its response to RAI 3.9-135, the applicant referred to the following additional documents that contain the requested information.

- DCD Reference 3L-5, "Steam Dryer - Acoustic Load Definition," NEDE-33312P, Revision 1, issued July 2009

- DCD Reference 3L-6, "Steam Dryer Structural Evaluation," NEDE-33313P, Revision 1, issued July 2009

RAI 3.9-135 was tracked as an open item in the SER with open items. NRC's "SER for GEH LTRs NEDE-33312P, NEDC-33408P, and NEDC-33408P Supplement 1," issued **August, 2010**, discussed the staff's evaluations of these references. Therefore, RAI 3.9-135 and its associated open item were closed.

The applicant described its procedure for assessing the integrity of the ESBWR steam dryer in Section 3L.4 of Appendix 3L to DCD Tier 2. Section 3L.4.4 describes the procedure for defining the fluctuating pressure acting on the steam dryer, and it uses a load interpolation algorithm (LIA) to compute a fine discretization of pressure-time histories over the steam dryer surfaces based on measurements made in the applicant's SMT facility. The LIA includes acoustic finite element models (AFEMs) as part of its load estimating process.

In RAI 3.9-136, the staff asked the applicant for the following information:

(a) The staff asked the applicant to describe the LIA method for review (including the AFEM procedures) and provide any data measured in the SMT that substantiates the method. In addition, the staff requested the documentation of uncertainties and bias errors in the LIA and AFEM.

(b) The staff asked the applicant to provide benchmarking data for the SMT. The applicant asserted that the BWR 3 configuration of the SMT facility has been benchmarked against plant data acquired from an instrumented dryer that confirms its capability to predict steam dryer acoustic load definitions. The staff requested this benchmarking information and confirmation that the SMT can be used to predict the frequency content of the forcing functions associated with acoustic flow tones (or singing) caused by flow over the branch lines for MSL SRVs.

In its response to RAI 3.9-136, the applicant referenced NEDE-33312P, Revision 1 to address parts (a) and (b) of this RAI. RAI 3.9-136 was tracked as an open item in the SER with open items. The staff has reviewed this report and NRC's "SER for GEH LTRs NEDE-33312P, NEDC-33408P, and NEDC-33408P Supplement 1," issued **August 2010**, presents the evaluation. Therefore, RAI 3.9-136 and its associated open item were closed.

In Section 3.L.4.6 of Appendix 3L to DCD Tier 2, the applicant described potential steam dryer FIV measurements, including the determination of the steam dryer as-built modal parameters. The applicant further stated that it will use impact hammer testing to determine the natural frequencies, mode shapes, and damping of the steam dryer components. The data will be used to verify portions of the steam dryer analytical models.

In RAI 3.9-137, the staff asked the applicant to do the following:

(a) Discuss the planned impact hammer testing (e.g., will the testing be conducted outside the plant, or with the steam dryer installed in the plant, with the skirt partially immersed in water) for the purposes of determining the steam dryer as-built modal parameters.

(b) Discuss the determination of the damping of the ESBWR steam dryer and describe how the damping will be applied to its stress analysis models of the steam dryer.

In its response to RAI 3.9-137, the applicant revised Section 3L.4.6, DCD, Tier 2, Revision 3, which included the response to the staff's RAI. The applicant stated that the dryer will be supported on blocks in the dryer/separator pool during hammer testing. It will be tested in ambient pressure and temperature at multiple conditions, including with the skirt in air and partially submerged in various levels of water. An instrumented hammer will be used to drive the dryer at several locations, with accelerometers throughout the dryer used to measure resulting vibrations. Mode shapes, resonance frequencies, and loss factors will be computed from the measured data. In addition, the applicant will assume a conservative damping level of 1 percent for its dryer vibration and stress analyses. The staff finds the applicant's answers and its modifications to the DCD acceptable because (1) the applicant has described the hammer testing of the steam dryer as requested and (2) the applicant will be using conservative values of damping for the stress analysis. However, the applicant did not explain how the response amplitude bias error of the dryer FEM will be determined using the hammer test results. The staff requested this information in RAI 3.9-137 S01.

In its response to RAI 3.9-137 S01, the applicant clarified its earlier response by stating that its dryer vibration testing may be conducted with either an electrodynamic shaker or instrumented impact hammer, and it has revised DCD, Tier 2, Section 3L.4.6, accordingly. The applicant plans to compute bias errors based on a comparison of autospectra from its measurements and accompanying FEM simulations instead of deriving them from the transfer functions based on the accelerometer responses. In the NRC's, "Report of the August 25, 2009 NRC Staff Audit on ESBWR RPV Internals," issued September 15, 2009, Audit Comment #14, the staff requested that the applicant justify why it has chosen to use autospectra rather than transfer functions to compute amplitude bias errors. The applicant responded by revising Section 5.2.3 of NEDE-33313P, Revision 2. The applicant stated that the process to compute response amplitude bias errors uses transfer functions instead of power spectral densities. Since transfer functions are the appropriate metrics to use for error calculation, the staff agrees with the applicant's response, and concludes that all aspects of RAI 3.9-137 were closed.

3.9.5.3.3.3 Steam Dryer Instrumentation for Startup Testing

In Table 3L-4 of Appendix 3L to DCD Tier 2, the applicant listed sensors that may be mounted to the steam dryer, the reactor dome, and other structures. In RAI 3.9-138, the staff asked the applicant to describe the specific instrumentation, including the number of sensors and locations, to measure pressure, strain, and acceleration of steam dryer components for the purpose of providing sufficient information to evaluate the performance of the ESBWR steam dryer and to assess its continued structural capability during plant operation. Furthermore, as part of this description, the staff asked the applicant to explain the instrumentation specifications, including the following:

(a) State how many accelerometers will be mounted to the steam dryer support ring and in what direction they will be oriented.

(b) Indicate how many accelerometers will be mounted to the steam dryer skirt, and how many in circumferential positions.

(c) Provide the orientation(s) in which the strain gauges on the steam dryer hood, steam dryer drain channels, and steam dryer skirt will be mounted, and indicate how many strain gauges will be mounted at these locations.

(d) State how many strain gauges will be mounted on the main steam lines, in what orientation(s), and in how many circumferential positions.

(e) Clarify the meaning of “steam dryer FIV instrument post” for the pressure transducer to be mounted in the vessel dome region.

RAI 3.9-138 was tracked as an open item in the SER with open items. In its revised response to RAI 3.9-138, the applicant stated that Table 3L-4 of DCD, Tier 2, Appendix 3L, provides the general locations for the FIV information. The final number, location, and orientation of the accelerometers and strain gauges will be available after the final structural evaluations are completed and the high-stress locations have been determined. DCD Appendix 3L.4.6 provides additional details regarding the steam dryer instrumentation.

Section 4.4.3 of LTR NEDC-33408P Supplement 1, Revision 1, provides information requested in Part (d) of RAI 3.9-138. When strain gauges are used to estimate acoustic pressure in the MSLs, they will be mounted at two locations (upper and lower locations) on each MSL directly downstream of the vessel nozzle in a region where side branches, valves, and venturis are not located between the upper and lower locations.

In response to part (e) of the RAI, the applicant explained that the steam dryer FIV instrument post, where a pressure transducer is mounted, is the support mass used to lead FIV instrumentation cabling from the top of the dryer to the vessel head penetration. The staff considers the responses to parts (d) and (e) adequate, because the additional information provided details which clarified the instrumentation arrangements for the main steam lines, and for a specific area of the dryer not clearly defined previously.

The applicant also provided some insight on planned dryer instrumentation (parts (a-c)), which will be placed near regions where the highest fluctuating stresses are expected. However, the information provided was not sufficient to fully address the RAI. In RAI 3.9-138 S01, the staff requested the additional instrumentation related information necessary to fully address RAI 3.9-138.

The applicant responded to RAI 3.9-138 S01 as follows:

> As stated in the revised response to RAI 3.9-138, the final number, location, and orientation of the accelerometers and strain gauges will be available after the final structural evaluations are completed and the high stress locations have been determined. The number and orientation of the strain gages and accelerometers is chosen so that the limiting locations (locations with the lowest margin to fatigue acceptance criteria from the results of stress analysis) on the steam dryer are monitored with redundancy in case there is failure of instrumentation sensors during the startup monitoring program. The applicant's past experience with the instrumentation of steam dryers has shown that 3 to 4 strain gages on the steam dryer skirt/drain channels and 4 to 5 strain gages on the upper steam dryer structure is sufficient for adequate monitoring of the steam dryer highest stressed locations. The applicant's experience has shown that two accelerometers, one mounted horizontally and the other mounted vertically can adequately monitor the rigid body motion of the support ring that would be indicative of steam dryer rocking. Additional accelerometers, as deemed necessary based on the results of the FIV stress analysis are mounted on the steam dryer skirt and dryer hood to act as backup to the steam dryer mounted strain gages.

The staff finds the response reasonable, but notes that GEH has not provided an actual instrumentation plan. Therefore, in RAI 3.9-138 S02, the staff asked the applicant to submit the actual instrumentation types and locations or provide alternate additional information to resolve this issue, such as the criteria and methods that will be used to determine instrument types and locations and corresponding ITAAC to verify that the instruments have been installed at appropriate locations.

The applicant responded to RAI 3.9-138 S02 by stating the following:

> Sections 2.3.2 and 4.4.2 of NEDC-33408P and Sections 4.4.3.1 and 4.4.4 of NEDC-33408P Supplement 1 provide the criteria and methods that will be used to determine the number and locations of pressure instruments. Appendix 3L of the DCD will be revised to reference these documents and to provide non-proprietary information related to strain gages and accelerometers.
> NEDE 33313P will be revised to describe the criteria and methods that will be used to determine the number and locations of strain gages and accelerometers. In addition, ITAAC will be added to Tier 1 of the DCD to verify that the instruments have been installed at appropriate locations.

The staff reviewed the proposed changes in DCD, Tier 1, Section 2.1.1 and Table 2.1.1-3; DCD, Tier 2, Appendix 3L; and NEDC-33313P and concluded that these changes, together with the information included in NEDC-33408P and its Supplement 1, are adequate to determine the number and locations of dryer instrumentation, including accelerometers, strain gauges, and pressure transducers. In addition, the applicant added ITAAC 12, 13, and 14 in DCD, Tier 1, Table 2.1.1-3, to verify that the instruments are installed at appropriate locations. The staff found this response acceptable , because the additional information added to the topical reports and DCD Appendix 3L provided the clarifying details of the instrumentation arrangement plan that were requested, and therefore all aspects of RAI 3.9-138 and its associated open item were closed.

In Section 3L.4.6 of Appendix 3L to DCD Tier 2, the applicant explained how the steam dryer instrumentation (strain gauges, accelerometers, and pressure transducers) will be monitored against established limits.

In RAI 3.9-139, the staff asked the applicant to provide the following information:

(a) Explain the determination of those limits for each type of instrumentation, particularly for the pressure transducers.

(b) List the corrective actions to be taken if the limit curves are exceeded and the steam dryer stresses are deemed not acceptable for higher plant power operation.

In its response to RAI 3.9-139(a), by letter dated April 2, 2007, as supplemented by letter dated August 7, 2007, the applicant stated that Section 3L.5.5.2 of Appendix 3L to DCD, Tier 2, Revision 5, describes the methodology for developing the strain gauge and acceleration response acceptance criteria. These criteria are based on the frequency and amplitude content of the design load definition in the structural analysis. The staff's review of Section 3L.5.5.2 reveals that the applicant has proposed two methods for developing acceptance criteria for strain gauges and accelerometers installed on the ESBWR steam dryer. Both of these methods account for the closely spaced frequencies and mode shapes that are associated with the steam dryer and use a strain energy weighing method applied to all modes over a given range of closely spaced frequency. The applicant calculated the maximum stress associated with each mode shape and then combined the weighted values of these stresses by ABS to predict the maximum stress in the steam dryer. Thus, these methods predict conservatively high values for the maximum stress anywhere on the structure. These high predictions are compared against a conservatively low acceptance criterion for fatigue failure of 68.95 MPa (10 ksi) to ensure that the steam dryer is not experiencing high alternating stresses that might cause fatigue failures. Therefore, the staff found these acceptance criteria for the steam dryer adequate. RAI 3.9-139(a) was closed.

In its response to RAI 3.9-139(b), the applicant stated that, if the limit curves are exceeded, it will (1) revise the load definition based on the measured loading, (2) repeat the stress analysis using this loading, and (3) establish the revised limit curves. If necessary, the applicant will perform a detailed stress analysis of the high-stress region of the dryer. If the stresses are still not acceptable, further power ascension will be delayed until the affected dryer components are appropriately modified. The response to RAI 3.9-139(b) is acceptable because it ensures the dryer's structural integrity during power ascension. Therefore, all aspects of RAI 3.9-139 were closed.

3.9.5.3.3.4 ESBWR Chimney Partitions Structural Integrity

Section 3L.3 of Appendix 3L to DCD, Tier 2, Revision 5, describes how the applicant assessed the structural integrity of the chimney partition assembly using SMT, computational flow analyses, and FEM and stress analysis. The applicant computed a maximum stress of 41 MPa (5.95 ksi) using static analyses (based on its determination of a 2-Hz pressure fluctuation in the partition flow), which is less than the allowable 68.95 MPa (10 ksi) established by ASME design codes. The applicant did not present details of the chimney partition evaluation analysis.

In RAI 3.9-140, the staff asked the applicant to provide the following information:

(a) Flow conditions for which the two-phase pressure measurements were made on the chimney partition, provide the prototype conditions that they simulate, and describe the expected steam/water mixture flow rates and speeds through the chimney partitions. In addition, provide the magnitude and frequency content of the associated loads. Finally, discuss how the loading conditions resulting from flow in the mixing chamber at the top of the chimney were included in the two-phase load definition on the partitions.

(b) Explain how its FEM considered fluid loading (resulting from exterior water and interior steam/water mixture) and the effects of the fluid loading on the model response, particularly for the 2-Hz pressure fluctuation. The applicant should also discuss the damping assumed in the chimney FEM, including the damping caused by the fluid loading.

(c) Describe the structural attachments and constraints of the chimney partitions and the chimney, and justify the modeling of the boundary conditions in the FEM analysis.

In its response to RAI 3.9-140(a), the applicant stated that the inlet flow conditions that were used in the test appear in Table 3L-1 in Appendix 3L to DCD Tier 2 and bound the actual flow conditions. The maximum load was measured in the 1/6-scale test at 7.5 kilopascals (kPa) (1.09 psi) (peak-to-peak/2) with 20 percent margin added, and the frequency was measured at 2 Hz. The applicant further stated that, regarding the loading conditions resulting from the flow in the mixing chamber at the top of the chimney with respect to its effect on partitions, the test facility contained a tank that simulated the upper mixing chamber that was effective at collecting water as it exited the partitions. The staff concluded that the test setup described effectively models the two-phase flow and simulates the pressure conditions that occur in the mixing chamber. Therefore, the staff found the applicant's response to RAI 3.9-140(a) acceptable.

In its response to RAI 3.9-140(b), the applicant stated that the FEM model applied a pressure load of 7.5 kPa (1.09 psi) uniformly on the plates and used the SRSS method for the sum of pressure loading between adjacent cells. This test focused on the chimney partitions and, as such, did not consider the effect of exterior water. The applicant further stated that, regarding the fluid loading, the eigenvalues of the partitions are 53.8 Hz [276 degrees Celsius (C) (529 degrees Fahrenheit (F))] and 56.6 Hz [20 degrees C (68 degrees F)] without added mass, which is significantly higher than the 2 Hz dominant frequency of the fluid excitation. Therefore, dynamic effects were neglected and a static analysis was performed; no damping effects were considered. The staff agrees with the applicant's conclusions, because the relative stiffness of the chimney partition structure is sufficiently separated from the frequency of the FIV forcing function to support a static analysis approach.

In its response to RAI 3.9-140(c), the applicant stated that the FEM analysis modeled the chimney partition cells as integral elastic bodies and assumed the outermost ends of the partitions to have fixed ends. The detailed design of the chimney partition structure will include structural support components at the outermost ends of the partitions to provide rigidity. The staff considered the applicant's response to RAI 3.9-140(c) acceptable, because the analytical model provided a reasonable representation of the proposed design. However, in the audit review at the applicant's offices in Wilmington, NC, on August 25, 2009, the staff determined that the design of the chimney partition still had not been completed. As a result, in order to verify this design commitment, the provision of the partition design and associated FIV stress analyses have been included as ITAAC 8b in Table 2.1.1-3 of DCD Tier 1, as discussed in Section 3.9.5.3.1 of this report and the SER for NEDE-33259P. The staff concludes that all aspects of RAI 3.9-140 were resolved.

3.9.5.3.3.5 ABWR/BWR Operating History Relevant to ESBWR Steam Dryer

In NEDE-33259P, the applicant described testing of the ABWR plant in Japan and provided a table of selected FIV parameters measured in the ABWR and the estimates for the ESBWR. The Japanese Ministry of International Trade and Industry has classified the reactor internals of this ABWR as prototype. However, the applicant did not include steam dryer data in the table. In RAI 3.9-141, the staff asked the applicant to provide steam dryer FIV data for the ABWR or another valid prototype relevant to the ESBWR design criteria, such as the presence of any strong tones in the fluctuating pressure incident on the steam dryer surfaces. In addition, the staff asked the applicant to estimate any differences in FIV response between the ABWR, or another valid prototype, and the ESBWR steam dryers.

In its revised response to RAI 3.9-141 the applicant stated the following:

> The prototype for the ESBWR steam dryer will build on the successful operating experience of the ABWR steam dryer. The ESBWR steam dryer also draws experience from operating plant replacement steam dryer program's fabrication, testing and performance. Steam dryers recently tested and installed in BWR/3 and BWR/4 plants had experienced high pressure loads under extended power uprate operating conditions. These loads were characterized by an abnormally high pressure tone at approximately 155 Hz that emanated from an acoustic resonance in one or more of the SRV standpipes. The replacement steam dryers were specifically designed to withstand the flow-induced vibration and acoustic resonance loading that led to fatigue failures in the dryers for these plants.

The staff finds the response acceptable because the prototype ESBWR steam dryer design will be based on the successful operating experience of the ABWR steam dryer and the replacement steam dryers installed in operating plants during modifications in support of power uprates. The replacement steam dryers are designed to withstand high fluctuating pressure loads resulting from acoustic resonance. In addition, the applicant has stated in Section 3L.4.4 of Appendix 3L to DCD, Tier 2, Revision 7, that SRV standpipes in the ESBWR have been designed so that feedback loading from potential sources of acoustic resonance in the MSL will not occur, thereby reducing the potential for high-frequency pressure fluctuations applied to the steam dryer.

Further, in response to the staff's request, the applicant provided Table 3L-1 in DCD Appendix 3L, which compares major configuration parameters of the ESBWR, ABWR prototype, and a BWR/3 replacement steam dryer. Therefore, RAI 3.9-141 was closed.

3.9.5.3.3.6 Discussions of ESBWR Reactor Pressure Vessel Internals Startup Testing Plans

In RAI 3.9-144A, the staff asked the applicant to describe the power ascension plan for the ESBWR that includes the following aspects:

(a) For initial startup, plant data at the ESBWR will be collected from instrumentation mounted directly on the steam dryer at significant locations (including the outer hood and skirt, and other potential high-stress locations) to verify that the stress on individual steam dryer components is within allowable limits during plant operation.

(b) The instrumentation directly mounted on the steam dryer will provide sufficient information to perform an accurate stress analysis of all steam dryer components and will include pressure sensors, strain gauges, and accelerometers.

(c) The ESBWR MSLs will be instrumented to collect data to determine steam pressure fluctuations in order to identify the presence of acoustic resonances and to allow the analysis of those pressure fluctuations to calculate steam dryer loading and stress.

(d) The direct steam dryer data will be used to calibrate the MSL instrumentation and data analysis before the removal or failure of the steam dryer instrumentation.

(e) The steam, FW, and condensate lines and associated components, including SRVs and POVs and their actuators, will be instrumented to measure vibration during plant operation to demonstrate that short- and long-term qualification limits are not exceeded for the piping and individual components.

Furthermore, in RAI 3.9-144B, the staff asked the applicant to describe the ESBWR startup test procedure, including the following:

(a) the stress limit curve to be applied for evaluating steam dryer performance

(b) specific hold points and their duration during power ascension with sufficient time intervals for interaction with NRC staff during power ascension

(c) activities to be accomplished during hold points that are of sufficient duration to accomplish those activities

(d) plant parameters to be monitored

(e) inspections and walkdowns to be conducted for steam, FW, and condensate systems and components during the hold points

(f) the method to be used to trend plant parameters

(g) acceptance criteria for monitoring and trending plant parameters and conducting the walkdowns and inspections

(h) actions to be taken if acceptance criteria are not satisfied

In response to RAI 3.9-144A(a) through (d), the applicant stated that Section 3L.4.6 of DCD, Tier 2, Appendix 3L, Revision 7, as well as the response to RAI 3.9-138 S01, presents the general description of steam dryer instrumentation and the power ascension plan. The general description includes guidelines for selecting and determining the total number of sensors and their distribution. In response to RAI 3.9-144A(a) and (b), the applicant stated that a proper distribution of the steam dryer pressure instrumentation is selected to provide a good measure of the acoustic loading through the frequency range of interest. However, the evaluation of the layout of the steam dryer pressure instrument locations using the RPV acoustic FEM ~~model~~ is not submitted. Similarly, the applicant stated that the strain gauge and accelerometer instruments are mounted in locations that provide measurements that are strongly coupled with projected high-stress locations. NEDE-33312P, Revision 1 issued July 2009, describes the specific information utilized to verify the FIV load definition during startup testing.

In RAI 3.9-144(a) and (b) S02, the staff requested the following information:

(i) Layout of the steam dryer pressure instrumentation locations or additional information on how the instrument locations will be determined and verified;

(ii) Specific information regarding the strain gage and accelerometer mounting locations or additional information on how the instrument locations will be determined and verified; and

(iii) Revised NEDE-33312P providing specific information to be used for verifying the FIV load definition during startup testing.

In the revised response to RAI 3.9-144A(c) and (d), the applicant stated that the MSLs are instrumented to measure the acoustic pressures in the piping. These measurements, along with the steam dryer pressure measurements, are used as input to an acoustic model for determining the pressures acting on the steam dryer. The applicant plans to use this load definition in performing confirmatory structural evaluations. In RAI 3.9-144(c) and (d) S02, the staff asked the applicant to provide a detailed description of how the pressures acting on the steam dryer will be determined using the measured acoustic pressures in the MSLs and on the steam dryer. In addition, the staff requested that the applicant explain how it will account for (i) the plant noise and the electrical noise, which may be present in the instrumentation system, in determining the acoustic pressure acting in the MSLs and (ii) any circumferential variation in the wall thickness of the MSLs.

Regarding RAI 3.9-144A(e), the applicant described the instrumentation for the steam, FW, and condensate lines and their components to measure vibration to demonstrate that applicable qualification limits are not exceeded. For example, the applicant indicated that instrumentation will be installed on two MSLs, an MSIV, and an SRV branch at two locations. These limited instrumentation locations do not appear sufficient to identify potential adverse flow effects on the MS system and its components during plant startup and power ascension. The applicant's response also appears to provide only limited instrumentation locations for the FW, condensate, and IC systems. Therefore, in RAI 3.9-144A(e) S01, the staff asked the applicant to discuss its plans to provide sufficient instrumentation and locations to demonstrate that potential adverse flow effects, such as those resulting from acoustic resonance, are not causing the qualification limits for the steam, FW, and condensate lines and their components to be exceeded during operation of the ESBWR. In a subsequent response, the applicant further described the instrumentation and locations for measurement of potential adverse flow effects, including acoustic resonance. The minimum extent of the instrumentation is summarized below and may be increased based on the results of the final as-built stress analyses for these systems:

<u>MS piping system</u>: All four MS lines will be instrumented with linear potentiometer displacement transducers (LVDTs) to measure vibration displacement time histories. The MS lines are also instrumented with strain gauges to monitor potential acoustic effects transmitted to the steam dryer, which NEDC-33408P discusses in further detail.

FW piping system: FW piping will include six LVDTs and four strain gauges on each FW loop, A and B, to measure the effects of FIVs.

IC system: Twelve LVDTs and 12 accelerometers will be located on four condensate lines, and six LVDTs and six accelerometers will be located on two steamlines.

SRVs: Two SRVs for each MS line will be instrumented with accelerometers, and one SRV for each MS line will be instrumented with strain gauges.

MSIVs: All four inboard MSIVs will be instrumented with accelerometers located on the valve operators.

The above instrumentation is considered the minimum necessary to ensure that fatigue degradation from potential FIV in these systems does not occur. Final details of gauge setup, location, and number may be increased during the final design process for these components. The detailed information for monitoring, trending, and inspection of the steam, FW, and condensate systems during the ESBWR startup testing will be developed and included in the startup test procedures described in DCD Section 14.2.8. NEDC-33408P, issued July 2009, and NEDC-33408P, Supplement 1 issued August 2009, which address load definition methodology specifically for the steam dryer, discuss separately the additional instrumentation for the MSLs and the steam dryer to measure potential acoustic feedback loading on the steam dryer. The staff's review of this supplemental response concludes that it provides sufficient information for the extent and locations of instrumentation necessary to monitor potential adverse flow effects in these systems during normal operating conditions. Based on the staffs' conclusions ~~for closure of~~ RAI 3.9-144A(e) S01 was closed.

In its revised response to RAI 3.9-144B(a), the applicant stated the following:

> The ESBWR start up test program is discussed in Section 3L.5 of DCD, Tier 2, Appendix 3L. The fatigue analysis performed for the ESBWR steam dryer will use a fatigue stress limit of 13.6 ksi. For the outer hood component, which is subjected to higher pressure loading in the region of the MS lines, the fatigue stress limit will be 10.8 ksi. The higher stress limit is justified because the dryer is a non-safety component, performs no safety functions, and is only required to maintain its structural integrity (no loose parts generated) for normal, transient, and accident conditions.

The proposed fatigue limits for ESBWR steam dryer components are acceptable because they are based on ASME Code Fatigue Curve C, presented in Figure I-9.2.2 of ASME Code, Section III. Fatigue Curve C provides the lowest fatigue limit for high-cycle fatigue damage and includes the maximum effect of retained mean stress, which consists of weld residual stresses and other fabrication stresses. The fatigue stress limit of 10.8 ksi for outer hood components is acceptable because it represents the current industry practice for analysis of steam dryers subject to adverse flow loading resulting from extended power uprate operation. For these reasons, RAI 3.9-144B(a) was closed. The staff has identified the stress analysis of steam dryer components at normal plant operating conditions as an ITAAC item to ensure that the fatigue limits specified were satisfied. ITAAC 8 in Table 2.1.1-3 of DCD Tier 1 lists this item.

In its response to RAI 3.9-144B(b)–(h), the applicant described an acceptable general description of the power ascension plan and startup test procedure for the design certification review with regard to potential adverse flow effects that might occur during operation of the

ESBWR. However, the applicant did not incorporate any of the clarifying information provided in the response to this RAI into the DCD. Therefore, in RAI 3.9-144B(b)–(h) S01, the staff requested that the applicant revise DCD, Tier 2, Appendix 3L, to include the information provided in the response to RAI 3.9-144B. In a subsequent response, the applicant revised DCD Appendix 3L.5, “Startup Test Program,” with the additional information from the RAI response and included cross-references to DCD Section 14.2 describing the ESBWR initial test program, including the reactor internals vibration measurement test. The staff found this revised response acceptable, because the applicant revised the appropriate sections of the DCD by incorporating the clarifying technical descriptions requested. Therefore, and based on the staff’s review, RAI 3.9-144B(b)–(h) S01 was closed.

In Enclosure 1 of the letter from R.E. Kingston of GEH to the NRC, dated June 8, 2009, the applicant responded to items (i) and (ii) in RAI 3.9-144 (a) and (b) S02 by referring to the response to RAI 3.9-138 S02, which the staff had already reviewed and found acceptable. Therefore, items (i) and (ii) in RAI 3.9-144(a) and (b) S02 were closed.

Regarding item (iii) in RAI 3.9-144(a) and (b) S02, the applicant stated that it will not revise NEDE-33312P because the requested information already exists in NEDC-33408P (Ref. 3) and NEDC-33408P, Supplement 1 (Ref. 4). Therefore, the applicant will revise the DCD to reference NEDC-33408P and NEDC-33408P, Supplement 1. The staff found this response acceptable. Therefore, item (iii) in RAI 3.9-144(a) and (b) S02 was closed.

In response to RAI 3.9-144(c) and (d) S02, which asked the applicant to explain how the dryer load will be determined using the measured acoustic pressures in the MSLs and on the steam dryer, the applicant referred to NEDC-33408P; NEDC-33408P, Supplement 1; and the revised DCD, Tier 2, Appendix 3L, which include the requested information. The staff found this response acceptable.

Regarding the effect of variations in the pipe wall thickness and diameter at the strain gauge locations, the applicant referred to NEDC-33408P, Supplement 1, which affirms that pipe thickness and diameter will be measured at the MSL strain gauge installation locations to determine the variation in the local dimensions, thereby minimizing uncertainty associated with dimensional tolerance. GEH also revised DCD, Tier 2, Appendix 3L, to provide this additional information. The staff found this response satisfactory.

Technical dialogue with the applicant related to resolution of RAI 3.9-144 S02 led to additional discussions regarding the effects of electrical and plant noise on instrumentation for the steam dryer load definition. With respect to the effect of electrical and plant noise, the applicant stated the following:

> Zero volt excitation data will be captured to determine the electrical noise present at the plant. The averaged 0-volt power spectral density (PSD) data will be plotted for each strain gage ring and compared with the bridge excitation data to separate the electrical sources from the acoustical sources. Noise associated with recirculation pump vane pass frequency is not an issue since the ESBWR does not use recirculation pumps. Plant noise (other than potentially the 60 Hz line noise) is typically not significant. DCD, Tier 2, Appendix 3L will be revised to provide this additional information.

While this response seems reasonable because the plant noise of the ESBWR is expected to be quieter than that of currently operating BWR plants, the staff asked the applicant to further clarify how the plant noise will be accounted for in the following two situations:

(a) When the PBLE methodology is *benchmarked* against data collected in BWR plants, which are known to be quite noisy

(b) If the plant noise of ESBWR is not negligible

Note that plant (or machinery) noise is likely to depend on the reactor operating conditions. This issue was discussed during the audit conducted by the staff on August 25, 2009, at the applicant's main offices in Wilmington, NC, and the subsequent conference call. This issue was identified as NRC Audit Comment 12 in the NRC's "Report of the August 25, 2009 NRC Staff Audit on ESBWR RPV Internals," issued September 15, 2009.

In its response to NRC Comment 12, the applicant added a commitment in Section 9.1 of NEDE-33313P, Revision 2, that the ESBWR dryer testing will include testing at very low steamflow when other plant equipment is operational to define the level of background noise on the dryer and MSL instruments. This will allow the applicant to assess the impact of plant noise on the ESBWR Transmatrix, in the event that the initial ESBWR has significant noise, and ensure that the Transmatrix and monitoring limits are conservative. For the case in which the MSL pressure is derived from strain gauge data, the applicant stated that with proper shielding the strain acquisition system, cabling, and gauges should provide an averaged strain noise floor reading at each monitoring location at or below 7×10^{-6} $\mu\varepsilon(\text{rms})^2/\text{Hz}$ and that it shall not be above 2×10^{-5} $\mu\varepsilon(\text{rms})^2/\text{Hz}$. The applicant further stated that, on subsequent units, the noise floor should be compared with the noise floor from the initial ESBWR unit. If the noise floor on the follow-on units is lower, then the impact of the lower noise floor on the bias and uncertainty of the PBLE loads for that unit shall be determined and the adjusted values used in the stress evaluation of that follow-on unit.

Examining existing MSL strain gauge spectra reveals that this noise floor will allow for accurate signal measurements up to a specified frequency. In the event the ESBWR high-frequency MSL signals are below the noise floor, the Transmatrix coefficients derived based on the ratios of the MSL signals and the instrumented prototype dryer signals will be in error. However, since all ESBWR plants will be nominally identical, these errors will not lead to nonconservative dryer load estimates in non-prototype plants, since the Transmatrix coefficients will lead to dryer loads identical to those measured directly on the prototype dryer. The staff found this response acceptable because the proposed approach would lead to conservative dryer loads.

The staff had another concern regarding the non-prototype ESBWR units if their MSL layout was modified in such a way as to invalidate the applicability of the steam dryer load definition based on the initial prototype ESBWR measurements. In its response, the applicant stated that in such situations the MSL measurements from the follow-on units will be compared to those from the prototype plant. The Transmatrix and the load definition bias and uncertainty values over the full frequency range will be reevaluated as needed and used or a safety factor agreed upon with the NRC will be applied to the non-prototype plant confirmatory dryer stress analyses performed after the startup of the follow-on unit. The staff found the response acceptable because the proposed resolution includes an assessment of the MSL layout changes, if any, on the steam dryer load definition and would require the staff's review and approval. NEDE-33313P, Section 9.1, documents further technical details on this subject. The staff review of GEH's additional response concluded that it provides sufficient information to close

RAI 3.9-144 S02 and the associated staff audit comment. Therefore, all aspects of RAI 3.9-144 were closed.

3.9.5.3.4 Criteria Used for Assessing the Adequacy of Internal Structures Other Than Steam Dryer and Chimney Assemblies, Including the Information from NEDE-33259P

The staff recognizes that the criteria used by the applicant for assessing the adequacy of RPV internal structures other than the steam dryer and chimney assemblies are based on applicable codes and standards. The staff finds acceptable the criterion used for judging which components require additional work and which components are considered acceptable and require no additional work because of the similarity of the ABWR and ESBWR design and operating conditions. During its review of NEDE-33259P, the staff formulated additional RAIs (see below) to question potential FIV issues and problems not addressed in the report.

In RAI 3.9-142, the staff asked the applicant to explain the fluctuating pressure expected to emanate from the various nozzles in the RPV adjacent to the chimney. This explanation should include the RWCU/SDC nozzle, the IC return nozzle, and the GDCS nozzle near the chimney side walls, as shown in Figure 2 on page 15 of NEDE-33259P.

In its response to RAI 3.9-142 dated November 22, 2006, the applicant stated the following:

> Of the three systems that have nozzles and associated piping in the chimney region of the RPV, only the RWCU/SDC operates during normal plant operating conditions and has an external pump to drive flow. The other two systems are passive systems that do not operate during normal plant conditions and rely on hydraulic principles to create flow.
>
> For the RWCU/SDC system, the RPV nozzle is used to remove water from the RPV during normal plant conditions. The flow rate in this mode is a maximum of 2 percent of the feedwater flow, and is provided by a pump with comparatively low capacity. The vane passing frequency (VPF) from this pump will be similar to other pumps, but the amplitude will be very low. The BWR operating experience has been that only small sensing line components have been impacted by external pump vane passing frequencies.
>
> The Isolation Condenser (IC) system is only operated when containment isolation occurs and heat removal from the reactor system is required. When this system is opened, steam flow drives each of the closed loops and flow enters the RPV from the IC return line nozzle. Plant operation with this system in operation will be very limited, and with the large mass of the chimney structure no FIV issues will occur.
>
> For the Gravity Driven Cooling System (GDCS) lines, the only time these are placed in operation is during LOCA conditions when makeup water is required for the RPV. The flow from these nozzles is gravity driven from an elevated pool. The low associated flow rates and limited operating time, if such an event should ever occur, will not result in any vibration issues.

The staff agrees with the applicant that the operation of the ICS and GDCS would not result in any vibration issues because these two systems are passive systems that do not operate during normal plant conditions and rely on hydraulic principles to create flow. In addition, plant operation with these systems engaged would be very limited.

However, the staff has a concern about the pump-driven RWCU/SDC system that might produce FIVs. Generally, the amplitudes of the pressure fluctuations resulting from VPFs from the pump are quite small. However, when the pulsation frequency coincides with the natural frequency of a component, the pressure pulsations can cause stresses of high magnitude even though the amplitude of the pressure fluctuations resulting from VPF is quite small. Small pressure fluctuations have been amplified in the steamlines of BWR plants and have caused pressure waves and vibrations that have damaged plant equipment, including steam dryers and SRVs. In RAI 3.9-142 S01, the staff asked the applicant to identify any vessel internal components that have natural frequencies that correspond to the pump VPFs. If so, the staff asked the applicant to submit analyses that clearly show that the stresses within those components are below the ASME Code fatigue limits.

In its response to RAI 3.9-142 S01, the applicant stated the following:

> Of the three systems that have nozzles and associated piping in the chimney region of the RPV, only the RWCU/SDC operates during normal plant operating conditions and has an external pump to drive flow. For the RWCU/SDC system, the RPV nozzle is used to remove water from the RPV during normal plant conditions. The flow rate in this mode is a maximum of 2 percent of the feedwater flow, and is provided by a pump with comparatively low capacity.
>
> The fluctuating pressure waves at the VPF produced by the RWCU/SDC pumps are not expected to affect the vessel internal components, or safety relief valves. Pressure waves at the VPF travels upstream and downstream from the pump. This pressure wave is attenuated due to flow path changes as it travels to the reactor. As the pressure wave enters the vessel, it is significantly attenuated because of the very significant increase in the flow area. The attenuation is expected to be related to the area ratio (vessel annulus area/nozzle area) squared. Thus, the small pressure fluctuations generated by the pumps is further reduced. In comparison to the current BWR forced-recirculation loops, which have much higher energy pumps and a shorter path of travel through piping and components the RWCU/SDC pumps produces much lower pressure induced vibration.

To ensure that resonance or near resonance conditions (between the vessel internals natural frequencies and the VPF) are not present, a comparison of the frequencies is made. The RWCU pump has 5 vanes and runs at 1780 rpm. This makes its VPF approximately 148 Hz. The Shutdown Cooling pump has 5 vanes running at 3550 rpm results in a VPF of approximately 296 Hz.

The applicant also provided the lowest natural frequencies of the reactor components of interest near the vessel nozzle (SLC piping and the Shroud/Chimney/Separator). The applicant stated that since these lowest natural frequencies are far removed from the VPF, no resonance or near resonance conditions are present. It is possible for the higher modes of these components to be near the VPF. However, the responses for these higher modes are negligibly small, since (1) the response varies inversely as the frequency squared, and (2) the complex higher mode shapes result in very low generalized forces.

The staff found this explanation acceptable, because the lower natural frequencies of the components of interest are sufficiently separated from the VPF to preclude application of potential forces associated with a resonance condition. Therefore, all aspects of RAI 3.9-142 S01 were closed.

In DCD, Tier 2, Section 4.1.2.2, the applicant stated that individual fuel assemblies in groups of four rest on orifice fuel supports that are mounted on top of the CRGTs. Each guide tube, with its orifice fuel support, bears the weight of four fuel assemblies and is supported on a CRD housing penetration nozzle in the bottom of the reactor vessel. It appears that the weld at the nozzle is subjected to the weight of four fuel assemblies, orifice fuel support, CRGT, and CRD housing, as well as other vertical and horizontal loads. In RAI 3.9-143, the staff asked the applicant to clarify the load path and ensure that the weld at the nozzle is adequate to accommodate these loads. In the event of weld failure, the staff asked the applicant to assess the adequacy of the CRGT and the CRD housing subjected to FIVs and the ability to insert the control rod, considering the boundary conditions at the top of the CRGT and failed weld at the nozzle, and the CRGT base coupling connection with the CRD housing.

The applicant responded to RAI 3.9-143 by stating the following:

> The CRD housing-to-CRD Stub Tube weld in the bottom head of the RPV carries the deadweight of four fuel assemblies, the orificed fuel support and the CRD guide tube. In addition, the weld carries the loads due to seismic and hydrodynamic accelerations as well as scram reaction loads, spring loads and vibratory loads. The load path is identical to that of earlier BWRs including the ABWR. A sketch of the CRD penetration was included in the applicant's response to RAI 4.5-19. The weld is analyzed, designed, manufactured and examined to be in full compliance with the requirements for ASME Code, Section III, Division 1, Class 1 pressure retaining components considering all the loads mentioned in the foregoing.
>
> The clearance between the CRD housing is controlled and kept as small as practicable for installation purposes. Thus, in the unlikely event of a complete weld failure, the transversal movement of the CRD Housing and the CRD Guide Tube is limited. FIV during this hypothetical condition would produce stresses in the CRD Guide Tube that are within the endurance limit as defined using the fatigue curve for austenitic SS, Figure I-9.2.1 of the ASME Code, Section III.
>
> A complete failure of the CRD housing-to-CRD Stub Tube weld is very unlikely. The existence of weld cracks in some older plants was discovered by leakage through the weld. The leakage started long in advance of any possibility of a complete weld failure. Also, the use of Columbium stabilized Alloy 82 weld material and Ni-Cr-Fe Alloy 600 stub tube material per ASME Code Case N-580-1 in the ESBWR has widely eliminated the concern for stress corrosion cracking in the weld and adjacent material.
>
> As mentioned in the foregoing, in the case of a complete weld failure, the transverse movement of the CRD Guide Tube is limited. The control rods and the control drive are designed to accommodate this misalignment during insertion of the control rods."

The staff determined that it was not clear how the applicant reached the above conclusion. Therefore, in RAI 3.9-143 S01, the staff asked the applicant to provide the following information to justify its conclusions:

(1) Maximum transversal movement of the CRD housing and the CRGT (a) during normal operation and (b) under the condition with weld failure

(2) Natural frequency of the worst system configuration with boundary conditions at the top of the CRGT, the CRGT base coupling connection with the CRD housing, and the failed weld at the bottom of the reactor vessel

(3) Maximum cross-flow and longitudinal flow velocities along the system configuration identified in (2) above, and those at the CRGT-CRD housing coupling location

(4) Results of the calculations for vortex shedding frequencies of the system configuration identified in (2) above, and the resulting maximum stress in the CRD

RAI 3.9-143 was tracked as an open item in the SER with open items. In response to RAI 3.9-143 S01, the applicant provided the following information:

> The reactor pressure vessel tube stub/CRD housing weld is part of the reactor coolant pressure boundary. As such it is designed, analyzed, fabricated, examined, and tested to ASME Section III Subsection NB Class 1 requirements and is assigned the highest quality group classification A. This safety-related weld is designed and analyzed using seismic Category I loads and load combinations as shown in Table 3.9.1 and 3.9.2 of the DCD Tier 2. This ensures the structural and functional integrity of the RPV and FMCRD. The capability to insert the control rods is maintained under all plant operating events and dynamic loading events and load combinations as discussed in response to RAI 3.9-43. The material selection and fabrication process provide an extremely high probability of weld integrity as discussed in DCD, Tier 2, Section 4.5. In conclusion there is an extremely low probability of leakage, of a rapidly propagating failure, and of gross rupture. If this weld were to fail (leak), it would be detected by the safety-related leak detection system as discussed in DCD, Tier 2, Subsection 5.2.5. The safety-related leak detection system indicates unidentified leakage through sump activity and sump level changes. The technical specifications specify limiting conditions of operation, required actions, surveillance requirements, and completion times to control the response as discussed in DCD, Tier 2, Chapter 16, Subsections 3.4.2 and 3.3.4.1. In the unlikely event of a gross weld rupture the radial clearance between the RPV tube stub and the CRD housing is very small (nominally 1/8 mm) which would minimize any transverse movement of a CRD housing. Frequency induced vibrations, stress, and flow are discussed in ESBWR Licensing Topical Report NEDE-33259.

The adequacy of the CRGT, CRD housing, and natural frequency and stress of the system configuration discussed in NEDE-33259P was based on the fixed end boundary condition at the penetration nozzle weld and not on the assumed complete weld failure. Therefore, if the applicant continues to conclude that the FIV during this hypothetical condition would produce stress in the CRGT that is within the endurance limit, as defined using the fatigue curve for austenitic steel (Figure 1-9.2.1 of ASME Code, Section III), the staff asked the applicant, in RAI 3.9-143 S02, to provide additional justification for its response to the four questions raised in RAI 3.9-143 S01. In response to RAI 3.9-143 S02, the applicant provided the following information:

> GEH no longer assumes the complete failure of the penetration nozzle weld. To ensure the structural integrity of the nozzle weld, it is analyzed, designed, fabricated, examined, and tested with the requirements of the ASME Code, Section III, Division 1, Class 1 pressure retaining components considering all the required loads mentioned in DCD, Tier 2, Tables 3.9-1 and 3.9-2.
>
> For early BWR operating plants (BWR/2 plants and one BWR/3 overseas plant), stress corrosion cracking of furnace sensitized stainless steel CRD stub tubes that occurred were detected by leakage through the narrow annulus gap at the penetration. Subsequent plants used Ni-Cr-Fe Alloy 600 material, which has proven through many years of service to be crack resistant. For ESBWR, Columbium stabilized alloy 82 weld material and Ni-Cr-Fe Alloy 600 stub tube material per ASME Code Case N-580-1 has been selected to provide long term resistance to stress corrosion cracking. In the cases where leakage occurred, it was demonstrated, unlike typical nozzle designs where pipe separation can occur, the inherent features of the stub tube design provides a means to detect relatively small amounts of leakage that is readily detected, and significant structural margin remains such that there is no impact on the performance of the CRD. Therefore, the complete failure of the CRD penetration connection is not credible for design purposes, and does not need to be evaluated from a flow induced vibration perspective.

Additionally, to ensure the ability to insert the control rod, the applicant explained that the FMCRD is designed, fabricated, and tested as follows:

(1) To quality standards commensurate with the importance of the safety-related functions to be performed in accordance with GDC 1 and 10 CFR 50.55a.

(2) To withstand the effects of a safe shutdown earthquake without loss of capability to perform its safety-related functions in accordance with GDC 2.

(3) To assure the extremely low probability of leakage or gross rupture in accordance with GDC 14.

(4) With appropriate margin to assure its reactivity control function under conditions of normal operation including anticipated operational occurrences in accordance with GDC 26.

(5) With appropriate margin, and in conjunction with the emergency core cooling system, to be capable of controlling reactivity and cooling the core under postulated accident conditions in accordance with GDC 27.

(6) To assure an extremely high probability of accomplishing it's safety-related functions in the event of anticipated operational occurrences in accordance with GDC 29.

The staff found in its evaluation of the applicant's response to RAI 3.9-143 S02 that GEH has reevaluated the penetration nozzle weld and concluded that its complete failure is not credible. Based on this assertion, the staff agrees that further FIV analyses of the CRGT and CRD housing and reconsideration of the ability to insert the control rod are not necessary. Also, in response to RAIs 3.9-143 and 3.9-143 S01, the applicant clarified the load path and provided the evidence to the NRC staff that the weld at the nozzle is adequate to accommodate these loads. Therefore, all aspects of RAI 3.9-143 were closed.

3.9.5.3.5 Loading Conditions

The staff finds acceptable the loading conditions for which CS structures and safety-related internal components must satisfy the design basis (see Section 3.9.5.2.6 of this report) because they include the significant loading events to which the structures and components are subjected.

As indicated in Section 3.9.5.2.5 of this report, the applicant performed simulated flow tests for the chimney partition. However, the applicant did not provide details of the loading on the chimney partition for the analysis of the chimney. As indicated in Section 3.9.5.2.5 of this report, the applicant has identified loading conditions for reactor internals. The applicant stated that it used the TRACG computer code to determine pressure differences for reactor internals during the events under different operating conditions. In RAI 3.9-145, the staff asked the applicant to describe the validation of this computer code in calculating the pressure differences for reactor internals during the events under normal, upset, emergency, and faulted conditions.

In its response to RAI 3.9-145, the applicant stated that it had previously responded to RAI—RAI 4.4-20, which also requests this information. Section 4.4 of this report contains the staff's evaluation of the applicant's response to RAI 4.4-20. Therefore, the staff considers RAI 3.9-145 closed.

DCD, Tier 2, Table 3.9-3, provides 11.2 kilopascal differential (1.6 pounds per square inch differential) as the maximum pressure difference for the steam dryer. However, there is likely to be a significant pressure variation across the outer hood of the steam dryer. In RAI 3.9-146, the staff asked the applicant to describe the capability of the TRACG computer code to calculate such spatial pressure variations.

In its response to RAI 3.9-146, the applicant stated that the TRACG code is not used to calculate the spatial variation across the outer hood. The shape of the outer hood significantly reduces the spatial variation of the static differential pressure when compared to the earlier designs, and the resulting spatial variation is fairly uniform. Since TRACG does not calculate the spatial variation across the outer hood, its results cannot be used for the dynamic analysis of the ESBWR steam dryer to ensure its structural integrity. However, this limitation of the TRACG code is not critical because, according to its response to RAI 3.9-136, the applicant will be using LIA to compute a fine spatial variation of pressure-time histories over the steam dryer surfaces based on measurements made in the applicant's SMTs. The applicant has presented its methodology for estimating the acoustic loading on the steam dryer in NEDE-33312P. The staff reviewed this report and presented its evaluation in a separate SER. The review of NEDE-33312P supersedes RAI 3.9-146.

Since the natural circulation of the working fluid in the ESBWR is a new feature and only occurs when the fuel assemblies generate heat, the staff asked the applicant, in RAI 3.9-147, to justify that the flow velocities and their distribution over the reactor internals are verified for FIV analysis and testing, in accordance with SRP Section 3.9.2.

In its response to RAI 3.9-147, dated November 22, 2006, the applicant explained how the working fluid flows in an ESBWR and highlighted positive aspects of the ESBWR design. The applicant stated that the flowpaths are cleaner in an ESBWR, with fewer flow disturbances. In addition, the flow rates within the core region are slower than in a forced-circulation plant, leading to lower hydrodynamic excitation and resulting vibration.

The staff determined that the applicant's explanation of the benefits of the ESBWR design regarding flow rates and patterns does not provide the information requested in the RAI. Therefore, in RAI 3.9.5-147 S01, the staff asked the applicant to justify that the flow velocities and their distribution over the reactor internals are verified for FIV analysis and testing, in accordance with SRP Section 3.9.2.

In its response to RAI 3.9-147 S01, the applicant made it clear that only mean flow velocities are needed, along with data from the ABWR to make FIV analyses. Reference was made to the response to RAI 3.9-49, which provides more details of the FIV analyses. The applicant's response to RAI 3.9-49, which the staff has reviewed and found acceptable, provides the basis for closure of RAIs 3.9-147 and 3.9-147 S01.

3.9.5.3.6 Reactor Pressure Vessel Internals Design Bases

The staff finds that the safety design basis and power generation design basis, as described in Section 3.9.5.2.6 of this report, are, in general, acceptable because they are based on the criteria established in applicable codes and standards for similar equipment, by manufacturer's standards, or by empirical methods based on field experience and testing. These criteria include the minimum safety factors provided for each of the four ASME Code Section III service conditions (Level A (normal), B (upset), C (emergency), and D (faulted)).

As indicated in Section 3.9.5.2.6 of this report, the applicant stated that, for the FIV of the chimney, the fundamental frequency of the chimney partition (54-56 Hz) was found to be much larger than the frequency of the maximum peak-to-peak pressure fluctuation (2 Hz). Therefore, the applicant performed an equivalent static analysis to show that the fatigue stress limits bounded the calculated stresses. Although the applicant did not provide details for the determination of the fundamental frequency or stress analysis, this method of approach is acceptable.

As indicated in Section 3.9.5.2.6 of this report, the applicant stated that the design and construction of the CS structures are consistent with ASME Code, Section III, Division 1, Subsection NG. In RAI 3.9-148, the staff asked the applicant to identify the specific paragraphs of Subsection NG that are followed for the design and construction of the CS structures. In addition, in DCD, Tier 2, Tables 3.9-4 through 3.9-7, the applicant provided the stress, deformation, and fatigue criteria for safety-related reactor internals (except CS structures), which are based on the criteria established in applicable codes and standards for similar equipment, by manufacturers' standards, or by empirical methods based on field experience and testing. Therefore, in RAI 3.9-148, the staff also asked the applicant to (1) identify the specific paragraphs of Subsection NG from which these criteria are derived or (2) if a basis other than the

ASME Code is used, identify and justify the other criteria (based on manufacturers' standards or empirical methods) that are used as the basis to develop the stress, deformation, and fatigue criteria for safety-related reactor internals.

In its response to RAI 3.9-148, the applicant stated that the stress analysis of the reactor core support structures is performed in accordance with ASME Code, Section III, Subsection NG, Subarticle NG-3200 for Service Conditions A, B, C, and D. In addition, the stress analysis uses ASME Code, Section III, Appendix F as applicable for Service Level D condition. The applicant uses an inelastic analysis method for a postulated blowout of a CRD housing caused by a weld failure, which is discussed in DCD, Tier 2, Section 3.9.5.4. The staff finds the response related to core support structure acceptable, because the analytical process is consistent with the requirements of ASME III, Subsection NG for the design of core support structures.

The applicant further stated that, for the stress analysis of reactor internal structures other than CS structures, it follows ASME Code, Section III, Subsection NG, Subparagraph NG-1122(c), which states: "The Certificate Holder shall certify that the construction of all internal structures is such as not to affect adversely the integrity of the core support structures." In DCD Section 3.9.5, the applicant selected the safety factors for ASME Code, Section III, Service Levels A, B, C, and D such that the calculated stress levels will meet the stress limits for CS structures given in ASME Code, Section III, Subarticle NG-3200. The staff finds this explanation for the first three requirements (a, b, and c) of Table 3.9-5 acceptable, because the non-mandatory use of CS structure stress limits for design of internal structure is a conservative approach exceeding ASME requirements, in accordance with ASME III Subparagraph NG-1122(b) .

The staff requested that the applicant identify the specific paragraphs of Subsection NG for Requirement (d) in Table 3.9-5 as applied to Service Condition Levels A and B. For Service Condition C, Requirement (d) provides a general limit of 0.6 ultimate strength (US), whereas Figure NG-3224-1 of Subsection NG provides a smaller limit of 0.5 US. The applicant needs to explain this difference. For Service Condition D, Requirement (d) provides a general limit of 0.8 US, whereas ASME Code, Section III, Appendix F, Subparagraph F-1341.2(b) provides a limit of 0.9 US. Therefore, Requirement (d) is acceptable for Service Level D.

Staff review of DCD Table 3.9-5 also indicated that the applicant should revise the footnote ([*]) to equations e, f, and g to read: "Equations e, f, g will not be used unless supporting data are provided to the NRC."

The applicant further stated that the other criteria shown in Tables 3.9-4 through 3.9-7 are developed from Subsection NG of ASME Code, Section III. In accordance with Subparagraph NG-3224.6, the deformation limit can be derived from the ultimate load determined by testing. The elastic limit, therefore, can be determined as a specified fraction of this load. In accordance with Subparagraphs NG-3228.4, NG-3224.1(e), and NG-3225, this fraction is 0.44, 0.6, and 0.88 for Service Levels A or B, C, and D, respectively. The staff finds this response acceptable.

The staff finds that the information presented in Table 3.9-5 does not address all its concerns; it requested the following information in RAI 3.9-148 S01:

(1) Identify the specific paragraphs of Subsection NG for Requirement (d) as applied to Service Condition Levels A and B.

(2) For Service Condition Level C, Requirement (d) provides a general limit of 0.6 US, whereas Figure NG-3224-1 provides a smaller limit of 0.5 US. Please explain this difference.

(3) The footnote (*) to equations e, f, g needs to be changed to read: "Equations e, f, g will not be used unless supporting data are provided to the NRC."

The following paragraphs discuss the staff's evaluation of the applicant's response to RAI 3.9-148 S01.

In response to RAI 3.9-148 S01, item (1), the applicant stated that, according to Requirement (d) in DCD, Tier 2, Table 3.9-5, for Service Levels A and B, the nominal primary stress evaluated using the elastic-plastic (EP) analysis is less than 0.4 times the US at temperature (i.e., EP ≤ 0.4 US).

The applicant explained that Subsection NG does not specifically refer to Requirement (d) for Service Levels A and B applicable to CS structures, and, therefore, to reactor internal structures. But, according to the applicant, this requirement for the reactor internal structures can be derived from Figure NG-3221-1, which requires the primary stress in the CS structures to be less than 0.44 L_u for Levels A and B service conditions, where L_u is determined from the test on a prototype or model, as defined in NG-3228.4, and is the equivalent of US. Thus, Requirement (d) is comparable to the ASME Code limit of 0.44 L_u for Service Levels A and B and satisfies the NG-1122(c) requirement that the reactor internal structures will not affect adversely the integrity of the CS structures. The staff found this explanation acceptable, because the non-mandatory use of CS structure stress limits for design of internal structure is a conservative approach exceeding ASME requirements, in accordance with ASME III Subparagraph NG-1122(b), and, therefore, this part of the RAI was closed.

In response to RAI 3.9-148 S01, item (2), the applicant stated that, according to Requirement (d) in DCD, Tier 2, Table 3.9-5, for Service Condition Level C, the nominal primary stress evaluated using EP analysis is less than 0.6 times the US at temperature (i.e., EP ≤ 0.6 US).

The applicant explained that Subsection NG does not specifically refer to Requirement (d) for Service Level C applicable to CS structures, and, therefore, to reactor internal structures. But, according to the applicant, this requirement for the reactor internal structures can be derived from Figure NG-3224-1, which requires the primary stress in the CS structures to be less than 0.6 L_e for Level C service conditions, where L_e is determined from the test on a prototype or model as defined in NG-3224.1(e) and is the equivalent of US. Thus, Requirement (d) is comparable to the ASME Code limit of 0.6 L_e for Service Level C and satisfies the NG-1122(c) requirement that the reactor internal structures will not affect adversely the integrity of the CS structures. The staff found this explanation acceptable, because the non-mandatory use of CS structure stress limits for design of internal structure is a conservative approach exceeding ASME requirements, in accordance with ASME III Subparagraph NG-1122(b), and, therefore, this part of the RAI was closed.

In response to RAI 3.9-148 S01, item (3), the applicant has agreed to revise the footnote to equations e, f, and g as suggested by the staff. The applicant has incorporated the revised footnote in Revision 6 of DCD, Tier 2, Table 3.9-5. The staff found this response acceptable. Based on the staff's evaluation, all aspects of RAI 3.9-148 were closed.

3.9.5.3.6.1 Deformation Limits for Reactor Pressure Vessel Internals

DCD, Tier 2, Table 3.9-4, provides deformation limits for safety class reactor internal structures. In RAI 3.9-149, the staff asked the applicant to provide the technical basis for the general limit listed in the table.

In its response to RAI 3.9-149, the applicant stated that, according to Appendix I to ASME Code, Section II, Part D, the allowable stress intensity value, S_m, for austenitic SS is 90 percent of the minimum yield strength at temperature. The applicant has selected the minimum strain, ε, just before yielding of irradiated SS to represent the strain corresponding minimum yield strength at temperature. The applicant stated that the magnitude of the minimum strain, ε, is based on experimental data from the industry.

The applicant defined the deformation limits in terms of minimum strain, ε, and the safety factors, SF_{min}, defined in DCD, Tier 2, Section 3.9.5.4, Revision 1. The deformation limits can be expressed as follows:

$$(P + Q)/E \leq (0.9/SF_{min}) \times \varepsilon$$

According to DCD, Tier 2, Section 3.9.5.4, safety factors, SF_{min}, for Service Levels A to D vary from 2.25 to 1.125.

The applicant further stated that, when experimental data from the actual material are used, the general deformation limit $1.00/SF_{min}$ may be used instead of $0.9/SF_{min}$, as shown in Table 3.9-4(b). In RAI 3.9-149 S01, the staff requested the following additional information for review:

(a) The applicant should provide a reference for the industry data for irradiated SS as mentioned in its response. In addition, the applicant should summarize these industry data, especially the neutron fluence and irradiation temperature for the irradiated steel considered here. The applicant should also provide the end-of-the-life neutron fluence for the vessel internals that will be subject to deformation limits.

(b) The applicant should provide the technical basis for the safety factors defined in DCD, Tier 2, Section 3.9.5.4, Revision 1.

(c) The applicant should explain the increase in the general deformation limit from $0.9/SF_{min}$ to $1.0/SF_{min}$ when experimental data from the actual material are used. The applicant should also identify any codes or standards that support such an increase in the general deformation limit.

In response to part (a) of RAI 3.9-149 S01, the applicant stated that, if GEH planned to perform any of the reactor internal structures qualification by experimental method, in accordance with equation b of Table 3.9-4, it will provide all of the supporting data to the staff for approval before using the equation. The applicant further stated that the neutron fluence data for significant internal components, such as the shroud, top guide, and core plate, can be found in Section 4.0 of the ESBWR neutron fluence evaluation, which is available for the NRC to review at the GEH licensing offices in Washington, DC, or Wilmington, NC. The staff finds this part of the response acceptable. Additionally, Chapters 4 and 5 of DCD Tier 2 address the radiation effects for the significant internal components. However, these chapters do not address the radiation effects for threaded fasteners for the ESBWR vessel internals. Section 3.9.5.3.6.3 of this report, which evaluates the response to RAI 3.9-245, further discusses this issue.

As a response to part (b) of the RAI, the applicant referred to its response to RAI 3.9-148. Since the staff found the response to the part of RAI 3.9-148 related to the safety factors defined in DCD, Tier 2, Section 3.9.5.4, acceptable, it found the response to RAI 3.9-149(b) acceptable.

With respect to part (c) of the RAI, the applicant stated that the general deformation can only be increased if sufficient, NRC-approved experimental data are available. ASME Code, Section III, Subsection NG, supports the increase in the ASME limit. Subparagraph NG-3224.6 states that any deformation limits prescribed by the design specification must be considered. The applicant also stated that the applicant is committed to obtain NRC approval before using the increased limit. Therefore, all aspects of RAI 3.9-149 were closed.

3.9.5.3.6.2 Reactor Pressure Vessel Internals Vibration Tests

Since no preoperational FIV testing of the ESBWR will occur because it operates in a natural recirculation mode (as noted in DCD, Tier 2, Section 3.9.2.4), the staff asked the applicant, in RAI 3.9-150, to discuss how the FEM computed natural vibration modes (vibration predictions) of the reactor internal components will be correlated with test data, as specified in SRP Section 3.9.5 and SRP Section 3.9.2, Item 4.

In its response to RAI 3.9-150, dated November 22, 2006, the applicant explained that, before startup testing, FEMs of the reactor internal components will be constructed and analyzed for their natural frequencies and mode shapes. Dynamic acceptance criteria for all accelerometers and strain gauges to be placed on the components will be developed based on the FEM results. In addition, impact hammer tests will be conducted before startup on all instrumented components with an open reactor vessel at ambient conditions. The test results will be used to guide FEM revisions if they are deemed necessary.

The applicant’s response states that impact tests will be performed for the first ESBWR. In RAI 3.9-150 S01, the staff asked the applicant to address in the DCD impact tests for the first and subsequent ESBWR plants. In response to RAI 3.9-150 S01, in a letter dated November 19, 2007, the applicant explained that the objective of the first ESBWR reactor internals (except steam dryer) hammer tests is to identify the natural frequencies, mode shapes, and modal damping of the components of interest. The natural frequencies and mode shapes will be compared with those calculated using FEMS. If the calculated natural frequencies and mode shapes differ significantly from those obtained from the hammer test, then the FEMs will be refined such that the natural frequencies and mode shapes are in better agreement. The hammer test results will also serve as verification that the FEMs represent the ESBWR components realistically. For ESBWR plants subsequent to the first one, no hammer tests are planned because it is expected that the design of the RPV internal structures in subsequent ESBWRs will be identical to that of the first ESBWR. The staff found the response acceptable because the applicant will validate its FEMs using the hammer test results. Therefore, this RAI was closed.

3.9.5.3.6.3 Potential Effects of Environmental Degradation Over a 60-Year Design Life

In DCD Section 3.9.5, Revision 5, the applicant stated that the ESBWR reactor plant design life is based on 60 years of plant operation. Therefore, according to Appendix A to 10 CFR Part 50, GDC 4, the RPV internal structures, including the steam dryer, should be designed to accommodate the effects of the environmental conditions associated with normal plant operation for a duration of 60 years. In RAI 3.9-245, the staff requested that the applicant describe the environmental conditions inside the reactor vessel and explain how the design of the reactor vessel internals accounts for potential degradation from environmental effects. The staff also asked the applicant to discuss potential degradation caused by environmental effects, such as intergranular and irradiation-assisted stress-corrosion cracking of SS and Inconel components, thermal embrittlement of cast SS components, and fatigue.

In its response to RAI 3.9-245, the applicant stated that the susceptibility of the reactor internal components to intergranular stress-corrosion cracking (IGSCC), irradiation-assisted stress-corrosion cracking (IASCC) and thermal aging would be low during the ESBWR design life of 60 years because the normal operating conditions inside the reactor vessel are consistent with previous BWR designs. In addition, the vessel internals, including steam dryers, are made of IGSCC-resistant materials. The use of cast SS materials is limited to Grade CF3 material for which thermal embrittlement is not a potential degradation concern. DCD Sections 5.2.3.2.2 and 4.5.2.1 address IASCC considerations. However, in DCD Sections 4.5.2 and 5.2.3.2, the applicant did not address the issue of radiation-induced loss of fracture toughness of the internal materials and stress relaxation of the bolts used to fasten the reactor internal components. In RAI 3.9-245 S01, the staff requested that the applicant explain whether the radiation-induced loss of fracture toughness of the internals materials and stress relaxation of the bolts would challenge the integrity of ESBWR reactor internals during the design life of 60 years.

In its response to RAI 3.9-245 S01 regarding the loss of fracture toughness, the applicant stated that the internal components being used in the ESBWR are bounded by the experience and levels of irradiation of current operating BWRs. As stated in DCD Sections 4.5.2 and 5.2.3.2.2, the ESBWR design incorporates materials and fabrication processes, as well as design features, to minimize welds and the potential for cracking. Therefore, radiation-induced loss of fracture toughness of the RPV internal structure materials and the stress relaxation of the bolts will not challenge the structural integrity of ESBWR reactor internals during its design life. The staff finds this response acceptable, because (a), the ESBWR RPV internals incorporate design features which tend to reduce degradation from irradiation, and (b), the irradiation levels during the 60-year design life of the RPV Internals threaded fasteners are within acceptable levels, as further discussed below.

Regarding stress relaxation of the bolts, the applicant stated that Section 3.9.3.9 of the DCD addressed radiation effects for threaded fasteners. In addition, the design process for the reactor internal components includes the effects of stress relaxation from irradiation on threaded fasteners. However, the staff did not find this information in DCD Section 3.9.3.9 or in DCD Chapters 4 and 5. Consequently, during an audit held in the applicant's offices on August 25, 2009, the staff requested the following information as NRC Audit Comment 17 in the NRC's "Report of the August 25, 2009 NRC Staff Audit on ESBWR RPV Internals," issued September 15, 2009:

(i) Locations of threaded fasteners used for the ESBWR RPV internals. What are the materials?

(ii) Provide a revised drawing of the connection between the chimney, shroud and top guide.

(iii) What is the estimated end-of-life fluence for these fasteners?

(iv) What may be the maximum radiation-induced stress relaxation? Will it cause loosening of the threaded fasteners?

(v) Are these fasteners susceptible to IASCC during the 60 years of service life?

(vi) What may be the loss of fracture toughness at the end of 60-year service life? Will it challenge the structural integrity of the fasteners?

In its response to NRC Comment 17, the applicant stated that the threaded fasteners for the core plate and top guide are the only fasteners that are located such that the effects of neutron radiation exposure are potentially significant. The material for these fasteners is Type XM-19 SS. The conservative estimates of axially averaged fast neutron fluence (E > 1 million electron volts) at peak azimuth for the ESBWR top guide studs and core plate studs at the end of 54 effective-full power years (EFPYs) are, respectively, 2.3×10^{19} neutrons per square centimeter (n/cm^2) and 1.0×10^{20} n/cm^2, and the corresponding stress relaxation are 8 percent and 22 percent. Since the core plate stud receives a larger fluence than the top guide stud, it is limiting. The design analysis of these fasteners ensures that sufficient preload is applied to prevent lift off after accounting for thermal and irradiation-induced relaxation over the design life. Additional margin is applied to these end-of-life load relaxation factors to ensure that loosening does not occur from vibration or other potential relaxation mechanisms.

In addition, the applicant stated that, since the IASCC threshold for SS is 5×10^{20} n/cm^2, IASCC is not considered a plausible mechanism for these fasteners. Similarly, loss of fracture toughness is not a concern for these fasteners because the threshold for any significant loss of fracture toughness is 2×10^{20} n/cm^2. The staff finds the response only partially acceptable. The applicant stated that the average axial fluence would not exceed the threshold for IASCC and loss of fracture toughness, but the response does not ensure that the peak values of the axial fluence for these fasteners would not exceed the thresholds. Thus, in RAI 3.9-245 S02, the staff requested the information about the peak fluence values for these fasteners. The staff also requested a comparison of fast neutron fluences for these fasteners in the ESBWR, ABWR, and operating reactors and an evaluation of the need for a surveillance program to monitor the fast neutron fluence for the studs to ensure that it remains below the threshold values for IASCC and loss of fracture toughness.

In its response to RAI 3.9-245 S02, the applicant stated that the peak fast neutron fluence for the top guide fasteners is conservatively estimated to be 8.9×10^{19} n/cm^2 at the end of 54 EFPYs, which is lower than the thresholds for IASCC and fracture toughness loss. Therefore, the top guide fasteners are not susceptible to IASCC and loss of fracture toughness during the 60-year design life.

The peak fast neutron fluence for the core plate fasteners is conservatively estimated to be 3.1×10^{20} n/cm^2 at the end of 54 EFPYs, which is lower than the thresholds for IASCC. Although the peak fluence is higher than the threshold for loss of fracture toughness, it is within the fluence range in which fully ductile fracture methods can be used for evaluating austenitic SS. In the vicinity of this fluence level, Type XM-19 SS retains significant tensile elongation and, therefore, any loss of fracture toughness with small fluence increases is likely to be small. Fracture toughness property measurements for material irradiated at higher fluence have confirmed high toughness as discussed in the Electric Power Research Institute's report, Boiling Water Reactor Vessel and Internals Project (BWRVIP)-66, "BWR Vessel and Internals Project, Review of Test Data for Irradiated Stainless steel Components (BWRVIP-66)," issued March 1999. Therefore, the top guide fasteners are not susceptible to IASCC and significant loss of fracture toughness during the 60-year design life. The staff finds the response acceptable, because the neutron fluence data for the RPV internals threaded fasteners demonstrate that the irradiation levels are below the threshold above which material degradation would be of concern.. The applicant has revised DCD, Tier 2, Section 5.3.2.1 and Table 5.3-4, to include this information about the fluence levels for the fasteners. The staff finds these revisions in Chapter 5 acceptable because ESBWR RPV fluence analysis results are also presented.

The applicant stated that it does not plan to include any surveillance program to address the concerns for IASCC and loss of fracture toughness because the peak fluence value at the ESBWR core plate stud is expected to be similar to that of ABWR and BWR/6 plants having comparable power ratings. The staff found this response acceptable, because operating experience from reactors with comparable fluence levels do not indicate the need for a specific surveillance program for these RPV internals components. Therefore, all aspects of RAI 3.9-245 were closed.

3.9.5.3.7 Combined License Information

The staff finds that the applicant has adequately identified the information regarding the design of reactor vessel internals that the COL applicant will provide.

In RAI 3.9-151(a), the staff asked the applicant to describe the information that the first COL applicant and subsequent COL applicants need to provide, at the time of application, related to reactor vessel internals, including the CS structures, beyond the information specified in DCD, Tier 2, Section 3.9.9.1. In addition, in RAI 3.9-151(b), the staff asked the applicant to describe the plans to confirm the stress analysis with respect to steam dryer instrumentation for ESBWRs to be constructed after the prototype.

In its response to RAI 3.9-151, dated November 22, 2006, the applicant stated the following:

> The program that the applicant intends to complete pertaining to FIV of reactor internal components is explained in NEDE-33259P. This plan includes the completion of analysis for the remaining reactor internal components, and the details of the measurement and inspection program to be implemented at the startup of the first ESBWR plant. The applicant's plan is to complete this work in 2007 prior to submittal of the first COL submittal. Regarding the steam dryer FIV program, the applicant is planning to implement design features that will reduce the FIV susceptibility of the steam dryer, and commitments related to testing at subsequent ESBWR plants is not appropriate until all the evaluation work is complete.

The applicant's response to RAI 3.9-151(a) regarding the program pertaining to FIV of reactor internal components indicates that NEDE-33259P addresses the issue, and the applicant planned to complete the program before the submittal of the first COL application. However, the applicant indicated in the response that it will not change the DCD as a result of this RAI. The staff finds the response unacceptable. In RAI 3.9-151(a) S01, the staff requested that the DCD include the information regarding the program pertaining to FIV of reactor internal components to make the COL applicant aware of it.

The applicant's response to RAI 3.9-151(b) regarding steam dryer instrumentation is incomplete. The applicant did commit to instrument the steam dryer bank hoods, end plates, skirt, drain channels, and support ring in its response to RAI 3.9-73. The applicant should incorporate this information in the DCD. In addition, the applicant should include commitments in the DCD related to the testing of the steam dryer at ESBWR plants after the first. In RAI 3.9-151(b) S01, the staff requested that this information regarding steam dryer instrumentation be included in the DCD**.**

In its response to RAI 3.9-151 S01, the applicant has updated DCD Section 3.9.9.1 to reflect the reactor internal components vibration program. GEH also updated DCD Section 3.9.2.4 and Appendix 3L.4.6 to describe the comprehensive steam dryer vibration program. The dryer in the lead ESBWR plant will be instrumented, as will the MSLs to monitor the acoustic loads and dryer stresses. In subsequent plants, the MSLs will be instrumented, and some instrumentation (pressure transducers) may be installed on the dryers to confirm the accuracy of the dryer loads. The staff found the response acceptable, because the revision to DCD 3.9.9.1 addresses the COL information item for the RPV internals vibration assessment program, and (b), the revision to DCD Appendix 3L addresses the steam dryer and MSL instrumentation required for the prototype ESBWR plant, and for subsequent ESBWR plants. Therefore, all aspects of RAI 3.9-151 were closed.

3.9.5.4 Conclusions

The staff has verified that the applicant provided sufficient information to support the adequacy of the design basis for the ESBWR reactor vessel CS structure and internal structures (reactor internals). The staff concludes that the design of reactor internals is acceptable and meets the requirements of GDC 1, 2, 4, and 10; 10 CFR 50.55a; and 10 CFR Part 52. This conclusion is based on the following findings:

(1) The applicant has met the requirements of GDC 1, 10 CFR 50.55a, and 10 CFR Part 52 by designing the reactor internals to quality standards commensurate with the importance of the safety functions performed. The design procedures and criteria for the reactor internals comply with the requirements of ASME Code, Section III, Subsection NG. The applicant has adequately evaluated the potential adverse flow effects on the reactor internals, including the steam dryer, up to full licensed power conditions.

(2) The applicant has met the requirements of GDC 2, 4, and 10 by designing components important to safety to withstand the effects of normal operation, maintenance, testing, and postulated accidents (including LOCAs) with sufficient margin to maintain their capability to perform safety functions. By incorporating the full requirements of ASME Code, Section III, Subsection NG, for construction of the reactor CS structures, the applicant has designed the reactor internals with appropriate margin to ensure adequate structural support of the reactor core during normal operation, including the effects of anticipated operational occurrences.

    The specified design transients, design and service loadings, and combination of loadings as applied to the design of the reactor internals provide reasonable assurance that during normal operating and postulated accident conditions the consequent deflections and stresses imposed on these structures and components will not exceed allowable stresses and deformation limits for the materials of construction. Limitation of stresses and deformations under such loading combinations is an acceptable basis for the design of these structures and components to withstand the most adverse loading events postulated to occur during service lifetime without loss of structural integrity or impairment of function.

The applicant committed to classification of the reactor internals as a prototype, in accordance with the guidance of RG 1.20, and to provide a milestone for submitting the vibration assessment program commensurate with a prototype classification, including instrumentation and measurement procedures, inspection procedures, and correlation with analytical results. DCD Section 3.9.9-1 lists this commitment as a COL action item. Section 3.9.2 of this report discusses further details of the reactor internals comprehensive vibration assessment program.

In addition, the applicant has committed to perform analysis of the number and locations of the pressure sensors, strain gauges, and accelerometers installed on the steam dryer for startup testing. These evaluations will verify that the startup test instrumentation will provide accurate prediction of the structural response of the steam dryer to those steady-state and anticipated transient conditions that correspond to normal operating conditions, as well as preoperational and initial startup test conditions. DCD, Tier 1, Table 2.1.1-3, lists these commitments as ITAAC 12, 13 and 14.

3.9.6 Functional Design, Qualification, and Inservice Testing Programs for Pumps, Valves, and Dynamic Restraints

3.9.6.1 *Regulatory Criteria*

ESBWR DCD, Tier 2, Section 3.9.3, “ASME Code Class 1, 2, and 3 Components, Component Supports and Core Support Structures,” Section 5.2.2, “Integrity of Reactor Coolant Pressure Boundary,” and Section 6.3.2, “Emergency Core Cooling Systems,” describe the design, qualification, and functional tests of certain major and safety-related active components and supports in the ESBWR. DCD, Tier 2, Section 3.9.6, “Inservice Testing of Pumps and Valves,” discusses inservice testing (IST) of certain safety-related pumps and valves typically designed as ASME BPV Code, Section III, Class 1, 2, and 3. DCD, Tier 2, Section 3.9.3.7, “Component Supports,” specifies that ASME BPV Code, Section III component supports shall be designed, manufactured, installed, and tested in accordance with all applicable codes and standards. Additional DCD Tier 2 sections describe the functional design, qualification, and testing of pumps, valves, and dynamic restraints. The NRC staff based its review of the ESBWR DCD for the functional design, qualification, and IST programs for pumps, valves, and dynamic restraints on compliance with the relevant requirements in 10 CFR 50.55a; 10 CFR Part 50, Appendix A, GDC 1, 2, 4, 14, 15, 37, 40, 43, 46, and 54; 10 CFR Part 50, Appendix B; and 10 CFR 52.47(a)(1)(iv) and 52.97(b)(1).

The acceptance criteria for the NRC review of the ESBWR DCD for the functional design, qualification, and IST programs for pumps, valves, and dynamic restraints include the following:

- Compliance with 10 CFR 50.55a and GDC 1 requires that pumps, valves, and dynamic restraints important to safety be designed, qualified, fabricated, installed, tested, and inspected to quality standards commensurate with the importance of the safety functions to be performed. Meeting the requirements of 10 CFR 50.55a and GDC 1 provides assurance that pumps, valves, and dynamic restraints important to safety are capable of performing their intended safety functions.

- Compliance with GDC 2 requires that components important to safety be designed to withstand the effects of expected natural phenomena, combined with appropriate effects of normal and accident conditions, without loss of capability to perform their safety functions. Meeting the requirements of GDC 2 provides assurance that pumps, valves, and dynamic restraints important to safety are capable of withstanding the effects of expected natural phenomena while performing their safety functions during and after the occurrence of those phenomena, as applicable.

- Compliance with GDC 4 requires that components important to safety be designed to accommodate the effects of, and be compatible with, the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents. Meeting the requirements of GDC 4 provides assurance that the components are capable of withstanding those effects and continuing to be capable of performing their intended safety functions.

- Compliance with GDC 14 requires that the RCPB demonstrate an extremely low probability of abnormal leakage, rapidly propagating failure, and gross rupture. Meeting the requirements of GDC 14 provides assurance that RCPB components will have an extremely low probability of leakage or failure.

- Compliance with GDC 15, “Reactor Coolant System Design,” requires that the reactor coolant system (RCS) be designed with sufficient margin to ensure that the design conditions of the RCPB are not exceeded during any condition of normal operation, including anticipated operational occurrences. Meeting the requirements of GDC 15 provides assurance that the RCS will perform its design functions.

- Compliance with GDC 37, “Testing of Emergency Core Cooling System,” requires that the ECCS be designed to permit appropriate periodic and functional testing to ensure the structural and leak-tight integrity of its components, as well as the operability and performance of the active components of the system. Meeting the requirements of GDC 37 provides assurance that components important to safety are capable of performing their intended safety function.

- Compliance with GDC 40, “Testing of Containment Heat Removal System,” requires that the containment heat removal system be designed to permit appropriate periodic and functional testing to ensure the structural and leak-tight integrity of its components, as well as the operability and performance of the active components of the system. Meeting the requirements of GDC 40 provides assurance that components important to safety are capable of performing their intended safety function.

- Compliance with GDC 43, “Testing of Containment Atmosphere Cleanup Systems,” requires that the containment atmospheric cleanup system be designed to permit appropriate periodic and functional testing to ensure the structural and leak-tight integrity of its components and the operability and performance of the active components of the system. Meeting the requirements of GDC 43 provides assurance that components important to safety will perform their safety intended function.

- Compliance with GDC 46, “Testing of Cooling Water System,” requires that the cooling water system be designed to permit appropriate periodic and functional testing to ensure the structural and leak-tight integrity of its components and the operability and performance of the active components of the system. Meeting the requirements of GDC 46 provides assurance that components important to safety are capable of performing their intended safety function.

- Compliance with GDC 54, “Systems Penetrating Containment,” requires that piping systems penetrating the primary reactor containment be provided with leak detection and isolation capabilities. Such piping systems shall be designed with a capability to test the operability of the isolation valves periodically to determine if valve leakage is within acceptable limits. Meeting the requirements of GDC 54 provides assurance that valves important to safety are capable of performing their intended safety function.

- Compliance with 10 CFR Part 50, Appendix B, requires that applicants establish and maintain an acceptable QA program, including design, testing, and records control. Meeting the requirements of 10 CFR Part 50, Appendix B, provides assurance that design, tests, and documentation, related to functional design, qualification, and IST programs for pumps, valves, and dynamic restraints, will comply with established standards and criteria, thereby ensuring that such equipment will be capable of performing its intended safety functions.

- Compliance with 10 CFR 50.55a(f) for pumps and valves, and 10 CFR 50.55a(g) for dynamic restraints, requires that applicable pumps, valves, and dynamic restraints whose function is required for safety be assessed for operational readiness in accordance with the applicable revision to the ASME Code for Operation and Maintenance of Nuclear Power Plants (OM Code). In 10 CFR 50.55a(b)(3), the regulations take exception to, or supplement, the ASME OM Code provisions for these components. Meeting the requirements of 10 CFR 50.55a(f) and (g) and 10 CFR 50.55a(b)(3) provides assurance that applicable pumps, valves, and dynamic restraints important to safety are capable of performing their intended safety function. The applicable ASME Codes for IST programs are as follows:

  – Pumps and valves in facilities with a construction permit issued on or after November 22, 1999, must be designed and be provided with access to enable the performance of IST to assess operational readiness as described in editions and addenda of the ASME OM Code incorporated by reference in 10 CFR 50.55a at the time the construction permit or design certification under 10 CFR Part 52, “Licenses, Certifications, and Approvals for Nuclear Power Plants,” was issued.

  – IST programs implemented during the initial 120-month interval must comply with the requirements in the latest edition and addenda of the OM Code incorporated by reference in 10 CFR 50.55a on the date 12 months before the date of issuance of the operating license under 10 CFR Part 50, or 12 months before the date scheduled for initial fuel loading under 10 CFR Part 52 for a COL.

  – IST programs implemented during the successive 120-month intervals must comply with the requirements of the latest edition and addenda of the OM Code incorporated by reference in 10 CFR 50.55a 12 months before the start of the 120-month interval.

- Compliance with 10 CFR 52.47(a)(21) requires that applications for design certification contain proposed technical resolutions of the unresolved safety issues and medium- and high-priority generic safety issues identified in the version of NUREG-0933 current on the date 6 months before application and that are technically relevant to the design.

- Compliance with 10 CFR 52.97 requires that the Commission identify within a COL under 10 CFR Part 52 the inspections, tests, and analyses that the licensee shall perform, and the acceptance criteria that, if met, are necessary and sufficient to provide reasonable assurance that the facility has been constructed and will be operated in conformity with the license, the provisions of the Atomic Energy Act, and the Commission's rules and regulations.

In evaluating the ESBWR design certification application for compliance with the above regulatory criteria, the NRC staff followed guidance provided in SRP Section 3.9.6 (Rev. 3), "Functional Design, Qualification, and Inservice Testing Programs for Pumps, Valves, and Dynamic Restraints." The staff also considered guidance provided in applicable Commission SECY papers, Commission SRM, GLs, RGs, and regulatory issue summaries. These documents are discussed in more detail as part of the staff evaluation in this section of this report.

3.9.6.2 *Summary of Technical Information*

ESBWR DCD, Tier 2, Section 3.9, "Mechanical Systems and Components," describes the functional design, qualification, and IST programs for pumps, valves, and dynamic restraints used in the ESBWR. For example, DCD, Tier 2, Section 3.9.2, "Dynamic Testing and Analysis of Systems, Components, and Equipment," addresses criteria, testing procedures, and dynamic analyses employed to ensure the structural and functional integrity of piping systems, mechanical equipment, reactor internals, and their supports under vibratory loadings. DCD, Tier 2, Section 3.9.2.2, "Seismic Qualification of Safety-Related Mechanical Equipment (Including Other RBV Induced Loads)," discusses the testing or analytical qualification of the safety-related major mechanical equipment and other ASME BPV Code, Section III, equipment including equipment supports.

ESBWR DCD, Tier 2, Section 3.9.3, "ASME Code Class 1, 2 and 3 Components, Component Supports and Core Support Structures," discusses the structural integrity of pressure-retaining components, their supports, and core support structures, which are designed in accordance with the rules of the ASME BPV Code, Section III, and the GDC of 10 CFR Part 50, Appendix A. DCD, Tier 2, Section 3.9.3.5, "Valve Operability Assurance," specifies that valves are functionally qualified to perform their active safety-related functions. For valve designs developed for the ESBWR that were not previously qualified, the qualification programs will meet the provisions of ASME Standard QME-1-2007, "Qualification of Active Mechanical Equipment Used in Nuclear Power Plants." For valve designs previously qualified to standards other than ASME QME-1-2007, DCD, Tier 2, Section 3.9.3.5, specifies key aspects of QME-1-2007 that will be used to confirm the functional capability of those valves. DCD, Tier 2, Section 3.9.3.5, also states that functional qualification of valves will address key lessons learned from industry efforts and provides examples of those lessons learned.

DCD, Tier 2, Section 3.9.3.5.1, "Major Active Valves," describes the qualification of specific valves, including main steam isolation valves (MSIVs), main steam safety/relief valves (SRVs), standby liquid control (SLC) injection valves, and depressurization valves (DPVs). DCD, Tier 2, Section 3.9.3.5.2, "Other Active Valves," discusses the qualification of additional safety-related active valves that are classified as ASME Code Class 1, 2, or 3, to perform their mechanical motion during dynamic loading conditions. DCD, Tier 2, Section 3.9.3.6, "Design and Installation of Pressure Relief Devices," discusses main steam SRVs, other safety/relief and vacuum breaker valves, and DPVs.

ESBWR DCD, Tier 2, Section 3.9.3.7, "Component Supports," specifies that ASME BPV Code, Section III, component supports shall be designed, manufactured, installed, and tested in accordance with all applicable codes and standards. DCD, Tier 2, Section 3.9.3.7.1, "Piping Supports," specifies that supports and their attachments for essential Code Class 1, 2, and 3 piping are designed in accordance with the ASME BPV Code, Section III, Subsection NF, up to the interface of the building structure, with jurisdictional boundaries as defined by Subsection NF. DCD, Tier 2, Section 3.9.3.7.1, states that the design of the nuclear power plant SSCs will provide access for the performance of IST and inservice inspection as required by the applicable ASME Code.

With respect to snubbers, DCD, Tier 2, Section 3.9.3.7.1, states that the inservice inspection and testing plan of snubbers is prepared in accordance with the requirements of the ASME Code and the applicable industry and regulatory guidance, including RG 1.192, "Operation and Maintenance Code Case Acceptability, ASME OM Code." DCD, Tier 2, Section 3.9.3.7.1, describes the design and testing of snubbers including applicable codes and standards. DCD, Tier 2, Section 3.9.3.7.1, specifies that the COL applicant will provide a full description of the snubber preservice and inservice inspection and test programs and a milestone for program implementation. The COL licensee will prepare a plant-specific table to be included as part of the inspection and test program for snubbers.

DCD, Tier 2, Section 3.9.6, "Inservice Testing of Pumps and Valves," discusses the IST program for pumps and valves for ESBWR plants. IST of certain ASME Code, Section III, Class 1, 2, and 3 pumps and valves is performed in accordance with the ASME OM Code as required by 10 CFR 50.55a(f), including limitations and modifications given in the regulations. DCD, Tier 2, Table 1.9-22, "Industrial Codes and Standards Applicable to ESBWR," specifies the ASME OM Code, 2001 Edition through 2003 Addenda, as applicable to the ESBWR. The design of the nuclear power plant SSCs will provide access for performance of IST and inservice inspection required by the applicable ASME Code. IST of pumps and valves is to be performed in conformance with the relevant requirements of 10 CFR Part 50, Appendix A, GDC 1, 37, 40, 43, 46, and 54, and 10 CFR 50.55a(f). DCD, Tier 2, Table 3.9-8, "Inservice Testing," provides a generic list of the valves to be included in the IST program for an ESBWR plant, including the valve number; quantity; description; valve and actuator type; ASME Code Class and category; valve function; normal, safety, and fail-safe positions; containment isolation function; and test parameters and frequencies.

The IST program includes periodic tests and inspections that demonstrate the operational readiness of safety-related components to perform their safety-related functions. DCD, Tier 2, Section 3.9.6, outlines the IST program based on the requirements of the ASME OM Code. DCD, Tier 2, Section 3.9.3.7.1, outlines the requirements for preservice and inservice examination and testing of dynamic restraints as defined in the ASME OM Code, Subsection ISTD. The IST program does not include pumps because the ESBWR design does not rely on pumps to mitigate the consequences of an accident or to maintain the reactor in a safe-shutdown condition.

Section 3.9.9, "COL Information," of ESBWR DCD Tier 2 specifies additional information to be provided by the COL applicant. For example, COL Information Item 3.9.9-3-A, "Inservice

Testing Programs," states that the COL applicant shall provide a full description of the IST program and a milestone for full program implementation as identified in DCD Section 3.9.6.1. COL Information Item 3.9.9-4-A, "Snubber Inspection and Test Program," states that the COL applicant shall provide a full description of the snubber preservice and inservice inspection and testing programs and a milestone for program implementation, including development of a data table identified in DCD Section 3.9.3.

ESBWR DCD, Tier 2, Section 3.10, "Seismic and Dynamic Qualification of Mechanical and Electrical Equipment," addresses methods of test and analysis employed to ensure the operability of mechanical and electrical equipment under the full range of normal and accident loadings to ensure conformance with the NRC regulations. DCD, Tier 2, Section 14.2.8.1.42, "Expansion, Vibration and Dynamic Effects Preoperational Test," includes provisions to verify that important components and piping are properly installed and supported such that expected steady-state and transient vibration and movement caused by thermal expansion does not result in excessive stress or fatigue to safety-related plant systems and equipment. The DCD specifies that vibration testing is performed on system components and piping during preoperational functional and flow testing. The testing will be performed in accordance with ANSI/ASME OM Code, Part 3, "Requirements for Preoperational and Initial Start-up Vibration Testing of Nuclear Power Plant Piping Systems," and will include visual observation and local and remote monitoring in specific steady-state operating modes and during transients (such as pump starts and stops, valve stroking, and significant process flow changes). Visual observations will confirm that excessive vibration is not occurring during plant startup. Further, measured vibration amplitudes must be within acceptable levels to ensure that fatigue failures will not occur over the life of the plant based on expected steady-state and transient operation.

ESBWR DCD Tier 1 includes ITAAC to provide assurance that important plant systems and components are capable of performing their design-basis functions. For example, DCD, Tier 1, Table 2.1.2-3, "ITAAC for the Nuclear Boiler System," includes ITAAC for feedwater isolation valves, main steam SRVs (e.g., applicable SRV ITAAC are 17, 18, 19, 20, 21, 22, and 23), main steam safety valves, and vacuum breakers. DCD, Tier 1, Table 2.2.4-6, "ITAAC for the Standby Liquid Control System," includes ITAAC for power-operated valves (POVs), check valves (CVs), and squib valves in the SLC system. DCD, Tier 1, Table 2.4.2-3, "ITAAC for the Gravity-Driven Cooling System (GDCS)," includes ITAAC for squib valves and CVs in the GDCS. DCD, Tier 2, Section 14.3.3.1, "Design of Piping Systems and Components," states that ITAAC will ensure that design reports for piping systems and ASME components are in order and will verify that the ASME Code requirements are met.

ESBWR DCD, Tier 2, Section 1.11, "Technical Resolutions of Task Action Plan Items, New Generic Issues, New Generic Safety Issues and Chernobyl Issues," indicates the technical resolutions of unresolved safety issues and new generic issues, medium- and high-priority generic safety issues, which are technically relevant to the ESBWR. For example, DCD Tier 2 includes Table 1.11-1, "Resolutions to NUREG-0933 Table II Task Action Plan Items, New Generic Issues, Human Factors Issues and Chernobyl Issues." DCD, Tier 2, Appendix 1A, "Response to TMI (Three Mile Island) Related Matters," includes Table 1A-1, "TMI Action Plan Items," that addresses the TMI Action Plan Items listed in 10 CFR 50.34(f). DCD, Tier 2, Appendix 1C, "Industry Operating Experience," includes Table 1C-1, "Operating Experience Review Results Summary—Generic Letters," and Table 1C-2, "Operating Experience Review Results Summary—IE Bulletin," which indicate the results of the applicant's review of NRC GLs and bulletins as applicable to the ESBWR.

3.9.6.3 *Staff Evaluation*

The NRC regulations require that safety-related equipment used in nuclear power plants be designed, fabricated, erected, tested, and maintained to quality standards commensurate with the importance of the safety functions they must perform. Design and qualification tests before installation will ensure that the equipment will operate, as intended, under its design-basis conditions. Testing before startup will verify the performance of the component in the "as-installed" configuration. Periodic IST is necessary to detect component degradation and to verify the continued capability of plant components to function under design-basis conditions.

The development of a plant-specific IST program falls outside the scope of design certification and remains the responsibility of the COL applicant. At the design certification stage, it is necessary to ensure that IST provisions of the ASME Code referenced in the DCD can be performed and that the ESBWR systems and components provide access to permit the performance of testing pursuant to 10 CFR 50.55a. The Commission's SRM, dated September 11, 2002, for Commission Paper SECY-02-0067, "Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC) for Operational Programs (Programmatic ITAAC)," dated April 5, 2002, stated that ITAAC for an operational program are unnecessary if the program and its implementation are fully described in the COL application and found to be acceptable by the NRC. The Commission also stated that the burden is on the COL applicant to provide the necessary and sufficient programmatic information for approval of the COL without ITAAC.

In its May 14, 2004, SRM for SECY-04-0032, "Programmatic Information Needed for Approval of a Combined License Without Inspections, Tests, Analyses and Acceptance Criteria," dated February 26, 2004, the Commission defined "fully described" as meaning that the program is clearly and sufficiently described in terms of the scope and level of detail to allow a reasonable assurance finding of acceptability. The Commission also noted that required programs should always be described at a functional level and at an increasing level of detail where implementation choices could materially and negatively affect the program effectiveness and acceptability. SECY-05-0197, "Review of Operational Programs in a Combined License Application and Generic Emergency Planning Inspections, Tests, Analyses, and Acceptance Criteria," dated October 28, 2005, summarizes the NRC position regarding the full description of operational programs to be provided by COL applicants.

RG 1.206, "Combined License Applications for Nuclear Power Plants (LWR Edition)," provides guidance in Section C.IV.4 for COL applicants with respect to fully describing plant operational programs. The applicant addressed these policy issues in its response to RAI 3.9-198, which the staff tracked as an open item in the SER with open items. In particular, the applicant revised ESBWR DCD Tier 2 to specify in COL Information Items 3.9.9-3-A and 3.9.9-4-A that the COL applicant shall provide a full description of the IST program and the snubber preservice and inservice inspection and testing programs, respectively, and milestones for implementation of those programs. The NRC staff finds these COL information items consistent with Commission guidance instructing the COL applicant to provide a full description of the IST operational program. Therefore, this issue was resolved for the ESBWR design certification, and RAI 3.9-198 and the associated open item were closed. As part of a COL application review, the NRC will evaluate the full description of the functional design, qualification, and IST program for pumps, valves, and dynamic restraints provided by the COL applicant to supplement the general program description provided in the ESBWR DCD.

The NRC staff reviewed the ESBWR design certification application for compliance with the NRC regulations and the applicable edition and addenda of the ASME Code for the functional design, qualification, and IST programs for pumps, valves, and dynamic restraints to be used in

ESBWR nuclear power plants. In performing its review, the staff followed the guidance in NRC SRP Section 3.9.6 to evaluate the ESBWR DCD for the consideration of lessons learned based on operating experience from plant components at current nuclear power plants and the results of NRC and industry research programs. Based on its review including specific aspects discussed below, the NRC staff finds the DCD provisions for the functional design and qualification of applicable plant components, and the generic description of the IST program for pumps, valves, and dynamic restraints to be used in an ESBWR nuclear power plant (including accessibility for the performance of IST activities) to satisfy the NRC regulations and to adequately consider operating experience and research results for a design certification application. Therefore, the staff finds the ESBWR DCD to be acceptable with respect to the functional design, qualification, and IST programs for pumps, valves, and dynamic restraints for the ESBWR design certification.

3.9.6.3.1 Scope

The ESBWR DCD, Tier 2, Revision 7, specifies that the IST program for pumps, valves, and dynamic restraints is based on the requirements of the ASME OM Code and its applicable subsections and appendices. DCD, Tier 2, Table 1.9-22, and Section 3.9.10, "References," specify the 2001 Edition with the 2003 Addenda of the ASME OM Code as applicable to the ESBWR. The NRC regulations in 10 CFR 50.55a(b)(3) incorporate by reference this edition and addenda to the ASME OM Code, with specific limitations and modifications. The NRC staff finds the application of the ASME OM Code, 2001 Edition with the 2003 Addenda, in accordance with the limitations and modifications in 10 CFR 50.55a, to be acceptable in describing the IST program for pumps, valves, and dynamic restraints for the ESBWR design certification. As discussed above, COL applicants must meet additional requirements with respect to the description of the IST program, which is to be provided as part of a COL application. In the following paragraphs of this section of this report, the staff discusses relevant aspects of its review of the ESBWR design certification application.

Paragraph ISTA-1100 of the ASME OM Code specifies that preservice and IST requirements be applied to pumps, valves, and dynamic restraints that are required to perform a specific function in shutting down a reactor to the safe-shutdown condition, in maintaining the safe-shutdown condition, or in mitigating the consequences of an accident. SRP Section 3.9.6 also states that other pumps, valves, and dynamic restraints not categorized as ASME Code Class 1, 2, or 3 might be included in the IST program if the NRC staff considers them to be safety-related. In RAI 3.9-152, the NRC staff requested that the applicant identify the safety-related systems for the ESBWR. In its response to RAI 3.9-152, the applicant referred to DCD, Tier 2, Table 3.6-1, "Safety-Related Systems, Components, and Equipment for Postulated Pipe Failures Inside Containment," and Table 3.6-2, "Safety-Related Systems, Components, and Equipment for Postulated Pipe Failures Outside Containment." In RAI 3.9-152 S01, the staff requested that the applicant clarify the safety-related systems that are used for shutting down the reactor and maintaining the reactor in a stable safe shutdown condition initially described in its response to RAI 3.9-152. In its response to RAI 3.9-152 S01, the applicant referred to specific sections in the ESBWR DCD for discussions of safety-related systems. In RAI 3.9-197, the staff requested that the applicant provide a list of systems used for shutting down the reactor and maintaining the reactor in a stable safe shutdown condition (rather than referencing specific DCD sections). In its response to RAI 3.9-197, the applicant provided a list of safety-related ESBWR systems, including the nuclear boiler system, isolation condenser system, control rod drive system, standby liquid control system, remote shutdown system, gravity-driven cooling system, containment system, and passive containment cooling system. Based on its review of the ESBWR design certification application, the NRC staff finds the scope of the IST program provided in ESBWR DCD, Tier 2, Table 3.9-8, to be consistent with the identified safety-related systems in the ESBWR DCD. Therefore, this issue was resolved for the ESBWR design certification, and RAI 3.9-152 was resolved. The COL applicant will need to confirm the program scope as part of its development of a full description of the IST program on a plant-specific basis. The COL licensee will finalize the scope of the IST program, and the NRC will inspect the IST program during plant construction and operation.

In RAI 3.9-153, the NRC staff requested that the applicant describe the method to be applied for the functional design and qualification of safety-related pumps in the ESBWR. In its response to RAI 3.9-153, the applicant stated that the ESBWR design does not include safety-related pumps. In its response to RAI 3.9-152, the applicant stated that postaccident long-term decay heat removal is performed by non-safety-related systems, which is acceptable as noted in Commission Paper SECY-94-084, "Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems in Passive Plant Designs," dated March 28, 1994. According to SECY-94-084, non-safety-related systems are acceptable for the decay heat removal function for periods longer than 72 hours after the accident. Therefore, these non-safety-related pumps and valves associated with postaccident decay heat removal are not subject to the IST requirements, because they are required only after the first 72 hours of a DBA. In that the ESBWR design does not use pumps to mitigate the consequences of a DBA, or to achieve or maintain the reactor in a safe-shutdown condition for the first 72 hours following a plant event, the NRC staff considers the absence of pumps from the IST program for an ESBWR plant to be acceptable. Therefore, RAI 3.9-153 was resolved. The treatment of specific pumps will be addressed as part of the program for the regulatory treatment of non-safety systems (RTNSS) discussed in Chapter 22 of this report.

ESBWR DCD, Tier 2, Section 1.11, with Table 1.11-1, indicates the technical resolutions of unresolved safety issues, new generic issues, and new medium- and high-priority generic safety issues that are technically relevant to the ESBWR. DCD, Tier 2, Appendix 1A, includes Table 1A-1, which addresses the TMI Action Plan Items listed in 10 CFR 50.34 (f). DCD, Tier 2, Appendix 1C, includes Tables 1C-1 and 1C-2, which indicate the results of the applicant's review of NRC GLs and bulletins applicable to the ESBWR. The NRC staff has reviewed the consideration of the TMI Action Plan Items, unresolved safety issues, generic issues, generic safety issues, GLs, and bulletins in the ESBWR DCD. These include, for example, NUREG-0933, Task Action Plan A-13; GL 89-10, "Safety-Related Motor-Operated Valve Testing and Surveillance," dated June 28, 1989; GL 95-07, "Pressure Locking and Thermal Binding of Safety-Related Power-Operated Gate Valves," dated August 17, 1995; and GL 96-05, "Periodic Verification of Design-Basis Capability of Safety-Related Motor-Operated Valves," dated September 18, 1996; and Bulletin 81-01, "Surveillance of Mechanical Snubbers," dated January 27, 1981. The staff finds that the ESBWR DCD adequately addresses the issues applicable to pumps, valves, and dynamic restraints and discusses specific examples in this report's section.

3.9.6.3.2 Valves

The NRC regulations require that safety-related valves be designed, fabricated, erected, tested, and maintained to quality standards commensurate with the importance of the safety functions they must perform. Design and qualification tests and analysis before installation will ensure that the valve will operate, as intended, under its design-basis conditions. Testing before plant startup will verify the performance of the valve in the "as-installed" configuration. Periodic IST is necessary to detect valve degradation and to verify that the valve's continued capability to function under design-basis conditions is maintained. Several sections of ESBWR DCD Tier 2 address issues related to the functional design, qualification, and IST programs for certain major valves including POVs, CVs, squib valves, SRVs, and DPVs. Based on its review of the specific aspects discussed below, the NRC staff finds that the DCD provisions for the functional design and qualification of valves, and the generic description of the IST program for valves to be used in an ESBWR (including accessibility for IST activities) satisfy the NRC regulations and address lessons learned from valve performance at current nuclear power plants and through NRC and industry research programs. Therefore, the provisions for the functional design, qualification, and IST program for valves are acceptable for the ESBWR design certification.

The applicant stated that specific valve designs had not yet been selected and qualified for most ESBWR safety-related applications in response to an NRC question on squib valve design in RAI 3.9-160 S02. Thus, for its ESBWR design certification review, the NRC staff evaluated the methodologies for the functional design and qualification and IST programs for safety-related valves described in the ESBWR DCD and discussed by the applicant in RAI responses. Per COL Information Items 3.9.9-3-A and 3.9.9-4-A, the COL applicant will be responsible for describing the implementation of the functional design and qualification methodology and providing a full description of the IST program for safety-related valves in support of the NRC review of the COL application. If an ESBWR COL is issued, the NRC staff will perform inspections to evaluate the implementation of the functional design, qualification, and IST programs of safety-related valves during construction and operation of the ESBWR plant.

The NRC staff requested in RAI 3.9-178 that the applicant addresses the lessons learned from past performance issues with valves at operating nuclear power plants as part of the ESBWR DCD provisions for the functional design and qualification of valves. In RAI 3.9-178 S01, the staff requested that the applicant clarify its initial planned revision to the ESBWR DCD regarding the use of ASME Standard QME-1-2007 provided in its response to RAI 3.9-178. In its response to RAI 3.9-178 S01, the applicant discussed its plan to revise the ESBWR DCD to specify the use of ASME Standard QME-1-2007, which incorporates lessons learned from operating experience and research programs for the design and qualification of valves. For example, ASME QME-1-2007 specifies the application of test-based programs under dynamic flow conditions for the functional qualification of POVs to ensure their design-basis capability. ASME QME-1-2007 also addresses the lessons learned from valve operating experience for the design and qualification of gate valves discussed in GL 95-07. Subsequently, the applicant revised ESBWR DCD, Tier 2, Section 3.9.3.5, “Valve Operability Assurance,” to specify that the qualification programs for valve designs developed for the ESBWR that were not previously qualified will meet the requirements of QME-1-2007. For valves that were previously qualified, the ESBWR DCD specifies key features of lessons learned from nuclear power plant operations and research programs included in QME-1-2007 as part of its design specifications. For example, qualification specifications (e.g., design specifications) consistent with Appendix QV-I, “Qualification Specification for Active Valves,” and Appendix QV-A, “Functional Specification for Active Valves for Nuclear Power Plants,” to QME-1-2007 will be prepared for previously qualified valves to ensure that the operating conditions and safety functions for which the valves are to be qualified are communicated to the manufacturer or qualification facility. Suppliers will submit, for the applicant’s review and approval, application reports as described in QME-1-2007 that describe the basis for the application of specific predictive methods and/or qualification test data to a valve application.

The applicant will also perform independent sizing calculations to verify actuator sizing conducted by the valve supplier. In September 2009, the NRC issued Revision 3 to RG 1.100, which accepts the use of the QME-1-2007 standard, with certain staff positions, for the functional design and qualification of safety-related pumps, valves, and dynamic restraints. The

NRC staff finds the provisions in the ESBWR DCD for functional design and qualification of valves to be acceptable for the ESBWR design certification in that the provisions incorporate the lessons learned from valve operating experience and research programs through application of the ASME QME-1-2007 standard for new valve qualification and key features of QME-1-2007 for previously qualified valves, where applied consistently with NRC acceptance of the standard in Revision 3 to RG 1.100.

As part of the NRC staff's consideration of the applicant response to RAI 3.9-178, the NRC conducted an audit of the design and procurement specifications for valves at the applicant's office in Wilmington, NC, in July 2009. The purpose of the audit was to confirm the implementation of the ESBWR DCD provisions for the design and qualification of applicable pumps, valves, and dynamic restraints and to support the full description of the IST and environmental qualification operational programs by the COL applicants. The audit followed the guidelines in the Office of New Reactors Office Instruction NRO-REG-108, Revision 0, "Regulatory Audits," dated April 2, 2009. As discussed in an NRC memorandum dated September 1, 2009 (ADAMS Accession No. ML092390403), the NRC staff reviewed ESBWR DCD IST Table 3.9-8 and several design and purchase specifications for various valve types. The audit identified specific aspects of the ESBWR DCD IST table and component specifications that needed clarification regarding such aspects as the valve types identified in the IST program table and the consideration of lessons learned from valve operating experience. In its response to the audit followup items in a letter dated September 21, 2009, the applicant indicated that the ESBWR DCD IST table and component specifications would be revised to incorporate the clarifications identified during the audit. In a letter dated November 12, 2009, the applicant discussed its review of Revision 3 of RG 1.100 for any necessary modifications to its valve specifications that reference the application of ASME Standard QME-1-2007. As indicated in the applicant's response to the audit followup actions, the ESBWR DCD includes the necessary clarifications to the DCD IST table identified during the audit.

On March 19, 2010, the NRC staff conducted a followup audit at the applicant's office in Washington, DC, to review the implementation of the followup actions specified by the applicant in its letter dated September 21, 2009. Based on this letter and the NRC followup audit on March 19, 2010, the staff considers the applicant to have resolved the audit followup actions related to functional design and qualification of valves in support of the ESBWR design certification application. The staff finds that the applicant is implementing the ESBWR DCD provisions for functional design and qualification of valves in the component specifications in a manner adequate to support the ESBWR design certification. Therefore, RAI 3.9-178 was resolved. The NRC staff may perform further audits of component specifications as part of COL application reviews or COL inspections. In its response to RAI 3.11-41, the applicant indicated that it would update ESBWR DCD, Tier 2, Table 1.9-21, "NRC Regulatory Guide Applicability to ESBWR," to reference Revision 3 of RG 1.100 for its acceptance of ASME Standard QME-1-2007 with the continued use of Revision 2 of RG 1.100 for other applications. As indicated in the RAI response, Revision 7 to ESBWR DCD, Tier 2, Table 1.9-21 references Revision 3 of RG 1.100 for its endorsement of ASME QME-1-2007 with Revision 2 of RG 1.100 used for other applications.

ESBWR DCD, Tier 2, Section 3.9.2, "Dynamic Testing and Analysis of Systems, Components, and Equipment," addresses criteria, testing procedures, and dynamic analyses employed to ensure the structural and functional integrity of piping systems, mechanical equipment, reactor internals, and their supports under vibratory loadings. DCD, Tier 2, Section 3.10, addresses methods of test and analysis employed to ensure the operability of mechanical and electrical equipment under the full range of normal and accident loadings to ensure conformance with the NRC regulations. DCD, Tier 2, Section 14.2.8.1.42, "Expansion, Vibration and Dynamic Effects Preoperational Test," states that its objective is to verify that critical components and piping runs are properly installed and supported such that expected steady-state and transient vibration and movement caused by thermal expansion do not result in excessive stress or fatigue to safety-related plant systems and equipment. Nuclear power plant operating experience has revealed the potential for adverse flow effects that can damage plant components as a result of vibration caused by hydrodynamic loads and acoustic resonance within reactor coolant, steam, and feedwater systems. The COL applicant will be responsible for describing the planned implementation of the provisions in the ESBWR DCD program to address potential adverse flow effects on safety-related valves and dynamic restraints within the IST program in the reactor coolant, steam, and feedwater systems from hydraulic loading and acoustic resonance during plant operation in support of the NRC review of a COL application.

The ASME OM Code specifies quarterly testing as the base testing frequency for valves but allows longer test intervals if quarterly testing is not practical for the plant design. DCD, Tier 2, Table 3.9-8, indicates an IST frequency of every refueling outage for certain valves. In RAI 3.9-159, the staff requested that the applicant provide justification for the testing frequency for each valve. In its response to RAI 3.9-159, the applicant stated that notes at the end of DCD, Tier 2, Table 3.9-8, provide the basis for an alternate frequency when the nominal exercise frequency of 3 months specified in the ASME OM Code, paragraph ISTC-3510, is not satisfied. For example, the bases might be related to location, or operation, where valve damage could result or system shutdown would be necessary. The staff was tracking RAI 3.9-159 as an open item in the SER with open items. In RAI 3.9-159 S01, the staff requested that the applicant provide the bases where the ESBWR design not yet finalized was unable to accommodate quarterly testing of components within the IST Program specified by the ASME OM Code.

In its response to RAI 3.9-159 S01, the applicant revised DCD, Tier 2, Table 3.9-8, to provide the bases for those IST intervals that exceed the quarterly frequency for individual valves. Therefore, RAI 3.9-159 and the associated open item were closed.

The ESBWR DCD references NUREG-1482, Revision 1, "Guidelines for Inservice Testing at Nuclear Power Plants: Final Report," issued March 2005, for the bases for deferral of IST stroke-time testing from quarterly intervals to refueling outage or cold-shutdown intervals for the ESBWR. In RAI 3.9-249, the NRC staff requested that the applicant confirm that the IST program for the ESBWR will satisfy the ASME OM Code IST provisions, consistent with the Commission policy that new reactors be designed to avoid relief from the ASME OM Code. In its response to RAI 3.9-249, the applicant stated that the ESBWR has been designed to avoid the need for relief from the ASME OM Code for inservice testing of valves. The applicant noted that paragraph ISTC-3521 of the ASME OM Code allows the deferral of quarterly exercise testing to refueling outages or cold shutdowns if full-stroke exercising is "not practicable during operation at power." The applicant stated that the ESBWR does not request deferral of quarterly testing in cases where the plant can be reasonably designed to accommodate the testing. The applicant provided a planned change to the ESBWR DCD in response to this RAI. Subsequently, the ESBWR DCD in Section 3.9.6.1.4, paragraph (1), specifies that the deferral of quarterly exercising will consider the ESBWR as a new plant design. The ESBWR DCD also states that the ESBWR is designed to accommodate quarterly stroke testing, where practical. The NRC staff finds that the ESBWR DCD provides assurance that the ESBWR design will accommodate quarterly valve testing, where practical, as consistent with Commission policy. Therefore, RAI 3.9-249 was closed.

Note (g) to ESBWR DCD, Tier 2, Table 3.9-8, provides justifications for Code-defined testing exceptions or alternatives as allowed by the ASME OM Code. Notes (g4) and (g5) in DCD, Tier 2, Table 3.9-8, indicate that the applicable valves cannot be tested at power because reverse flow cannot be established. In RAI 3.9-250, the NRC staff requested that the applicant clarify that the applicable valves can be tested with reverse flow during shutdown conditions. In its response to RAI 3.9-250, the applicant confirmed that reverse flow can be established during shutdown conditions for the five valve applications addressed by Notes (g4) and (g5). The valves covered by Notes (g4) and (g5) are inside the drywell and cannot be accessed during power operation. For condenser purge line isolation valve B32-F014, test connections upstream and downstream of this valve allow testing (including reverse flow leakage testing) during shutdown conditions. For high-pressure nitrogen CVs B32-F017 and F018, and nitrogen supply line inboard CVs P54-F010 and F027, an isolation valve and a test line upstream of each valve permits reverse flow leakage testing during shutdown conditions. The NRC staff considers the applicant's response to clarify the testing of these valves consistent with the ASME OM Code. Therefore, RAI 3.9-250 was closed.

In RAI 3.9-251, the NRC staff requested the applicant to reevaluate specific justifications in Note (g) in the DCD IST table that referenced temporary loss of system redundancy in deferring test intervals. The temporary loss of system redundancy during an inservice test is covered by limiting conditions for operations in plant technical specifications. Therefore, the loss of system redundancy is not acceptable as a basis for deferral of IST to a refueling outage or cold-shutdown interval. In its response to RAI 3.9-251, the applicant stated that it would revise the ESBWR DCD to resolve this comment. Subsequently, DCD, Tier 2, Table 3.9-8 specifies that the frequency for stroke testing of valves C41-F002 and P25-F023, F024, F025, and F026 will be 3 months. The NRC staff finds the change to the ESBWR DCD to be acceptable in accordance with the ASME OM Code. Therefore, RAI 3.9-251 was closed.

ESBWR DCD, Tier 2, Section 3.9.6, specifies the use of NUREG-1482 (Rev. 1) in the development of the IST program for plants referencing the ESBWR design certification. For example, NUREG-1482 provides guidance for the preparation of IST program documentation and tables. The NRC staff will evaluate the full description of the IST program provided by a COL applicant during review of the COL application (COL Information Items 3.9.9-3-A and 3.9.9-4-A). Following COL issuance, the staff will evaluate the development and implementation of the IST program before and during plant operation, including the application of guidance in NUREG-1482.

The following sections discuss specific aspects of the NRC staff review pertaining to various types of valves.

3.9.6.3.2.1 Power-Operated Valves

POVs include such valves as motor-operated valves (MOVs), air-operated valves, hydraulic-operated valves, and solenoid-operated valves. POVs must be designed and qualified to perform their safety functions and to be periodically tested to assess their operational readiness to perform safety functions. The NRC staff reviewed the information in the ESBWR DCD Tier 2 to evaluate the functional design, qualification, and IST program for POVs to perform their safety functions in the ESBWR based on NRC regulations and lessons learned from nuclear power plant operating experience and NRC and industry research programs.

In RAI 3.9-199, the NRC staff requested that the applicant discuss its plans to designate POVs as Tier 2* components based on past challenges in providing assurance of their design-basis capability, as demonstrated by operating experience at nuclear power plants. In its response to RAI 3.9-199, the applicant noted that POVs and/or MOVs had been designated as Tier 2* components in the appendices to 10 CFR Part 52 providing the design certification rules for the ABWR, System 80+, AP600, and AP1000 reactor designs. The applicant determined that POVs will be designated as Tier 2* components because the ESBWR design is passive. However, the applicant did not designate MOVs as Tier 2* components because none of the ESBWR MOVs have active, safety-related functions. The NRC staff considers the designation of POVs as Tier 2* components in the ESBWR design to be acceptable as it is consistent with the approach taken for other design certifications. Therefore, RAI 3.9-199 was closed.

In RAI 3.9-161, the NRC staff requested that the applicant describe the functional design and qualification for POVs with safety functions in the ESBWR. In its response to RAI 3.9-161, the applicant stated that the design function of each active safety-related valve is described under the corresponding system discussion in DCD Tier 2. For example, DCD, Tier 2, Section 3.9.2.2, "Seismic Qualification of Safety-Related Mechanical Equipment (Including Other RBV Induced Loads)," discusses the testing or analytical qualification of the safety-related major mechanical equipment and other ASME Code Section III equipment, including equipment supports. DCD, Tier 2, Section 3.9.3, "ASME Code Class 1, 2, and 3 Components, Component Supports and Core Support Structures," discusses the structural integrity of pressure-retaining components, their supports, and core support structures, which are designed in accordance with the rules of the ASME BPV Code, Section III, and applicable GDC of the NRC regulations. DCD, Tier 2, Section 3.9.3.5, "Valve Operability Assurance," specifies that safety-related valves are qualified by testing and analysis and by satisfying the stress and deformation criteria within the valves. In RAI 3.9-178 S01, the staff requested the applicant to clarify its intention to use ASME Standard QME-1-2007 for the qualification of valves. In response to RAI 3.9-178 S01, the applicant revised ESBWR DCD, Tier 2, Section 3.9.3.5, to include provisions for the functional design and qualification of POVs used in the ESBWR, including the application of ASME Standard QME-1-2007. As noted above, the staff finds the provisions in the ESBWR DCD for the functional design and qualification of POVs to be acceptable for the ESBWR design certification where implemented consistent with NRC acceptance of ASME QME-1-2007 in Revision 3 of RG 1.100. Therefore, RAI 3.9-161 was resolved.

In RAIs 3.9-180 to 3.9-196, 3.9-188 S01, and 3.9-189 S01, the NRC staff requested that the applicant discuss specific provisions in the ESBWR DCD related to the IST program for POVs. In response to these RAIs, the applicant updated the IST provisions for POVs in ESBWR DCD, Tier 2, Section 3.9.6.1.5, "Specific Valve Test Requirements." Based on an ESBWR design change, a revision to the ESBWR DCD Tier 2 removed references to IST provisions for MOVs where the motor actuators for the four valves originally specified as MOVs for the ESBWR were replaced with other power actuators. As indicated in the ESBWR DCD, POVs will be tested in accordance with the ASME OM Code, Subsection ISTC. DCD Table 3.9-8 provides the specific testing activities for each valve. The IST program will consider the guidance in NRC Regulatory Issue Summary 2000-03, "Resolution of Generic Safety Issue 158: Performance of Safety-Related Power-Operated Valves Under Design Basis Conditions," dated March 15, 2000, which incorporates lessons learned from MOV analyses and tests in response to GL 89-10 and GL 96-05. DCD, Tier 2, Section 3.9.6, states that the COL applicant is responsible for describing how the IST program addresses these lessons learned. DCD, Tier 2, Section 3.9.6.8, "Non-Code Testing of Power-Operated Valves," provides a general description of additional periodic testing to be performed on POVs to verify their design-basis capability. COL Information Item 3.9.9-3-A specifies that the COL applicant shall provide a full description of the IST program and a milestone for full program implementation. The ESBWR DCD generally describes the IST program for POVs to be used at an ESBWR plant and includes appropriate references to NRC and industry guidance for the periodic verification of the design-basis capability of POVs at nuclear power plants. The ESBWR DCD allows the COL applicant flexibility in developing a full description of its IST program on a plant-specific basis. The NRC staff finds that the general IST program description provided in the DCD is acceptable for the ESBWR design certification because the ESBWR DCD provisions are consistent with the ASME OM Code and the specification of the need for the IST program to address lessons learned from valve operating experience as described in applicable NRC and industry documents. Therefore, the RAIs listed in this paragraph were resolved for the ESBWR design certification. The COL applicant will need to fully describe the IST program for POVs to supplement the general provisions in the ESBWR DCD in accordance with the COL information items.

In RAI 5.4-61, the NRC staff requested that the applicant reinstate design details for the MSIVs and any other valves that had been removed in a revision to the ESBWR DCD. In its response to RAI 5.4-61, the applicant provided a comparison of the design parameters specified in the applicable revisions to the ESBWR DCD. The applicant indicated that it would include design aspects related to valve pattern and type, disk force balance on opening, valve actuation method, actuator description, and stem speed control in DCD, Tier 2, Section 5.4.5.2.2, “Main Steam Isolation Valves Description.” Subsequently, DCD, Tier 2, Section 5.4.5.2.2, specifies that the MSIVs will be gate pattern valves with reducing venturi inlet and outlet nozzles with removable internal parts. The ESBWR DCD also specifies that the MSIV actuator will be a high-pressure piston cylinder type that is capable of developing sufficient force to open or close the valve against a differential pressure up to reactor design pressure, and to close against worst-case break flow. The design for operating power will come from process-medium integral actuation or high-pressure nitrogen (or nitrogen-spring) yoke-mounted actuation. The valve operating speed will be controlled by cylinder inlet and exhaust path orifice sizing and will be factory set to provide the design stroke speed under rated operating and accident flow conditions. In its RAI response, the applicant also provided a planned DCD change to specify similar design attributes for the feedwater isolation valves (FWIVs) in DCD, Tier 2, Section 5.4.5.3.2, “Detailed Feedwater Isolation Valves Description.” Subsequently, DCD, Tier 2, Section 5.4.5.3.2, specifies that the FWIVs will be gate pattern valves with reducing venturi inlet and outlet nozzles to fit the steamline diameter to the valve. The FWIV actuator will be a high-pressure piston cylinder type that is capable of developing sufficient force for closing the valve at the design pressure differential indicated in the DCD, and for opening the valve as required to support feedwater injection for reactor makeup. FWIV operating power will come from process-medium integral actuation or high-pressure nitrogen (or nitrogen-spring) yoke-mounted actuation. FWIV operating speed will be controlled by cylinder inlet and exhaust path orifice sizing and will be factory set to provide the design stroke speed under rated operating and accident flow conditions. The NRC staff finds that the design attributes specified in the ESBWR DCD for the MSIVs and FWIVs demonstrate that these valves will be manufactured in compliance with NRC regulations and consistent with nuclear power plant operating experience with valves in similar service. Therefore, RAI 5.4-61 was closed for this IST section.

3.9.6.3.2.2 Check Valves

The NRC staff reviewed DCD, Tier 2, Sections 3.9.3.5.2, 3.9.6.1, and 6.3.2.7.2, to confirm that ESBWR CVs will be designed, manufactured, qualified, installed, and periodically tested to provide assurance of their capability to perform the applicable safety functions. As part of its review, the staff evaluated the provisions in ESBWR DCD Tier 2 for the functional design, qualification, and IST program for CVs to perform their safety functions in the ESBWR based on NRC regulations and lessons learned from nuclear power plant operating experience.

For the ESBWR, bias-open CVs are used in the GDCS for the passive plant design. In RAI 3.9-158, the NRC staff requested that the applicant describe how the CV test results will measure and identify the flow required to open the valve and to maintain the valve disc in a stable full-open position. The staff also asked the applicant to describe the techniques and acceptance criteria used to assess the degradation and the performance of the CVs if nonintrusive techniques will be used for CV testing. In RAI 3.9-158 S01, the staff requested that the applicant address operational issues related to the GDCS CV orientation. In a letter dated March 27, 2008, the applicant indicated that the GDCS CVs might be horizontally or vertically mounted.

After reviewing that RAI response, the NRC staff requested in RAI 3.9-200 that the applicant discuss specific aspects of the GDCS piping and CV design and applicable IST provisions. The staff discusses these specific aspects related to the GDCS CVs in several paragraphs below for each portion of RAI 3.9-200.

In its response to RAI 3.9-200, the applicant stated that the GDCS CVs will be installed either in a horizontal piping run and be held normally open by a spring, or in a vertical piping run and be held normally open by gravity. In either approach, the net force keeping the valve open will be minimized to a value sufficient to ensure that the valve is open with no differential pressure. To minimize the reverse flow and differential pressure necessary to close the valve, the applicant stated that valve opening will be resisted by a light spring, sized such that the valve is fully open with no differential pressure where the disk weight is equal to the spring force at the fully open position. In the event of an accident that results in squib valve initiation before the reactor pressure falls below the GDCS injection pressure, the GDCS check valves will be closed by the reactor pressure. If an accident results in reactor depressurization, the GDCS CVs will remain closed until the reactor pressure reaches the GDCS injection pressure with a fraction of a 1 pound per square inch (psi) reverse differential pressure. GDCS injection will begin at a low flow rate and gradually increase as the reactor continues to depressurize.

With respect to potential water hammer scenarios, the applicant stated that the GDCS CVs will be designed to minimize the impact loads resulting from valve closure. For example, a fast-acting design with a lightweight disk will be used such that damage from deceleration of the GDCS system fluid will not occur. With respect to possible steam formation in the GDCS piping and subsequent condensation-induced water hammer, the applicant stated that the piping between the GDCS pools and the RPV is a continuous loop seal that is expected to remain full of water. The applicant also noted that the gradual increase in GDCS injection flow during an event will preclude rapid pressure changes that could lead to water hammer conditions. With respect to CV closure force, the applicant stated that the CV will be designed and qualified to ensure that it remains open under normal operating conditions (zero differential pressure) and closes under low reverse differential pressure and flow conditions. With respect to stable CV operation, the applicant stated that the GDCS CVs will begin to open with a fraction of a 1-psi reverse differential pressure across the valves and will be fully open when the reactor pressure drops to the GDCS injection pressure such that no chatter or flutter will occur. The applicant stated that valve qualification will verify CV performance under these conditions. With respect to the potential for slow reactor pressure increase conditions that might cause the GDCS CVs to remain partially open, the applicant clarified that there are no slow reactor pressure increase conditions under either normal or design-basis conditions following actuation of the GDCS injection valves.

With respect to the IST program provisions, the applicant noted that DCD, Tier 2, Table 3.9-8, specifies that the GDCS CVs will be tested during refueling outages with the performance of open/close exercise testing, leakage testing, and position indication verification. The applicant stated that exercise testing will verify that the GDCS valves are held open with no differential pressure or flow and that the valves close on low reverse differential pressure or flow.

In paragraph (A) in RAI 3.9-200 S01, the NRC staff requested that the applicant revise the ESBWR DCD to include the design, qualification, and testing provisions for GDCS CVs indicated in the response to RAIs 3.9-200, 3.9-201, and 3.9-203. In its response to RAI 3.9-200 S01, the applicant stated that it would include in Section 6.3 of the DCD the key design attributes of the GDCS CVs described in the applicable RAI responses. The applicant also noted that ITAAC 10a and 10b in Table 2.4.2-3 of DCD Tier 1 will address the verification that these design attributes are met in the design and qualification of the GDCS CVs. In RAI 3.9-200 S02, the staff requested that the applicant include in the ESBWR DCD the consideration of potential water hammer effects in the design process for the GDCS and its CVs. In its response to RAI 3.9-200 S02, the applicant agreed to include this consideration in the DCD. Subsequently, the ESBWR DCD incorporates the design attributes for the GDCS CVs identified in the applicable RAI responses discussed in this paragraph. The staff finds that DCD, Tier 2, Section 6.3, provides an acceptable description of the design attributes for the GDCS CVs that address the GDCS performance requirements. Therefore, RAI 3.9-158 and this portion of RAI 3.9-200 were closed.

In paragraph (a) in RAI 3.9-200, the NRC staff requested that the applicant confirm that it will evaluate potential water hammer loads from the reverse flow of water in the GDCS line closing the CV following squib valve actuation. In its response to RAI 3.9-200, the applicant stated that the open CV will have a spring force that will exactly balance the weight of the disk to minimize the reverse flow and differential pressure to close it. In paragraph (B)(1) in RAI 3.9-200 S01, the NRC staff requested that the applicant verify that the design process will include an evaluation of the GDCS CV closure loads. In response to RAI 3.9-200 S01, the applicant indicated that a revision to DCD, Tier 2, Section 6.3, would specify the evaluation of GDCS CV closure loads in the design process. Subsequently, DCD, Tier 2, Section 6.3, includes the consideration of potential water hammer effects in the GDCS design process. Therefore, this portion of RAI 3.9-200 was closed.

In RAI 3.9-200(b), the NRC staff requested that the applicant discuss the design and analysis of applicable components for loading due to the formation of steam in the GDCS piping during depressurization of the reactor coolant following a postulated accident. In its response to RAI 3.9-200, the applicant stated that the GDCS piping is a continuous loop seal that is expected to remain full of water without steam voids following a reactor depressurization. In paragraph (B)(2) of RAI 3.9-200 S01, the NRC staff requested that the applicant discuss the control of the water temperature in the GDCS line to prevent steam formation when the reactor depressurizes, or provide assurance that the steam that forms will not result in excessive loading to the GDCS or reduction in the necessary GDCS injection flow. In its response to RAI 3.9-200 S01, the applicant referred to its response to RAI 21.6-112, which discusses the inability of steam and noncondensable gases to flow from the RPV into and up the GDCS line by the steam-condensing capacity of the flow from the intact GDCS lines. In response to RAI 6.3-89, the applicant provided a planned revision to DCD, Tier 2, Section 6.3.2, to specify a minimum slope for the GDCS injection lines and equalization lines upward into the RPV to prevent steam and noncondensable gases from flowing into the GDCS injection lines and equalization lines from the reactor vessel. Revision 7 to ESBWR DCD, Tier 2, Section 6.3.7.2, “System Description,” for the GDCS specifies that the GDCS injection and equalizing lines have a minimum downward slope of 1:48 to the applicable GDCS squib valve, and a minimum upward slope of 1:48 to the applicable RPV injection or equalizing line nozzle. The staff finds that GEH has clarified the design capability of the GDCS lines, and has specified the minimum slope of the GDCS lines in the ESBWR DCD to prevent the flow of steam or noncondensable gases into the GDCS. Therefore, this portion of RAI 3.9-200 was closed.

In RAI 3.9-200(c), the NRC staff requested that the applicant discuss the force necessary for closure of the GDCS CVs. In its response to RAI 3.9-200, the applicant indicated that the GDCS CVs will be designed and qualified to ensure that they will remain open under normal operating conditions with no differential pressure and will close under low reverse flow and differential pressure conditions. In paragraph (B)(3) of RAI 3.9-200 S01, the NRC staff requested that the applicant verify that the design process will consider the expected reverse CV closure loads in the qualification of the GDCS CVs, piping, and other components. In its response to RAI 3.9-200 S01, the applicant indicated that it would revise Section 6.3 to specify that the design process will include consideration of the expected reverse CV closure loads in the qualification of the GDCS CVs, piping, and other components. Subsequently, DCD, Tier 2, Section 6.3, includes this design provision. Therefore, this portion of RAI 3.9-200 was closed.

In RAI 3.9-200(d), the NRC staff requested that the applicant discuss the provisions to provide assurance that for all conditions of GDCS injection, the valve disk of the CV will be stable and in the fully open position, without damage or wear caused by chatter or flutter of the disk. In its response to RAI 3.9-200, the applicant referenced its description of the operation of the GDCS CVs in response to other portions of this RAI, and noted that the valve qualification will verify CV performance under its design conditions. The NRC staff finds the provisions in the ESBWR DCD including the application of ASME Standard QME-1-2007 (as accepted in Revision 3 to RG 1.100) to be sufficient for the qualification of the GDCS CVs. Therefore, this portion of RAI 3.9-200 was closed.

In RAI 3.9-200(e), the NRC staff requested that the applicant discuss the potential for the GDCS CVs to remain partially open under conditions of slow pressure increase of the RCS that could allow backflow to the cooling water pools. In its response to RAI 3.9-200, the applicant stated that there are no slow pressure increase conditions of the RCS under either normal or design-basis conditions following actuation of the GDCS injection valves. The applicant indicated that, when the injection squib valves actuate, the pressure on the downstream side of the CVs will be decreasing. In paragraph (B)(4) of RAI 3.9-200 S01, the NRC staff requested that the applicant discuss the potential for a slow pressure increase to occur later during a postulated event that might cause the GDCS CVs to remain partially open. In its response to RAI 3.9-200 S01, the applicant described the sequence for GDCS squib valve actuation and initial GDCS injection following actuation of the automatic depressurization system. The applicant reported that some backflow might occur into the GDCS injection lines or pools if brief pressure transients result in the RPV pressure slightly exceeding the GDCS injection pressure, but that the RPV level would not be significantly affected. The NRC staff considers the applicant’s response to adequately clarify the flow sequence for the GDCS injection lines. Therefore, this issue was resolved.

In RAI 3.9-201, the NRC staff requested that the applicant address the need for high-point venting of gases that could collect in the GDCS lines and might cause binding or restriction of necessary injection flow. In response to RAI 3.9-201, the applicant stated that the four trains of injection lines for the GDCS run from the GDCS pools down to the RPV inlet nozzles. DCD, Tier 2, Table 6.3-2, provides the minimum elevation change between the GDCS pool surface and the RPV nozzles to ensure that the pool outlet is higher than the RPV nozzles. Further, the applicant stated that each GDCS injection branch line makes a U-shape bottom loop at the lowest elevation before rising to tie into the RPV nozzle. The applicant also stated that there is no elevated piping loop above the GDCS outlet and RPV inlet nozzle levels. The GDCS design includes a closed squib valve at the bottom of each U-shape pipe loop with the pipe legs on both sides of the squib valve filled with water. The water in the GDCS piping from the squib valve to the RPV inlet nozzle prevents noncondensable gases from entering the GDCS. The GDCS piping from the squib valve to the GDCS pool is self-venting, with each pool vented to the drywell. The applicant stated that there are two 1-in. test lines on each GDCS injection branch line for use during refueling outages with one connection on each side of the squib valve. The applicant stated that high points between the pool outlets and the RPV inlet nozzles will not exist. ITAAC Item 24 in DCD, Tier 1, Table 2.4.2-3, specifies that the GDCS injection piping is installed to allow venting of noncondensable gases to the GDCS pools and the RPV to prevent collection in the GDCS injection lines. The applicant stated that this ITAAC will provide assurance that no high points will exist in the GDCS injection lines. In summary, the applicant stated that there are no high points in the piping where gases can collect, the GDCS piping is self-venting, and the presence of a water-filled loop seal in the piping prevents entry of any gases.

In RAI 3.9-201 S01, the NRC staff requested that the applicant discuss the potential effects on GDCS injection flow from gases in the system and their consideration as part of the design process. The staff also requested that the applicant revise the ESBWR DCD to include provisions for the design of the GDCS to prevent the collection of noncondensable gases as specified in the RAI response. In its response to RAI 3.9-201 S01, the applicant noted its response to RAI 21.6-112, which discussed the large hydrostatic head that drives the GDCS flow and its steam-condensing capacity which would condense any steam in the GDCS line and sweep any noncondensable gases into the RPV. The applicant also indicated that the loop seal design of the GDCS will provide a cold leg of water upstream of the squib valve to provide steam-condensing capacity. The applicant indicated that ITAAC Item 24, included in DCD, Tier 1, Table 2.4.2-3, will ensure that the as-built piping installation for the GDCS conforms to a design that allows venting of noncondensable gases to the GDCS pools and to the RPV to prevent collection in the GDCS injection lines. The NRC staff finds the clarification of the GDCS design configuration and the specification of the ITAAC to verify the as-built piping installation to be acceptable. Therefore, RAI 3.9-201 was closed.

In RAI 3.9-202, the NRC staff requested that the applicant describe how the GDCS configuration with a squib valve and a normally open CV meets the regulatory requirements for isolation of the RCPB. The NRC regulations in 10 CFR 50.55a(c)(2) require that non-ASME Class 1 components be isolated from the RCPB with two closed valves or, if one or both valves are open, each valve must be capable of automatic isolation. In its response to RAI 3.9-202, the applicant stated that the open CV is considered an automatic isolation valve consistent with 10 CFR Part 50, Appendix A, GDC 55, "Reactor Coolant Pressure Boundary Penetrating Containment." Although the ESBWR GDCS configuration with a squib valve in series with one open CV differs from the configuration addressed by GDC 55, the staff notes that the squib valve will remain sealed and not leak compared to a conventionally seated valve (e.g., a gate or globe valve). Further, the spurious failure of the disk pressure-retaining integrity (e.g., by spurious valve actuation) would not result in a loss of GDCS pressure integrity or loss of the GDCS safety function, provided that the GDCS components are designed to accommodate the resulting loads. In RAI 3.9-202 S01, the NRC staff requested that the applicant verify that the design process will address GDCS fluid dynamic loading to support the determination that the GDCS configuration with a squib valve in series with a CV satisfies the NRC regulations for isolation of the GDCS interface. In its response to RAI 3.9-202 S01, the applicant agreed that

GDC 55 is not applicable to the GDCS configuration and clarified that the response was intended to support the reliance on the GDCS CVs as automatic valves. The applicant also corrected an earlier response to specify that the RCPB ends at the GDCS CVs, with the distinction between Class A and Class B to be outboard of the CVs. The NRC staff finds that the applicant's response has acceptably clarified the configuration of the GDCS injection lines in a manner consistent with the NRC regulations. Therefore, RAI 3.9-202 was closed.

In RAI 3.9-203, the NRC staff requested that the applicant discuss any CVs or other valve types in vertical flow lines in ESBWR safety-related systems, or those within the scope of RTNSS, and the provisions for functional design, qualification, and IST of those valves. In its response to RAI 3.9-203, the applicant stated that the detailed pipe routing had not been completed for the ESBWR. Valves will be installed in horizontal piping runs with the valve stems oriented vertically to the extent possible. The applicant stated that installation of a 4-in. or larger valve with a stem oriented more than 15 degrees from vertical will require specific review and approval as required by NEDE-33271P, "NP-2010 COL Demonstration Project: Project Design Manual (PDM)." Orientation will also be addressed as part of valve qualification through ASME QME-1-2007 or by analysis of the differences in the valve qualification and QME-1-2007. The applicant stated that the IST program or other periodic testing described in the ESBWR DCD will monitor degradation that might occur due to installation orientation in ESBWR plants. In RAI 3.9-203 S01, the NRC staff requested that the applicant make NEDE-33271P available for NRC staff review. In its response to RAI 3.9-203 S01, the applicant submitted the applicable proprietary section of NEDE-33271P. The NRC staff finds the description of the design process for valve orientation to be sufficient to resolve this issue. Therefore, RAI 3.9-203 was closed.

In RAI 3.9-204, the NRC staff requested that the applicant specify appropriate changes to the DCD to ensure adequate functional design, qualification, and IST for valves in vertical flow lines in the ESBWR. In response to RAI 3.9-204, the applicant stated that, based on its response to RAI 3.9-203, no changes to the DCD were necessary. The NRC staff addresses DCD changes through other RAIs described in this section of this report. Therefore, RAI 3.9-204 was closed.

In RAI 3.9-2, the NRC staff requested that the applicant discuss the design conditions and qualification testing for the GDCS CVs. In its response to RAI 3.9-2, the applicant described the GDCS CVs and their testing. Although hinge pin wear in tilting disc CVs was identified as a specific failure mode from nuclear power plant operating data, the ESBWR GDCS CVs will experience only light duty during normal operation. In RAI 3.9-157, the staff requested that the applicant discuss the monitoring of the CV hinge pin condition. In its response to RAI 3.9-157, the applicant stated that the GDCS CVs are designed such that the valve is fully open when zero differential pressure is applied across the valve. The applicant indicated that GDCS CVs will not be in active flow streams and, therefore, will not be subject to the excessive cycling or wear that has damaged hinge pins in CVs at nuclear power plants. In addition, the applicant updated DCD, Tier 2, Section 6.3.2.7.2, to include a description of the GDCS CV. For example, the DCD states that the GDCS CV is classified as Quality Group A, seismic Category I, and ASME BPV Code, Section III, Class 1. The staff tracked RAI 3.9-157 as an open item in the SER with open items. In RAI 3.9-157 S01, the staff requested that the applicant describe the IST Program activities for the GDCS CVs. In response to RAI 3.9-157 S01(, the applicant summarized the IST program activities for the GDCS CVs as specified in DCD Table 3.9-8. This summary shows quarterly exercising and leak rate testing during each refueling outage. Based on the consideration of CV hinge pin wear and IST activities established for the GDCS CVs, the staff considers this issue to be resolved. Therefore, RAI 3.9-2 and RAI 3.9-157, and the associated open item, were closed.

In RAI 3.9-154, the NRC staff requested that the applicant provide the acceptance criteria and their basis to assess CV degradation and performance characteristics. In its response to RAI 3.9-154, the applicant stated that GDCS CV position verification will be accomplished during preoperational testing by providing flow to fully close and open the valve through the use of test line connections. The valve will be capable of being fully closed and opened. Test line connections will remain available for the COL licensee to perform routine testing as part of the IST program. The applicant also indicated that the acceptance criteria will be based on functional characteristics of the valve procured for the plant construction. As noted above, DCD Tier 2 includes a COL information item requiring the COL applicant to provide a full description of the IST program. The staff considers the general description of the IST program for the GDCS CVs to be consistent with the ASME OM Code as incorporated by reference in 10 CFR 50.55a and acceptable for the ESBWR design certification. Therefore, RAI 3.9-154 was closed.

3.9.6.3.2.3 Safety/Relief Valves, Containment Vacuum Breakers and Vents, Safety/Relief Valve Rupture Disks, and Other Relief Valves

The NRC staff reviewed the information in ESBWR DCD Tier 2 to evaluate the functional design, qualification, and IST programs for SRVs, containment vacuum breakers and vents, SRV rupture disks, and other relief valves to perform their safety functions in the ESBWR. The staff based its review on the NRC regulations and lessons learned from nuclear power plant operating experience. In addition to meeting the requirements of the ASME BPV Code, Section III, for pressure boundary integrity, RCS SRVs, containment vacuum breakers, SRV rupture disks, and other relief valves are required by Section III of the ASME BPV Code to be capacity certified to adequately discharge the necessary fluid flow to ensure system overpressure protection. The Section III requirements are applicable to these devices to ensure correct configuration, function, and capacity certification for several major safety-related systems, including the RCS and containment boundary. In addition to the ASME BPV Code, Section III, requirements, the NRC staff reviews the methodology for qualification and testing of relief devices, including issues based on operational experience, and valve performance or system functions.

In RAI 3.9-164, the NRC staff requested that the applicant identify any pressure relief devices that are part of the reactor containment boundary and verify that they will be designed and qualified to meet the applicable ASME BPV Code, Section III, provisions. In its response to RAI 3.9-164, the applicant specified that the only pressure relief devices within the reactor containment are the nuclear boiler system SRVs, which provide pressure relief protection for the RCPB. These SRVs are classified as ASME Code Class 1 components in accordance with DCD Tables 3.2-1 and 3.2-2. The NRC staff finds these pressure relief devices will be designed and qualified to meet ASME Code, Section III, requirements for Class 1 components. These relief valves are included in the IST program and are identified as B21 valves F003 and F006 in DCD Table 3.9-8. Therefore, this portion of RAI 3.9-164 was resolved.

In RAI 5.2-20, the NRC staff requested that the applicant describe the design features of the ESBWR SRVs. In its response to RAI 5.2-20, the applicant stated that the detailed design and selection of the ESBWR SRVs are not yet final. Lessons learned from valves installed in current operating BWRs will be considered during the selection phase for the ESBWR SRVs. The applicant will evaluate potential valve suppliers during the selection phase, with an emphasis on performance in the areas of setpoint drift, actuator reliability, and seat leakage.

In RAI 5.2-22, the NRC staff requested that the applicant discuss the provisions employed to ensure that valve and actuator specifications include design requirements for operation under expected environmental conditions. In its response to RAI 5.2-22, the applicant stated that a purchase specification will define the design and qualification requirements for the SRVs, including environmental and dynamic qualification for environmental conditions (such as radiation, temperature, pressure, and humidity) and seismic and dynamic conditions (such as required response spectra).

In its responses to RAIs 5.2-20 S01 and 5.2-22 S01, the applicant provided additional information regarding the design and selection of the ESBWR SRVs. In particular, the applicant stated that ASME BPV Code, Section III, NB-7540, “Safety Valves and Pilot Operated Pressure Relief Valves with Auxiliary Actuating Devices,” will serve as a reference for the ESBWR design. The applicant also referred to ASME BPV Code, Section III, NB-7510, “Safety, Safety Relief and Relief Valves,” and NB-7520, “Pilot Operated Pressure Relief Valves,” for applicable rules for overpressure protection system valves. DCD, Tier 1, Table 2.1.2-2, Item 1, contains an ITAAC to confirm the configuration of the nuclear boiler system that includes programmatic reviews of SRV design and environmental qualifications. The staff considers the design and qualification of ESBWR SRVs to be adequately addressed for the ESBWR design certification based on the provisions in the ESBWR DCD for the functional design and qualification of valves that impose the applicable ASME Code requirements, incorporate lessons learned from valve performance experience, and provide specific ITAAC that include SRV qualification. Therefore, RAIs 5.2-20 and 5.2-22 were resolved.

In RAI 5.2-25, the NRC staff requested that the applicant discuss the frequency of visual inspection and maintenance of the ESBWR SRVs. In its response to RAI 5.2-25, the applicant reported that the SRVs are mounted on flanges and can be removed for maintenance or bench testing during normal plant shutdown. In DCD, Tier 2, Section 3.9.6 and Table 3.9-8 indicate that the SRVs are tested in accordance with the IST program. Every 5 years during reactor plant shutdown, the valves are subject to a complete visual examination, set pressure testing, and seat tightness testing. External and flange seating surfaces of the SRVs are 100-percent inspected when any valve is removed for maintenance or bench testing. At every refueling outage, valve position verification and exercising tests are performed for the SRVs. The valve manufacturer will provide an equipment instruction manual, which will specify maintenance recommendations and instructions for servicing and overhaul of valve components and parts. The applicant stated that the instruction manual is a committed deliverable to the plant owner, and therefore, its contents are incorporated into the plant maintenance procedures to ensure that the design life will not be exceeded for any SRV component. The staff considers this description of the procurement process for valves to be consistent with the design, qualification, and IST provisions specified in Sections 3.9.3 and 3.9.6 in the ESBWR DCD Tier 2. Therefore, RAI 5.2-25 was resolved.

As noted above, the NRC staff requested in RAI 3.9-164 that the applicant identify any pressure relief devices that are part of the reactor containment boundary and verify that they are designed and qualified to meet the applicable ASME BPV Code, Section III, requirements for Class 2 components. In its response to RAI 3.9-164, the applicant stated that Class 2 pressure relief devices apply to pressure-retaining portions of the primary containment that are not included in Class 1 and that accomplish safety-related functions as defined in DCD, Tier 2, Section 3.2.3.2. The SLC system accumulator tank relief valve (F030A/B) and the containment drywell wetwell vacuum breaker valve (F002) are classified as Safety Class 2 and are designed and qualified to meet ASME BPV Code, Section III, requirements for Class 2 components.

These valves are included in the IST program as identified in DCD Table 3.9-8. Therefore, RAI 3.9-164 was resolved.

In RAI 3.9-165, the NRC staff requested that the applicant discuss the design and qualification of the ESBWR containment vacuum breaker valves. In its response to RAI 3.9-165, the applicant stated that DCD, Tier 2, Table 3.9-8, lists vacuum breaker valve F002 and isolation valve F001 as included in the IST program. The table also includes wetwell gas space discharge valves (or suppression pool gas space vent valves). These valves are ASME BPV Code, Section III, Class 2 components. Sections 3.10 and 3.11 of DCD Tier 2 specify the seismic, dynamic, and environmental qualifications for these components. The NRC staff finds that the design (including capacity) certification and procurement for the ESBWR containment vacuum breaker valves will be performed for ASME Code Class 2 components. Therefore, RAI 3.9-165 was resolved.

DCD Section 5.2.2 discusses the design of SRV rupture disks. In RAI 3.9-173, the NRC staff requested that the applicant verify that the SRV rupture disks meet the requirements of the ASME BPV Code, Section III, and are included in the IST program. In its response to RAI 3.9-173, the applicant confirmed that these rupture disks meet the ASME BPV Code, Section III, requirements and will be included in the IST program. In response to the RAI, the applicant updated DCD, Tier 2, Table 3.9-8, to include the SRV rupture disks with their Code class and category, valve function, and test parameters and frequencies. Therefore, RAI 3.9-173 was resolved.

In RAIs 3.9-166 and 167, the NRC staff requested that the applicant verify that ESBWR system piping is protected from thermally induced pressurization. In its response to RAI 3.9-166, the applicant stated that the current level of detail for the design of piping and piping penetrations for ESBWR primary containment does not include the requested information. To address this issue, the applicant revised DCD, Tier 2, Section 6.2.4, to specify that containment penetration piping will be evaluated for entrapped liquid subject to thermally induced pressurization following isolation. The DCD also indicates that the preferred pressure relief method is through a self-relieving penetration by selection and orientation of an inboard isolation valve that permits excess fluid to be released inward to the containment. The DCD notes that use of a separate relief valve is permissible on a case-by-case basis. The staff tracked RAIs 3.9-166 and 167 as open items in the SER with open items. In RAI 3.9-166 S01, the staff requested that the applicant discuss the basis for assigning responsibility for pressure relief devices to the COL licensee. In its response to RAI 3.9-166 S01, the applicant stated that responsibility for design and selection of system overpressure protection is addressed under the ASME Code. In RAI 3.9-166 S02, the staff requested the applicant to clarify the design requirements for pressure relief devices. In its response to RAI 3.9-166 S02, the applicant confirmed that the design of relief valves will be in accordance with the ASME Code and that verification that relief valves meet their design requirements is covered by existing ITAAC, including design ITAAC in DCD, Tier 1, Table 3.1-1 (“ITAAC for the Design of Piping Systems and Components”) and system-specific ITAAC associated with ASME Code, Section III, piping.

In its response to RAI 3.9-167, the applicant reported that individual system piping design is not presently developed to address thermally induced pressurization, but that overpressure protection is a design responsibility under the piping design codes, including ASME BPV Code, Section III, and ASME/ANSI B31.1, Power Piping Code. The applicant stated that the ASME Code defines owner responsibilities for review and acceptance, which must be performed by the COL licensee. As part of the ITAAC completion the COL licensee will ensure that records for the as-built plant design will be available to confirm that overpressure protection is adequate.

Per COL Information Items 3.9.9-3-A and 3.9.9-4-A the COL applicant will ensure that the IST program includes the necessary relief valves. Based on the consistency of the DCD provisions with the ASME Code and specific ITAAC to address overpressure protection, this issue was resolved. Therefore, RAI 3.9-166, RAI 3.9-167, and the associated open items were closed.

In RAI 3.9-168, the NRC staff requested that the applicant provide information with respect to the scope of valves that meet ASME BPV Code, Section III, requirements. In particular, the staff requested that the applicant verify that all relief devices that perform a function of providing pressure relief to ensure the integrity of safety-related SSCs are designed, qualified, and capacity certified to meet all applicable requirements of the ASME BPV Code, Section III, and are included in the IST program. In its response to RAI 3.9-168, the applicant stated that relief devices that provide a pressure relief function to ensure the integrity of all safety-related SSCs are classified in accordance with DCD Table 3.2-1. Therefore, these relief devices are designed, manufactured, and qualified, including capacity certification, in accordance with the ASME BPV Code, Section III. ESBWR pressure relief devices include nuclear boiler system SRVs (F006 and F003), the SLC system accumulator tank relief valve (F030A/B), and the containment drywell wetwell vacuum breaker valve (F002), which are included in the IST program. In RAI 3.9-168 S01, the staff asked the applicant to discuss the exclusions and alternatives from the ASME OM Code noted in item (f) of Table 3.9-8 of DCD Tier 2 and explain their bases. The staff tracked RAI 3.9-168 as an open item in the SER with open items. In response to RAI 3.9-168 S01, the applicant revised Table 3.9-8 to provide more detailed justifications for the test intervals for these valves. In RAI 3.9-168 S02, the staff requested the applicant to justify the testing frequencies for ESBWR pressure relief devices. In its response to RAI 3.9-168 S02, the applicant discussed the test interval justifications for specific SRVs, vacuum breakers, and other valves and revised Table 3.9-8 and Chapter 16 and 16B technical specification surveillance requirements to ensure consistency with the ASME OM Code. The staff considers the ESBWR DCD provisions for the IST program activities for these valves to be consistent with the ASME OM Code as incorporated by reference in 10 CFR 50.55a. Therefore, RAI 3.9-168 and the associated open item were closed.

In RAI 3.9-169, the NRC staff requested that the applicant provide information with respect to piping and valve load interaction. For all relief devices that perform a function of providing pressure relief to ensure the integrity of safety-related SSCs, the staff requested that the applicant verify that all valve discharge fluid dynamic loads have been included in the analysis of the upstream and downstream piping. The staff also asked the applicant to verify that the fluid dynamic loads imposed by the piping onto the relief devices do not exceed those for which the valve has been qualified to open and close, as required. In its response to RAI 3.9-169, the applicant stated that the individual system piping design was not sufficiently developed to address which piping systems or portions of systems include relief valves for overpressure protection. The staff tracked RAI 3.9-169 as an open item in the SER with open items. The staff issued RAI 3.9-169 S01 related to pressure relief devices, which was similar to RAI 3.9-166 S01. As discussed above for RAI 3.9-166, the staff considers the DCD provisions to be adequate to permit closure of RAI 3.9-169 and the associated open item.

In RAI 3.9-170, the NRC staff requested that the applicant provide the system design pressures, design set pressures and tolerances, and certified relief capacities for the ESBWR safety-related relief devices. The staff tracked RAI 3.9-170 as an open item. In its response to RAI 3.9-170, the applicant stated that individual system piping design and equipment procurement are not presently developed sufficiently to address which piping systems or portions of systems include relief valves for overpressure protection. For the ESBWR, overpressure protection will be a design responsibility under the piping design codes, such as the ASME BPV Code, Section

III, and the ASME/ANSI B31.1, Power Piping Code. Design reports, including consideration of overpressure protection, are required in accordance with ESBWR DCD, Tier 2, Section 3.9.3. The applicant noted that owner responsibilities for review and acceptance, data collection and recording, and records for the as-built plant design are assigned to the COL licensee. The applicant noted that design control, procurement document control, and unit design drawings are areas of responsibility for QA outlined in DCD, Tier 2, Chapter 17. The NRC staff finds the provisions in the ESBWR DCD to be consistent with the applicable ASME codes for overpressure protection and, therefore, to be adequate for the ESBWR design certification. Therefore, RAI 3.9-170 was resolved.

3.9.6.3.2.4 Pyrotechnic-Actuated (Squib) Valves

ESBWR DCD, Tier 2, Table 3.9-8, indicates that pyrotechnic-actuated (squib) valves are used to perform important functions in several ESBWR systems, including the nuclear boiler system, the SLC system, and the GDCS. DCD, Tier 2, Section 6.3, “Emergency Core Cooling Systems,” discusses the use of squib valves in providing protection against postulated LOCAs. For example, DCD Section 6.3.2.7, “Gravity-Driven Cooling System,” describes the design, function, and actuation of GDCS squib valves. The NRC staff reviewed the provisions in the ESBWR DCD to evaluate the functional design, qualification, and IST programs for squib valves to perform their safety functions in the ESBWR based on the NRC regulations and lessons learned from nuclear power plant operating experience.

In RAI 3.9-1, the NRC staff requested that the applicant discuss the design and testing of the DPVs that are part of the automatic depressurization system for the ESBWR nuclear boiler system. In its response to RAI 3.9-1, the applicant reported that testing of the DPVs was conducted during development of the simplified boiling-water reactor (SBWR) in the 1990s. The design of these valves remains the same for the ESBWR, except that the quantity of valves has increased to accommodate the larger ESBWR plant size. ESBWR DCD, Tier 2, Section 5.4.16, “References,” includes GE Report GEFR-00879, “Depressurization Valve Development Test Program Final Report,” issued October 1990.

In RAI 3.9-1 S01, the staff requested that the applicant make available GE Report GEFR-00879 for review. On December 20, 2007, the NRC staff reviewed this DPV report at the applicant’s offices in Washington, DC. The staff tracked RAI 3.9-1 as an open item in the SER with open items.

In RAI 3.9-1 S02, the NRC staff requested that the applicant discuss the size of the DPV prototype test valves in relation to the production valves. In its response to RAI 3.9-1 S02, the applicant stated that the DPV prototype valves were full sized.

In RAI 3.9-1 S03, the NRC staff requested that the applicant discuss design aspects, quality assurance, maintenance, and qualification testing of the DPVs based on NRC staff review of GEH Report GEFR-00879. In its response to RAI 3.9-1 S03, the applicant indicated that the valve tested for the SBWR program was a full-size prototype of the DPV to be installed in the ESBWR. The performance requirements for the ESBWR DPVs are the same as those for the SBWR DPVs, but the ESBWR design includes more DPVs. The DPV test flow rate bounded the design requirement. DPV testing performed at Wyle Laboratories was in accordance with the Wyle Quality Assurance Program based on 10 CFR Part 50, Appendix B. DCD, Tier 2, Section 5.4.13.4, discusses maintenance of the DPVs, which includes periodic initiator continuity checks, booster assembly testing, and actuator internals inspections. The applicant’s corrective action program is tracking design improvements as a result of the DPV testing, including redesign of specific internal components. In addition, the functional design and qualification of the DPVs, as well as the other ESBWR squib valves with safety functions, will apply the provisions of the ASME Standard QME-1-2007, as specified in DCD, Tier 2, Section 3.9.3.5. Finally, Table 2.1.2-3, "ITAAC for the Nuclear Boiler System," in ESBWR DCD Tier 1, specifies ITAAC to demonstrate the functional capability and flow capacity of DPVs to be used at the ESBWR plant. Based on the information provided in support of the design certification application and the use of ASME Standard QME-1-2007 as accepted in Revision 3 of RG 1.100, the staff finds that the applicant has adequately addressed this issue for the ESBWR design certification. Therefore, RAI 3.9-1 and the associated open item were closed.

In RAI 3.9-160, the NRC staff requested that the applicant describe the functional design and qualification of the GDCS squib valves. In its response to RAI 3.9-160, the applicant stated that the manufacturer will conduct mechanical testing of GDCS squib valves before their delivery to a plant site. The testing will include a full range of pressures and temperatures from ambient conditions to design-basis conditions. In RAI 3.9-160 S01, the staff requested the applicant to specify the acceptance criteria for design and qualification of the GDCS squib valves. In its response to RAI 3.9-160 S01, the applicant revised ESBWR DCD, Tier 2, Section 6.3.2.7.2, to provide more specific requirements for the design and qualification of the GDCS squib valves. The applicant also stated that the valve specification and purchase order will include detailed design requirements (e.g., pressure, flow, and temperature). The applicant indicated that the valve vendor will be required to demonstrate that the valves are capable of performing their required functions under the conditions specified in the valve specification and/or purchase order. In RAI 3.9-160 S02, the staff requested that the applicant provide additional information regarding the GDCS squib valves and deluge valves. In its response to RAI 3.9-160 S02, the applicant referenced ITAAC in DCD, Tier 1, Table 2.4.2-3, applicable to the GDCS squib and deluge valves. The applicant reported that operating experience exists with smaller squib valves in the SLC system in operating BWR nuclear power plants and that no generic issues have been identified with the current squib valve design. The applicant stated that the specific valve designs have not been selected and qualified for most ESBWR safety-related applications, including the GDCS injection and deluge squib valves. The GDCS squib valves will be functionally qualified to perform their required functions and meet all design requirements as discussed in DCD, Tier 2, Section 3.9.3.5, which requires the implementation of ASME Standard QME-1-2007. The NRC staff finds that the qualification of the design for these applications will ensure that the flow coefficients specified in ESBWR DCD Tier 2 will be met and that the flow path will not be inadvertently blocked when the valve is actuated.

In its review of DCD Tier 2, the staff noted that Section 6.3.2.7.2, "System Description," specifies that the GDCS injection squib valve will be designed such that, in the event of squib actuation, no missiles are generated that could impact the operation of any system valves, components, or instrumentation. In RAI 6.3-88, the NRC staff requested that the applicant address this design criterion for the GDCS deluge valve. In its response to RAI 6.3-88, the applicant stated that the design criterion for not generating missiles is applicable to the GDCS deluge line squib valves. Subsequently, ESBWR DCD Revision 6, incorporated this design criterion for the GDCS deluge line squib valves.

In RAI 6.3-89, the NRC staff requested that the applicant revise the DCD to specify that the GDCS squib valves will have a sample of their initiators test-fired before initial plant operation. In its response to RAI 6.3-89, the applicant provided a planned revision to ESBWR DCD, Tier 2, Section 6.3.2, in response to the RAI. Subsequently, Revision 7 to ESBWR DCD, Tier 2, Section 6.3.2.7.4, "Testing and Inspection Requirements," specifies that preoperational and periodic testing of the igniters and booster subassemblies of the GDCS squib valves will be performed to quantify, measure, or detect degradation and provide assurance that the GDCS squib valves will perform their safety-related function. The ESBWR DCD also specifies that preoperational testing will be conducted before initial plant startup and that periodic testing will be conducted during the refueling and maintenance outage at the end of each plant operating cycle. The NRC staff finds the functional design and qualification process for the GDCS squib valves and the general description of the IST activities for the GDCS squib valves to be acceptable for the ESBWR design certification. In light of the design considerations and safety significance of squib valves in new reactors, the need for improved surveillance activities for squib valves is being considered by the nuclear industry, ASME, and U.S. and international nuclear regulators. During the NRC audit of the design specifications for ESBWR components, GEH indicated that the design of squib valves to be used in the GDCS and other applications (such as DPVs) for the ESBWR had not been determined. COL applicants referencing the ESBWR design will be responsible for establishing appropriate surveillance activities for squib valves. For example, the IST Program for squib valves will need to incorporate lessons learned from the design and qualification process for these valves such that surveillance activities provide reasonable assurance of the operational readiness of squib valves to perform their safety functions.

In RAI 3.9-171, the NRC staff requested that the applicant describe how the explosives in the squib valves in the ESBWR plant are qualified to ensure the correct rate and total amount of energy release for proper valve actuation, under limiting environmental and aging conditions. The staff also asked the applicant to provide information for the sample IST of the squib explosives that demonstrates the acceptability of the rates and total amounts of energy release. The staff tracked RAI 3.9-171 as an open item. In its response to RAI 3.9-171, the applicant described the qualification process for pyrotechnic-actuated valves used in the ESBWR. Qualification for pyrotechnic actuator valve designs will meet the requirements described in DCD, Tier 2, Section 3.9. Further, IST activities for squib valves will be performed according to the IST program schedule at regular intervals to ensure that the capability of the pyrotechnic actuators is maintained from fabrication through both shelf-life and installed service-life. Based on the provisions in DCD Section 3.9.3.5 for the application of ASME Standard QME-1-2007 as accepted in Revision 3 of RG 1.100, the staff finds the provisions in the ESBWR DCD for the design, qualification, and testing of squib valves, and their applicable ITAAC, to establish adequate confidence in the capability of those valves to perform their safety function and to be acceptable for the ESBWR design certification. Therefore, RAI 3.9-171 was closed.

ESBWR DCD, Tier 2, Section 9.3.5, “Standby Liquid Control System,” discusses the design bases, system design, safety evaluation, and instrumentation for the SLC system. The SLC system is classified as safety-related and is designed as a seismic Category I system. It provides a diverse backup capability for reactor shutdown that is independent of normal reactor shutdown provisions and supplies makeup water to the RPV to mitigate the consequences of a LOCA. The SLC system is automatically initiated for anticipated transient without scram (ATWS) and LOCA events, but manually initiated for its shutdown function. Each of the two trains in the SLC system provides 50-percent injection capability and includes a nitrogen-pressurized accumulator containing sodium pentaborate solution and two parallel squib valves to an injection line. The reactor operator can manually initiate the SLC system from the main control room. ATWS mitigation logic can initiate the SLC system automatically upon determination of specific conditions. The SLC system also acts as part of the ECCS to provide makeup water to the RPV during a LOCA event by injecting the boron solution from the accumulators. The SLC system is designed to conform to the GDC in 10 CFR Part 50, Appendix A. For example, the SLC system is designed as seismic Category I and includes redundancy in the parallel squib valves. Valves in the SLC system are periodically tested to ensure operability. DCD, Tier 2, Section 14.2.8, specifies preoperational testing to demonstrate adequate system performance. The pyrotechnic charges in the squib valves are replaced periodically during plant shutdowns, with subsequent laboratory testing to confirm end-of-life capability. Upon system actuation, verification of injection is available within 30 seconds by observation of accumulator level and pressure. Redundant SLC system injection shutoff valves are automatically closed in response to accumulator level instrumentation. The shutoff valves can also be manually closed from the main control room.

The NRC staff reviewed the description of the SLC system, including its squib valves, provided in the ESBWR DCD as part of this section. ITAAC in DCD, Tier 1, Section 2.4.2, also address the SLC system. The functional design, qualification, and IST programs for valves within the SLC system are within the scope of DCD, Tier 2, Section 3.9. As discussed in this report, the NRC staff has determined that the provisions in the ESBWR DCD for the functional design, qualification, and IST programs for safety-related valves in the SLC system to be used for an ESBWR design are acceptable for the ESBWR design certification.

3.9.6.3.3 Dynamic Restraints

The NRC staff reviewed the information in DCD Tier 2 to evaluate the functional design, qualification, and IST programs for dynamic restraints to perform their safety functions in the ESBWR. The staff based its review on the NRC regulations and lessons learned from nuclear power plant operating experience. Paragraph ISTA-1000 of the ASME OM Code specifies that the general preservice and IST requirements be applied to dynamic restraints that are required to perform a specific function in shutting down a reactor to the safe-shutdown condition, in maintaining the safe-shutdown condition, or in mitigating the consequences of an accident. Subsection ISTD of the OM Code specifies the preservice and inservice examination of the snubbers. SRP Section 3.9.6 also states that other snubbers, not categorized as Code Class 1, 2, or 3, may be included in the IST program if the NRC staff considers them to be safety-related. DCD, Tier 2, Section 3.9.3, specifies technical provisions supporting the design basis for the dynamic restraints that restrain piping in response to dynamic excitation and associated differential movement. Based on its review, with specific aspects discussed below, the NRC staff finds that the DCD provisions for the functional design and qualification, and the general description of the IST program for dynamic restraints to be used in an ESBWR, satisfy the NRC regulations and, therefore, are acceptable for the ESBWR design certification.

In RAIs 3.9-114, 3.9-117, and 3.9-175, the NRC staff requested that the applicant discuss the qualification and production testing of snubbers outlined in the ESBWR DCD. In response to these RAIs, the applicant submitted a proposed revision to ESBWR DCD, Tier 2, Section 3.9.3.7.1 to provide more specific provisions for the qualification and production testing of snubbers. Upon review of the proposed revision to the DCD, the staff determined that additional RAIs were necessary. In RAI 3.9-114 S01, the staff requested the applicant to clarify the consideration of load sharing among snubbers. In RAI 3.9-117 S01, the staff requested the applicant to address specific aspects of qualification and production testing for snubbers. In RAI 3.9-175 S01, the staff requested the applicant to cross reference the related portions of DCD, Tier 2, Section 3.9.6, in Section 3.9.3. In response to RAI 3.9-114 S01, RAI 3.9-117 S01, and RAI 3.9-175 S01, the applicant revised DCD, Tier 2, Section 3.9.3.7.1(3)c, to provide additional details of snubber design and testing. For example, the applicant specified in the DCD that snubber production and qualification test programs will be performed with strict adherence to the manufacturer’s snubber installation and instruction manual and that the test program will be periodically audited during implementation. Further, the codes and standard used for snubber qualification and production testing are ASME BPV Code, Section III and subsection NF; ASME QME-1 (Section QDR); and ASME OM Code, Subsection ISTD. In response to RAI 3.9-114 S01, the applicant also clarified that each snubber in a snubber pair is typically designed to accommodate the full seismic restraint load and that the other snubber would pick up any additional load if a delayed engagement occurs. The NRC staff considers the provisions for qualification of dynamic restraints in the DCD to be consistent with the ASME Code and industry guidance and, therefore, to be acceptable for the ESBWR design certification. As a result, RAIs 3.9-114, 3.9-117, 3.9-175, and the associated open item were resolved.

Section 3.9.3.7.1(3)e of the ESBWR DCD Tier 2 references the ASME OM Code for both preservice and inservice testing of dynamic restraints. The ASME OM Code, Subsection ISTD, provides the requirements for the preservice examination and testing of dynamic restraints in paragraphs ISTD-4000 and ISTD-5000. DCD, Tier 2, Section 3.9.3.7.1(3)e, states that snubber maintenance, repairs, replacements, and modifications are performed in accordance with the requirements of the ASME OM Code, Subsection ISTD. DCD Tier 2, COL Information Item 3.9.9-4-A, requires the COL applicant to provide a full description of the snubber preservice and inservice inspection and testing program and a milestone for program implementation, including development of a data table. The NRC staff finds the provisions in the ESBWR DCD referencing the ASME OM Code, and the responsibility of the COL applicant to provide a full description of the snubber preservice and inservice inspection and testing program, to be acceptable for ESBWR design certification.

In RAI 3.9-248, the NRC staff requested that the applicant clarify a reference to the ASME BPV Code, Section XI, and the ASME OM Code with respect to the IST program for snubbers. In response to RAI 3.9-248, the applicant stated that the snubber inservice examination and testing program will be in accordance with the ASME OM Code and that it would revise the ESBWR DCD to address this RAI. Subsequently, Revision 6 of ESBWR DCD Tier 2 Section 3.9.3.7.1(3)b referenced the ASME OM Code (rather than ASME BPV Code, Section XI) for the IST Program for snubbers. Therefore, RAI 3.9-248 was closed.

Task Action Plan Item A-13, "Snubber Operability Assurance," in NUREG-0933 addresses the design and qualification of dynamic restraints in nuclear power plants. ESBWR DCD, Tier 2, Table 1.11-1, summarizes the criteria for the structural and mechanical performance parameters used for snubbers, and the installation and inspection considerations for snubbers, in response to Task Action Plan Item A-13 for the ESBWR design certification application as described in DCD, Tier 2, Section 3.9.3. The pipe support design specification requires that the snubbers be designed in accordance with ASME Code, Section III, Subsection NF. The snubbers are tested to ensure proper performance during seismic and other RBV events and under anticipated operational transient loads or other mechanical loads associated with the design requirements of the plant. The preservice examination will verify the following: (1) there are no visible signs of damage or impaired operability as a result of storage, handling, or installation, (2) the snubber load rating, location, orientation, position setting, and configuration are according to design drawings and specifications, (3) snubbers are not seized, frozen, or jammed, (4) adequate swing clearance is provided to allow snubber movements, (5) if applicable, fluid is to the recommended level and is not to be leaking from the snubber system, and (6) structural components (e.g., pins, fasteners) are installed correctly. If the period between the initial preservice examination and initial system preoperational tests exceeds 6 months, the first, fourth, and fifth items are reexamined. Snubbers that are installed incorrectly or otherwise fail to meet the above requirements will be repaired or replaced and reexamined in accordance with the above criteria. Similarly, DCD, Tier 2, Table 1C-2, "Operating Experience Review Results Summary—IE Bulletins," references DCD, Tier 2, Section 3.9.3, for consideration of the operating experience issues discussed in NRC Bulletin 81-01. The NRC staff finds that the provisions for the design and qualification and IST program for dynamic restraints, as specified in DCD, Tier 2, Section 3.9.3, address lessons learned from the operating experience with dynamic restraints in a manner that resolves Task Action Plan Item A-13 and Bulletin 81-01 for the ESBWR design certification.

3.9.6.4 *Conclusions*

The NRC staff reviewed the ESBWR design certification application for compliance with the NRC regulations and the applicable edition and addenda of the ASME Code as incorporated by reference in 10 CFR 50.55a for the functional design, qualification, and IST programs for pumps, valves, and dynamic restraints to be used in ESBWR nuclear power plants. The staff also evaluated the ESBWR DCD for the consideration of lessons learned from operating experience with plant components at current nuclear power plants and the results of NRC and industry research programs. Based on its review, the NRC staff concludes that the DCD provisions for the functional design and qualification of pumps, valves, and dynamic restraints to be used in an ESBWR, and the general description of the IST programs for those components, satisfy the NRC regulations and address operating experience and research results in an adequate manner for a design certification application. Therefore, the staff concludes that the ESBWR DCD is acceptable with respect to the functional design, qualification, and IST programs for pumps, valves, and dynamic restraints for the ESBWR design certification.

As discussed in this section, ESBWR DCD Tier 1 includes ITAAC to provide assurance that important plant systems and components are capable of performing their design-basis functions. Further, ESBWR DCD Tier 2 includes COL information items that require the COL applicant to provide a full description of the IST program and the snubber preservice and inservice inspection and testing programs, and milestones for full implementation of those programs. As part of the review of a COL application for an ESBWR nuclear power plant, the NRC staff will evaluate the full description of the functional design, qualification, and IST programs for pumps, valves, and dynamic restraints provided by the COL applicant. The staff will also confirm the completion of the applicable ITAAC for ESBWR components during plant construction to ensure that design reports for piping systems and ASME components are in order and to confirm that the NRC regulations and ASME Code requirements are met.

3.10 Seismic and Dynamic Qualification of Mechanical and Electrical Equipment

3.10.1 Regulatory Criteria

The following regulatory requirements and guidelines provide the basis for the acceptance criteria for the review by the NRC staff:

- GDC 1, "Quality Standards and Records," and GDC 30, "Quality of Reactor Coolant Pressure Boundary," of Appendix A to 10 CFR Part 50, as related to qualifying equipment to appropriate quality standards commensurate with the importance of the safety functions to be performed;

- GDC 2 and Appendix S, "Earthquake Engineering Criteria for Nuclear Power Plants," to 10 CFR Part 50, as related to qualifying equipment to withstand the effects of natural phenomena such as earthquakes;

- GDC 4, as related to qualifying equipment being capable of withstanding the dynamic effects associated with external missiles and internally generated missiles, pipe whip, and discharging fluids that cause jet impingement forces;

- GDC 14, “Reactor Coolant Pressure Boundary,” as related to qualifying equipment associated with the reactor coolant boundary so as to have an extremely low probability of abnormal leakage, rapidly propagating failure, or gross rupture;

- Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants,” to 10 CFR Part 50, as related to qualifying equipment using the QA criteria provided;

- RG 1.63, “Electric Penetration Assemblies in Containment Structures of Nuclear Power Plants,” issued February 1987;

- RG 1.122, “Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components,” Revision 1, issued February 1978;

- RG 1.61, “Damping Values for Seismic Design of Nuclear Power Plants,” issued March 2007;

- RG 1.92, “Combining Modal Responses and Spatial Components in Seismic Response Analysis,” Revision 2, issued July 2006;

- RG 1.29, “Seismic Design Classification,” Revision 3, issued September 1978;

- RG 1.100, “Seismic Qualification of Electrical and Mechanical Equipment for Nuclear Power Plants,” Revision 2, issued June 1988; and,

- RG 1.97, “Criteria for Accident Monitoring Instrumentation for Nuclear Power Plants,” Revision 4, issued June 2006.

3.10.2 Summary of Technical Information

Section 3.10 of ESBWR DCD, Tier 2, Revision 7, addresses methods of test and analysis employed to ensure the operability of mechanical and electrical equipment (including instrumentation and controls) under the full range of normal and accident loadings (including seismic and reactor building vibration (RBV)). Mechanical and electrical equipment is designed to withstand the effects of earthquakes (i.e., seismic Category I requirements) and other accident-related loadings. Mechanical and electrical equipment covered by this section includes equipment associated with systems that are essential for reactor shutdown, containment isolation, reactor core cooling, and containment and reactor heat removal, or are otherwise essential in preventing significant release of radioactive material to the environment. This section also covers equipment (1) that performs the above functions automatically, (2) that is used by the operators to perform these functions manually, and (3) whose failure can prevent the satisfactory accomplishment of one or more of the above safety functions. In addition, this section covers instrumentation that is needed to assess plant and environs conditions during and after an accident, as described in RG 1.97.

Most of the information presented in Section 3.10 of DCD Tier 2 relates to the seismic and dynamic qualification methods and procedures for electrical equipment and its supports. The applicant stated that the mechanical components and equipment, and the electrical components that are integral to the mechanical equipment, are dynamically qualified as described in Section 3.9 of DCD Tier 2. The seismic and dynamic qualification methodology described in Section 4.4 of applicant's Licensing Topical Report NEDE-24326-1-P, "General Electric Environmental Qualification Program," issued January 1983, applies to mechanical as well as electrical equipment.

3.10.3 Staff Evaluation

The staff performed its review of ESBWR DCD, Tier 2, Revision 3, Section 3.10, related to the seismic and dynamic qualification of mechanical and electrical equipment, in accordance with the criteria and procedures delineated in SRP Section 3.10, draft Revision 3, issued April 1996.

The staff performed a comparison of the SRP version used during the review with the 2007 version of the SRP. The 2007 version did not include any additional requirements, generic issues (GIs), bulletins (BLs), GLs, or technically significant acceptance criteria beyond those identified in the version used by the staff. Therefore, the staff finds that the use of draft Revision 3 of SRP Section 3.10, issued in 1996, is acceptable for this review.

In 1980, the NRC staff raised a safety concern that seismic qualification of mechanical and electrical equipment in some older vintage nuclear power plants (i.e., plants with construction permit applications docketed before about 1972) had not been conducted by the licensees in accordance with the licensing criteria for seismic qualification of equipment acceptable at that time [i.e., IEEE Standard 344 -1975; RG 1.100, Revision 1 (1977); and SRP Section 3.10]. Therefore, equipment in those older vintage nuclear power plants (NPPs) may not have been adequately qualified to ensure its structural integrity and/or proper functionality in the event of a safety shutdown earthquake (SSE). The NRC, as a result, established an Unresolved Safety Issue (USI) A-46 Program (later called Task Action Plan (TAP) A-46) in December 1980, and issued a GL 87-02, entitled, "Verification of Seismic Adequacy of Mechanical and Electrical Equipment in Operating Reactors, Unresolved Safety Issue (USI) A-46," on February 19, 1987, to address this safety concern.

USI A-46 Program was resolved, using a generic approach, by implementing the NRC approved Generic Implementation Procedure (GIP-2) proposed by an industry group. Each affected licensee of the 67 USI A-46 plants was required to: (1) perform a plant-specific evaluation (including detailed plant walkdowns) of certain classes of mechanical and electrical equipment in accordance with the criteria and guidelines delineated in the GIP-2 and (2) search for and resolve the outliers that required plant modifications.

For technical resolution of this issue, the applicant stated, in Table 1.11-1 of DCD Tier 2, that the seismic qualification of ESBWR equipment is addressed in Sections 3.7 and 3.10 of DCD Tier 2. USI A-46 Program or TAP A-46 is not applicable for new nuclear power plants.

Seismic qualification of mechanical and electrical equipment for ESBWR plants is described in DCD, Tier 2, Section 3.10, with the generation of Required Response Spectra described in DCD, Tier 2, Section 3.7. The staff evaluations of these areas are provided in Sections 3.7 and 3.10 of this report, respectively.

Appendix S to 10 CFR Part 50 states the following:

> This appendix applies to applicants for a design certification or COL pursuant to Part 52 of this chapter or a construction permit or operating license pursuant to Part 50 of this chapter on or after January 10, 1997. However, for either an operating license applicant or holder whose construction permit was issued prior to January 10, 1997, the earthquake engineering criteria in Section VI of Appendix A to 10 CFR Part 100 continue to apply.

However, DCD, Tier 2, Revision 1, Section 3.10(1), did not list Appendix S to 10 CFR Part 50 as a required regulation. In RAI 3.10-1, the staff asked the applicant to explain the absence of a stated need for compliance with the requirements of Appendix S to 10 CFR Part 50 in ESBWR DCD, Tier 2, Section 3.10.

In its response to RAI 3.10-1 S01, the applicant stated that the ESBWR design will meet the requirements in Appendix S to 10 CFR Part 50 and that it will revise DCD Section 3.10(1) as noted in the markup attached to the applicant's response. The staff verified that the applicant implemented the revised markup in ESBWR DCD, Tier 2, Revision 3. Therefore, RAI 3.10-1 is closed.

3.10.3.1 *General Seismic and Dynamic Qualification Criteria for Mechanical and Electrical Equipment*

In DCD, Tier 2, Section 3.10, the applicant stated that the qualification of seismic Category I mechanical and electrical equipment is accomplished by testing, analysis, a combination of testing and analysis, or by experience data.

Response spectra define the input motion for the qualification of equipment and supports. As described in DCD, Tier 2, Section 3.7, the building dynamic analysis generates the required response spectra (RRS). They are grouped by buildings and by elevations. This RRS definition incorporates the contribution of RBV dynamic loads as specified by the load combinations in Tables 3.9-2 and 3.9-3 of DCD Tier 2. When one type of equipment is located at several elevations and/or in several buildings, the governing response spectra are specified.

Section 3.7 of this report provides the staff's evaluation of response spectra input motion for qualifying mechanical and electrical equipment and their supports.

The applicant also stated that Table 3.2-1 of ESBWR DCD Tier 2 identifies principal seismic Category I SSCs. Most of these are safety-related items, as explained in Section 3.2.1 of DCD Tier 2. The safety-related functions, defined in DCD, Tier 2, Section 3.2, include those essential for reactor shutdown, containment isolation, reactor core cooling, reactor protection, containment and reactor heat removal, and emergency power supply, or that are otherwise essential in preventing significant release of radioactive material to the environment.

The applicant further stated that DCD, Tier 2, Section 3.9, and Section 4.4 of NEDE-24326-1-P regarding the applicant's Environmental Qualification Program describe the seismic and dynamic qualification program for mechanical components and equipment and the electrical components that are integral to the mechanical equipment. The program conforms to the requirements of IEEE-323, "Qualifying Class 1E Equipment for Nuclear Power Generating Stations," as modified and endorsed by RG 1.89, "Environmental Qualification of Certain Electric Equipment Important to Safety for Nuclear Power Plants," and meets the criteria contained in IEEE-344, “Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations,” as modified and endorsed by RG 1.100.

For seismic and dynamic qualification of mechanical and electric equipment in the ESBWR, DCD Tier 2 lists three versions of IEEE-344 as the guidelines to be followed—(1) IEEE-344 2004, (2) RG 1.100, Revision 2, which endorses IEEE-344-1987 with some conditions, and (3) Section 4.4 of NEDE-24326-1-P regarding the applicant’s Environmental Qualification Program, which uses IEEE-344-1975 as its guidelines. In RAI 3.10-2, the staff asked the applicant to state specifically which parts (chapters or sections) of each version of the IEEE-344 guidelines ESBWR DCD Tier 2 will meet. The NRC noted that RG 1.100 Revision 2 does not endorse IEEE-344-2004, and the staff does not endorse Section 10 (regarding experience) of IEEE-344-2004 in its entirety.

In its response to RAI 3.10-2, the applicant stated that the ESBWR will meet IEEE-344-1987, and that it will revise DCD Table 1.9-22 as noted in a markup attached to the response. The staff reviewed the applicant’s response and found it to be incomplete. First, the response should indicate that the ESBWR will meet IEEE-344-1987, as endorsed by RG 1.100, Revision 2. Second, in the revised Table 1.9-22, the applicant should delete “Note: more recent version exists” under “Title.” In RAI 3.10-2 S01, the staff asked the applicant to address in DCD, Tier 2, Section 3.10, whether it commits to the conditions that RG 1.100, Revision 2, places on IEEE-344-1987 and to explain the purpose of adding “(R1993)” and the note to Table 1.9-22.

In its response to RAI 3.10-2 S01, the applicant stated that “(R1993)” means that the IEEE-344 Committee reaffirmed the 1993 edition without any changes that year. The applicant further stated that IEEE-344-1987 (R1993) meets the conditions in RG 1.100, Revision 2.

However, the applicant’s response to RAI 3.10-2 S01 was incomplete. Revision 2 of RG 1.100 places some restrictions on the use of the criteria and procedures provided in IEEE-344-1987, in particular on the application of the qualification by experience. Therefore, the applicant was incorrect in stating that IEEE-344-1987 (R1993) meets the conditions in RG 1.100, Revision 2. However, in the applicant’s responses to RAIs 3.10-3 and 3.10-4, the applicant stated that it does not use an operating experience database for equipment seismic qualification and does not maintain a database for operating experience. Thus, in RAI 3.10-2 S02, the staff asked the applicant to delete all the statements related to experience data in DCD, Tier 2, Revision 3 (e.g., the first and last paragraphs of Section 3.10.1.1 and the second sentence of Section 3.10.2). In addition, the staff asked the applicant to confirm in the DCD that Section 9 of IEEE-344-1987 is not applicable to the ESBWR.

In ESBWR DCD, Tier 2, Revision 4, the applicant deleted all the statements related to experience data and stated in Section 3.10.1.1 that it does not use qualification by actual seismic experience, as permitted by IEEE-344-1987. Therefore, RAI 3.10-2 is closed.

Section 4.4.3 of NEDE-24326-1-P defines “operating experience” in terms of the environmental qualification of equipment. The 1987 and 2004 versions of IEEE-344 also provide guidelines for qualification by experience, including both earthquake experience data and test experience data. In ESBWR DCD Tier 2, the applicant committed to meeting the requirements of IEEE-344. In RAI 3.10-3, the staff asked the applicant to clarify, in sufficient detail, whether the database documents described in NEDE-24326-1-P are consistent with and satisfy the requirements in IEEE-344. The staff further asked the applicant to discuss the level of documentation currently available for the cited experience database for seismic and dynamic qualification of mechanical and electrical equipment. The staff also asked the applicant to discuss whether such documentation is sufficiently complete for staff audit or review.

In its response to RAI 3.10-3, the applicant stated that it does not use operating experience for equipment qualification and that it does not maintain any database for operating experience. The applicant further stated that it would not change the DCD in response to this RAI. The staff determined that the applicant's response was not acceptable because, if the applicant does not use operating experience for equipment qualification, it should delete Section 3.10.2.4 of DCD Tier 2 in its entirety, as well as all statements regarding the use of operating experience in Section 3.10.

In RAI 3.10-3 S01, the staff asked the applicant to clarify in the DCD the use of qualification by experience. In its response to RAI 3.10-3 S01, the applicant stated that it does not use operating experience as a basis for equipment qualification. Instead, the applicant follows IEEE-344 by using testing, analysis, or a combination of the two, as explained in its response to RAI 3.11-1. The staff has verified that the applicant has deleted Section 3.10.2.4 and all statements regarding the use of operating experience in Section 3.10 of DCD, Tier 2, Revisions 3 and 4. Therefore, the staff considers RAI 3.10-3 closed.

The following sections provide the staff's specific evaluation of the methods and procedures for qualifying mechanical and electrical equipment and their supports.

3.10.3.2 *Seismic and Dynamic Qualification of Safety-Related Mechanical Equipment (Including Other Loads Induced by Reactor Building Vibration)*

ESBWR DCD, Tier 2, Section 3.9.2.2, describes the criteria for dynamic qualification of safety-related mechanical equipment and associated supports and the qualification testing and/or analysis applicable to the major components on a component-by-component basis. Seismic and other events that may induce RBV are considered. The applicant stated that, in some cases, a module or assembly consisting of mechanical and electrical equipment is qualified as a unit (e.g., the hydraulic control unit). The discussion of these modules appears in DCD, Tier 2, Sections 3.9.2 and 3.9.3, instead of in Section 3.10. However, DCD, Tier 2, Section 3.10, discusses electrical supporting equipment such as control consoles, cabinets, and panels.

Section 3.9.2 of this report provides the staff evaluation of the methodology and criteria used for seismic and dynamic qualification of mechanical equipment by analysis and a combination of testing and analysis. However, the evaluation of some common issues related to seismic and dynamic qualification criteria addressed in this report applies to both mechanical and electrical equipment.

3.10.3.3 *Methods and Procedures for Qualifying Electrical Equipment*

ESBWR DCD, Tier 2, Section 3.10, describes the general methods and procedures for qualifying seismic Category I electrical equipment by testing, analysis, combined testing and analysis, or experience data. The qualification program includes ensuring the operability of the equipment during and after the SSE loads and Service Level D RBV dynamic loads, and the continued structural and functional integrity of the equipment after low-level earthquake loading of lesser magnitude (DCD, Tier 2, Section 3.7) and Service Level B RBV dynamic loads.

Regarding qualification by testing (DCD, Tier 2, Section 3.10.2.1), the applicant stated that the testing methodology includes the hardware interface requirements and the test methods. With regard to interface requirements, the applicant stated that intervening structures or components (e.g., interconnecting cables, bus ducts, conduits) that serve as interfaces between the equipment to be qualified and that supplied by others are not qualified as part of this program. However, the effects of interfacing are considered. When applicable, accelerations and frequency content at the locations of interfaces with interconnecting cables, bus ducts, conduits, and other intervening structures and components are determined and documented in the test report. This information is specified in the form of interface criteria.

In testing for SSE loading and RBV dynamic loads, the applicant stated that an SSE test including other appropriate Service Level D RBV dynamic loads is performed on all test specimens. This test is conducted to demonstrate that equipment will perform its safety-related function throughout an SSE (as defined in DCD, Tier 2, Section 3.7) combined with Service Level D RBV dynamic loads. The strong motion of the test lasts a minimum of 15 seconds in each orientation. The operability of equipment must be verified.

The applicant further stated that the test method is biaxial, random single- and/or multi-frequency excitation to envelop generic RRS levels in accordance with Section 7 of IEEE-344. Representative samples of equipment and supports are selected for use as test specimens. The test specimen is mounted to the test table so that inservice mounting, including interfaces, is simulated. Equipment is tested in an operational condition. Most pieces of seismic Category I electrical equipment have safety-related function requirements before, during, and after seismic events. Other items (such as plant status display equipment) have requirements only before and after seismic events. All equipment is operated at appropriate times to demonstrate its ability to perform its safety-related function. If a malfunction is experienced during any test, the final test report determines and documents the effects of the malfunction. The applicant indicated that the final test report contains a summary of test and analysis results, which is readily available for audit.

Based on the review of the applicant's approach for testing equipment as described above, the staff finds the applicant's test methods acceptable.

Regarding qualification by analysis (DCD, Tier 2, Section 3.10.2.2), the applicant stated that dynamic analysis or an equivalent static analysis, described in DCD, Tier 2, Section 3.7.3, is employed to qualify the equipment. If the fundamental frequency of the equipment is above the input excitation frequency (cutoff frequency of RRS), the equipment is considered rigid. In this case, the load on each component can be determined statically by concentrating its mass at its center of gravity and multiplying the values of the mass with the appropriate maximum floor acceleration (i.e., floor spectra acceleration at the high-frequency asymptote of the RRS) at the equipment support point.

The applicant indicated that a static coefficient analysis may also be used for certain equipment in lieu of the dynamic analysis. No determination of natural frequencies is made in this case. The seismic loads are determined statically by multiplying the actual distributed weight of the equipment by a static coefficient equal to 1.5 times the peak value of the RRS at the equipment mounting location, at a conservative and justifiable value of damping. This method is only applicable to equipment with simple frame-type structures and can be represented by a simple model. For equipment having a configuration other than a simple frame-type structure, this method may be applied when justification can be provided for the static factor that is used on a case-by-case basis. However, if the equipment is determined to be flexible (i.e., with the fundamental frequency of the equipment within the frequency range of the input spectra) and not simple enough for equivalent static analysis, a dynamic analysis method is applied.

In analyses for seismic and RBV dynamic loads, the applicant stated that an analysis must be performed to show that the structural and functional integrity of the equipment is maintained under low-level earthquake loads, including appropriate RBV dynamic loads in combination with normal operating loads. The analysis must also show that, subsequently, the SSE loads, including appropriate RBV dynamic loads, do not result in the failure of the equipment to perform its safety-related function(s). The demonstration of qualification is documented, including the requirements of the equipment specification, the results of the qualification, and the justification that the methods used are capable of demonstrating that the equipment does not malfunction.

Based on the review of the applicant's approach for qualification of equipment by analysis as described above, the staff finds the applicant's analysis methods acceptable.

Regarding qualification by combined testing and analysis (DCD, Tier 2, Section 3.10.2.3), the applicant stated that, in some instances, it is not practical to qualify the equipment solely by testing or analysis. This may be because of the size of the equipment, its complexity, or the many similar configurations. Large equipment may be impractical to test because of limitations in vibration equipment loading capability. This method can be used to qualify the equipment by exciting the equipment to levels at least equal to the expected response from the SSE loads, including appropriate RBV dynamic loads, by using analysis to justify the excitation, and by using the test data on modal frequencies to verify the mathematical model. The method can also be used for extrapolation of similar equipment and extrapolation of dynamic loading conditions. The applicant stated that the test results combined with the analysis allow the model of the similar equipment to be adjusted to produce a revised stiffness matrix and to allow refinement of the analysis for the modal frequencies of the similar equipment. The result is a verified analytical model that is used to qualify the similar equipment. The model can also predict failure under the increased or different dynamic load excitation.

Based on the review of the applicant's approach for the qualification of equipment by combined testing and analysis as described above, the staff finds the applicant's approach acceptable.

Regarding qualification by experience (DCD, Tier 2, Section 3.10.2.4), the applicant stated that it follows the methods outlined in IEEE-344. When existing test data or experience data are available, the equipment database is reviewed to determine if the previous testing or experience meets or exceeds the new requirements of the equipment qualification. Depending on the source and level of documentation detail available, an appropriate approach is taken and documentation prepared to justify the qualification for the new requirements. The applicant further stated that, for the equipment to be qualified by reason of operating experience, documented data must be available confirming that the following criteria have been met as appropriate:

- the equipment providing the operating experience is identical or justifiably similar to the equipment to be qualified;
- the equipment providing the operating experience has operated under service conditions that equal or exceed in severity the service conditions and functional requirements for which the equipment is to be qualified; or,

- the installed equipment can, in general, be removed from service and subjected to partial type testing to include the dynamic environments for which the equipment is to be qualified.

As indicated in the staff's evaluation of the applicant's response to RAI 3.10-3 in Section 3.10.3.1 of this report, the staff had concerns about the applicant's approach for the qualification of equipment by experience. As described above, the applicant indicated that it would follow the methods outlined in IEEE-344. In RAI 3.10-4, the staff asked the applicant to clarify which version of IEEE-344 it commits to following. As indicated in RAI 3.10-2 and discussed in Section 3.10.3.1 of this report, the NRC staff does not accept some aspects of the criteria in Section 10 of IEEE-344-2004. For example, the staff does not agree with the use of median-centered spectra to define the RRS for candidate equipment and the use of the mean of the test response spectra to define test experience spectra. The staff also finds inadequate the provisions for meeting the operating-basis earthquake (OBE) requirements, for meeting OBE test experience spectra requirements, and for demonstrating operability during and after the SSE loads and Service Level D RBV dynamic loads. In RAI 3.10-4, the staff noted some unacceptable criteria provided in IEEE-344-2004 as described above and asked the applicant to (1) discuss, in detail, the criteria and procedures for seismic and dynamic qualification of electric equipment by experience for the ESBWR, including the experience database and all pertinent references for the experience database, (2) state whether it intends to commit to particular industry standard guidelines for the seismic qualification of ESBWR mechanical equipment by experience and discuss the experience database and all pertinent references for the experience database, and (3) state at what stage the specific, detailed experience database documents will be available for staff audit or review.

In its response to RAI 3.10-4, the applicant stated that it does not use operating experience for equipment qualification and that it does not maintain any database for operating experience. The applicant further stated that it would not make any DCD changes in response to this RAI. The staff finds the applicant's response unacceptable because, if the applicant does not use operating experience for equipment qualification, it should delete Section 3.10.2.4 of DCD Tier 2 in its entirety and all statements regarding the use of operating experience in Section 3.10.

In RAI 3.10-4 S01, the staff asked the applicant to address a question similar to that described in RAI 3.10-3 S01, but related to IEEE-344-1987. The applicant's response to RAI 3.10-4 S01 was the same as its response to RAI 3.10-3 S01. Therefore, the staff's evaluation of the response to RAI 3.10-4 S01 is the same as that for RAI 3.10-3 S01. RAI 3.10-4 is closed.

In Section 4.4.2.5.1 of NEDE-24326-1-P, item (d) provides information related to the dynamic event and aging tests. The applicant stated that the dynamic tests shall simulate the effect of five upset events (the OBE combined with appropriate hydrodynamic loads) and inservice hydrodynamic loads having a long duration in order to simulate dynamic event aging followed by one faulted event (the SSE combined with appropriate hydrodynamic loads). The dynamic tests will be performed on aged products unless otherwise justified. The applicant also presented the detailed methods of calculating hydrodynamic loads with specific proprietary numbers and testing procedures. In RAI 3.10-6, the staff asked the applicant to clarify (1) the applicability of the above methods with respect to the ESBWR and to provide the basis for the numbers used, and (2) the last sentence of item (d) concerning the hydrodynamic load tests. In its response to RAI 3.10-6, the applicant presented its calculations and indicated that the numbers presented were obtained based on the plant design life. However, the numbers presented are inconsistent with those stated in item (d) of NEDE-24326-1-P. Furthermore, the applicant did not respond to the second part of the RAI concerning the hydrodynamic load tests. RAI 3.10-6 was being tracked as an open item in the SER with open items.

In RAI 3.10-6 S01, the staff asked the applicant to respond to the exact questions asked in RAI 3.10-6 (1) and (2), to clearly state the differences in SRV actuation events assumed, and to justify the inconsistency. In its response to RAI 3.10-6 S01, the applicant stated that the advanced BWR design and earlier BWR designs assume many SRV openings over the plant lifetime during postulated design-basis anticipated operational occurrences that cause reactor pressure to increase to the SRV setpoints. The ESBWR design (with the isolation condenser system and its larger steam volume) results in zero SRV openings during design-basis anticipated operational occurrences, because the isolation condenser system is sized to prevent them with three of four trains in operation. This is the major contributor to the reduction of SRV actuation events. Thus, the number of SRV actuation events in the DCD is still conservative. The staff considers the applicant's response to RAI 3.10-6 acceptable. Therefore, RAI 3.10-6 and associated open item are closed.

3.10.3.4 *High-Frequency Seismic Excitations*

Recent ground motion studies for some hard rock sites indicate that the resulting seismic inputs to SSCs contain high-frequency excitations. For the seismic qualification of mechanical and electrical equipment, some safety-related active components in nuclear power plants have been qualified by IEEE-344-type tests with intentional high-frequency contents to account for concurrent BWR hydrodynamic loads. However, the vast majority of the existing seismic test data available in the industry are those tested with input frequencies up to 33 hertz (Hz), although the test response spectra may have shown the zero period acceleration (ZPA) of up to 100 Hz.

The inadvertent high-frequency contents shown in the ZPA, because of ball-joints and kinematic linkages of shake tables, present in the seismic qualification of equipment by IEEE-344-type tests for the past 30 years are the noise signals that may not have the proper frequency contents with sufficient energy to be compatible with the amplified region of the RRS at high frequencies. For existing qualification test data to be valid for resolving high-frequency concerns, the adequacy of the frequency content and the stationarity of the frequency content of the synthesized waveform used for the tests must be demonstrated. The frequency content of the Fourier transform of the test waveform or the frequency content of the power spectral density of the test waveform must be compatible with the amplified portion of the RRS. Guidelines on frequency content and stationarity appear in Annex B to IEEE-344-2004.

In view of these concerns, the staff, in RAI 3.10-8, asked the applicant to address the adequacy of the seismic qualification of ESBWR mechanical and electrical equipment for plant sites with high-frequency seismic excitations. RAI 3.10-8 was being tracked as an open item in the SER with open items. In its response to RAI 3.10-8, the applicant provided the following explanations:

> "DCD Tier #2, Rev 4, Section 3.7.1.1 Design Ground Motion states "The ESBWR standard plant SSE design ground motion is rich in both low and high frequencies. The low-frequency ground motion follows RG 1.60 ground spectra anchored to 0.3 g. The high-frequency ground motion matches the North Anna ESP site-specific spectra as representative of most severe rock sites in the Eastern US.""

The following sections discuss ESBWR seismic requirements:

- Section 3.7.1.1.1 Low-Frequency Ground Motion
- Section 3.7.1.1.2 High-Frequency Ground Motion
- Section 3.7.1.1.3 Single Envelope Ground Motion

The seismic design response spectra of the Single Envelope Ground Motion, also termed Certified Seismic Design Response Spectra (CSDRS), containing both Low-Frequency Ground Motion and High-Frequency Ground Motion are utilized in generation of in-structure response spectra for use in seismic qualification of mechanical and electrical equipment.

ESBWR is a boiling water reactor and seismic qualification of mechanical and electrical equipment meets IEEE 344-1987, the RRS includes intentional high-frequency contents to account for concurrent BWR hydrodynamic loads for the affected systems and equipment.

Section 3.7.3 Seismic Subsystem Analysis discusses qualification to codes and IEEE-344 for piping and equipment.

Section 3.10 Seismic and Dynamic Qualification of Mechanical and Electrical Equipment discusses ESBWR electrical and mechanical equipment qualification to IEEE 344-1987. The adequacy of the seismic qualification of ESBWR mechanical and electrical equipment for plant sites with high-frequency seismic excitation follows Annex B to IEEE 344-1987 guidelines on frequency content and stationarity to demonstrate that the frequency content of the Fourier transform of the test waveform or the frequency content of the power spectral density of the test waveform is compatible with the amplified portion of the RRS. Note "Annex B Frequency Content and Stationarity" is essentially the same in IEEE 344-1987 and IEEE 344-2004.

ESBWR SSE RRS include intentional high-frequency contents for hard rock sites, additional high frequency content for applicable hydrodynamic loads, and demonstrates frequency content and stationarity. Therefore, seismic qualification of ESBWR mechanical and electrical equipment is adequate for plant sites with high-frequency seismic excitations."

The staff finds the applicant's response acceptable because ESBWR SSE RRS includes all the known high-frequency seismic and hydrodynamic excitations on its evaluation, and RAI 3.10-8 and associated open item are closed.

3.10.3.5 *Analysis or Testing of Mechanical and Electrical Equipment Supports*

The applicant stated that, when possible, combined stresses of the mechanically designed component supports are maintained within the limits of the ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NF, up to the interface with building structure, while the combined stresses of the structurally designed component supports defined as building structure in the project design specifications are maintained within the limits delineated in DCD Section 3.8. The supports of most of the electrical equipment (mostly control panels and racks, other than motor and valve-mounted equipment supports) are tested with the equipment installed. Otherwise, a dummy is employed to simulate inertial mass effect and dynamic coupling to the support.

3.10.3.5.1 Nuclear Steam Supply System Electrical Equipment Supports (Other than Motors and Valve-Mounted Equipment)

The applicant stated that the seismic and other RBV dynamic load qualification tests on equipment supports are performed over the frequency range of interest. In general, the testing of seismic Category I supports is accomplished using the procedure described below.

The applicant indicated that assemblies (e.g., control panels) containing devices that have dynamic load malfunction limits established are tested by mounting the assembly on the table of a vibration machine in the manner it is to be mounted when in use and conducting vibration testing by running a low-level resonance search. As with the devices, the assemblies are tested in the three major orthogonal axes. The resonance search is run in the same manner as described for devices. If resonances are present, the transmissibility between the input and the location of each device is determined by measuring the accelerations at each device location and calculating the magnification between it and the input. The applicant stated that, once known, the transmissibilities could be used analytically to determine the response at any seismic Category I device location for any given input. As long as the device input accelerations are determined to be below their malfunction limits, the assembly is considered a rigid body with a transmissibility equal to one so that a device mounted on it would be limited directly by the assembly input acceleration.

The applicant indicated that four basic generic types of control panels and racks constitute the majority of seismic Category I electrical assemblies—vertical board, instrument panel, relay rack, and National Electrical Manufacturers Association Type 12 enclosure. One or more of each type is tested to full acceleration levels and qualified using the above testing procedures. From these tests, it is concluded that most of the panel types have more than adequate structural strength and that the acceptability of a given panel design is just a function of its amplification factor and the malfunction levels of the devices mounted in it. The applicant stated that subsequent panels are, therefore, tested at lower acceleration levels and the transmissibilities measured for the various devices as described. By dividing the devices' malfunction levels by the panel transmissibility between the device and the panel input, the panel dynamic qualification level could be determined. Several high-level tests are run on selected generic panel designs to ensure conservativeness in using the transmissibility analysis as described.

The applicant stated that some of the supports are qualified by analysis only. Analysis is used for passive mechanical devices and is sometimes used in combination with testing for larger assemblies containing seismic Category I devices. For example, a test is run to determine if there are natural frequencies in the support equipment within the critical frequency range of interest. If the support is determined to be free of natural frequencies in the critical frequency range, then it is assumed to be rigid, and a static analysis is performed. If natural frequencies are present in the critical frequency range, then calculations of transmissibility and responses to varying input accelerations are used to determine if seismic Category I devices mounted in the assembly would operate without malfunctioning.

Based on the review of the applicant's approach for the analysis or testing of nuclear steam supply system equipment supports as described above, the staff finds the applicant's approach acceptable.

3.10.3.5.2 Nonnuclear Steam Supply System Electrical Equipment Supports

Supports for Battery Racks, Instrument Racks, Control Consoles, Cabinets, and Panels

The applicant stated that response spectra for floors where seismic Category I equipment is located are supplied to each vendor. The vendor submits test data, operating experience, and/or calculations to verify that the equipment did not suffer any loss of function before, during, or after the specified dynamic disturbance. Analysis and/or testing procedures are in accordance with DCD, Tier 2, Section 3.10.2. The applicant further stated that these supports are inseparable from their supported items and are qualified with the items or with dummy loads. During testing, the supports are fastened to the test table with fastening devices or methods used in the actual installation, thereby qualifying the total installation.

Cable Trays and Conduit Supports

The applicant stated that seismic Category I cable trays and conduit supports are designed by the response spectrum method. Analysis and dynamic load restraint measures are based on combined limiting values for static load, span length, and response to excitation at the natural frequency. The structural capacity of the tray is used as a factor to determine the spacing of the fixed support points and to provide restraint against excessive lateral and longitudinal movement of the cable tray system. Provisions for differential motion between buildings are made by breaks in the trays and flexible connections in the conduit.

The applicant further stated that the following loadings are used in the design and analysis of seismic Category I cable tray and conduit supports:

1) dead loads and live loads—112 kilograms per meter (kg/m) (75 pounds of mass per linear foot (lbm/linear-ft)) load used for 0.46-meter (m) (18-in.) and wider trays, 75 kg/m (50 lbm/linear-ft) load used for 0.31-m (12-in.) and narrower trays

2) dynamic loads—SSE loads plus appropriate RBV dynamic loads

Dynamic Analysis

Regardless of cable tray function, all supports are designed to meet seismic Category I requirements. Seismic and appropriate RBV dynamic loads are determined by dynamic analysis using appropriate response spectra.

The floor response spectra used are those generated for the supporting floor. In case supports are attached to the walls or to two different locations, the upper-bound envelope spectra are used. In many cases, to facilitate the design, several floor response spectra are combined by an upper-bound envelope.

Based on the review of the limited information in DCD, Tier 2, Section 3.10.3.2, the staff finds the applicant's approach for the design and analysis of cable trays and conduit supports to be reasonable and acceptable. However, DCD, Tier 2, Section 3.10.3.2, does not present specific criteria. The staff requested additional information and evaluated the applicant's response to the requested information in Section 3.9.2 of this report.

Local Instrument Supports

The applicant stated that, for field-mounted seismic Category I instrument supports, the following bases are applicable:

- the mounting structures for the instruments have a fundamental frequency above the excitation frequency of the RRS; and,
- the stress level in the mounting structure does not exceed the material allowable stress when the mounting structure is subjected to the maximum acceleration level for its location.

Instrument Tubing Support

The applicant stated that the following bases are used in the seismic and appropriate RBV dynamic loads design and analysis of seismic Category I instrument tubing supports:

- the supports are qualified by the response spectrum method;
- dynamic load restraint measures and analysis for the supports are based on combined limiting values for static load, span length, and computed dynamic response; and,
- the seismic Category I instrument tubing systems are supported so that the allowable stresses permitted by Section III of the ASME Boiler and Pressure Vessel Code are not exceeded when the tubing is subjected to the loads specified in DCD, Tier 2, Section 3.9.2, for Class 2 and 3 piping.

Based on the review of the applicant's approach for analysis or testing of nonnuclear steam supply system equipment supports as described above, the staff finds the applicant's approach acceptable.

3.10.3.6 *Combined Operating License Information*

In Section 3.10.4 of ESBWR DCD, Tier 2, Revision 1, the applicant stated that "COL holders shall maintain the equipment qualification records including the reports (see Subsections 3.10.2.1 and 3.10.2.2) in a permanent file readily available for audit." The applicant also stated that "COL holders shall prepare a Dynamic Qualification Report (DQR) identifying all seismic Category I electrical equipment and their supports," and specified what the DQR should contain.

However, the applicant did not address the qualification records for equipment included in Section 3.10.2.3 (regarding qualification by combined testing and analysis) and Section 3.10.2.4 (regarding qualification by experience), or their availability for review and audit. In RAI 3.10-5, the staff asked the applicant to discuss the availability of qualification records and reports for equipment included in DCD, Tier 2, Sections 3.10.2.3 and 3.10.2.4, for the purpose of staff review and audit.

In its response to RAI 3.10-5, the applicant stated that it will revise DCD, Tier 2, Sections 3.10.2.3 and 3.10.2.4, to include documentation of qualification, as noted in a markup attached to the response. The response also indicated that the applicant will revise DCD, Tier 2, Section 3.10.4, to include Sections 3.10.2.3 and 3.10.2.4 as noted in the markup.

In the markup for Section 3.10.2.3, the applicant specified whether the qualification documentation required in the report is accomplished by analysis and testing or by extrapolation from similar equipment. The staff reviewed the markups for Sections 3.10.2.3 and 3.10.4 and determined that they are acceptable.

In RAIs 3.10-5 S01 and 3.10-5 S02, the staff asked the applicant to clarify the use of the operating experience in DCD, Tier 2, Section 3.10.2.4, and the qualification records maintenance requirement in Section 3.10.4. The staff also asked when the DQRs will be made available for staff review and audit. RAI 3.10-5 was being tracked as an open item in the SER with open items.

In its resolution of RAIs 3.10-3 and 3.10-4 and its responses to RAIs 3.10-5 S01 and 3.10-5 S02, the applicant deleted DCD, Tier 2, Section 3.10.2.4 (regarding operating experience), added Section 3.10.1.4, and revised Section 3.10.4 to require the COL applicant to describe the requirements of the DQR and to provide a milestone for completing the DQR in accordance with Section 3.10.1.4.

In RAIs 3.10-5 S03 and 3.10-5 S04, the staff requested that the applicant revise the COL information for DQRs in DCD, Tier 2, Revision 4, and state that the COL applicant should submit, in accordance with RG 1.206, “Combined License Applications for Nuclear Power Plants,” an implementation program for the seismic and dynamic qualification of ESBWR mechanical and electrical equipment, including milestones and completion dates with appropriate information to allow staff audit.

As discussed in its response to RAIs 3.10-5 S03 and 3.10-5 S04, the applicant stated that requirements for verification of the seismic and dynamic qualification have been included in ITAAC. NRC regulation 10 CFR 52.99, “Inspection during Construction,” contains a requirement that the COL holder submit to the NRC, no later than 1 year after issuance of the COL, its schedule for completing the ITAAC. The submittal of information by the COL applicant will be consistent with the requirement of 10 CFR 52.99. The staff considers the applicant’s response acceptable because the staff will be made aware of the schedule and have the opportunity to verify test results as soon as they are available. Therefore, RAI 3.10-5 and its associated open item are closed.

3.10.4 Conclusions

Section 3.10.2 of this report summarizes the areas of technical review performed by the staff for the seismic and dynamic qualification of mechanical and electrical equipment. On the basis of its review, the staff concludes that the applicant has defined appropriate criteria and methodology for a seismic and dynamic qualification program for mechanical and electrical equipment, which meet the regulatory guidelines delineated in Section 3.10.1 of this report. This program, which will be implemented for mechanical, instrumentation, and electrical equipment, is consistent with the recommendations of IEEE 344-1987; the guidance of RGs 1.61, 1.92, and 1.100, Revision 2; and Section 3.9.3 of the SRP. This program also meets applicable portions of GDC 1, 2, 4, 14, and 30 in Appendix A and Appendix B and Appendix S to 10 CFR Part 50. Therefore, the staff finds the program acceptable.

3.11 <u>Environmental Qualification of Mechanical and Electrical Equipment</u>

3.11.1 Regulatory Criteria

The applicant addressed the environmental qualification (EQ) of mechanical, electrical, and instrumentation and control (I&C) equipment for the ESBWR DCD, Tier 2, Section 3.2, Section 3.11, and Appendix 3H. The NRC staff based its review of the EQ of mechanical, electrical, and I&C equipment on the relevant requirements set forth in 10 CFR and the applicable Commission policy directives, as described below:

- The regulation at 10 CFR 50.49, requires establishing a program for qualifying electrical and I&C equipment important to safety located in a harsh environment. Equipment important to safety must be able to perform acceptably during all anticipated operating conditions, even after being degraded because of exposure to service conditions during its qualified life.

- GDC 1 requires that components important to safety be designed, fabricated, erected, and tested to quality standards, commensurate with the importance of the safety function to be performed. Equipment important to safety must be able to perform its design safety functions under all anticipated operating conditions, which include normal environmental conditions, anticipated operational occurrences (AOOs), and accident and postaccident environmental conditions.

- GDC 2 requires that components important to safety be designed to withstand the effects of natural phenomena without loss of capability to perform their safety function. The design bases for these components must consider the effects of the most severe natural phenomena anticipated for the site, together with normal and accident plant operating conditions (i.e., EQ) and the importance of the safety function to be performed. Equipment important to safety must be able to perform its design safety functions under all anticipated operating conditions, which include normal environmental conditions, AOOs, and accident and postaccident environmental conditions.

- GDC 4 requires that components important to safety be designed to accommodate the effects of, and be compatible with, the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including LOCAs. Components must be protected against dynamic effects, including those of missiles, pipe whipping, and discharging fluids, that may result from equipment failures and from events and conditions outside the nuclear power unit. Equipment important to safety must be able to perform its design safety functions under all anticipated operating conditions, which include normal environmental conditions, AOOs, and accident and postaccident environmental conditions.

- GDC 23 requires that protection systems be designed to fail in a safe state, or in a state demonstrated to be acceptable on some other defined basis, if conditions such as postulated adverse environments (e.g., extreme heat or cold, pressure, steam, water, or radiation) are experienced. Components that are subject to environmental design and qualification requirements must consider the failure mode of the equipment.

- Criterion III, of Appendix B to 10 CFR Part 50, requires establishing measures to ensure that applicable regulatory requirements and the associated design bases are correctly translated into specifications, drawings, procedures, and instructions. These measures should include provisions to ensure that appropriate quality standards are included in design documents and that deviations from established standards are controlled. A process should also be established to determine the suitability of equipment that is essential to safety-related functions and to identify, control, and coordinate design interfaces between participating design organizations. Where a test program is used to verify the adequacy of a specific design feature, it shall include suitable qualification testing of a prototype unit under the most adverse design conditions. Equipment important to safety must be able to perform its design safety functions under all anticipated operating conditions, which include normal environmental conditions, AOOs, and accident and postaccident environmental conditions.

- Criterion XI, of Appendix B, requires establishing a test control plan to ensure that all tests needed to demonstrate a component's capability to perform satisfactorily in service are identified and performed in accordance with written procedures that incorporate the requirements and acceptance limits contained in applicable design documents. Equipment important to safety must be able to perform its design safety functions under all anticipated operating conditions, which include normal environmental conditions, AOOs, and accident and postaccident environmental conditions.
- Criterion XVII, of Appendix B, requires maintaining sufficient records to furnish evidence of activities affecting quality. The records must include inspections, tests, audits, monitoring of work performance, and materials analysis. Records must be identifiable and retrievable. Equipment important to safety must be able to perform its design safety functions under all anticipated operating conditions, which include normal environmental conditions, AOOs, and accident and postaccident environmental conditions.
- In a staff requirements memorandum dated February 22, 2006, for SECY-05-0197, "Review of Operational Programs in a Combined License Application and Generic Emergency Planning Inspections, Tests, Analyses, and Acceptance Criteria," dated October 28, 2005, the Commission approved the use of a license condition for operational program implementation milestones that are fully described or referenced in the FSAR. SECY-05-0197 identified the EQ program as an operational program.

In evaluating the ESBWR design certification application for compliance with the above regulatory criteria, the staff followed guidance provided in SRP Section 3.11, Revision 3. The staff also considered guidance provided in applicable NRC and industry documents. This section of this report identifies these documents.

3.11.2 Summary of Technical Information

In DCD, Tier 2, Section 3.2, the applicant stated that SSCs are categorized as safety-related (as defined in 10 CFR 50.2) or non-safety-related. Safety-related SSCs are those relied upon to remain functional during and following design-basis events to ensure (1) the integrity of the reactor coolant pressure boundary, (2) the capability to shut down the reactor and maintain it in a safe condition, or (3) the capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures comparable to the applicable guideline exposures set forth in 10 CFR 50.34(a)(1). The applicant stated that DCD Tier 2, Section 3.2, defines and identifies safety-related mechanical equipment (e.g., pumps, motor operated valves, SRVs, and check valves). The applicant stated that safety-related SSCs conform with the QA requirements of Appendix B to 10 CFR Part 50. Non-safety-related SSCs have QA provisions applied commensurate with the importance of their function.

In DCD, Tier 2, Section 3.11, the applicant described the EQ of mechanical and electrical equipment, including safety-related analog and digital I&C equipment. The applicant stated that electrical equipment within the scope of this section includes all three categories of 10 CFR 50.49(b). The equipment qualification program also includes the dynamic and seismic qualification of safety-related electrical and mechanical equipment. The equipment qualification program includes safety-related electrical and mechanical equipment located in harsh and mild environments. Equipment supporting RTNSS functions located inside containment are included in the equipment qualification program and are qualified using the appropriate methods for their location. The remainder of the RTNSS equipment is qualified as outlined in DCD, Tier 2, Section 19A. DCD, Tier 2, Table 3.11-1, "Electrical and Mechanical Equipment for Environmental Qualification," provides a list of applicable electrical and mechanical equipment, with the quantity, location, function, required operating time, and qualification program.

The applicant identified, in DCD, Tier 2, Section 3.11.1.2, the following general requirements for environmental design and qualification of safety-related mechanical and electrical equipment, which are used to implement the relevant requirements of the NRC regulations:

- The equipment is designed to be able to perform its design safety functions under all AOOs and normal, accident, and postaccident environments, and for the length of time for which its functions are required.
- The environmental capability of the equipment is demonstrated by appropriate testing and analyses.
- A QA program meeting the requirements of Appendix B to 10 CFR Part 50 is established and implemented to provide assurance that all requirements have been satisfactorily accomplished.

DCD, Tier 2, Section 3.11.2, specifies that the equipment qualification program generates and maintains a list of EQ equipment in harsh and mild environments. Table 3.11-1 identifies the systems containing EQ equipment. The applicant stated that the environmental qualification document (EQD) summarizes the qualification results for all EQ equipment. The EQD is current and in an auditable form for the entire period during which the covered item is installed or is stored for future use to permit verification that each item meets the equipment qualification requirements.

In DCD, Tier 2, Section 3.11.3, the applicant stated that EQ equipment is qualified to the worst-case environmental conditions for the areas in which they are located for the duration that they are required to perform their safety-related function. The environmental design basis includes the safety-related function for each item of safety-related equipment and its acceptance criteria; electromagnetic interference/radio frequency interference (EMI/RFI) and voltage surges; and environmental conditions, including temperature, equipment heating, HVAC and lack of HVAC, inside and outside maximum and minimum temperatures, and time dependency of temperatures. The applicant stated that the qualification parameters shall include margins to account for normal variations in commercial production of equipment and reasonable errors in defining satisfactory performance. Margin is defined as the difference between the most severe specified service conditions of the plant and the conditions used for qualification. The environmental conditions shown in the Appendix 3H tables do not include margins. The applicant defined the margins associated with temperature, pressure, and radiation in DCD Section 3.11.3.

For mechanical and electrical equipment required to perform an intended function from within minutes of the occurrence of the event up to 10 hours into the event, DCD Section 3.11.3.1 specifies that the equipment must be shown to remain functional in the accident environment for a period of at least 1 hour in excess of the time assumed in the accident analysis, unless a time margin of less than 1 hour can be justified. For equipment with a required time of operation during an accident and post accident period of more than 10 hours, the equipment is to be demonstrated to remain functional under such conditions for a period of time at least 10 percent longer than the required operation time.

The applicant stated that EQ equipment in harsh environments is analyzed for significant aging mechanisms. A significant aging mechanism is accounted for in the qualification program. An aging mechanism includes time-temperature degradation, cycle aging, and normal radiation exposure. Artificial aging is determined from the Arrhenius equation. Cycle aging conservatively simulates the degradation during the required operating cycles. Age conditioning is not required for EQ equipment without a significant aging mechanism or for EQ safety-related equipment in a mild environment.

The qualification for chemical exposure for EQ equipment in harsh environments is by test. This chemical exposure test ensures that EQ equipment is qualified for the worst-case chemical conditions according to the requirements of IEEE Standard (Std.) 323-1974, “Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations.” The applicant stated that equipment in the lower portions of the containment is potentially subject to submergence. Appendix 3H contains the chemical composition and resulting pH to which safety-related equipment is exposed during normal operating and accident conditions. The EQ safety-related electrical equipment, including computer- based I&C, in mild environments is not exposed to chemicals.

EQ equipment that is submerged during or after a design-basis event is tested for the resulting worst-case submergence. Additionally, synergistic effects are considered when they have a significant effect on equipment performance.

EQ equipment is qualified for EMI, RFI, electrostatic discharge, and voltage surge. The qualification for EMI/RFI and voltage surges for EQ equipment in harsh and mild environments is by test, consistent with RG 1.180, “Guidelines for Evaluating Electromagnetic and Radio-Frequency Interference in Safety-Related Instrumentation and Control Systems.”

In DCD, Tier 2, Section 3.11.4.1, the applicant stated that safety-related electrical equipment that is located in a harsh environment will be qualified by test or other methods, as described in IEEE Std. 323-1974 and permitted by 10 CFR 50.49(f). An equipment-type test is the preferred method of qualification. The equipment qualification program meets the guidance of RG 1.89, “Environmental Qualification of Certain Electric Equipment Important to Safety for Nuclear Power Plants,” for safety-related electrical equipment in harsh environments.

Safety-related mechanical equipment that is located in a harsh environment will be qualified by analysis consistent with ASME Code, Section III-2001, “Rules for Construction of Nuclear Power Plant Components.”

The EQ equipment in a harsh environment will have a maximum qualified life of 60 years. The qualified life is verified using methods and procedures of qualification and documentation as stated in IEEE Std. 323-1974.

The safety-related batteries will be qualified to meet IEEE Std. 535-1986, “Standard for Qualification of Class 1E Lead Storage Batteries for Nuclear Power Generating Stations,” with the exception that the duty cycle is 72 hours and supplemental discharge cycle testing will be required to meet the harsh environment qualification process of IEEE Std. 323-1974. The detailed test plan is provided in LTR NEDE-33516P, Revision 0, “ESBWR Qualification Plan Requirements for a 72-Hour Duty Cycle Battery,” issued July 2009.”

In DCD, Tier 2, Section 3.11.4.2, the applicant stated that the design and /purchase specifications for safety-related equipment located in mild environments will include the environmental design basis for normal environmental conditions and AOO requirements. Vendors for all EQ safety-related equipment, excluding safety-related computer-based I&C equipment, located in a mild environment, must provide a certificate of conformance certifying that the equipment has been qualified to ensure the performance of its required safety-related functions in the applicable environment for the time that the safety-related function is required.

In DCD, Tier 2, Section 3.11.4.3, the applicant stated that EQ safety-related computer- based I&C equipment complies with RG 1.209, “Guidelines for Environmental Qualification of Safety-Related Computer-Based Instrumentation and Control Systems in Nuclear Power Plants.” Type testing is the preferred qualification method to demonstrate performance to the environmental design basis for normal environmental conditions and AOO requirements for the equipment location for the time that the safety-related function is required.

In DCD, Tier 2, Section 3.11.4.4, the applicant stated that the procedures and results of qualification by tests, analyses, or other methods are documented, maintained, and reported in accordance with the requirements of 10 CFR 50.49(j), RG 1.209, and IEEE Std. 323-2003, Section 7.2. The EQD summarizes the qualification results for all equipment identified in Section 3.11.2, including the following:

- the environmental parameters and methodology used to qualify the requirement for harsh and mild environments.

- the system component evaluation work sheets, which include a summary of environmental conditions and qualified conditions.

Compliance with the applicable portions of the GDC in Appendices A and B to 10 CFR Part 50 is described in the NRC- approved LTR on the applicant’s EQ program, NEDE-24326-1-P, “General Electric Environmental Qualification Program,” issued January 1983.

DCD, Tier 2, Section 3.11.7, specifies that the COL applicant will provide a full description and a milestone for program implementation of the EQ program that includes completion of the plant-specific EQD according to Section 3.11.4.4.

DCD, Tier 2, Appendix 3H, documents the environmental conditions for the zones where safety-related equipment is located. The environmental parameters addressed are temperature, pressure, relative humidity, radiation, and chemical conditions. The containment vessel, RB, and CB are considered for equipment qualification of safety-related equipment.

DCD, Tier 1, Section 3.8, states that the EQ program includes safety-related electrical and mechanical equipment located in harsh and mild environments. The EQ program also includes RTNSS equipment located in harsh environments. DCD, Tier 1, Table 3.8-1, specifies that environmentally qualified mechanical and electrical equipment located in a harsh environment can perform its safety-related function under normal, abnormal and DBA environmental conditions. This ITAAC also addresses analyses, testing, inspection, and documentation for the EQ of mechanical equipment located in a harsh environment.

3.11.3 Staff Evaluation

The following general requirements related to the EQ of mechanical, electrical, and I&C equipment that is important to safety appear in 10 CFR 50.49; GDC 1, 2, 4, and 23 in Appendix A to 10 CFR Part 50; and Criteria III, XI, and XVII in Appendix B to 10 CFR Part 50:

- The equipment shall be designed to have the capability of performing its design safety functions under all AOOs and normal, accident, and postaccident environments, and for the length of time for which its function is required.
- The EQ of equipment located in a harsh environment shall be demonstrated by appropriate testing and analyses.
- A QA program meeting the requirements of Appendix B to 10 CFR Part 50 shall be established and implemented to provide the assurance that all requirements have been satisfactorily accomplished.
- EQ records must be maintained in an auditable form to permit verification that each item of mechanical, electrical, and I&C equipment is qualified for its application and meets its specified performance requirements when subjected to the environmental conditions identified above.

The staff limited its evaluation of the EQ program to a review of the applicant's submittals on its approach to selecting and identifying equipment required to be environmentally qualified for the ESBWR design, qualification methods proposed, and the information in Appendix 3H to DCD Tier 2. Guidance for the staffs evaluation appears in SRP Section 3.11; NUREG-0588, "Interim Staff Position on Environmental Qualification of Safety-Related Electrical Equipment," Revision 1, issued July 1981, for seismic Category I; RG 1.89, Revision 1; and 10 CFR 50.49. For COL applicants referencing the ESBWR certified design, the staff will review specific details of their EQ programs using the evaluation bases mentioned above.

3.11.3.1 *Completeness of Qualification of Electrical Equipment Important to Safety*

The categories of electrical (electrical and I&C, including digital I&C) equipment important to safety must be qualified in accordance with the following three provisions of 10 CFR 50.49(b):

(1) 10 CFR 50.49(b)(1)—safety-related electrical equipment (relied on to remain functional during and after design-basis events to ensure that certain functions are accomplished)

(2) 10 CFR 50.49(b)(2)—non-safety-related electrical equipment whose failure, under the postulated environmental conditions, could prevent satisfactory performance of the safety functions of the safety-related equipment

(3) 10 CFR 50.49(b)(3)—certain postaccident monitoring equipment (seismic Category 1 and 2 postaccident monitoring equipment, as specified in RG 1.97, "Instrumentation for Light-Water-Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident," Revision 2, issued December 1980)

In DCD, Tier 2, Section 3.11.4.2, the applicant stated that vendors of safety-related equipment, except for computer-based I&C equipment, located in a mild environment, are required to submit a certificate of compliance certifying that the equipment has been qualified, to ensure that it will perform its required safety-related function in its applicable environment. In DCD, Tier 2, Section 3.11.4.3, the applicant stated that safety-related computer-based I&C equipment complies with RG 1.209. For all EQ safety-related computer-based I&C equipment, located in a mild environment, type testing is the preferred qualification method to demonstrate performance to the environmental design basis for normal environmental conditions, and AOO requirements for the equipment location for the time that the safety-related function is required.

The environmental parameters listed in Appendix 3H to DCD Tier 2 include thermodynamic (pressure, temperature, and relative humidity), radiation, and chemical spray. The equipment qualification program must also include submergence (if subject to submergence), aging (equipment qualified by test must be preconditioned by natural or artificial aging), and synergistic effects in accordance with 10 CFR 50.49(e). On the basis of its review, the staff finds that the applicant adequately addressed submergence, aging, and synergistic effects.

The staff reviewed the maximum bulk temperatures presented in the DCD Section 3H tables and determined, by review of the applicant's analyses and other staff evaluations, that these temperatures were reasonable for use in EQ assessments.

DCD Revision 5, Section 3.H.3.1, states that Tables 3H-2 through 3H-4 define thermodynamic conditions for normal operating conditions for areas containing safety-related equipment. The component inside a panel located in a harsh environment may be exposed to a higher temperature than the ambient room temperature because of internally generated heat. In RAI 3.11-28, the staff asked the applicant to indicate that the temperatures listed in Tables 3H-2 through 3H-4 represent the maximum temperature seen by a component inside a panel. In its response to RAI 3.11-28, the applicant stated that aging analysis and accelerated aging tests to determine qualified life identify the service temperature, which considers sources of higher than ambient heat, such as, internally generated heat, from the periods of time that safety-related equipment is energized, enclosed, collocated, and adjacent heat sources, as addressed in Section 3.11.3.1. The EQ documentation includes the equipment aging analyses, tests, and qualified life at the service temperature.

In RAI 3.11-28 S01, the staff asked the applicant to provide details on how it will determine the service temperature of electrical equipment, including computer-based I&C systems. In its response to RAI 3.11-28 S01, the applicant stated that the service temperature within electrical equipment cabinets can be achieved by test, analysis, or a combination of the two methods. A combination of test and analysis is essential if it is not practical to type test the electrical equipment as a whole unit. Then, it is necessary to determine the service temperature for the individual modules to properly plan and conduct the elemental type test. The applicant stated that the temperature inside an energized electrical cabinet will be higher than the ambient room temperature of the environment in which it is exposed. The temperature increase values at certain locations and gradients between locations inside a cabinet are based on many variables, including thermal conductivity and emissivity of the cabinet itself; number and location of chassis installed; power output or thermal load of each chassis; and air flow, either natural or forced, around and through the cabinet, as well as other heat sinking methods not involving airflow directly.

The applicant further stated that the electrical and electronic equipment designer will ensure that the product meets or exceeds the performance requirements, including equipment service temperatures, included in the EQ- type test parameters. This is accomplished through five main steps: (1) design, (2) analysis, (3) test, (4) demonstration, and (5) documentation. The applicant concluded that the design, analysis, test, demonstration, and documentation approach and thermal management techniques represent common engineering design practice and will be employed in the detailed design of the ESBWR. Since the procurement specifications for electrical equipment, including computer-based I&C, will establish the requirements for the design, analysis, test, demonstration, and documentation that will be met by the equipment designer and supplier, the staff finds that the equipment will perform its intended functions. The applicant stated that DCD, Tier 2, Section 3.11.1.3, will be revised to include an equipment definition. Additionally, DCD, Tier 2, Section 3.11.4.3, 3rd paragraph, 5th bullet will be revised to read “testing of a representative sample of the equipment as a complete system contained within its cabinet or enclosure is preferred.” The staff considers the proposed changes to be enhancements. The staff confirmed that DCD, Revision 7 incorporated the changes discussed above. RAI 3.11-28 and RAI 3.11-28 S01 were resolved.

In Appendix 1A to DCD Tier 2, in response to TMI Action Item II.B.2, “Plant Shielding for Post-Accident Access,” the applicant stated that it reviewed the radiation and shielding under ESBWR postaccident operations and designed radiation shielding to keep radiation doses to equipment below levels at which disabling radiation damage occurs. The staff finds this to be acceptable, on the basis that radiation shielding protects the equipment required to be environmentally qualified from the radiation environment.

DCD, Revision 5, Chapter 3, Appendix 3H, specifies, among other things, plant environmental conditions for the DBAs that have the potential to cause severe radiological conditions for safety-related equipment. Appendix 3H, Table 3H-6, and Table 3H-7, provide the radiological conditions for safety-related equipment in these buildings following DBAs.

In RAI 3.11-20 and RAI 3.11-20 S01, the staff asked the applicant to provide the source term used to calculate integrated gamma doses inside the RB and CB. In its response to RAI 3.11-20, the applicant stated that Tables 3H-6 and 3H-7 had been mislabeled as “Environment for Normal Operating Conditions,” and that these tables now provide radiation environmental conditions during reactor accidents. Subsequently, in its response to RAI 3.11-20 S01, the applicant stated that the values in these tables are based on typical EQ doses and that equipment will be qualified in accordance with the EQ program in DCD, Tier 2, Section 3.11.3, using the methodology and guidance provided in Appendix I, to RG 1.183, “Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors.” The applicant further stated, in the response, that it will develop the integrated doses later to verify them for specific locations in the RB and CB, in accordance with DCD Tier 1, Table 3.8-1. The staff finds that the applicant’s commitments in its response to RAI 3.11-20 S01 are acceptable and thus, RAI 3.11-20 and RAI 3.11-20 S01 were resolved. Therefore, the staff found that the source terms used to calculate integrated gamma doses inside the RB and CB are acceptable, as the applicant will develop and verify them later as an ITAAC item.

Appendix 3H, Table 3H-11, provides (1) operating dose rates using NUREG-1465, “Accident Source Terms for Light-Water Nuclear Power Plants,” issued February 1995, and (2) 6- month integrated doses, in upper and lower areas of the drywell as well as the wetwell and SP gas space. In RAI 3.11-23, the staff asked the applicant to provide the methodology used to calculate the 6-six month integrated doses using NUREG-1465. In its response to RAI 3.11-23, the applicant provided the parameters, assumptions, and equations used for determining 6-month integrated doses using the models provided in RADTRAD, “A Simplified Model for Radionuclide Transport and Removal and Dose Estimation.” RADTRAD is an NRC computer code developed by Sandia National Laboratories for the NRC to estimate transport and removal of radionuclides and doses at selected receptors. The staff reviewed the response and found that the parameters, assumptions, and equations used for determining 6- month integrated doses using the models provided in RADTRAD were acceptable. Therefore, RAI 3.11-23 was resolved.

As part of its review of Appendix 3H, the staff reviewed the radiation data in Table 3H-5, Table 3H-6, and Table 3H-11. These tables provide the radiological conditions for safety-related equipment inside the RB and the containment vessel both during both operating and accident conditions. The staff reviewed this information to evaluate both the operating dose rates and the 60-year integrated doses, as well as to compare the calculated integrated doses with the integrated dose qualification criteria for the equipment in these plant buildings, to ensure that the calculated integrated doses did not exceed the equipment integrated dose qualification criteria.

In comparing the nominal operating dose rates inside the containment vessel provided in Table 3H-5 with the operating dose rates provided in the plant layout figures in DCD Section 12.3, the staff was unable to determine how the applicant arrived at the operating dose rates for the upper and lower drywell listed in Table 3H-5. In response to the resulting RAI 3.11-24, the applicant stated that the operating drywell dose rates listed in Table 3H-5 are based on actual calculations for the ABWR design, which were then scaled (for power differential and conversion of dose to exposure in air units) to apply to the ESBWR. The staff finds the applicant's response to RAI 3.11-24 to be acceptable since it provides the basis for the containment dose rate values provided in both Figures 12.3 and Table 3H-5. The staff compared the nominal operating dose rate values in Table 3H-5 with the comparable values in Figures 12.3 and found that, other than a few areas in the lower drywell that are classified as being radiation Zone J (>5 sieverts/hour) (very high radiation areas and therefore considered to be inaccessible during operations), the expected dose rates during normal operations for the remainder of the areas inside the containment vessel are bounded by the dose rates contained in Table 3H-5. Therefore, the staff found the dose rates in Table 3H-5 to be conservative and RAI 3.11-24 was resolved.

In evaluating the 60-year integrated doses shown in Table 3H-5 for various areas inside the containment vessel, the staff noted that the 60-year integrated gamma doses listed for the upper and lower drywell areas exceeded the equipment qualification values for both electronic equipment and other equipment located in these areas. The staff noted similar inconsistencies with the integrated dose values contained in Table 3H-6. The staff issued RAIs 3.11-25 and 3.11-26 to ascertain why several of the integrated dose values listed in these two tables exceeded the equipment qualification values. In response to these RAIs, the applicant stated that specific plant design features to maintain radiation exposure to equipment at less than the equipment qualification levels inside containment during normal operations will be evaluated during the detailed design process and in accordance with DCD, Tier 1, Table 3.8-1. For those cases where the calculated integrated dose to a piece of equipment exceeds the integrated dose qualification criteria for that piece of equipment, the applicant committed to evaluating and incorporating specific plant design features, such as shielding or other methods, to reduce the integrated dose to that piece of equipment to levels below the equipment qualification criteria. The staff subsequently issued supplemental RAI 3.11-26 S01 to request that the applicant modify DCD Section 3.11.3.1 to more clearly address the steps in the design process to reduce the dose to equipment, in the event that the integrated dose to equipment exceeds the equipment integrated dose qualification criteria. In Revision 6 to the DCD, the applicant modified Section 3.11.3.1 to address the staff's concerns discussed in RAI 3.11-26 S01. On the basis of the applicant's acceptable responses to these RAIs, RAI 3.11-25, RAI 3.11-26, and RAI 3.11-26 S01 were resolved.

The staff noted that the postaccident integrated dose values in the containment vessel specified in Table 3H-11 exceeded the equipment qualification values for the 72-hour period for which the equipment located in this area must remain available or operational. In response to the staff's

RAI 3.11-27, the applicant stated that it will evaluate specific design features to maintain radiation exposure to equipment below equipment qualification levels inside the containment during accident conditions. The applicant will perform this evaluation in accordance with the ITAAC in DCD, Tier 1, Table 3.8-1. The staff found this response to be acceptable and RAI 3.11-27 was resolved.

In DCD, Tier 2, Section- 3.11.7, the applicant stated that the COL applicant will provide a full description and a milestone for program implementation of the EQ program that includes completion of the plant-specific EQD according to Section 3.11.4.4.

The EQ program is an operational program according to SECY-05-0197. The staff finds that the applicant has proposed an ITAAC to verify that EQ equipment has been qualified according to NRC regulations.

In DCD, Revision 3, Tier 2, Section 3.11.5, the applicant stated that the COL holders shall prepare the EQD, summarizing the qualification results for all equipment identified in DCD Section 3.11.1. In RAI 3.11-7, the staff asked the applicant to provide the basis for having the COL holder address the EQ of 10 CFR 50.49(b) electrical equipment. In its response to RAI 3.11-7, the applicant stated that it would change the requirement for addressing the EQ program from the COL holder to the COL applicant. The applicant provided a revised Section 3.11.5. The staff found the applicant's response acceptable. The staff confirmed that DCD, Revision 4, included the COL applicant in Section 3.11.5. Therefore, RAI 3.11-7 is resolved.

In DCD, Revision 3, Tier 2, Section 3.11.2.2, the applicant stated that vendors of equipment located in a mild environment are required to submit a certificate of compliance certifying that the equipment has been qualified to ensure that it will perform its required safety-related function in its applicable environment. The DCD also states that a surveillance and maintenance program shall be developed to ensure the operability of the equipment during its design life. In RAI 3.11-9, the staff asked the applicant to provide examples of the EQ methods and standards for electrical equipment (including I&C and digital I&C) located in mild environments, and the surveillance and maintenance program to be developed to ensure functionality during its design life. In its response to RAI 3.11-9, the applicant stated that the ESBWR design will incorporate the new guidance of RG 1.209. Additionally, the applicant provided examples of qualification methods for equipment in a mild environment, including specification and certification to temperature extremes, EMI, RFI, voltage surge testing, and seismic performance analysis and/or testing. For example, the video display unit in the control room will be specified and certified to temperature extremes; tested for EMI, RFI, and voltage surges; and seismically tested. A surveillance and /maintenance program will be based on the vendor's recommendations, which may be supplemented with operating experience and typically would include inspections, adjustments, modifications, and calibration. The staff found the proposed markup to the DCD acceptable because it is consistent with the guidance of SRP Section 3.11**.** The staff confirmed that above changes are incorporated in the DCD, Revision 4. Therefore, RAI 3.11-9 is resolved.

In RAI 3.11-13, the staff asked the applicant whether the EQ program will meet the guidance of RG 1.97, as required by 10 CFR 50.49. In its response to RAI 3.11-13, the applicant stated that the EQ program will meet the guidance of RG 1.97, and it would add to DCD Section 3.11 a reference to RG 1.97. The staff confirmed that DCD, Revision 4, included RG 1.97 in Section 3.11.1.1. Therefore, RAI 3.11-13 is resolved.

In RAI 3.11-14, the staff asked the applicant whether the EQ program will meet the guidance of NUREG-0588. In its response to RAI 3.11-14, the applicant stated that the EQ program is based upon conformance with the NRC-approved final rule for electric equipment qualification, 10 CFR 50.49, which superseded NUREG-0588. The NRC staff's position is that, for future plants, RG 1.89 provides the principal guidance for implementing the requirements and criteria of 10 CFR 50.49 for the EQ of electrical equipment that is important to safety and located in a harsh environment. However, certain NUREG-0588 seismic Category I guidance may be used if RG 1.89 does not provide relevant guidance. For example, NUREG-0588 provides detailed guidance for issues such as establishing the temperature and pressure conditions inside containment for LOCA and MSL break conditions, environmental conditions for outside containment, selection of qualification methods, qualification by test, test sequence, margin, and aging. As such, the staff recommended that the applicant add NUREG-0588 to the list of references applicable to its EQ program. In response to RAI 3.11-14 S01, the applicant stated that it would add NUREG-0588 as a reference into DCD, Tier 2, Revision 5. The staff determined that the markup of the DCD was acceptable. The staff confirmed that DCD, Revision 5, included NUREG-0588 in Section 3.11.8. RAI 3.11-14 and 3.11-14 S01 were resolved.

3.11.3.2 *Qualification Methods*

3.11.3.2.1 Electrical Equipment

RG 1.89 and NUREG-0588 define detailed procedures for qualifying safety-related electrical equipment located in a harsh environment. The criteria in these documents also apply to other equipment important to safety defined in 10 CFR 50.49.

In DCD, Tier 2, Revision 3, Section 3.11.2.2, the applicant noted that 10 CFR 50.49(b) electrical equipment that is located in a harsh environment is qualified by test or other methods as described in IEEE-323-2003. Because the NRC had not endorsed IEEE-323-2003, the staff asked the applicant, in RAI 3.11-11, to provide appropriate justification for deviations from IEEE-323-1974, consistent with current regulatory practice. In its response to RAI 3.11-11, the applicant noted that the NRC had recently endorsed IEEE-323-2003 in RG 1.209. Additionally, IEEE-323-2003 has effectively the same requirements for qualification in harsh environments as IEEE-323-1974. The acceptance of IEEE-323-2003 in RG 1.209 applies only to the EQ of safety-related, computer-based I&C systems for service in a mild environment. For electric equipment important to safety in a harsh environment, RG 1.89 describes the methods acceptable to the NRC staff for complying with 10 CFR 50.49 and IEEE-323-1974 describes the basic procedures for qualifying Class 1E equipment and interfaces. The NRC staff has not yet endorsed IEEE-323-2003 for the EQ of electrical equipment in a harsh environment. RAI 3.11-11 was being tracked as an open item in the SER with open items. The staff confirmed that DCD, Revision 5, Section 3.11.4.1 indicated that all three categories of 10 CFR 50.49(b) electrical equipment located in a harsh environment are qualified by test or other methods, as described in IEEE- 323-1974 and permitted by 10 CFR 50.49(f). Based on the above, RAI 3.11-11 was resolved.

In reviewing Revision 5 of the DCD, the staff determined that the methodology used by the applicant for the ESBWR relied on IEEE-323-1974. As indicated in the footnote to 10 CFR 50.49 and stated in NUREG-0588 and RG 1.89, the guidance in IEEE-323-1974 is acceptable to the NRC staff for qualifying equipment within the scope of 10 CFR 50.49. In DCD, Tier 2, Revision 5, Section 3.11.1.1, the applicant added a note following the title description of IEEE-323-2003, stating that this version applies unless otherwise indicated. In

RAI 3.11-30, the staff asked the applicant to modify the note to state that this version applies to electrical equipment in a mild environment only. In its response to RAI 3.11-30, the applicant stated that the note following the IEEE-323-2003 would be modified to clearly indicate that this version only applies to electrical equipment in a mild environment. The staff found the applicant's response acceptable. The staff confirmed that DCD, Section 3.11, Revision 6, includes this change. Therefore, RAI 3.11-30 is resolved.

In RAI 3.11-31, the staff asked the applicant to modify the statement "The ESBWR equipment qualification program meets the requirements of RG 1.89 for safety-related electrical equipment in harsh environment," to read "The ESBWR equipment qualification program meets the guidance of RG 1.89 for safety-related electrical equipment in harsh environment." In its response to RAI 3.11-31, the applicant stated that the statement would be revised to read, "The ESBWR equipment qualification program meets the guidance of RG 1.89." The staff found the applicant's response acceptable. The staff confirmed that the applicant incorporated this change into DCD, Section 3.11, Revision 6. Therefore, RAI 3.11 -31 is resolved.

In RAI 3.11-33, the staff asked the applicant to identify equipment in a mild environment, either in Section 3.11.4.2 or Section 3.11.4.3 in Table 3.11-1. In its response to RAI 3.11-33, the applicant stated that it would revise Table 3.11-1 to include a category for "Computer-Based I&C Systems," as defined in Section 3.11.4.3. This provides three distinct categories of equipment – Mechanical, Electrical, and Computer-Based I&C. Table 3.11-1 includes a designation for harsh environment, and note 4 of Table 3.11-1 states that the omission of a designation for harsh, indicates a mild environment. A distinct category for "Mild Environment" is not necessary. The staff found the applicant's response acceptable. The staff confirmed that the applicant incorporated this change in DCD, Revision 6, Section 3.11. Therefore, RAI 3.11-33 is resolved.

EMI qualification follows the requirements defined in Military Standard (Mil Std.) 461E, "Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment," issued August 1999, and International Electrotechnical Commission (IEC) 61000-4, "Electromagnetic Compatibility (EMC)." In RAI 3.11-35, the staff asked the applicant to include these standards in Section 3.11.1.1. On October 9, 2008, the applicant stated that it would add Mil Std. 461E and IEC 61000-4 to Section 3.11.1.1. The staff found the applicant's response acceptable. The staff confirmed that the applicant incorporated in DCD, Revision 6, Section 3.11. Therefore, RAI 3.11-35 is resolved.

In RAI 3.11-39, the NRC staff requested that the applicant (1) revise DCD, Tier 2, Table 1.9-22, to read, "Revise the reference for TR-102323 to the approved 1994 version (accepted by the NRC staff's SER dated April 17, 1996) or submit TR-102323 Revision 3, 2004 for staff review," (2) clarify how the DCD meets RG 1.180, Section A, which states, "Methods for addressing electromagnetic compatibility (EMC) constitute Tier 2* information under the 10 CFR Part 52 requirements," is met, and (3) revise DCD Tier 1, Table 3.8-1, Item 3, to remove the option of demonstrating qualification by analysis alone, and revise DCD, Tier 2, Section 3.11.4.3, to state that "analysis alone cannot be used to demonstrate qualification." Subsequent consistency issues arose, and the staff required further clarifications, were required because of the previous versions of the applicant's RAI responses. In its responses, the applicant provided all DCD changes necessary to address the staff's RAI and followup issues. The staff found the applicant's response to reference the 1994 version of TR-102323, clarify how DCD meets RG 1.180, and to remove the "qualification by analysis alone" statement from the DCD acceptable. The staff confirmed that DCD, Revision 7, incorporated the changes discussed above. RAI 3.11-39 was resolved.

In RAI 3.11-40, the staff asked the applicant to modify DCD, Tier 1, Section 1.1.1, to state that both EMI and RFI tests are covered by the ITAAC located in Section 3.8 of DCD Tier 1. In its response, the applicant stated that Section 1.1.1 will be revised to read, "Electromagnetic Interference (EMI) and Radio Frequency Interference (RFI) susceptibility and emissions qualification is performed by type testing for the safety-related digital instrumentation and control equipment. ITAAC address analyses of material data for safety-related mechanical equipment located in a harsh environment. ITAAC are located in Section 3.8 to cover environmental qualification of digital instrumentation and control equipment located in a mild environment. Environmental qualification of electrical (including digital I&C) and mechanical equipment located in a harsh environment is covered in Section 3.8 ITAAC." Additionally, RAI 14.3-449 S02 addresses equipment qualification and further clarifies requirements in Section 3.8 and the definition in Section 1.1.1 but does not change the intent. The staff found the applicant's revision of DCD, Tier 1, Section 1.1.1 to state that the ITAAC located in Section 3.8 covers EMI and RFI testing was acceptable. The staff confirmed that DCD, Revision 7, incorporated the changes discussed above. Therefore, RAI 3.11-40 is resolved**.**

In response to RAI 8.3-64, regarding qualification of safety-related batteries, on April 17, 2009, the applicant stated that IEEE Std. 535 does not apply to duty cycles longer than 8 hours, and the ESBWR has a battery duty cycle of 72 hours. The applicant further stated that it will modify DCD Section 3.11.4.1 to reflect that the duty cycle of safety-related batteries in ESBWR is different from the duty cycle basis in IEEE Std. 535. Safety-related batteries are qualified to meet IEEE Std. 535 by type test, with the exception that the duty cycle is 72 hours and supplemental discharge cycle testing is required to meet the harsh EQ process of IEEE Std. 323-1974. Additionally, the equipment qualification process for batteries includes the evaluation of significant aging mechanisms that are related to failure mechanisms from radiation exposure, time-temperature aging, and cycle aging; age testing for significant aging mechanisms for a 20-year qualified life; seismic tests; and performance testing for the 72-hour duty cycle. On July 27, 2009, the applicant provided LTR, NEDE-33516P, "ESBWR Qualification Plan Requirements for a 72-Hour Duty Cycle Battery." The applicant revised DCD Section 3.11.8 to include LTR, NEDE-33516P as Reference 3.11-6. Additionally, the applicant revised DCD Section 3.11.4.1 to include "see Reference 3.11-6." The applicant provided a detailed testing plan in the Topical Report. The acceptability of the 72-hour duty cycle battery qualification plan is evaluated in the SER for NEDE-33156P. The staff confirmed that DCD, Revision 6, Section 3.11, incorporated these changes. Based on the applicant's response and NEDE-33156P, RAI 8.3-64 was resolved.

In Table 3H-6 of Appendix 3H to DCD Tier 2, the applicant stated that electronic equipment is qualified for a gamma dose of less than 100 Gray (Gy) ($1x10^4$ rad). The NRC staff's position, as discussed in SRP Section 3.11, Revision 3, is that a mild radiation environment for electronic equipment is a total integrated dose of less than 10 Gy ($1x10^3$ rad). In RAI 3.11-12, the staff asked the applicant to provide details regarding methods to qualify electronic equipment for a gamma dose of less than 100 Gy ($1x10^4$ rad). In its response to RAI 3.11-12, the applicant stated that it will define a mild radiation environment for electronic equipment as a total integrated dose of less than 10 Gy ($1x10^3$ rad) and a mild radiation environment for other equipment as less than 100 Gy ($1x10^4$ rad). Therefore, the analysis will be the qualification method for electronics exposed to a total integrated dose less than 10 Gy ($1x10^3$ rad). A test will be the qualification method for electronics exposed to a total integrated dose of 10 Gy ($1x10^3$ rad) or higher. The applicant provided revised Section 3.11.4 and Appendix 3H. On the basis of its review, the staff found that the applicant satisfactorily resolved the staff's concern. The staff confirmed that Revision 4 of the DCD incorporated the above changes. Therefore, RAI 3.11-12 is resolved.

The applicant stated that the NRC-approved LTR on the applicant's EQ program (NEDE-24326-1-P), describes compliance with the applicable portions of the GDC in Appendix A to 10 CFR Part 50, and the QA criteria in Appendix B to 10 CFR Part 50.

3.11.3.2.2 Safety-Related Mechanical Equipment

The NRC staff followed the acceptance criteria in SRP Section 3.11 in reviewing the EQ of safety-related mechanical equipment in the ESBWR. In particular, mechanical components must be designed to be compatible with postulated environmental conditions, including those associated with a LOCA. A process must be established to determine the suitability of materials, parts, and equipment needed for safety-related functions, and to verify that the design of such materials, parts, and equipment is adequate. Equipment records must be maintained with the results of tests and material analyses used as part of the environmental design and qualification process for each component. For the EQ of mechanical equipment, the staff concentrated its review on materials that are sensitive to environmental effects (e.g., seals, gaskets, lubricants, fluids for hydraulic systems, and diaphragms). The staff's review included the following objectives: (a) identify safety-related mechanical equipment located in harsh environment areas, including required operating times, (b) identify nonmetallic subcomponents of such equipment, (c) identify the environmental conditions for which the equipment must be qualified, (d) identify nonmetallic material capabilities, and (e) evaluate environmental effects. For mechanical equipment located in a mild environment, design and purchase specifications can be used to demonstrate acceptable environmental design.

The staff reviewed ESBWR DCD, Tier 1, Section 3.8, and DCD, Tier 2, Sections 3.2 and 3.11, and Appendix 3H, which include provisions that address the SRP acceptance criteria for the EQ of safety-related mechanical equipment. The ESBWR DCD establishes an EQ methodology for applicable safety-related mechanical equipment and their nonmetallic subcomponents, and specifies environmental conditions to be evaluated for the resulting environmental effects. Because mechanical equipment will experience the same environmental conditions as those defined in 10 CFR 50.49 for electrical equipment, such conditions can be used in reviewing the EQ of mechanical equipment. Based on its review, including specific aspects discussed below, the staff finds the initial EQ provisions in the DCD for safety-related mechanical equipment to satisfy the NRC regulations for a design certification application. Therefore, the staff finds the ESBWR DCD to be acceptable with respect to the EQ of safety-related mechanical equipment.

As discussed in Section 3.9.6 of this report, the applicant will be procuring equipment for COL applicants referencing the ESBWR design. The applicant will address the key features of lessons learned from nuclear power plant operations and research programs as part of its design and procurement specifications for nuclear power plant components. As part of its review, the staff conducted an audit of design and procurement specifications at the applicant's office in Wilmington, NC, in July 2009. The purpose of the audit was to confirm the implementation of the DCD provisions for the design and qualification of applicable pumps, valves, and dynamic restraints, and to support the full description of the inservice testing and EQ operational programs by COL applicants. As discussed in the NRC's "Summary of the July 20-24, 2009, Regulatory Audit of Design Specification of Risk Significant ESBWR Components Economic Simplified Boiling Water Reactor (ESBWR) Design Certification," issued September 2009, the staff reviewed several design and purchase specifications for various equipment, including EQ specifications. In its response to the audit followup items, in a letter dated September 21, 2009, the applicant indicated that it would revise component specifications to incorporate the clarifications identified during the audit. The applicant also stated that the EQ specifications are intended to support procurement of equipment for the ESBWR. On March 19, 2010, the staff conducted a followup audit at the applicant's office in Washington, DC, to review implementation of the followup actions specified by GEH in its letter dated September 21, 2009. Based on this letter and the NRC followup audit on March 19, 2010, the NRC staff considers the applicant to have resolved the audit followup actions documented in GEH's "Supplemental Response to Action Items from the Summary of the Follow-up Audit on documentation of ESBWR Section 3.9.1 Computer Codes PISYS08 & ANSI714 related to RAI 3.9-254 and RAI 3.9-255," issued June 4, 2010, related to the EQ program in support of the ESBWR design certification application. Therefore, Open Item OI-SRP-3.11-CIB2-01 was resolved.

In its audit response dated September 21, 2009, the applicant stated that the operational aspects of the EQ program (such as establishment of equipment maintenance intervals) are beyond the scope of the ESBWR design certification and will be addressed by the COL applicant. Therefore, COL applicants will be responsible for describing the operational aspects of the EQ program in support of their applications to construct and operate ESBWR plants. As part of a COL application review, the NRC will evaluate the description of the operational aspects of the EQ of electrical and mechanical equipment provided by the COL applicant to supplement the initial EQ provisions described in the ESBWR DCD. Following COL issuance, the staff will conduct inspections of the development and implementation of the EQ operational program during plant construction and operation.

In RAI 3.11-1, the staff requested that the applicant discuss, in the DCD, the EQ methods and standards to be applied to mechanical equipment located in harsh environments. In its response to RAI 3.11-1, the applicant stated that it had not completed the selection of specific equipment for the ESBWR. The EQ program will be based on the methodology and guidelines in NEDE-24326-1-P when the equipment is selected. In its response to RAI 3.11-1 S01, the applicant referred to NUREG-1503, "Final Safety Evaluation Report Related to the Certification of the Advanced Boiling Water Reactor (ABWR) Design," issued July 1994, for NRC acceptance of NEDE-24326-1-P. In NUREG-1503, the staff stated that use of NEDE -24326-1-P was acceptable, with the incorporation of specific guidance on a time-margin analysis for equipment qualification. DCD, Tier 2, Section 3.11.3.1 incorporates the specific language for the equipment operating time found to be acceptable by the staff in NUREG-1503 for the use of NEDE-24326-1-P. Based on the acceptance of NEDE-24326-1-P as part of the ABWR design certification, the staff considers the use of this topical report to be acceptable for the ESBWR design certification. Therefore, RAI 3.11-1 is resolved.

In RAI 3.11-2, the staff requested that the applicant discuss the EQ methods and standards to be applied to mechanical equipment located in mild environments. In its response to RAI 3.11-2, the applicant stated that all safety-related equipment located in a mild environment will require the vendor to supply a certificate of compliance with the provisions of NEDE-24326-1-P. DCD, Tier 2, Section 3.11.4.2, specifies a certificate of conformance from the vendor of the safety-related equipment to be located in a mild environment to certify performance according to the environmental design basis. As discussed above, the staff accepted the use of NEDE-24326-1-P in NUREG-1503. Therefore, RAI 3.11-2 is resolved.

In RAI 3.11-3, the staff requested that the applicant clarify the basis for the EQ of safety-related mechanical equipment. In its response to RAI 3.11-3, the applicant stated that the basis for the EQ of safety-related mechanical equipment is the methodology and guidelines provided in NEDE-24326-1-P. Further, DCD Tier 2, Section 3.11.7, specifies, in COL Information Item 3.11-1-A, "Environmental Qualification Document," that the COL applicant will provide a full description and a milestone for program implementation for the EQ program that includes completion of the plant-specific EQD, according to DCD, Tier 2, Section 3.11.4. With the use of NEDE-24326-1-P accepted in NUREG-1503 and clarification of the responsibility of the COL applicant in the DCD, RAI 3.11-3 was resolved.

Because 10 CFR 50.49(j) applies to electrical equipment, the staff requested, in RAI 3.11-4, that the applicant discuss the provisions for recording and maintaining the results of the EQ of safety-related mechanical equipment. In its response to RAI 3.11-4, the applicant stated that recording and maintaining the results of the EQ of the safety-related mechanical equipment follows 10 CFR 50.49(j), RG 1.89, and IEEE Std. 323. COL licensees will have auditable records available that describe the EQ method used for mechanical and electrical equipment. Thereafter, such records will be updated as equipment is replaced, tested, or qualified. In response to RAI 3.11-4 S01, the applicant stated that DCD, Tier 2, Section 3.11, requires the EQ of mechanical equipment to meet 10 CFR 50.49(j) and IEEE Std. 323. The applicant also refers to RG 1.89 for the implementation of IEEE Std. 323. The applicant states that DCD, Tier 2, Section 13.4, requires EQ operational programs to be fully described, in accordance with SECY-05-0197 and RG 1.206. The staff found that the DCD provisions for documenting the EQ of mechanical equipment are consistent with NRC regulations and guidance. Therefore, RAI 3.11-4 is resolved.

In RAI 3.11-5, the staff requested that the applicant discuss the evaluation of the degradation of the performance of ESBWR equipment under adverse environments (such as the reduction in electric motor output under high- temperature conditions). In its response to RAI 3.11-5, the applicant indicated that EQ considerations for equipment performance degradation from the environmental aging conditions will follow the EQ program guidelines addressed in NEDE-24326-1-P. In RAI 3.11-5 S01, the staff asked the applicant to address the potential performance degradation of mechanical equipment under environmental conditions (such as electric motor output). In its response to the RAI 3.11-5 S01, the applicant stated that expected extremes in power supply voltage, range, and frequency, as defined in the product performance specifications, are applied under NEDE-24326-1-P, along with testing. Further, the ESBWR design does not include safety-related motor-operated valves. The staff found that the applicant’s response clarifies the applications of the accepted report NEDE-24326-1-P in addressing the potential EQ degradation of mechanical equipment under adverse environments. Therefore, RAI 3.11-5 is resolved.

DCD, Tier 2, Section 3.11.3.1, discusses the environments to be included in the environmental design basis for electrical and mechanical equipment within the scope of the EQ program. In RAI 3.11-38, the staff requested that the applicant clarify the consideration of applicable environments for the qualification of mechanical equipment. In its response to RAI 3.11-38, the applicant stated that all environments discussed in DCD, Tier 2, Section 3.11.3, are applicable to EQ equipment, including mechanical equipment, in the EQ program. Subsequently, Revision 6 of DCD, Tier 2, Subsection 3.11.3.1, specifies that the environments included in the environmental design basis are considered for electrical and mechanical equipment in the EQ program. The NRC staff considers the DCD change to clarify the applicability of the environments in the environmental design basis to mechanical equipment within the scope of the EQ program. Therefore, RAI 3.11-38 is resolved.

3.11.4 Combined Operating License Information

The applicant stated that the COL applicant will address the following item:

3.11-1-A EQD: The COL applicant will provide a full description and a milestone for program implementation of the EQ program that includes completion of the plant-specific EQD according to Section 3.11.4.4 of the DCD.

3.11.5 Generic Issues and Operational Experience

The staff evaluated the following generic issues (Task Action Plan items), operational experience (Generic Letter), and TMI Action Plan.

3.11.5.1 *Task Action Plan Items*

A-24: Qualification of Class 1E Safety-Related Equipment

The NRC required construction permit applicants that were issued safety evaluation reports after July 1, 1974, to qualify all safety-related equipment to IEEE Std. 323-1974. From the time this standard originated, the industry developed methods that were used to qualify equipment in accordance with the standard. The NRC determined that a generic approach was required to assess the adequacy of the EQ methods and acceptance criteria used by nuclear steam supply system and balance-of-plant vendors. The staff designated this as Issue A-24 in NUREG-0933, "Resolution of Generic Safety Issues," updated in August 2008. This issue was resolved with the publication of NUREG-0588, Revision 1, issued July 1981.

In DCD, Tier 2, Section 3.11, the applicant stated that it described the EQ methodology in detail in the NRC-approved report, NEDE-24326-1-P. The applicant also stated that this methodology addresses the requirements of GDC 1, 2, 4, and 23, and 10 CFR 50.49, as well as the guidance of RG 1.89, and IEEE Std. 323.

On the basis of its review, discussed in Section 3.11 of this report, the staff concludes that the applicant's approach to EQ of Class 1E equipment complies with the requirements of 10 CFR 50.49. Issue A-24 was resolved for the ESBWR design.

C-1: Assurance of Continuous Long-Term Capability of Hermetic Seals on Instrumentation and Electrical Equipment

This issue concerns the long-term capability of hermetically sealed instruments and equipment that must function in postaccident conditions. More specifically, certain classes of instrumentation that are equipped with seals are sensitive to steam and vapor. If the seals become defective as a result of personnel error in the maintenance of such equipment, such errors could lead to the loss of a seal and of equipment functionality. The objective of this issue is to establish confidence that sensitive equipment has an effective seal for the lifetime of the plant.

The criterion for this issue is compliance with the review criteria of SRP Section 3.11 for the EQ of electrical equipment.

DCD, Tier 2, Appendix 3H, defines the environmental conditions with respect to limiting design conditions for all safety-related mechanical and electrical equipment. Equipment important to safety that is located in a harsh environment must perform its proper safety function during normal, abnormal, test, DBA, and postaccident environments, as applicable.

DCD, Tier 2, Section 3.11, Table 3.11-1, contains a list of EQ equipment (mechanical and electrical, including digital I&C equipment) located in areas of mild and harsh environments.

The applicant calculated the environmental conditions for the zones where EQ equipment is located for normal, abnormal, test, accident, and postaccident conditions and documented them in DCD, Tier 2, Appendix 3H. Environmental conditions are tabulated by zones contained in the referenced building arrangements.

EQ electrical equipment that is located in a harsh environment is qualified by test or other methods, as described in IEEE Std. 323 and permitted by 10 CFR 50.49(f). The qualification methodology is described in detail in the NRC-approved report, NEDE-24326-1-P. This report also addresses compliance with the applicable portions of 10 CFR Part 50, Appendix A, and the QA criteria of 10 CFR Part 50, Appendix B. Additionally, the report describes conformance to NUREG-0588 and the RGs and IEEE standards referenced in SRP Section 3.11. Furthermore, the EQ of computer- based I&C equipment important to safety complies with RG 1.209. Type testing is the preferred qualification method to demonstrate performance to the environmental design basis for normal environmental conditions and AOO requirements for the equipment location for the time that the safety-related function is required.

Based on the above discussion, since the applicant will qualify electrical equipment, including computer- based I&C equipment, important to safety in accordance with applicable guidance, including NUREG- 0588, the staff concludes that the applicant adequately addressed this issue for the ESBWR design.

3.11.5.2 *Generic Letter*

Generic Letter 82-09, “Environmental Qualification of Safety-Related Electrical Equipment,” issued on April 20, 1982, addresses technical questions raised by the licensees in the area of operator display instrumentation, safety-related equipment, replacement parts, mild environment, submergence outside containment, radiation, containment service conditions, 1-hour minimum operating time, and aging, and to clarify certain aspects of the qualification requirements. In DCD, Tier 2, Section 3.11, the applicant committed to following 10 CFR 50.49, RG 1.89, and IEEE Std. 323. The NRC-approved report, NEDE-24326-1-P describes the qualification methodology in detail. Based on the staff’s review, this generic letter was resolved for the ESBWR design by the application of the accepted report NEDE-24326-1-P.

3.11.5.3 *TMI Action Plan II.B.2*

TMI Action Plan Issue II.B.2, “Plant Shielding,” addresses the review of a radiation and shielding design of spaces around systems that may, as a result of an accident, contain accident source term radioactive materials, and a design, as necessary, to permit adequate access to important areas and to protect equipment from the radiation environment. This issue was resolved and the requirements are provided in 10 CFR 50.34(f)(2)(vii).

In Appendix 1A to DCD Tier 2, in response to TMI Action Item II.B.2, the applicant stated that it had reviewed the radiation and shielding of the ESBWR under postaccident conditions has been made, and that the radiation shielding is designed to keep radiation doses to equipment below levels at which disabling radiation damage occurs. The staff finds this to be acceptable, on the basis that radiation shielding protects, from the radiation environment, the equipment required to be environmentally qualified. Section 12.4 of this report provides an additional discussion on plant shielding.

3.11.6 Conclusions

The staff reviewed the ESBWR design certification application for compliance with the NRC regulations for the EQ of safety-related mechanical, electrical, and I&C equipment to be used in ESBWR nuclear power plants. The NRC staff concludes that the general description of the EQ of safety-related mechanical, electrical, and I&C equipment satisfies the NRC regulations in an adequate manner. Therefore, the staff concludes that the ESBWR DCD is acceptable with respect to the EQ of safety-related mechanical, electrical, and I&C equipment. As discussed in this section of this report, DCD Tier 1 includes ITAAC regarding the EQ of mechanical, electrical, and I&C equipment. Further, DCD Tier 2 includes a COL information item that requires the COL applicant to provide a full description and a milestone for program implementation for the EQ program that includes completion of the plant-specific EQD. As discussed in this section of this report, the operational aspects of the EQ program are beyond the scope of the ESBWR design certification and will be addressed by the COL applicant. Therefore, COL applicants will be responsible for describing the operational aspects of the EQ program in support of their applications to construct and operate ESBWR plants. As part of the review of a COL application, the staff will evaluate the full description of the operational program for the EQ of mechanical, electrical, and I&C equipment. The staff will also confirm the completion of the applicable ITAAC for ESBWR components during plant construction to ensure that design reports for mechanical, electrical, and I&C components are in order, and to confirm that the NRC regulations are met. Following COL issuance, the NRC staff will conduct inspections of the development and implementation of the EQ operational program during plant construction and operation.

3.12 Piping Design

This section provides the NRC staff's safety evaluation of design acceptance criteria for the ESBWR piping system design documented in DCD Tier 2, submitted by GEH. The evaluation includes those portions of DCD Section 3.7.3, and Section 3.9, that are applicable to piping systems. The staff used the NRC acceptance criteria and guidelines documented in the GDC found in Appendix A to 10 CFR Part 50, Sections 3.7.3 and 3.9 of NUREG-0800 (hereafter referred to as the SRP), RGs, and other NRC regulatory guidance documents (e.g., NUREG reports, NRC bulletins) to evaluate the piping design information given in the ESBWR DCD. In addition, the staff performed a detailed audit of the piping design criteria, including an independent confirmatory analysis of a portion of the MS piping system for the ESBWR standard plant.

3.12.1 Introduction

The staff evaluated the adequacy of the structural integrity and functional capability of safety-related piping systems associated with the design of the ESBWR standard plant. The review included not only the ASME Boiler and Pressure Vessel Code (hereafter referred to as the ASME Code) Class 1, 2, and 3 piping and pipe supports, but also buried piping, instrumentation lines, the interaction of nonseismic Category I piping with seismic Category I piping, and any safety-related piping designed to industry standards other than the ASME Code. The following sections of this report provide the staff's evaluation of the adequacy of the ESBWR piping analysis methods, design procedures, acceptance criteria, and verification of the design. The staff's evaluation included the following:

- regulatory criteria

- applicable codes and standards
- analysis methods to be used in the piping design
- modeling of piping systems
- pipe stress analysis criteria
- pipe support design criteria
- MS piping confirmatory analysis

The staff must arrive at a final safety determination that, if the COL applicant successfully completes the piping design and analyses and complies with the ITAAC, as required by 10 CFR Part 52 (and as stated in DCD, Tier 1, Section 3.1), using the design methods and acceptance criteria discussed here, then the COL applicant will have provided adequate assurance that the piping systems will perform their safety-related functions under all postulated combinations of normal operating conditions, system operating transients, postulated pipe breaks, and seismic and thermal-hydraulic dynamic events.

3.12.2 Regulatory Criteria

The staff used the 2007 version of the SRP (NUREG-0800) during the review. The staff reviewed DCD, Tier 2, Revision 7, Sections 3.7.3 and 3.9, in accordance with SRP Section 3.7.3, Section 3.9.1, Section 3.9.2, and Section 3.9.3. The primary basis of this review is the information provided in DCD, Tier 2, Sections 3.7.2, 3.7.3, 3.9.1, 3.9.2, and 3.9.3 related to piping and pipe support design, as well as other related information documented in DCD, Tier 2, Sections 1.9, 3.2, 3.6, 3.8, and 5.2, and Appendices 3B, 3C, 3D, and 3K, as appropriate. The applicant's piping and pipe support design criteria, including the analysis methods and modeling techniques, are acceptable if they meet codes and standards and are consistent with regulatory guidance documents commensurate with the safety function to be performed. This will ensure that the piping design criteria meet the relevant requirements of 10 CFR 50.55a and the following GDC found in Appendix A to 10 CFR Part 50:

- GDC 1, "Quality Standards and Records"
- GDC 2, "Design Bases for Protections against Natural Phenomena"
- GDC 4, "Environmental and Dynamic Effects of Design Bases"
- GDC 14, "Reactor Coolant Pressure Boundary"
- GDC 15, "Reactor Coolant System Design"

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

- 10 CFR 50.55a and GDC 1, as they relate to piping systems, pipe supports, and components being designed, fabricated, erected, constructed, tested, and inspected to quality standards commensurate with the importance of the safety function to be performed

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

- GDC 4, with regard to piping systems and pipe support important to safety being designed to accommodate the effects of, and to be compatible with, the environmental conditions of normal as well as postulated events, such as a LOCA, and dynamic effects

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

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

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

The NRC established requirements in 10 CFR Part 50 to ensure the pressure boundary leakage integrity of the piping components and structural integrity of the pipe supports in nuclear power plants. The staff evaluated the design, materials, fabrication, erection, inspection, and testing of piping and pipe supports using the following industry codes and standards, RGs, and staff technical reports:

- ASME Code, Section III, which contains the material specifications, design criteria, fabrication and construction requirements, construction testing and examination techniques, and structural integrity testing of the piping and pipe supports

- RG 1.29, “Seismic Design Classification,” Revision 3, September 1978

- RG 1.61, “Damping Values for Seismic Design of Nuclear Power Plants,” October 1973

- RG 1.84, “Design, Fabrication and Material Code Case Acceptability,” Section III, Revision 33, August 2005

- RG 1.92, “Combining Modal Responses and Spatial Components in Seismic Response Analysis,” Revision 2, July 2006

- RG 1.199, “Anchoring Components and Structural Supports in Concrete,” November 2003

- RG 1.207, “Guidelines for Evaluating Fatigue Analyses Incorporating the Life Reduction of Metal Components Due to the Effects of the Light-Water Reactor Environment for New Reactors,” March 2007

- NUREG-0484, “Methodology for Combining Dynamic Responses,” Revision 1, May 1980

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

- NUREG-1367, “Functional Capability of Piping Systems,” November 1992

3.12.3 Codes and Standards

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

In DCD, Tier 2, Section 1.9 and Table 3.2-3 list all applicable codes and standards that will be used for the ESBWR design of ASME Code Class 1, 2, and 3 pressure-retaining components and their supports. Table 1.9-3 identifies the SRP Section 3 applicability and differences (if any), Table 1.9-20 identifies the SRP and BTP applicability, Table 1.9-21 identifies the RG applicability, and Table 1.9-22 identifies the ASME and other code editions. In DCD, Tier 2, Section 5.0, Table 5.2-1 identifies ASME Code cases that are applicable to the RCPB components, including piping and pipe supports.

3.12.3.1 *ASME Boiler and Pressure Vessel Code*

DCD, Tier 1, Section 3.1, establishes that the ASME Code, Section III, will be used for the design of ASME Code Class 1, 2, and 3 pressure-retaining components and their supports. For Quality Group D piping and its supports, DCD, Tier 2, Table 3.2-3, indicates that the ASME/ANSI Standard B31.1 (hereafter referred to as B31.1 piping) will be used for the design. The ASME Code is considered Tier 1 information; however, the specific edition and addenda are considered Tier 2 information because of the continually changing technical features associated with the design and construction practices (including inspection and examination techniques) of the ASME Code. Designating a specific edition and addenda during the design certification stage may result in inconsistencies between design and construction practices during the detailed design and construction stages. The ASME Code involves a consensus process to reflect the evolving design and construction practices of the industry. Although the reference to a specific edition of the ASME Code for the design of ASME Code class components and their supports is suitable for use in making a safety finding during the design certification stage, the construction practices and examination methods of an updated ASME Code that would be effective at the COL application stage must be consistent with the design practices established at the design certification stage.

The staff finds that the specification of the ASME Code as Tier 1 information and the specific edition and addenda as Tier 2 information is appropriate because it would provide the means for the COL applicant to revise or supplement the referenced ASME Code edition with portions of the later Code editions and addenda needed to ensure consistency between the design of the ESBWR pressure-retaining components and their supports and construction practices. In this manner, the updated reference ASME Code to be used at the time of the COL application will be consistent with the latest design, construction, and examination practices at that time. However, when the staff finds that there is a need to specify certain design parameters from a specific ASME Code edition or addenda during its design certification review, particularly when that information is important in establishing a significant aspect of the design or is used by the staff to reach its final safety determination, the various sections of this safety evaluation reflect such considerations.

ESBWR DCD, Tier 2, Table 1.9-22, initially identified the use of the 2004 edition of the ASME Code. The staff had not accepted the 2004 edition of the ASME Code in accordance with 10 CFR 50.55a. In RAI 3.12-1, the staff requested that the applicant identify the ASME Code edition and applicable addenda for the design of the ESBWR piping systems at this design certification stage. In its response to RAI 3.12-1, the applicant stated that the ESBWR piping system design will use the 2001 edition of the ASME Code, including the addenda through 2003, consistent with 10 CFR 50.55a(b). However, the applicant did not address how this change would satisfy the requirements of 10 CFR 50.55a(b), including the limitations and modifications specified in 10 CFR 50.55a(b)(1). In response, the applicant revised the DCD, Tier 2, Revision 3, Table 1.9-22, listing for applicable ASME Code, Section III, Division 1, NB, NC, ND, NF, and NG, to add the statement, "Note: All limitations and modifications specified in 10 CFR 50.55a(b)(1) are required to be met." Inclusion of this note in DCD, Tier 2, Table 1.9-22, provides sufficient commitment to all limitations and modifications specified in 10 CFR 50.55a(b)(1). The staff found that the revision to DCD, Tier 2, Table 1.9-22, provided an acceptable resolution of RAI 3.12-1. Therefore, RAI 3.12-1 was closed.

Based on the above, all ASME Code Class 1, 2, and 3 pressure-retaining components and their supports must be designed in accordance with the requirements of ASME Code, Section III, using the specific edition and addenda identified in ESBWR DCD Tier 2.

3.12.3.2 *ASME Code Cases*

ASME Code cases that are acceptable to the staff for the design of ASME Code Class 1, 2, and 3 piping systems are those either conditionally or unconditionally approved in RG 1.84. The staff review is based on Revision 33 of RG 1.84, issued August 2005. This RG includes ASME Code cases listed up to Supplement 6 (or 2003 addenda) to the 2001 edition of the ASME Code. However, the COL applicant may submit with its COL application for staff review and approval future ASME Code cases that are endorsed in RG 1.84 at the time of the COL application, provided that they do not alter the staff's safety findings on the ESBWR certified design.

ASME Code cases listed in Table 5.2-1 of the DCD applicable to the piping and pipe support design are listed below. The staff identified concerns with the use of these ASME Code cases. The concerns, which were included in RAI 3.12-2, are discussed below:

- ASME Code Case N-71-17, "Additional Materials for Subsection NF, Classes 1, 2, 3, and MC Component Supports Fabricated by Welding, Section III, Division 1." The DCD referenced this ASME Code case. However, the staff has conditionally accepted Revision 18 of this Code case (N-71-18) in RG 1.84. In response to RAI 3.12-2 S01 the applicant indicated that no additional material is used in the ESBWR design; hence, there is no impact regardless of whether Revision 17 or 18 of ASME Code Case N-71 is used. However, after discussion during the site audit at the GEH offices in San Jose, CA, on January 9–12, 2007, about the need to reference this ASME Code case, the applicant indicated that it would delete this ASME Code case from the DCD. DCD Tier 2 deleted the ASME Code case from Table 5.2-1. Since no additional materials will be used in the ESBWR piping design, the staff concludes that deleting the reference to this ASME Code case is acceptable.

- ASME Code Case N-122-1, "Procedure for Evaluation of the Design of Rectangular Cross Section Attachments on Class 1 Piping, Section III, Division 1." The DCD referenced Revision 1 of this ASME Code case. However, the staff endorsed Revision 2 of this Code case (N-122-2) in RG 1.84. In response to RAI 3.12-2, the applicant revised DCD Tier 2, Table 5.2-1, to show that Revision 2 for this ASME Code case (N-122-2) is the applicable Code case for use in the ESBWR piping design, consistent with RG 1.84. The staff finds that ASME Code Case N-122-2 meets the guidance in RG 1.84.

- ASME Code Case N-247, "Certified Design Report Summary for Component Standard Supports, Section III, Division 1, Classes 1, 2, 3 and MC." ASME has annulled this unconditionally approved Code case as noted in RG 1.84. In response to RAI 3.12-2, the applicant deleted the ASME Code case in DCD, Tier 2, Table 5.2-1, and stated that the design report summary is provided in accordance with ASME Code, Section NCA-3551.1, for the ESBWR piping design. Since the applicant provides this design report summary for the ESBWR piping design, the staff finds this acceptable.

- ASME Code Case N-249-14, "Additional Material for Subsection NF, Classes 1, 2, 3 and MC Component Supports Fabricated Without Welding, Section III, Division 1." The staff conditionally accepts this ASME Code case in RG 1.84.

- ASME Code Case N-318-5, "Procedure for Evaluation of the Design of Rectangular Cross Section Attachments on Class 2 or 3 Piping, Section III, Division 1." In DCD, Tier 2, Revision 1, Table 5.2-1, the applicant stated that this ASME Code case was conditionally accepted. However, the staff unconditionally accepted this ASME Code case in RG 1.84. In response to RAI 3.12-2, the applicant revised DCD, Tier 2, Table 5.2-1, to allow the unconditional use of ASME Code Case N-318-5. The staff finds that this modification meets the guidance in RG 1.84.

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

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

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

- ASME Code Case N-608, "Applicable Code Edition and Addenda, NCA-1140(a)(2), Section III, Division 1." ASME has annulled this Code case as noted in RG 1.84. In response to RAI 3.12-2 (MFN 06-119, Supplement 1), the applicant deleted this ASME Code case from DCD, Tier 2, Table 5.2-1, and stated that the applicable ASME Code edition and addenda are identified in accordance with ASME Code Section NCA-1140(a)(2), requirements. Since the applicant will follow the ASME Code to identify the applicable Code edition and addenda, the staff finds this acceptable.

In addition, DCD, Tier 2, Sections 3.7.1.2, 3.7.3.5, and 3.9.3.7.1, as well as Table 3.7-1, initially referenced the following ASME Code cases:

- ASME Code Case N-411-1, “Alternative Damping Values for Response Spectra Analysis of Classes 1, 2, and 3 Piping, Section III, Division 1.” The staff conditionally accepted this ASME Code case in the past (subject to certain limitations), but ASME subsequently annulled it, as noted in RG 1.84. In response to RAI 3.12-2, the applicant deleted this ASME Code case from DCD, Tier 2, Table 5.2-1, and revised the text in Sections 3.7.1.2 and 3.7.3.5 and the footnote to Table 3.7.1 to include the ASME Code case damping, as illustrated in Figure 3.7-37, which depicts all five conditions stated in RG 1.84 as alternative damping values for piping. In addition, the applicant included a sixth condition extending the use of the damping values beyond 33 Hz, since the cutoff frequency for the ESBWR design is 100 Hz. In accordance with RG 1.84, the use of this Code case with all of its conditions is still acceptable to the staff, even though ASME has annulled it. Further, the staff endorsed damping values consistent with ASME Code Case N-411 for piping systems in RG 1.61, Revision 1, issued March 2007. The staff finds the alternative piping damping proposed by the applicant to be consistent with current staff guidance and therefore acceptable.

- ASME Code Case N-420, “Linear Energy Absorbing Supports for Subsection NF, Class 1, 2, and 3 Construction, Section III, Division 1.” ASME annulled this Code case as noted in RG 1.84. In response to RAI 3.12-2, the applicant deleted this ASME Code case from DCD, Tier 2, Table 5.2-1, and deleted the discussion pertinent to these supports in DCD, Tier 2, Sections 3.7.1.2 and 3.9.3.7.1(6). The applicant stated that the ESBWR does not use linear energy-absorbing supports. Since linear energy-absorbing supports are not used in the ESBWR piping design, the staff finds this acceptable.

- ASME Code Case N-476, Supplement 89.1, “Class 1, 2, & 3, and MC Linear Component Supports—Design Criteria for Single Angle Members, Section III, Division 1, Subsection NF.” ASME annulled this Code case as noted in RG 1.84. In response to RAI 3.12-2, the applicant deleted the footnotes in DCD, Tier 2, Sections 3.9.3.7.1, 3.9.3.7.2, and 3.9.3.8, referring to ASME Code Case N-476. During the site audit at the GEH offices in San Jose, CA, on January 9–12, 2007, the applicant stated that the ESBWR design of pipe supports uses the single-angle criteria given in the ASME Code under mandatory Appendix NF-II, “Design of Single Angle Members,” in lieu of this ASME Code case. The staff finds the use of ASME Code, mandatory Appendix NF-II, acceptable.

The staff found that the applicant acceptably resolved the concerns raised in RAI 3.12-2. The staff concluded that the ASME Code cases referenced in DCD Tier 2, as discussed above, meet the guidelines of RG 1.84 or have been reviewed and endorsed by the staff, and are acceptable for use in the ESBWR design. Therefore, RAI 3.12-2 was closed.

3.12.3.3 *Design Specifications*

ASME Code, Section III, requires that a design specification be prepared for Class 1, 2, and 3 components, such as pumps, valves, and piping systems. The design specification is intended to become a principal document governing the design and construction of these components and should specify loading combinations, design data, and other design inputs. The Code also requires a design report for Class 1, 2, and 3 piping and components. In the DCD, the applicant committed to constructing all safety-related components, such as vessels, pumps, valves, and piping systems, to the applicable requirements of the ASME Code, Section III.

The staff reviewed one piping system design specification during the site audit at the GEH offices in Wilmington, NC, on May 22–26, 2006. The staff recognized that the piping design specification Revision 0 is preliminary and identified to the applicant all the items that would need enhancement in a future revision of the design specification. On the basis of the audit result, the staff finds that the process being used by the applicant to prepare design specifications to meet the ASME Code requirements is acceptable.

DCD Tier 1, ITAAC tables indicate that ASME Code, Section III, piping is designed in accordance with ASME Code requirements and that inspection of ASME Code design reports and required documents will be conducted.

3.12.3.4 *Conclusions*

On the basis of the evaluation of DCD, Tier 2, Sections 3.7.3 and 3.9, the staff concludes that the piping systems important to safety are designed to quality standards commensurate with their importance to safety. The staff's conclusion is based on the following:

- The applicant satisfied the requirements of GDC 1 and 10 CFR 50.55a by specifying appropriate codes and standards for the design and construction of safety-related piping and pipe supports.

- The applicant identified ASME Codes and Code cases that may be applied to ASME Code Class 1, 2, and 3 piping and pipe supports and that are acceptable to the staff.

- The applicant proposed ITAAC activities for inspection of piping design documents to ensure that the piping design meets ASME Code requirements.

3.12.4 Analysis Methods

GDC 1 requires that SSCs important to safety be designed, fabricated, erected, tested, and inspected to quality standards commensurate with the importance of the safety functions to be performed. Where generally recognized methods of analysis are used, SSCs must be identified and evaluated to determine their applicability, adequacy, and margin of safety to withstand the loadings as a result of normal operating, transient, and accident conditions.

GDC 2 requires that the piping and pipe supports withstand the effects of earthquakes combined with the effects of normal or accident conditions.

The staff reviewed the applicable information in DCD, Tier 2, Sections 3.7.3 and 3.9, related to the design transients and methods of analysis used for all seismic Category I piping and pipe supports designated as ASME Code Class 1, 2, and 3 under ASME Code, Section III, as well as those not covered by the Code. The applicant performs system and subsystem analyses on an elastic basis. Analysis methods used for piping systems include the response spectrum method (both USM and ISM), time-history method, and static coefficient method. Experimental stress analysis methods are also used to evaluate two specific piping support types (snubbers and whip restraints). Finite element computer programs are generally used to develop mathematical models of the pipe elements (e.g., straight sections, elbows, bends, tees) supported by hangers and anchors and restrained by pipe guides, struts, and snubbers. Plant conditions for all service levels (A, B, C, D, and Testing), as defined in the ASME Code, are considered for determining the loading conditions and their combination methods.

DCD, Tier 2, Table 3.9-1, lists the plant design transient events affecting the piping systems and includes plant operating thermal-hydraulic events and dynamic loading events caused by accidents, earthquakes, and certain operating conditions. DCD, Tier 2, Table 3.9-2, provides the load combination and acceptance criteria for all ASME components. DCD, Tier 2, Table 3.9-9, identifies the specific load combinations and acceptance criteria for Class 1 piping. In DCD, Tier 2, Revision 2, the applicant added Tables 3.9-10 through 3.9-12, which provide the load combinations and acceptance criteria for snubber, strut, and anchor or guide types of pipe supports. In DCD, Tier 2, Section 3.7.3, the applicant stated that the guidelines given in nonmandatory Appendix N to ASME Code, Section III, for dynamic analysis methods and in ASME Code, Section III, for design requirements are applicable to ESBWR piping. Since it has not explicitly endorsed Appendix N in its entirety, the staff requested, in RAI 3.12-10, that the applicant provide the technical justification for any criterion in Appendix N that differs from the guidance in the current SRPs and RGs. In response to RAI 3.12-10, the applicant withdrew the use of this appendix for the ESBWR piping design and is relying instead on the criteria given in the NRC SRPs and RGs. The staff found this acceptable. Therefore, RAI 3.12-10 was closed. Section 3.12.4.11 of this report discusses further staff evaluation of the use of Appendix N to ASME Code, Section III.

3.12.4.1 *Experimental Stress Analysis*

DCD, Tier 2, Section 3.9.1.3, identifies several components for which experimental stress analysis is performed in conjunction with analytical evaluation. Such components in piping systems include piping seismic snubbers and pipe whip restraints. The experimental stress analysis methods comply with Appendix II to ASME Code, Section III. This meets the guidance of SRP Section 3.9.1, and therefore, the staff finds it acceptable. DCD, Tier 2, Section 3.9.3.7.1, discusses the design and testing of snubbers. Section 3.12.7.6 of this report discusses the staff's evaluation of the application of snubbers in the design of piping. Section 3.6.2 of this report presents the staff's evaluation of the experimental stress analysis methods for pipe whip restraints.

3.12.4.2 *Response Spectrum Method with Uniform Support Motion*

DCD, Tier 2, Section 3.7.3.1, indicates that the analysis methods described in Section 3.7.2.1 for building structures also apply to piping systems. DCD, Tier 2, Section 3.7.2.1.2(a), describes the dynamic analysis procedure using the response spectrum method with USM. First, a mathematical model is constructed to reflect the dynamic characteristics of the piping system. The mode shapes and natural frequencies of the piping model are computed. The modal participation factors for each mode are calculated using a given direction of earthquake motion. The spectral accelerations for each mode are determined using the appropriate response spectrum curve for the damping level, as discussed in DCD, Tier 2, Section 3.7.3.5. The analysis procedures described in Section 3.7.2.13 are applicable to systems composed of subsystems that have different damping properties. Enveloped response spectra are used for a piping system supported at points with different dynamic excitations. Participation factors and spectral accelerations of each mode, along with the modal responses, are calculated from the mode shapes. The responses include the modal forces, stresses, and deflections. For a given direction, the modal responses are combined in accordance with the methods described in DCD, Tier 2, Section 3.7.3.7.

The modal response calculations are performed for each of the three earthquake directions (two horizontal and one vertical). DCD, Tier 2, Section 3.7.2.6, indicates that when the response spectrum method or static coefficient method of analysis is used, the maximum responses caused by each of the three components are combined by taking the SRSS of the maximum codirectional responses caused by each of the three earthquake components.

Forces and moments from the differential supporting structure movements are induced in piping systems that are anchored and restrained to floors and walls of structures that have differential movements during a seismic event. Static analyses are performed to determine responses to these structure movements as described in DCD, Tier 2, Section 3.7.3.12. The support displacements are calculated, as described in DCD, Tier 2, Section 3.7.3.9, and are imposed in a conservative manner using the static analysis method for each orthogonal direction. This is known as seismic anchor movement (SAM) analysis. Since the ESBWR is not designed for the OBE, the SAM responses are included in Service Level D load combinations. Section 3.12.6.15 of this report discusses this further.

The staff reviewed DCD Section 3.7.2.7, and the piping analysis computer program. The staff identified an inconsistency between the DCD description and the piping analysis computer code (PISYS08). The staff issued RAI 3.9-255 to ask the applicant to discuss the methods used in PISYS08 to combine modal response and address missing mass and how those methods relate to the methods in RG 1.92, Revisions 1 and 2. In its response, the applicant stated that the double sum equation in RG 1.92, Revision 1, is used, and the residual rigid response of the missing mass modes is included for piping analyses. The applicant also revised the DCD to reflect the methods used in the PISYS08 code for piping analyses. Because the applicant's proposed double sum method is more conservative than the double sum equation method described in RG 1.92, Revision 2, the staff finds this acceptable. Section 3.9.1 of this report presents the complete evaluation of the response to RAI 3.9-255.

3.12.4.3 *Response Spectrum Method with Independent Support Motion*

The ISM method may be used as an alternative to the enveloped response spectrum method. DCD, Tier 2, Section 3.7.2.1.2(b), presents the theory and development of the governing equations of motion for this method. DCD, Tier 2, Section 3.7.3.9, describes additional requirements associated with the application of this method. This section discusses the conditions that must be met when the ISM method of analysis is used. First, a support group is defined by supports that have the same time-history input. This usually means all supports located on the same floor, or portions of a floor, of a structure. Second, the responses from the motion of supports in two or more different groups are combined by the SRSS procedure.

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

Volume 4, Section 2, of NUREG-1061 presents the current staff position for modal and group combinations in the ISM method of analysis. The staff position recommends that group responses be combined by the absolute sum method for inertial or dynamic components. Both modal and directional responses are combined by the SRSS method; the modal combination is performed without considering the effects of closely spaced frequencies. For SAM components, the maximum absolute responses from each directional input for each group are combined by the absolute sum, and the directional responses are combined by the SRSS method. Finally, the dynamic and SAM responses are combined by the SRSS rule.

The staff noted some differences between the ISM method of response combinations presented in DCD, Tier 2, Section 3.7.3.9, and the method recommended in NUREG-1061 (e.g., the SRSS method described in the DCD and absolute sum method discussed in NUREG-1061 for combining group responses for a given direction differ). In RAI 3.12-3, the staff requested that the applicant either follow the recommendations in NUREG-1061 for the ISM method of analysis or provide the technical justification for an alternative method. The staff discussed the issue pertaining to combining group and modal responses for the ISM method of analysis used in the ESBWR piping design with the applicant during the site audit at the GEH offices in San Jose, CA, on January 9–12, 2007. NUREG-1061 delineates the staff recommendations regarding response combination methods for ISM, while RG 1.92 provides guidance for the USM method of analysis. The applicant committed to providing a study to show that the piping system responses from the ISM method using the SRSS group combination will bound the responses from a corresponding time-history analysis of the same ESBWR piping system model for representative piping systems. RAI 3.12-3 was tracked as an open item in the SER with open items.

The applicant provided a study to justify its use of SRSS of the group combinations with the ISM method. The study included two piping models. The first model included MS lines 2 and 3 from the RPV nozzles to the containment penetrations, including the SRV discharge piping from the MSL branches to the wetwell penetration anchors. The second model included one feedwater line from the RPV to the containment penetration. The study compared piping stresses and support loads generated using multisupport time-history analyses with the applicant's proposed use of ISM with SRSS group combinations. Multisupport time-history analysis provides the most accurate method of performing the dynamic analysis because it retains the phase relationship between the group responses. The applicant's study found that the resulting stresses and support loads obtained using ISM with SRSS group combinations bound the multisupport time-history loads and stresses at most locations in the piping runs. However, in a few support locations, the multisupport time-history analysis loads were greater, with a maximum exceedance of 8 percent. The applicant proposed to modify the criteria in DCD, Tier 2, Section 3.7.3.9, to require that an additional 10-percent margin be applied to the design requirements for piping stress and pipe support loads when using ISM with SRSS of the group combinations.

The staff reviewed the applicant's study and determined that the applicant had conducted a study based on a limited sample. In RAI 3.12-3 S04, the staff requested that the applicant provide technical justification to demonstrate that the ISM method and criteria proposed for the ESBWR can be applied globally to all piping in all different locations (or in a limited set of locations, such as inside containment). The staff also noted that the applicant's study analyses used only two ISM groups (RPV and inside RCCV) with the SRSS procedure.

The applicant responded as follows:

> When the ISM response spectrum method of analysis (Subsection 3.7.2.1.2) is used, a support group is defined by supports that have the same time-history input. This usually means all supports located on the same floor, or portions of a floor, of a structure. For piping inside the RCCV, the typical pipe routing is from the reactor pressure vessel to the containment penetration in the RCCV. As explained in supplement 4 of this RAI, the analysis results for two typical piping systems (main steam and feedwater), that have this type of pipe routing, when using the SRSS procedure were found to be more conservative than the time history analyses method when a 10 percent margin is applied to the SRSS results. The remaining piping that is in containment that are part of the reactor coolant pressure boundary are the isolation condenser (IC), reactor water cleanup/shutdown cooling (RWCU/SDC), control rod drive (CRD), standby liquid

control (SLC) and gravity driven cooling system (GDCS) system piping. All of these pipes have pipe routing that originates from the reactor vessel and connects to containment structures in a similar manner as the qualification cases. Therefore, these pipes are also sufficiently phase uncorrelated, and the SRSS criteria established in DCD Subsection 3.7.3.9 is applicable. For piping outside the RCCV, the absolute sum procedure for an ISM analysis shall be used. DCD Section 3.7.3.9 will be revised to be consistent with this statement.

In this letter, the applicant also amended DCD Section 3.7.3.9 as follows:

When the ISM response spectrum method of analysis (Subsection 3.7.2.1.2) is used, a support group is defined by supports that have the same time-history input. This usually means all supports located on the same floor, or portions of a floor, of a structure. The highest response spectrum for any support in a given group is used as input for the entire support group. This approach is appropriate since the time histories for supports within each group are time phase correlated. In most cases, the support at the highest elevation has the highest response spectrum and is used for the group. For piping inside the RCCV, the responses caused by motions of supports in two groups are combined by the SRSS procedure since it has been demonstrated that the phases for the independent support motions are sufficiently uncorrelated, and the analysis results for two typical piping systems (main steam and feedwater) using the SRSS procedure are more conservative than the time history analyses method when a 10 percent margin is applied to the SRSS results. In most cases, the number of support groups can be restricted to two ISM groups (RPV and inside RCCV), but in piping analysis cases where additional support motion groups are used within the RCCV, the absolute sum procedure for an ISM analysis shall be used. For piping outside the RCCV, the absolute sum procedure for an ISM analysis shall be used.

To use the SRSS method for independent support response spectrum analysis, it is required to include 10 percent margin in the design requirements for piping stress and piping support loads to address the uncertainties that may exist from the use of the SRSS method rather than the absolute sum method for the group combination method when performing an ISM analysis.

The staff reviewed the applicant’s response and amendment to DCD, Tier 2, Section 3.7.3.9. The staff determined that the study meets the staff’s recommendation in NUREG-1061 and concluded that, for piping inside the RCCV, the applicant proposed a 10-percent margin to the resulting stresses and support loads, obtained using two ISM support groups with SRSS group combination from the applicant’s study, provides assurance that the applicant’s proposed position is conservative.

For piping outside the RCCV, the applicant-proposed to use absolute sum procedure for an ISM analysis meeting the recommendation in SRP Section 3.12.II.A.iii. Therefore, RAI 3.12-3 and its associated open item were resolved.

3.12.4.4 *Time-History Method*

A time-history analysis may be performed using either the modal superposition method, direct integration method in the time domain, or the complex frequency response method in the frequency domain.

DCD, Tier 2, Section 3.7.2.1.1, describes the modal superposition method. This approach involves the calculation of the natural frequencies, mode shapes, and appropriate damping factors of the particular system toward the solution of the equations of dynamic equilibrium. The orthogonality of the mode shapes is used to effect a coordinate transformation of the displacements, velocities, and accelerations such that the response in each mode is independent of the response of the system in any other mode. Through this transformation, the problem becomes one of solving a set of “n” independent differential equations rather than simultaneous differential equations. As long as the system is linear, the principle of superposition holds, and the total response of the system oscillating simultaneously in “n” modes may be determined by direct addition of the responses of the individual modes.

DCD, Tier 2, Section 3.7.2.1.1, describes the direct integration method. This method involves the direct step-by-step numerical integration of the equations of motion (such as the Newmark β-method and the Wilson-θ method) and does not require the solution of an eigenvalue problem. The response in all modes is calculated simultaneously. In direct integration analysis, the damping is input in the form of α and β damping constants, which give the percentage of critical damping, λ, as a function of the circular frequency, ω, as described in DCD, Tier 2, Section 3.7.2.13. DCD, Tier 2, Section 3.7.2.1.1, indicates that the numerical integration time step, Δt, must be sufficiently small to accurately define the dynamic excitation and to render stability and convergence of the solution up to the highest frequency of significance. For most of the commonly used integration methods, the maximum time step is limited to one-tenth of the smallest period of interest, which is generally the reciprocal of the cutoff frequency.

The applicant indicated that, in accordance with industry practice and as described in Section 3.2.2.1(c) of American Society of Civil Engineers Standard 4-98, “Seismic Analysis of Safety-Related Nuclear Structures,” an acceptable approach for selecting the time step (Δt) is that the Δt used shall be small enough that the use of one-half of Δt does not change the response by more than 10 percent. In RAI 3.12-4, the staff requested that the applicant either clarify whether this is part of the piping analysis requirements or provide a technical justification for not considering this criterion along with the other criterion described above for seismic and hydrodynamic loading analyses. In its response, the applicant stated that the convergence criterion of using one-half of Δt to result in no more than a 10-percent change in response is part of the requirement for time-history analysis. GEH updated DCD, Tier 2, Section 3.7.2.1.1, accordingly. The staff reviewed the changes in the DCD Revision 2, and found this technically acceptable. However, GEH stated that the approach is an alternative approach rather than part of the requirement in the time-history method of analysis. DCD, Tier 2, Revision 3, Section 3.7.2.1.1, deleted the words “an alternative approach” and replaced it with “the approach.” Since this will ensure that the subject criterion will be part of the requirements instead of an alternate, and because it is an industry practice typically used in time-history analysis, the staff found the revision of DCD Tier 2 acceptable. Therefore, RAI 3.12-4 was resolved.

DCD, Tier 2, Section 3.7.2.1.1, describes another time-history method using the complex frequency approach to solve the system of equations of motion. This method requires that the transfer functions be determined first and the applied forces be transformed into the frequency domain. The transfer functions can be computed directly from the system equations of motion or from the normal mode approach. The Fast Fourier Transform algorithm is commonly used for the transformation between the time domain and frequency domain.

DCD, Tier 2, Section 3.7.2.1.1, also indicates that, for the frequency domain solution, the dynamic excitation time history is digitized with time steps no larger than the inverse of two times the highest frequency of significance. In RAI 3.12-5, the staff requested that GEH provide the technical justification showing why this approach is sufficiently accurate to capture the piping system response. In its response to RAI 3.12-5, the applicant stated that the piping analysis does not use the frequency domain solution. This analysis methodology applies to structural evaluations. GEH revised DCD, Tier 2, Revision 2, Section 3.7.2.1.1, to indicate that the piping system response analysis does not use the frequency domain solution. The staff found this acceptable; therefore, RAI 3.12-5 was resolved.

DCD, Tier 2, Section 3.7.2.6, indicates that the total seismic response is predicted by combining the responses from the three orthogonal components (two horizontal and one vertical) of the earthquake. When separate time-history analyses are performed for each directional component, the combined response may be obtained by taking the SRSS of the maximum codirectional responses caused by each component. As an alternative, the combined response may be obtained by algebraically adding the codirectional responses from each analysis at each time step, or the total response may be obtained directly by applying the three component motions simultaneously in one analysis. Whenever these alternative methods are used, the three component input motions must be mutually statistically independent.

When developing seismic floor response spectra for use as input to a response spectrum analysis for piping and equipment analysis, the peaks of the floor response spectra, obtained from a time-history analysis, are generally broadened by ±15 percent to account for modeling uncertainties, as stated in DCD, Tier 2, Section 3.7.2.9. However, GEH did not discuss how the hydrodynamic load response spectra and the building time-history responses account for these uncertainties. In RAI 3.12-6, the staff asked GEH to describe how the uncertainties in the material properties of the structure/soil and the modeling techniques used in the analysis to develop the loading are addressed in (1) the use of hydrodynamic building response spectra and (2) a time-history analysis of piping systems subjected to seismic and hydrodynamic loadings. In its response to RAI 3.12-6, the applicant stated that, when the calculated floor acceleration time history is used in the time-history analysis of piping and equipment, the uncertainties in the time history are accounted for by expanding and shrinking the time history within $1/(1\pm0.15)$ so as to change the frequency content of the time history within ±15 percent. Alternatively, a synthetic time history that is compatible with the broadened floor response spectra may be used. The methods of peak broadening are applicable to seismic and other building dynamic loads. GEH updated DCD, Tier 2, Revision 2, Section 3.7.2.9, to include the stated criteria. The staff found this update acceptable; therefore, RAI 3.12-6 was resolved. Section 3.7.2.3.9 provides the staff evaluation of this method.

The staff reviewed the DCD Tier 2 descriptions of the modal superposition and the direct integration time-history analysis methods and found them to comply with the applicable guidelines of SRP Sections 3.7.2 and 3.9.2; therefore, they are acceptable.

3.12.4.5 *Static Coefficient Method*

DCD, Tier 2, Section 3.7.2.1.3, provides an alternative method of analysis that allows a simpler technique but yields more conservative results. This method does not require frequency calculation of the system, and the loads are statically applied at each mass point by a multiplying static coefficient equal to 1.5 times the maximum spectral acceleration at the appropriate damping value of the input floor response spectrum. The static coefficient of 1.5 is intended to account for the effect of both multifrequency excitation and multimode response for linear and frame-type structures. If the system behaves essentially as a single-DOF system, a factor of 1.0 instead of 1.5 can be used. Also, when the system is rigid, the ZPA can be used instead of the maximum spectral acceleration of the input spectra. A component is considered to be rigid when its fundamental frequency is equal to or greater than the frequency at which the input response spectrum returns to approximately the ZPA.

SRP Section 3.9.2.II.2.a(2) discusses the following conditions that should be met before using this method of analysis:

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

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

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

While the description in DCD, Tier 2, Section 3.7.2.1.3, is consistent with the third bullet, the description in the DCD does not adequately address the first and second bullets above. In RAI 3.12-7, the staff requested that GEH provide a description to address these two items. In its response to RAI 3.12-7, the applicant stated that the use of the static coefficient method satisfies the requirements of SRP Sections 3.7.2 and 3.9.2 and committed to updating DCD, Tier 2, Section 3.7.2.1.3, to include these two conditions. The staff reviewed the proposed changes to the DCD and found that, although the original request was addressed satisfactorily, GEH added the statement, “If the fundamental frequency of the structure is known, the spectral acceleration value at this frequency can be multiplied by a factor of 1.5 to determine the response.” This may yield a nonconservative piping response when the fundamental frequency falls between spectral peaks or to the soft side of the spectral peak. During the site audit at the GEH offices in Wilmington, NC, on May 22–26, 2006, GEH agreed to revise the statement to read, “If the fundamental frequency of the structure is known, the highest spectral acceleration value at or beyond the fundamental frequency can be multiplied by a factor of 1.5 to determine the response.” GEH revised DCD, Tier 2, Section 3.7.2.1.3, as stated above. The revised criteria comply with the applicable guidelines of SRP Section 3.9.2. The staff found this acceptable; therefore, RAI 3.12-7 was resolved.

3.12.4.6 *Inelastic Analysis Method*

DCD, Tier 2, Section 3.9.1.4, initially discussed the use of the inelastic analysis method to evaluate the effects of postulated gross piping failure when subject to a Service Level D event loading condition. DCD, Tier 2, Section 3.6.2, provides the loading combinations and design criteria for pipe whip restraints used to mitigate the effects of postulated piping failures, which are reviewed separately in Section 3.6.2 of this report. GEH did not provide any details of the scope and the analysis approach used in the inelastic analysis methods for ESBWR piping design. Therefore, in RAI 3.12-8, the staff requested that GEH describe the inelastic analysis methods to be used in the ESBWR piping design. In its response to RAI 3.12-8, the applicant stated that the ESBWR piping design and analysis do not use inelastic analysis methods. The staff reviewed DCD, Tier 2, Section 3.9.1.4, and found that GEH revised this section to indicate that inelastic analysis methods are not used in the ESBWR piping design analyses except for pipe whip restraints. Section 3.6.2 of this report provides the staff evaluation of pipe whip restraints. The staff found the applicant's discussion of inelastic analysis methods acceptable; therefore, RAI 3.12-8 was resolved.

3.12.4.7 *Small-Bore Piping Analysis Methods*

DCD, Tier 2, Section 3.7.3.16, defines small-bore piping as piping that is 50 mm (approximately 2 in.) and less nominal pipe size and small branch lines as 50 mm (approximately 2 in.) and less nominal pipe size. This DCD section indicates that it is acceptable to use small-bore piping handbooks in lieu of performing a system flexibility analysis, using static and dynamic mathematical models, to obtain loads on the piping elements. These loads may then be used to calculate stresses in accordance with equations in Subsections NB, NC, and ND-3600 of the ASME Code, Section III, and ASME Standard B31.1, whenever the following conditions are met:

- The small-bore piping handbook is currently accepted by the regulatory agency for use on equivalent piping at other nuclear power plants.
- When the small-bore piping handbook is serving the purpose of the design report, it meets all of the ASME requirements for a piping design report. This includes the piping and its supports.
- Formal documentation exists showing that piping designed and installed to the small-bore piping handbook (1) is conservative in comparison to the results from a detailed stress analysis for all applied loads and load combinations using static and dynamic analysis methods defined in DCD, Section 3.7.3, (2) does not result in piping that is less reliable because of a loss of flexibility or because of an excessive number of supports, and (3) satisfies required clearances around sensitive components.

The small-bore piping handbook methodology is not applied when specific information is needed on the (1) magnitude of pipe and fittings stresses, (2) pipe and fitting cumulative usage factors, and (3) accelerations of pipe-mounted equipment or locations of postulated breaks and leaks. The small-bore piping handbook methodology is not applied to piping systems that are fully engineered and installed in accordance with the engineering drawings.

The staff reviewed the methodology described in DCD, Tier 2, Section 3.7.3.16, which indicates that the static and dynamic analysis methods defined in Section 3.7.3 of the DCD will be used to provide the formal documentation showing that piping designed and installed consistent with the small-bore piping handbook is conservative in comparison to a detailed stress analysis. During the site audit at the GEH offices in Wilmington, NC, on May 22–26, 2006, as part of the resolution of RAI 3.12-15, the staff discussed the use of the piping handbook in the design of the ESBWR small-bore piping system. GEH has not developed any such handbook to be used for the design certification; therefore, no handbook was available for the audit. However, the staff finds that the criteria presented in DCD, Tier 2, Section 3.7.3.16, for the piping handbook are acceptable. Section 3.12.5.4 of this report further discusses this issue as part of the decoupling criteria.

3.12.4.8 *Nonseismic/Seismic Interaction (II/I)*

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

For nonseismic Category I piping systems attached to seismic Category I piping systems, the analysis of the seismic Category I piping should consider the dynamic effects of the nonseismic Category I system. In addition, the nonseismic Category I piping from the attachment point to the first anchor should be evaluated to ensure that under all loading conditions it will not cause a failure of the seismic Category I piping system. Section 3.7.3.8 in DCD Tier 2 contains criteria that are consistent with these staff positions, as well as the applicable portions of SRP Section 3.9.2 and RG 1.29, Revision 3; therefore, these criteria are acceptable.

3.12.4.9 *Main Steamline and Bypass Line in the Turbine Building*

Section 3.2.1 of this report discusses the design criteria applied to the MS and bypass line in the TB.

3.12.4.10 *Buried Piping*

DCD, Tier 2, Section 3.7.3.13, discusses the design of seismic Category I buried piping, conduits, tunnels, and auxiliary systems. The analysis considered the following items:

- Two types of ground-shaking-induced loadings are considered for design:

  (1) relative deformations imposed by seismic waves traveling through the surrounding soil or by differential deformations between the soil and anchor points

  (2) lateral earthquake pressures and ground water effects acting on structures

- The effects of static resistance of the surrounding soil on piping deformations or displacements, differential movements of piping anchors or equipment, and bent geometry and curvature changes are considered. When applicable, procedures using the principles of the theory of structures on elastic foundations can be used.

- When applicable, the effects caused by local soil settlements, soil arching, and the like are considered.

These criteria conform to the applicable guidelines in SRP Section 3.9.2. However, GEH did not offer any details on how the criteria are to be applied in the design of buried piping. Therefore, in RAI 3.12-9, the staff requested that GEH discuss the design criteria for buried pipes. In its response to RAI 3.12-9, the applicant stated that the ESBWR design contains no buried seismic Category I piping. To further clarify this statement, in a followup question during the site audit at the GEH offices in Wilmington, NC, on May 22–26, 2006, GEH also confirmed that no Category I buried piping is located within buried tunnels between the nuclear island and other surrounding structures in the ESBWR design. GEH revised DCD, Tier 2, Section 3.7.3.13, to indicate that the ESBWR design does not include buried seismic Category I piping. The staff found this clarification acceptable; therefore, RAI 3.12-9 was resolved.

3.12.4.11 *ASME Code, Section III, Appendix N*

The criteria provided in Appendix N to ASME Code, Section III, which is a nonmandatory appendix, may conflict with some current staff technical positions. For those cases in which the methodology in Appendix N conflicts with current staff positions discussed here or contained in the SRP or RGs, the staff positions should be followed unless an alternative approach has been justified. DCD Tier 2 initially referred to Appendix N to the ASME Code; however, GEH did not provide any details as to which guidelines in Appendix N are applicable to the design of ESBWR piping. Therefore, in RAI 3.12-10, the staff requested that GEH identify the specific guidelines applicable to the ESBWR piping design. In its response to RAI 3.12-10, the applicant responded that the NRC guidance documents (the SRP and RGs) will be used in lieu of Appendix N. GEH deleted all references to Appendix N to the ASME Code, Section III, from DCD, Tier 2, Sections 3.7.3 and 3.7.2.9. The staff found this clarification acceptable; therefore, RAI 3.12-10 was resolved.

3.12.4.12 *Conclusions*

On the basis of the evaluations in Section 3.12.4, the staff determined that the analysis methods to be used for all seismic Category I piping systems, as well as nonseismic Category I piping systems that are important to safety, are acceptable. The analysis methods utilize piping design practices that are commonly used in the industry and provide an adequate margin of safety to withstand the loadings that result from normal operating transients and accident conditions. The staff's conclusion is based on the following:

- GEH satisfied the requirement of GDC 1 and 10 CFR 50.55a by specifying appropriate codes and standards for the design and construction of safety-related piping and pipe supports.

- GEH satisfied the requirements of GDC 2 by specifying appropriate analysis methods for designing piping and pipe support against seismic loads.

3.12.5 Modeling of Piping Systems

GDC 2 requires that components important to safety be designed to withstand the effects of natural events, including earthquakes. Appendix B to 10 CFR Part 50 requires that design quality be controlled to ensure the structural and functional integrity of seismic Category I components. Piping systems are typically evaluated using computer programs with idealized mathematical models of the piping. Modeling techniques should conform with generally recognized engineering practice, and computer programs should be verified in accordance with one or more methods suggested in SRP Section 3.9.1. A piping benchmark program, described in NUREG/CR-6049, is also available for the verification process.

DCD, Tier 2, Section 3.7.3.3, describes piping modeling techniques, and DCD, Tier 2, Section 3.9.1.2, discusses quality control of computer programs and computer results.

3.12.5.1 *Computer Codes*

DCD, Tier 2, Appendix 3D, describes the major computer programs to be used in the analysis and design of safety-related components, equipment, and structures. According to this appendix, the quality of these programs and computer results is controlled. The programs are verified for their application by appropriate methods, such as hand calculations, or compared with the results from similar programs, experimental tests, or published literature, including analytical results or numerical results to the benchmark problems.

The appendix describes several structural analysis computer programs, including NASTRO4V, ANSYS, and SAG. These programs are used for the qualification of equipment and components such as the FMCRD, pumps and motors, and heat exchangers. Section 3.10 of this report discusses the staff evaluation of programs related to equipment qualification. Piping-related computer programs include PISYS, ANSI7, RVFOR, TSFOR, LUGST, EZPYP, DISPL, PDA, LION, and ANSYS05. Response spectra generation computer programs consist of ERSIN and RINEX.

DCD, Tier 2, Appendix 3D, indicates that the computer program PISYS is used for the static and dynamic analysis of the piping system to determine the structural and functional integrity of the pipe. In PISYS, finite element models of a piping system, formed by assembling stiffness matrices, represent standard piping components. The piping elements are connected to each other via nodes called pipe joints. Through these joints, the model interacts with the environment, and loading of the piping system becomes possible. PISYS is based on the linear elastic analysis in which the resultant deformations, forces, moments, and accelerations at each joint are proportional to the loading, and the superposition of loading is valid.

DCD Tier 2 also indicates that PISYS has a full range of static and dynamic load analysis options. Static analyses include deadweight, uniformly distributed weight, thermal expansion, externally applied forces, moments, imposed displacements, and differential support movement (pseudostatic load case). Dynamic analyses include mode shape extraction, response spectrum analysis, and time-history analysis by modal combination or direct integration. In the response spectrum analysis (i.e., the USM or ISM response spectrum analysis), the user may request modal response combinations in accordance with RG 1.92. In the ground motion (uniform motion) or independent support time-history analysis, the normal mode solution procedure is selected. In analysis involving time-varying nodal loads, the step-by-step direct integration method is used.

DCD, Tier 2, Section 3D.4.2, describes ANSI7 as another computer code used for calculating stresses and cumulative usage factors for Class 1, 2, and 3 piping components in accordance with Subsections NB, NC, and ND-3650 of the ASME Code, Section III. ANSI7 is also used to combine loads and calculate combined Service Level A, B, C, and D loads on piping supports and pipe-mounted equipment.

DCD, Tier 2, Section 3D.4.4, indicates that GEH used the computer codes RVFOR and TSFOR in the analyses of the MS piping systems subjected to transient loads. As described in DCD, Tier 2, Sections 3D.4.4.1 and 3D.4.4.2, RVFOR calculates forces caused by SRV discharge loads at different segments and points of the SRV discharge line of the MS piping system. TSFOR calculates the initial flow conditions in MS piping and forcing functions on each pipe segment resulting from TSV closure. Both computer codes use the method of characteristics.

Appendix B to 10 CFR Part 50 requires design control measures to verify the adequacy of the design of safety-related components. DCD, Tier 2, Section 3.9.1.2, indicates that the quality of the programs and the computer results are controlled either by GEH or by outside computer program developers. In addition, the programs are verified by one or more of the methods recommended in SRP Section 3.9.1.

To permit the staff to complete its review of the computer programs to be used in the ESBWR design, in RAI 3.12-11, the staff requested that GEH provide the following additional information:

(a) which computer programs have already been used during the design certification phase and which programs may be used in the future during the COL application phase,

(b) which programs have already been reviewed by the NRC on prior plant license applications. GEH should include the program name, version, and prior plant license application. As stated in SRP Section 3.9.1, this will eliminate the need for the licensee to resubmit, in a subsequent license application, the computer solutions to the test problems used for verification, and;

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

In its response to RAI 3.12-11, the applicant identified that it used computer codes PISYS07 (an updated version of PISYS) and ANSI713 (an updated version of ANSI7) in the design certification phase. GEH also stated that all of the programs identified in DCD, Tier 2, Appendix 3D.4, are available to COL applicants and may be used in the future during the COL application phase. During the site audit at the GEH offices in Wilmington, NC, on May 22–26, 2006, the staff reviewed these two computer codes, as well as the computer codes RVFOR06D (an updated version of RVFOR) and TSFOR01D (an updated version of TSFOR). The staff found that the user's manuals for PISYS and ANSI7 and the code validation documents for all of the four computer codes audited were incomplete. (The user's manuals for RVFOR and TSFOR are part of the code validation documents since both are smaller codes compared to PISYS and ANSI7). During the site audit at the GEH offices in San Jose, CA, on January 9–12, 2007, the staff reviewed the completed user's manuals for the PISYS and ANSI7 computer codes and the code validation documents for all four computer codes (PISYS, ANSI7, RVFOR, and TSFOR).

The user's manuals for PISYS07 (NEDE-32352, 1998) and ANSI713D (NEDE-23518, Revision 1, "A Piping System Analysis Program for Workstation Application—ANSI713D User's Manual," Class 2, issued October 2000) describe the program functions. GEH did not update the programs to the current requirements given in the ASME Code and regulatory guidance documents described in DCD Tier 2 (e.g., modal, spatial, and group combination methods to be used in the modal response spectrum analyses in PISYS and ASME Code load combination methods in ANSI7). GEH indicated that it would compare the design criteria used in the two computer codes with the design criteria presented in DCD Tier 2, including the commitment to satisfy the requirements in ASME Code, Section III, 2001 Edition through the 2003 Addenda, subject to the limitations and conditions specified in 10 CFR 50.55a(b)(1).

The staff reviewed the code validation documents for RVFOR06D (DRF No. A12-00145, dated December 18, 1998) and TSFOR01D (DRF No. A12-00146, dated November 13, 1997) and found that they meet the guidance in SRP Section 3.9.1. The staff noted during the site audit at the GEH offices in Wilmington, NC, on May 22–26, 2006, that GEH has been using the TSV closure analysis based on the flow rate and pipe diameter data from the Lungmen plant, which may differ from the ESBWR. In response to the staff's concern about this approach, GEH performed new calculations using ESBWR-specific design parameters and documented the results in GENE-0000-0051-9296, Revision 1, eDRF Section 0000-0051-9296, dated January 10, 2007. The staff reviewed this document during the site audit at the GEH offices in San Jose, CA, on January 9–12, 2007, to ensure that the flow rate and pipe diameter data input to this analysis were applicable to the ESBWR design of the MS piping system and found them acceptable.

GEH provided the benchmark document, GE-NE-0000-0063-1917-00, eDRF-0000-0063-1916, Revision 0, Class III, issued January 2007, entitled "PISYS Program Benchmark with NUREG/CR-6049." As a result of the staff's review of this document, during the site audit at the GEH offices in San Jose, CA, on January 9–12, 2007, the staff noted a few cases of differences between the PISYS analysis and the NUREG/CR-6049 benchmark analysis that exceeded the acceptance criteria presented in NUREG/CR-6049. The report did not discuss these differences. Further review of the GEH benchmark document revealed that the PISYS analysis was based on the use of the double sum method for modal combination, while the NUREG analysis was based on the absolute sum method for closely spaced modes. GEH committed to providing technical justification for the differences noted, as part of the supplement to the RAI 3.12-11 response. RAI 3.12-11 was tracked as an open item in the SER with open items.

GEH modified the PISYS program to comply with RG 1.92, Revision 2. In addition, GEH benchmarked the new version of PISYS (PISYS08) with NUREG/CR-6049. GEH indicated that the results of the PISYS08 benchmark analyses were within the NUREG/CR-6049 acceptance criteria.

GEH also provided NEDE-23518, Revision 1, the validation document for the ANSI computer code. The document evaluates stresses and cumulative usage factors for Class 1 piping components in accordance with ASME Code requirements.

The staff performed an onsite review to evaluate the validity of the PISYS08 and ANSI7 programs. Section 3.9.1 of this report documents the evaluation of these computer codes.

The staff also performed a confirmatory piping stress analysis of a representative piping system in the ESBWR standard plant. The purpose of this analysis was to verify the adequacy of the computer program and piping analysis methods used by GEH to perform the piping analyses that were audited by the staff on May 22–26, 2006, at the GEH offices in Wilmington, NC. Section 3.12.6.20 of this report discusses the findings of the confirmatory analysis. RAI 3.2-11 and its associated open item were closed.

3.12.5.2 *Dynamic Piping Model*

DCD, Tier 2, Section 3.7.3.3, describes the procedures used for analytical modeling of piping systems. For the dynamic analysis of seismic Category I piping, each system is idealized as a mathematical model consisting of lumped masses interconnected by elastic members. The stiffness matrix for the piping system is determined using the elastic properties of the pipe material. This includes the effects of torsional, bending, shear, and axial deformations, as well as changes in stiffness as a result of curved members.

DCD, Tier 2, Section 3.7.3.3.1, indicates that finite element models for seismic Category 1 piping systems are constructed to reflect the dynamic characteristics of the system. The continuous system is modeled as an assemblage of pipe elements (straight sections, elbows, and bends) supported by hangers and anchors and restrained by pipe guides, struts, and snubbers. Pipe and hydrodynamic fluid masses are lumped at the nodes and connected by zero-mass elastic elements, which reflect the physical properties of the corresponding piping segment. The mass node points are selected to coincide with the locations of large masses, such as valves, pumps, and motors, and with locations of significant geometry change. All concentrated weights on the piping systems, such as valves, pumps, and motors, are modeled as lumped mass rigid systems if their fundamental frequencies are greater than the cutoff frequency, as defined in DCD, Tier 2, Section 3.7.2.1.1. On straight runs, mass points are located at spacing no greater than the span that would have a fundamental frequency equal to the cutoff frequency when calculated as a simply supported beam with uniformly distributed mass. The analytical model includes the torsional effects of valve operators and other equipment with an offset center of gravity with respect to the piping centerline. Furthermore, all pipe guides and snubbers are modeled using representative stiffness values. The equivalent linear stiffness of the snubbers is based on certified test results provided by the vendor.

Section 3.12.7 of this report addresses the modeling of the stiffness and potential mass effects of pipe supports, equipment to which the pipe is attached, and building steel/structures supporting the pipe supports. DCD, Tier 2, Section 3.7.3.3.2, provides criteria for modeling lumped masses for equipment in a dynamic analysis. In RAI 3.12-12, the staff requested that GEH clarify whether these criteria are also applied to the development of piping system mathematical models. During the site audit at the GEH offices in San Jose, CA, on January 9–12, 2007, the staff reviewed the changes made by GEH in DCD, Tier 2, Revision 2, Section 3.7.3.3.1, and found that a sentence referencing DCD, Tier 2, Section 3.7.3.3.2, for additional criteria regarding lump masses for components, was not appropriate as documented in the "Audit Trip Report, Audit of GE's Economic Simplified Boiling Water Reactor (ESBWR) Piping and Pipe Support Design, January 9 through 12, 2007," issued May 3, 2007. GEH deleted this sentence from the DCD. Since DCD, Tier 2, Section 3.7.3.3.1, provided acceptable criteria for the modeling of lumped masses, the staff found this acceptable and RAI 3.12-12 was closed.

DCD, Tier 2, Section 3.7.3.3.3, initially stated that modifications to the normal linear-elastic piping analysis methodology used with conventional pipe supports are required to calculate the loads acting on the supports and on the piping components when special engineered supports are used. These modifications are needed to account for greater damping of the energy absorbers and the nonlinear behavior of the limit stops. The DCD also indicates that if these special devices are used, "the modeling and analytical methodology shall be in accordance with methodology accepted by the regulatory agency at the time of certification or at the time of application, per the discretion of the applicant." In RAI 3.12-13, the staff asked GEH to clarify whether this statement means that the review of the piping methodology by the staff will be performed at the time of design certification or at the time of COL application and how this could be done at the discretion of the applicant. In its response to RAI 3.12-13, the applicant did not address the question adequately. Subsequently, GEH revised Sections 3.7.3.3.3 and 3.9.3.7.1(6) to state that special engineered pipe supports shall not be used in the ESBWR design, as documented in the Audit Trip Report issued May 3, 2007. Since special engineered supports (e.g., energy absorbers and limit stops) are not used in the ESBWR piping design, the staff found the resolution to RAI 3.12-13 acceptable. Therefore, RAI 3.12-13 was closed.

3.12.5.3 *Piping Benchmark Program*

DCD, Tier 2, Appendix 3D, Section 3D.4.1, indicates that the PISYS program has been benchmarked against NRC piping models. NEDO-24210, issued August 1979 (Reference 3D-1 of Appendix 3D), documents the results for mode shapes and USM analysis options. The ISM analysis option has been validated against NUREG/CR-1677. In RAI 3.12-14, the staff requested that GEH address the following items regarding computer code benchmark procedures:

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

(b) Where in the ESBWR DCD are the requirements for the COL applicant to benchmark the use of any piping analysis program(s) in accordance with the current DCD validation methods and NUREG/CR-6049?

In its response to RAI 3.12-14, the applicant stated that in the last paragraph of DCD, Tier 2, Appendix 3D, Section 3D.4.1, the following will be added: "Subsequently, the PISYS07 program, which is used for ESBWR piping analysis, has been benchmarked against NUREG/CR-6049. If applicable, COL applicants are also required to benchmark piping computer codes against NUREG/CR-6049." During the October 26, 2009, audit, the staff reviewed the draft ANSI714 user's manual and found that PISYS08 was used in lieu of PISYS07 for generation of loads and stresses for input in ANSI714 to perform resulting stresses for various load combinations and fatigue usage factors. The staff issued RAI 3.9-255 S02 to ask GEH to confirm whether PISYS08 has been used or will be used for ESBWR design certification. GEH confirmed that PISYS08 will be used for the ESBWR, and Section 3D.4.1 of DCD Tier 2 has been revised to reflect this and to provide additional details on the PISYS08 computer programs. The staff reviewed the revision of Section 3D.4.1 and performed an onsite review to ensure that the V&V documentation for the PISYS08 and ANSI714 computer codes is complete. Section 3.9.1 of this report documents the evaluation of these computer codes. Based on resolution of RAI 3.9-255 S02 discussed in Section 3.9.1, RAI 3.12-14 was closed.

3.12.5.4 *Decoupling Criteria*

DCD, Tier 2, Section 3.7.3.16, defines small branch lines as those lines that can be decoupled from the analytical model used for the analysis of the main run piping to which the branch lines are attached. Branch lines can be decoupled when the ratio of run to branch pipe moment of inertia is 25 to 1 or greater. In addition to the moment of inertia criterion for acceptable decoupling, these small branch lines must be designed with no concentrated masses, such as valves, in the first one-half span length from the main run pipe. They must also have sufficient flexibility to prevent restraint of movement of the main run pipe. The small branch line is considered to have adequate flexibility if its first anchor or restraint to movement is at least one-half pipe span in a direction perpendicular to the direction of relative movement between the pipe run and the first anchor or restraint of the branch piping. A pipe span is defined as the length tabulated in Table NF-3611-1, "Suggested Piping Support Spacing," of the ASME Code, Section III, Subsection NF. For branches that cannot meet the preceding criteria for sufficient flexibility, the applicant will demonstrate acceptability by using an alternative criterion for sufficient flexibility or by accounting for the effects of the branch piping in the analysis of the main run piping.

DCD, Tier 2, Section 3.7.3.17, provides the criteria for decoupling seismic Category I piping from seismic Category II piping, which typically occurs at the seismic Category I transition valve(s). Two options are presented—one anchors the valve and analyzes the Category I subsystem, and the other analyzes the Category I subsystem through the valve to either the first anchor point in the Category II subsystem or includes portions of the Category II subsystem such that there are at least two seismic restraints in each of the three orthogonal directions. These options ensure that the seismic Category I subsystem is adequately designed to exclude any impact from the seismic Category II subsystem during an earthquake.

DCD, Tier 2, Section 3.7.3.17, also indicates that, where small seismic Category II piping is directly attached to seismic Category I piping, it can be decoupled from seismic Category I piping. However, GEH did not describe how the small branch piping will be analyzed in the piping design for both inertial and SAM responses (e.g., small-bore handbook, or like other (larger) piping, equivalent static method or dynamic analysis). In RAI 3.12-15, the staff requested that GEH identify the analysis method for decoupled small-bore piping from a large piping system.

GEH updated its DCD to state the following:

> Where small seismic Category II piping is directly attached to seismic Category I piping, it can be decoupled from seismic Category I piping. For dynamic and seismic anchor motion analyses,
>
> (1) Decouple criterion is 25 to 1 in the ratio of “moment of inertia” of run pipe to branch pipe.
>
> (2) Amplified response spectra from the seismic and dynamic analyses used in the large bore piping analysis (run pipe) are applied to the small branch piping interfaces. The seismic and dynamic displacements at the connection point use the run pipe displacements.
>
> (3) Formal analysis methods and procedures similar to the main pipe should be used, or more conservative handbook analysis may also be used.
>
> (4) Branch pipe decoupling using response spectrum analysis can use one of the following options.
>
> 1. Place the branch line close (4 times pipe diameter, for example) to large bore pipe supports.
>
> 2. Demonstrate that the applicable pipe segment is “dynamically rigid”.
>
> 3. Overlapping analysis. (1) Include the small bore pipe up to two supports in all three directions to the large bore pipe, (2) analyze the small bore pipe again.
>
> 4. The dynamic analysis obtains the accelerations at the supports on both sides of the run pipe side (Aa), and side (Ab), and at the small branch at (Ac). Envelope the adjusted amplified response spectra (ARS) from both sides of the run pipe supports, (Ac/Aa) and (Ac/Ab), in all three directions and apply to the branch pipe analysis.

5. From large bore piping analysis, obtain the ARS at the branch location to apply to the branch pipe analysis. (A referenced program is ERSIN01 user's manual.)

The staff reviewed the five options of the attached branch piping decoupling analysis methods. The staff finds these options acceptable because they either ensure that there is no significant amplification of the large pipe response at the branch line attachment or account for the amplification of the large pipe in the analysis of the branch line.

The third option involves analysis of a portion of the branch line with the large pipe and a separate analysis for the remaining portion of the branch line. The option requires use of an overlap region in both analyses because the analysis model does not terminate at a rigid anchor. The purpose of the overlap region is to ensure that the effects of the piping on both sides of the overlap region have been captured in the analyses. The original criteria proposed by GEH did not meet the staff guidance in NUREG/CR-1980, "Dynamic Analysis of Piping, Using the Structural Overlap Method," issued March 1981. GEH committed to revising the DCD to reference NUREG/CR-1980. GEH updated its DCD to address the analysis related to the overlap region as follows:

> The decouple criterion is 25 to 1 in the ratio of "moment of inertia" of run pipe to branch pipe. In the event that this criterion cannot be met and decoupling is also needed, then the decouple method as outlined in NUREG/CR-1980 is used. The following specific criteria from NUREG/CR-1980 are applied. In general, based on the current capability of modeling software the entire system is incorporated into one model instead of using the overlap method.
>
> (1) The overlap region has enough rigid restraints and includes enough bends in three directions to prevent the transmission of motion due to modal excitation from one end to the other and to reduce to a negligible level the sensitivity of the structure to the direction of excitation. Specifically, there are at least four rigid restraints in each of three mutually perpendicular directions in the overlap region (including the ends). For axial restraints only this requirement may be relaxed to a single restraint in any straight segment.
>
> (2) For cases where multiple spectra are involved at the different anchor points the spectrum to be used for each subsystem analysis is dependent on the rigidity of the overlap region. If the fundamental natural frequency of the overlap is demonstrated to be at least 25 percent higher than the highest significant forcing frequency, then the envelope spectrum of the spectra associated with the boundaries of each separate subsystem is acceptable. If this rigidity of the overlap region is not demonstrated or its frequency characteristics do not meet the criterion stated above the full system anchor-to-anchor envelope spectrum is used for all subsystems.
>
> (3) The envelope of the support forces is increased by 10 percent for design purposes.

RAI 3.12-15 was tracked as an open item in the SER with open items. The staff reviewed the revised DCD Section 3.7.3.17 and determined that GEH had added adequate criteria in accordance with the staff's guidance described in NUREG/CR-1980 for the overlap method. Therefore, the staff found its concern in RAI 3.12-15 and their associated open items were resolved.

3.12.5.5 *Conclusions*

On the basis of the discussions above and the evaluation of DCD, Tier 2, Sections 3.7.3 and 3.9, the staff concludes that design control measures are acceptable to ensure the quality of computer programs and design methods. The staff's conclusion is based on the following:

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

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

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

3.12.6 Pipe Stress Analysis Criteria

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

GDC 14 requires that the RCPB components be designed, fabricated, erected, and tested to ensure an extremely low probability of abnormal leakage, rapidly propagating failure, and gross failure. GDC 15 requires that the RCS be designed with sufficient margin to ensure that the design conditions are not exceeded. The design of the RCPB piping components should protect against catastrophic failure, initiation and propagation of a crack, or propagation of an undetected flaw through the pressure boundary (i.e., fatigue failure).

3.12.6.1 *Seismic Input (Envelope versus Site-Specific Spectra)*

DCD, Tier 2, Section 3.7.1, indicates that the ESBWR standard plant is designed for an SSE ground motion defined by an RG 1.60 response spectrum anchored to a peak PGA of 0.3g in both horizontal and vertical directions. Amplified building response spectra generated for the ESBWR standard plant account for the North Anna early site permit and generic site conditions. GEH proposed that the COL applicant use the site-enveloping response spectra described in the DCD to complete the design and analyses of the ESBWR piping systems. Section 3.7.1 of this report discusses the acceptability of this approach.

The staff recognizes that the site-enveloping response spectra for the ESBWR plant contain conservatisms that may be excessive for certain specific site conditions. If amplified building response spectra are generated using site-dependent properties, then the approach and method used must be submitted to the staff for review and approval as part of the COL application. The method used to generate the amplified building response spectra should be consistent with the method accepted by the staff, as discussed in Section 3.7.2 of this report.

3.12.6.2 *Design Transients*

In DCD, Tier 2, Table 3.9-1, GEH lists the design transients for five groups of plant operating conditions and the number of cycles for each event within the group that are normally used for fatigue evaluation of ASME Code Class 1 piping and components.

The operating conditions are as follows:

- ASME Service Level A: normal conditions
- ASME Service Level B: upset condition—incidents of moderate frequency
- ASME Service Level C: emergency condition—incidents of low frequency
- ASME Service Level D: faulted condition—incidents of extremely low frequency
- testing conditions

Section 3.9.1 of this report documents the evaluation of ESBWR design transients.

3.12.6.3 *Loadings and Load Combinations*

The staff reviewed DCD, Tier 2, Section 3.9.3.1, in accordance with SRP Section 3.9.3. The loadings and load combinations should be sufficiently defined to provide the basis for design Code 1, 2, and 3 components and Class CS core support structures for all conditions. The acceptability is based on comparisons with positions in Appendix A to SRP Section 3.9.3 and with appropriate standards acceptable to the staff.

Note 3 to DCD, Tier 2, Table 3.9-2, indicates that the method used in the combination of dynamic responses of piping loadings must be consistent with NUREG-0484, Revision 1. In DCD, Tier 2, Table 3.9-9, for load combinations and acceptance criteria for Class 1 piping systems (and new Tables 3.9-10, 3.9-11, and 3.9-12 for pipe supports added to DCD Tier 2), the load combinations for Service Levels C and D use the SRSS method of combination between SRV and other LOCA hydrodynamic loads. As noted in NUREG-0484, Revision 1, use of the SRSS method is acceptable when it is shown that a nonexceedance probability (NEP) of 84 percent or higher is achieved when combining responses resulting from two time-dependent loads. The staff accepts the use of the SRSS combination of LOCA and SSE loads as discussed in NUREG-0484. However, for the combination of other dynamic loads (e.g., LOCA and SRV loads), GEH should demonstrate that the same NEP acceptance criterion is satisfied. Both RAI 3.8-9 and RAI 3.12-17 raised this issue. RAI 3.12-7 was tracked as an open item in the SER with open items. The staff reviewed the GEH response to RAI 3.8-9 S05 for justifying the use of SRSS combination for other dynamic loads. The staff concludes that the GEH position meets the provision of NUREG-0484, Revision 1. Section 3.8.1.3 documents the staff evaluation leading to the RAI acceptance. On this basis, RAI 3.12-17 and its associated open item were resolved.

Since the ESBWR piping design eliminates the OBE, changes and additions to ASME Code, Section III, Subsections NB-3600, NC-3600, and ND-3600, are necessary to include the SAM responses in the load combinations other than the normal design equations. DCD, Tier 2, Table 3.9-2 (for Class 2 and 3 piping), includes these modifications, and Section 3.12.6.5 of this report discusses them. However, in note 12 to DCD, Tier 2, Table 3.9-2, GEH did not include any additions or changes to the Class 1 piping requirements in ASME Code, Section III, Subsection NB-3600, for Equations 10 and 11 (similar to the additions or changes made for Class 2 and 3 piping). In RAI 3.12-18, the staff requested that the applicant address the requirement for seismic anchor motion stress limit.

GEH revised note 12 to DCD, Tier 2, Table 3.9-2, with changes and additions to ASME Code, Section III, Subsections NB-3600, NC-3600, and ND-3600 for Class 1, 2, and 3 piping design. The seismic anchor movement (S_{SAM}) for Class 1 in Equation 12a and for Classes 2 and 3 in Equation 12b are additional requirements consistent with the ABWR (note 7 to DCD, Tier 2, Table 3.9-2) design certification acceptance criteria. The staff found the resolution to RAI 3.12-18 acceptable. Therefore, RAI 3.12-18 was closed.

During the site audit at the GEH offices in Wilmington, NC, on May 22–26, 2006, the staff noted that DCD, Tier 2, Section 3.9.3.4, did not initially identify direct loading of the SRV discharge and LOCA on submerged components in the suppression pool as one of the loads in the piping analysis. In RAI 3.12-38, the staff requested that GEH include the direct loads both in the DCD and in the MS piping analysis. GEH revised DCD, Tier 2, Section 3.9.3.4, to state, "For submerged piping and associated supports, the applicable direct external loads (i.e., hydrodynamic etc.) applied to the submerged components shall be included in the analysis." The staff found the resolution to RAI 3.12-38 acceptable. Therefore, RAI 3.12-18 was closed.

On the basis of its review, the staff concludes that appropriate combinations of operating transients and accident loadings are specified to provide a conservative design envelope for the design of piping systems. The load combinations are consistent with the guidelines in SRP Section 3.9.3 and the staff position on single-earthquake design and are, therefore, acceptable.

3.12.6.4 *Damping Values*

DCD, Tier 2, Table 3.7-1, lists the damping values of various structures and components, including piping, for use in SSE dynamic analysis. Note 1 to this table indicates that damping values of ASME Code Case N-411-1 may be used, as permitted by RG 1.84, for ASME Code, Section III, Division 1, Class 1, 2, and 3, and B31.1 piping. These damping values are applicable in analyzing piping response for seismic and other dynamic loads filtering through building structures in the high-frequency range beyond 33 Hz.

The staff asked GEH to indicate whether the damping values corresponding to ASME Code Case N-411-1 and meeting the conditions of RG 1.84, Revision 33, will be used for the ISM method. In RAI 3.12-19, the staff requested that GEH provide the technical basis for using these damping values for the ISM method. GEH deleted the references to ASME Code Case N-411-1 from Section 3.7 of the DCD. To maintain this option in the ESBWR piping design, a new Figure 3.7-37, introduced in DCD Tier 2, explicitly describes the frequency-dependent ASME Code Case N-411-1 damping curve and associated conditions permitted by RG 1.84, including the limitations for use with the ISM method. The new figure includes all of the conditions listed in RG 1.84 for this ASME Code Case. In addition, GEH also stated that the ESBWR piping design will not use any linear energy-absorbing supports. The staff finds this acceptable; therefore, RAI 3.12-19 was resolved.

In NUREG-0933, "Resolution of Generic Safety Issues," issued August 2008, Generic Issue Item 119.2 notes that seismic damping values used in seismic design are too conservative when the values in RG 1.61, Revision 0, are adopted. The use of higher damping values would result in nuclear plant piping systems having significantly fewer snubbers and supports and an overall better balance of design, considering all piping loads. On that basis, GEH is using RG 1.61, Revision 1. The staff has determined that GEH adequately addressed Generic Issue 119.2 as indicated in NUREG-0933.

3.12.6.5 *Combination of Modal Responses*

DCD, Tier 2, Section 3.7.2.7, states that the analysis methods meet the requirements in RG 1.92, Revision 2, for combining the modal response and the missing masses. DCD, Tier 2, Section 3D.4.1.1, states, "In conjunction with RG 1.92 Rev. 1, PISYS has been benchmarked in accordance with NUREG/CR-6049." The staff issued RAI 3.9-255 to clarify this inconsistency. The applicant's response revised the DCD as follows:

> The analysis methods meet the requirements in RG 1.92, Revision 2, for combining the modal response and the missing masses, except that for piping analyses, the double sum equation in RG 1.92, Revision 1 is used and the residual rigid response of the missing mass modes is included.

RG 1.92, Revision 2, states the following:

> The more conservative methods of combining modal responses (as described in Revision 1) remain acceptable. However, if applicants for new licenses choose to use Revision 1 methods for combining modal responses, their analyses should address the residual rigid response of the missing mass modes (as discussed in Regulatory Positions C.1.4.1 and C.1.5.1 of this guide).

The staff reviewed the response and the revised DCD. The response clarifies that GEH is using the double sum equation of RG 1.92, Revision 1, for combination of modal responses, which is conservative and meets the staff recommendation. On this basis, the staff finds the response acceptable.

Section 3.7.2.3.7 of this report presents the staff evaluation of the combination methods of modal responses. Section 3.12.4.3 of this report discusses specific guidance on the combination methods to be used for the ISM method of analysis.

DCD, Tier 2, Section 3.7.2.7, defines the cutoff frequency for modal responses as the frequency at which the spectral acceleration returns approximately to the ZPA of the input response spectrum. In RAI 3.12-20, the staff asked GEH to explicitly define the cutoff frequency for the ESBWR piping design. In its response to RAI 3.12-20, the applicant stated that the ZPA cutoff frequency for modal response analysis of subsystems for seismic and other building dynamic loads is 100 Hz or the rigid frequency, as defined as f_2 in DG-1127 (proposed Revision 2 of RG 1.92), "Combining Modal Responses and Spatial Components in Seismic Response Analysis," issued February 2005. GEH updated DCD Tier 2, Section 3.7.2.7, accordingly. However, during the site audit at the GEH offices in San Jose, CA, on January 9–12, 2007, the staff requested that GEH further clarify the definition of f_2. DCD, Tier 2, Section 3.7.2.7, Step 1, defines the ZPA cutoff frequency as 100 Hz or the f_{zpa} defined in Figures 1, 2, and 3 of RG 1.92, Revision 2. GEH also reviewed other chapters in the DCD that were appropriately modified to refer to the requirements of Step 1 of Section 3.7.2.7 for ZPA cutoff frequency determination. The staff finds that the resolution to RAI 3.12-20 is consistent with RG 1.92 and is, therefore, acceptable.

3.12.6.6 *High-Frequency Modes*

DCD, Tier 2, Section 3.7.2.7, presents a procedure to account for high-frequency modes. This procedure requires only the computation of individual modal responses for lower frequency modes (below the ZPA). Thus, the more difficult higher frequency modes need not be determined. The procedure for calculating the higher frequency modes (missing mass) is based on the pseudostatic inertial forces excited at the ZPA. The results using the procedure for the high-frequency modes are combined with the response from the low-frequency modes by the SRSS method. The procedure ensures inclusion of all modes of the structural (or piping) model and proper representation of DOF masses.

The DCD also provides an alternative procedure to account for high-frequency modes. In this alternative, modal responses are computed for enough modes to ensure that the inclusion of additional modes does not increase the total response by more than 10 percent. Modes that have natural frequencies lower than that at which the spectral acceleration returns approximately to the ZPA are combined in accordance with RG 1.92. Higher mode responses are combined algebraically (i.e., they retain their sign) with each other. The absolute value of the combined higher modes is then added directly to the total response from the combined lower modes.

Section 3.7.2.3.7 of this report presents the staff evaluation of the procedures described above for high-frequency modes in a seismic analysis.

For the analyses of vibratory loads (other than seismic) with significant high-frequency input (e.g., above 100 Hz for the ESBWR), the staff's positions are described below.

In RAI 3.12-21, the staff asked the applicant to address the methodology for the combination of high-frequency modal results for the USM/ISM analysis method. The high-frequency modes must be combined in accordance with the guidelines provided in RG 1.92, Revision 2. Use of other combination methods will require further justification and staff approval before use. In response to RAI 3.12-21, the applicant stated that the modal combination for the high-frequency modes that are above the cutoff frequency for vibratory loads is performed in accordance with Appendix A to SRP Section 3.7.2, since RG 1.92, Revision 1, does not address the missing mass contribution. However, the criteria presented in Appendix A to SRP Section 3.7.2 could yield nonconservative results for calculating the residual rigid response of the missing mass modes. Appendix A to RG 1.92, Revision 2, provides the updated criteria for the missing mass contribution to the total response. GEH is committed to using the RG 1.92, Revision 2, piping design criteria for missing mass contribution and revised DCD, Tier 2, Section 3.7.2.7, to be consistent with the staff position in RG 1.92, Revision 2. Therefore, the staff considered this issue resolved.

As documented in the Audit Trip Report issued May 3, 2007, during the site audit at the GEH offices in San Jose, CA, on January 9–12, 2007, GEH stated that the DCD does not include provisions for nonlinear analysis; hence, no such analysis is needed since the gap or clearance of the supports is considered sufficiently small for the ESBWR piping design. GEH revised its first response to this part of the RAI to eliminate the potential use of nonlinear analyses, thus preventing the issue from becoming a COL Information item. This approach is acceptable to the staff.

RAI 3.12-21 was tracked as an open item in the SER with open items. Based on the above evaluation, the staff found that RAI 3.12-21 and its associated open item were resolved.

3.12.6.7 *Fatigue Evaluation for ASME Code Class 1 Piping*

DCD, Tier 1, Section 3.1, indicates that, for the ASME Code Class 1 piping systems and components, the fatigue analysis must include environmental effects, and the ASME Code Class 1 piping fatigue requirements must be met.

The ASME Code, Section III, requires an evaluation of all ASME Code Class 1 piping for cumulative fatigue damage. The staff issued RG 1.207 to provide guidelines for evaluating analyses of environmentally assisted fatigue. In RAI 3.12-22, the staff requested that GEH describe the analysis method that will be used to perform the fatigue analysis, including the environmental effects. GEH revised its DCD to address the effects of the reactor environment on fatigue as follows: "For Class 1 piping, stresses are calculated on an elastic basis and evaluated in accordance with NB-3600 of the ASME B&PV Code, and fatigue usage is in accordance with RG 1.207 and NUREG/CR-6909."

RAI 3.12-22 was tracked as an open item in the SER with open items. Because GEH addressed environmentally assisted fatigue in accordance with the staff's recommendations described in RG 1.207, the staff found that RAI 3.12-22 and its associated open item were resolved.

GEH uses the fatigue usage factor of 0.4 as part of its criteria to identify Class 1 pipe break locations. This is a relaxation of the staff position specified in SRP Section 3.6.2. GEH's basis for the relaxation of the break criteria is that implementation of RG 1.207 would result in an increase in break locations. The proposed criterion of 0.4 is consistent with the criterion provided in ANS-58.2, "Design Basis for Protection of Light Water Nuclear Power Plants against the Effects of Postulated Pipe Rupture," and is acceptable to the staff.

3.12.6.8 *Fatigue Evaluation of ASME Code Class 2 and 3 Piping*

DCD, Tier 2, Section 3.9.3.1, indicates that many of the ESBWR components are classified as ASME Code Class 2 or 3 or Quality Group D. In the event that any non-Class 1 component is subjected to cyclic loadings of a magnitude and/or duration so severe that the 60-year design life cannot be ensured by the required ASME Code calculations, COL applicants referencing the ESBWR design shall identify these components and either provide an appropriate analysis to demonstrate the required design life or provide designs to mitigate the magnitude or duration of the cyclic loads. For example, thermal sleeves may be required to protect the pressure boundary from severe cyclic thermal stress at points where hot and cold fluids mix. Also, DCD, Tier 1, Section 3.1, indicates that, for the ASME Code Class 2 and 3 piping systems and their components that will be subjected to severe thermal transients, the design must consider the effects of these transients.

In RAI 3.12-23, the staff requested more detailed information on the fatigue evaluation of ASME Code Class 2 and 3 and Quality Group D piping systems that are subject to cyclic loadings. In its response to RAI 3.12-23, the applicant stated that the Class 2 and 3 fatigue analyses are performed in accordance with ASME Code, Section III, Subsection NC-3611.2. The allowable stress reduction coefficient, f, is consistent with Table NC-3611.2-1. GEH added a sentence in DCD Tier 2 stating that, if an NB-3600 analysis is performed for Class 2 or 3 pipe as part of a Class 1 piping system, all the analysis requirements for Class 1 pipe as specified in the DCD and the ASME Code will be met. The staff found this acceptable; therefore, RAI 3.12-23 was resolved.

3.12.6.9 *Thermal Oscillations in Piping Connected to the Reactor Coolant System*

NRC Bulletin 88-08, "Thermal Stresses in Piping Connected to Reactor Cooling Systems," dated June 22, 1988, requested that licensees and applicants review systems connected to the RCS (including the RPV) to determine whether any sections of this piping that cannot be isolated may be subject to temperature oscillations that could be induced by leaking valves. GEH did not describe how it addressed thermal oscillations in piping connected to the RCS. Therefore, in RAI 3.12-24, the staff asked GEH to evaluate the piping design of systems that are connected to the RCS for potential thermal oscillations as discussed in NRC Bulletin 88-08. In its response to RAI 3.12-24, the applicant identified several piping systems that may be vulnerable to such thermal oscillations. During the site audit at the GEH offices in Wilmington, NC, on May 22–26, 2006, the staff discussed with GEH each of these systems, along with their P&IDs, as documented in the "Audit of GE's Economic Simplified Boiling Water Reactor (ESBWR) Piping Design Criteria, Sample Analyses, Design Procedures and Specifications; and Discussion of RAI Responses, May 22-26, 2006," July 19, 2006. GEH provided a revised response discussing the systems that may be subject to thermal oscillations as described in NRC Bulletin 88-08.

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

- 1.1 Standby Liquid Control System (C41) Squib Valves. In this case, the problem of leaks does not exist because of the design of the squib valves.

- 1.2 The Gravity-Driven Cooling System (E50) Squib Valves. In this case, the problem of leaks does not exist because of the design of the squib valves.

- 1.3 Nuclear Boiler System (B21) RPV Head Vent Piping Drain Isolation Valve. If the physical location of the valve is close to the RPV, the potential for a thermal oscillation problem exists. The design of the pipe routing will be completed to prevent this from occurring.

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

- 2.1 Nuclear Boiling System (B21) RPV Head Vent Piping Drainline Isolation Valves. In the ESBWR, globe-type valves with bellow seals are provided to prevent leakage from occurring.

During the site audit at the GEH offices in San Jose, CA, on January 9–12, 2007, the staff discussed these systems further with GEH, as documented in the Audit Trip Report issued

May 3, 2007. Based on this discussion, GEH indicated that, to satisfy NRC Bulletin 88-08, the design of the above three systems (C41, E50, and B21) for the ESBWR piping design is subject to the following:

- All systems with the potential for thermal oscillations from leaking valves, including the standby liquid control system (C41) and the GDCS (E50), must contain squib valves for isolation from an RCPB component. Since the operation of these valves is controlled by explosives that knock out the valve disc from its completely sealed position, the staff determined that leaks through this type of valve would not occur.

- The routing of the nuclear boiler system (B21) RPV head vent piping drainline must be designed to prevent any leakage from occurring. Also, the isolation valve must be a globe-type valve with bellow seals. Based on the discussions with GEH, the staff determined that the ESBWR design of the subject piping system would prevent any leaks from occurring.

Based on the above commitments by GEH, as documented in the Audit Trip Report issued May 3, 2007, its approach to satisfying the issues discussed in NRC Bulletin 88-08 is acceptable. The staff concludes that RAI 3.12-24 was resolved, based on the GEH revision of its response to RAI 13.12-24 S01 to reflect the above discussion.

3.12.6.10 *Thermal Stratification*

Thermal stratification is a phenomenon that can occur in long runs of horizontal piping when two streams of fluid at different temperatures flow in separate layers without appreciable mixing. Under stratified flow conditions, the top of the pipe may be at a much higher temperature than the bottom. This thermal gradient produces pipe deflections, support loads, pipe-bending stresses, and local stresses that the original piping design may not have taken into account. The effects of thermal stratification have been observed in both BWR and PWR feedwater piping as discussed in NRC Information Notice (IN) 84-87, “Piping Thermal Deflection Induced by Stratified Flow,” dated December 3, 1984, and NRC IN 91-38, “Thermal Stratification in Feedwater System Piping,” dated June 13, 1991. In RAI 3.12-25, the staff requested that GEH address ESBWR systems that may experience thermal stratification. In its response to RAI 3.12-25, the applicant identified several piping systems that are vulnerable to thermal stratification. During the site audit at the GEH offices in Wilmington, NC, on May 22–26, 2006, the staff discussed each of these systems, as documented in the audit report issued July 19, 2006, along with their P&IDs, with GEH. The applicant provided a revised response to RAI 13.12-25 S01 discussing the potential for systems to be subject to thermal stratification effects as discussed in IN 84-87 and IN 91-38.

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

GEH stated that the ESBWR systems have been designed to minimize thermal stratification. In the case of WNP-2 (described in IN 84-87), an unusual design feature of the WNP-2 plant allows the feedwater system to be heated by the RWCU system. The RWCU return lines join two 24-in. feedwater lines upstream from two isolation check valves, but downstream from normally open motor-operated valves. This allows reverse RWCU system flow back through the feedwater system. Then, under low feedwater flow conditions, cold feedwater can flow along the bottom of the pipe. In many BWRs, the RWCU system enters the feedwater system between the inboard and outboard isolation check valves to prevent reverse flow of the RWCU system into the feedwater system. In the case of the ESBWR, the RWCU/SDC system feeds water into the nuclear boiler system in the feedwater section between two check valves (DCD, Tier 2, Figure 5.1-2, "Nuclear Boiler System Schematic Diagram") to prevent reverse flow of the RWCU/SDC system into the feedwater system.

GEH further stated that the ABWR feedwater piping circumferential temperatures have been measured at various locations during startup and shutdown tests. The testing also included various designed operation transients. GEH has incorporated these test data, as well as conservatisms, into the design duty cycle diagrams. Therefore, the feedwater design requirements do include stratification evaluation based on the measured data.

DCD, Tier 2, Section 3.9.2.1.2, includes stratification testing for the feedwater system piping to be performed on the initial ESBWR plant to confirm that the thermal stratification inputs to the piping analysis are conservative.

DCD, Tier 2, Section 14.2.8.2.9, states that a special test will be performed on the feedwater discharge piping inside and outside of containment to monitor the conditions and effects of temperature stratification that may exist. This special test will be conducted during heatup, hot standby, postscram, IC operation, and reactor shutdown. During the performance of this test, thermal displacements, strains, and temperature measurements will be taken on at least one of the main feedwater headers inside and outside the containment, at selected feedwater riser piping, and at selected feedwater RPV nozzles to measure thermal cycling.

Based on the revised response to RAI 13.12-25, the staff concludes that the GEH design minimizes the occurrence of thermal stratification effects. Furthermore, if thermal stratification exists within the feedwater discharge piping, the special test discussed in DCD, Tier 2, Section 14.2.8.2.9, will identify the presence of such a phenomenon. The staff found this acceptable; therefore, RAI 3.12-25 was resolved.

3.12.6.11 *Safety/Relief Valve Design, Installation, and Testing*

DCD, Tier 2, Section 3.9.3.5.1, indicates that the typical SRV design described in DCD, Tier 2, Section 5.2.2.2, is qualified by type test to IEEE 344 for operability during a dynamic event. The structural integrity of the configuration during a dynamic event is demonstrated by both the ASME Code Class 1 analysis and test. A mathematical model of this valve is included in the MS line system analysis, in the same way as the MSIVs.

In accordance with TMI Action Item II.D.1 of NUREG-0737, both PWR and BWR licensees and applicants are required to conduct testing to qualify the RCS SRVs and associated piping and supports under expected operating conditions for design-basis transients and accidents. Section 20.6 of this report discusses and evaluates the GEH response to TMI Action Item II.D.1 of NUREG-0737.

In RAI 3.12-26, the staff asked GEH to describe the SRV design parameters and the criteria that will need to be specified to the COL applicant to ensure that the specific piping configuration and SRVs, purchased and installed at the COL applicant stage, will match the test and design parameters used at the design certification stage. For example, the minimum rise time for the

SRV operation can greatly affect the transient loads imposed on the piping system. Also, changes in the discharge piping system configuration may affect the SRV loadings.

In its response to RAI 3.12-26, the applicant stated that SRV tests were performed at Wyle in Huntsville, AL, in August 1981. The tests measured the forces resulting from SRV discharge. The tests confirmed that a 20-millisecond (msec) opening time should be used. A paper entitled "Comparison of the Performances of the Strut and Snubber Subject to Dynamic Load," by H.L. Hwang and E.O. Swain, at the Proceedings of International Nuclear Power Plant Thermal Hydraulics and Operations Topical Meeting, in Taipei, Taiwan, Republic of China, October 22–24, 1984, presented the test results.

Section 3D.4.4.1 of Appendix 3D to DCD Tier 2 describes the computer program RVFOR, used in the SRV load calculation. This program is available for the COL applicant to use whenever needed. The user's manual will also include example input and output data. The staff reviewed the GEH response and found that the applicant addressed only the rise time parameter. GEH provided a revised response indicating that Sections 5.2 and 15.2 of DCD Tier 2 specify many of the SRV design parameters and criteria. GEH will prepare the procurement specification for the SRV that will define the SRV requirements necessary to be consistent with the SRV parameters used in the steamline stress analysis that supports the ESBWR certification.

GEH also stated that the SRV opening time for forcing function analysis (20 msec) is defined in the Piping Design Specification 26A6910, "ASME Code, Section III Class-1 Main Steam Piping System," Section 5.2.2.4. DCD, Tier 2, Section 3.9.3.6, has appropriately stated that many of the design parameters and criteria are referenced to other DCD sections, and the procurement specification will define the SRV requirements consistent with parameters used in the MS piping analysis. The staff found this acceptable; therefore, RAI 3.12-26 was resolved.

DCD, Tier 2, Section 3.9.3.6, contains the design and installation criteria applicable to the mounting of pressure relief devices used for the overpressure protection of ASME Code Class 1, 2, and 3 components. For the MS SRV, time-history integration is the method of analysis applied to determine the response to relief valve operation. The resulting loads on the SRV, the MS line, and the discharge piping are combined with loads from other effects as specified in DCD, Tier 2, Section 3.9.3.1.

DCD, Tier 2, Section 3.9.3.6, also indicates that the design of other ESBWR SRVs incorporates SRV opening and pipe reaction load considerations required by ASME Code, Section III, Appendix O. These include the additional criteria in SRP Section 3.9.3.II.2 and those identified in ASME Code, Subsection NB-3658, for pressure and structural integrity. Their operability is demonstrated either by dynamic testing or analysis of similarly tested valves or a combination of both in compliance with the guidelines of SRP Section 3.9.3.

3.12.6.12 *Functional Capability*

DCD, Tier 2, Table 3.9.2, provides load combinations and allowable stress limits for ASME Code Class 1, 2, and 3 piping systems. These stress limits do not exceed the limits designated for Service Level D in the ASME Code, Section III. The Service Level D limits are 3.0 S_m (not to exceed 2.0 S_y) for ASME Code Class 1 piping and 3.0 S_h (not to exceed 2.0 S_y) for Class 2 and 3 piping. Note 13 to DCD, Tier 2, Table 3.9-2, further indicates that all ASME Code Class 1, 2, and 3 piping systems that are essential for safe shutdown under the postulated events listed in the table are designed to meet the recommendations in NUREG-1367, "Functional Capability of Piping Systems," issued November 1992.

Dynamic testing conducted by the Electric Power Research Institute, GEH, and the NRC has established that these stress levels do not result in a loss of piping functional capability. The staff finds that the proposed stress levels for ensuring the functional capability of essential piping systems comply with the guidelines in SRP Section 3.9.3 and are, therefore, acceptable.

3.12.6.13 *Combination of Inertial and Seismic Motion Effects*

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

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

When required for certain evaluations, such as support design, the responses caused by the inertial and relative displacement effects should be combined by the absolute sum method in accordance with SRP Section 3.9.2 for the USM method of analysis and the SRSS method in accordance with NUREG-1061 for the ISM method of analysis. In lieu of this method, time histories of support excitations may be used, in which case both inertial and relative displacement effects are already included.

Sections 3.7.3.9 and 3.7.3.12 of DCD Tier 2 describe the methodology for considering the effects caused by relative building movements. The displacements that are obtained from the dynamic building analysis are applied to the piping anchors and restraints corresponding to the maximum differential displacements that could occur. Three analyses are performed—one for each of the two horizontal differential displacements and one for the vertical. The resulting stresses in the piping are treated as secondary stresses. SRP Section 3.9.2 specifies absolute sum combination of the primary with the secondary responses for the USM method of analysis. The staff position applicable to the ISM method of analysis, presented in Volume 4, Section 2, of NUREG-1061, is to use SRSS for combining the primary with the secondary responses. This relaxation of SRSS combination for ISM in the inertial and SAM response combination may be primarily because of the conservative group combinations suggested in NUREG-1061.

GEH did not discuss the combination method for the primary and secondary responses to be used in the piping design. In RAI 3.12-27, the staff asked GEH to provide this information for all analysis methods used in the piping design. In its response to RAI 3.12-27, the applicant stated that DCD, Tier 2, Section 3.7.3.12, describes the effect of differential building movement on piping systems that are anchored and restrained to floors and walls of buildings that may have differential movements during a dynamic event. In general, piping systems are anchored and restrained to floors and walls of buildings that may have differential movements during a seismic event. The movements may range from insignificant differential displacements between rigid walls of a common building at low elevations to relatively large displacements between separate buildings at a site with high seismic activity.

GEH also stated that the piping system differs from multiply supported equipment. For the piping system, the induced displacements in compliance with NB-3653 are treated differently than the inertia displacements. GEH further stated that the SRSS method is a standard industrial practice to combine the inertial responses and SAM responses caused by relative displacements. The staff requested that GEH provide a technical justification for using the SRSS combination of the inertial and SAM responses for the USM method of analysis. RAI 3.12-27 was tracked as an open item in the SER with open items.

GEH provided a proposed a revision to DCD, Tier 2, Section 3.7.3.12, which requires that inertia and SAM responses be combined by the absolute sum method for piping support design. The staff reviewed the updated DCD. The updated DCD, Tier 2, Revision 7, Section 3.7.3.12, states that when the piping analysis is performed using USM analysis, in accordance with SRP Section 3.9.2, the absolute sum method is used to combine the inertial and the seismic anchor motion results for both piping and piping support design. This position meets the staff's recommendation in SRP Section 3.9.2. The staff found this acceptable, and RAI 3.12-27 and its associated open item were resolved.

3.12.6.14 *Cutoff Frequency for Hydrodynamic Loadings*

DCD, Tier 2, Section 3.7.2.7, indicates that the ZPA cutoff frequency for dynamic analysis is 100 Hz, as defined in Figures 2 and 3 of RG 1.92. This value is applicable to suppression pool hydrodynamic loadings for use in the piping system dynamic analyses. Section 3.12.6.5 of this report evaluates this issue.

3.12.6.15 *Operating-Basis Earthquake as a Design Load*

Appendix S to 10 CFR Part 50 allows the use of single-earthquake design by providing the applicant an option to use an OBE value of one-third the maximum vibratory ground acceleration of the SSE and to eliminate the requirement to perform explicit response analyses for the OBE.

SECY-93-087 provides supplemental criteria for fatigue, seismic anchor motion, and piping stress limits that should be applied when the OBE is eliminated. Section 3.1.1 of NUREG-1503 discusses the staff position on the use of a single-earthquake design for SSCs in the ABWR plant. For fatigue evaluation, two SSE events with 10 maximum stress cycles per event (or an equivalent number of fractional cycles) should be considered. The effects of SAM resulting from the SSE should be considered in combination with the effects of other normal operational loadings that might occur concurrently.

For the Class 1 primary stress evaluation, seismic loads need not be evaluated for consideration of Level B Service Limits for Equation 9. However, for satisfaction of primary plus secondary stress range limits in Equation 10, the full SSE stress range or a reduced range corresponding to an equivalent number of fractional cycles must be included for Service Level B limits. These load sets should also be used for evaluating fatigue effects. In addition, the stress that is caused by the larger of the full range of SSE anchor motion or the resultant range of thermal expansion plus half the SSE anchor motion range must not exceed 6.0 S_m. For Class 2 and 3 piping, seismic loads are not required for consideration of occasional loads in satisfying the Level B Service Limits for Equation 9. Seismic anchor motion stresses are not required for consideration of secondary stresses in Equation 10. However, stresses that result from the combination of range of moments caused by thermal expansion and SSE anchor motions must not exceed 3.0 S_h.

DCD, Tier 2, Section 3.7.3.2, indicates that the SSE is the only design earthquake considered for the ESBWR. The fatigue evaluation of ASME components will consider two SSE events with

10 peak stress cycles per event. Alternately, an equivalent number of fractional vibratory cycles may be used (but with an amplitude not less than one-third of the maximum SSE amplitude) when derived in accordance with Appendix D to IEEE 344-1987. The staff finds this commitment consistent with the NRC guidance document previously discussed and the Commission-approved staff recommendations on the issue of OBE elimination. The staff finds that GEH adequately addressed Generic Item 119.3 of NUREG-0933.

3.12.6.16 *Welded Attachments*

DCD Tier 2 lists ASME Code cases used for the analysis of local stresses at welded attachments to piping (e.g., lugs, trunnions, or stanchions). ASME Code Case N-318-5 is acceptable to the staff and is endorsed in RG 1.84. In RG 1.84, the staff also endorses ASME Code Case N-391-2 for hollow circular welded attachments on Class 1 piping and ASME Code Case N-392-3 for hollow circular welded attachments on Class 2 and 3 piping. Thus, these ASME Code cases listed in DCD Tier 2 are acceptable.

3.12.6.17 *Composite Modal Damping*

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

DCD, Tier 2, Section 3.7.2.13, provides the analysis procedure for damping to be used in the ESBWR plant design. Section 3.7.2.3.13 of this report evaluates the adequacy of the various methods to determine composite modal damping.

3.12.6.18 *Minimum Temperature for Thermal Analyses*

The DCD did not provide a minimum temperature at which an explicit piping thermal expansion analysis would be required. In RAI 3.12-28, the staff requested that GEH clarify this issue. In its response to RAI 3.12-28, the applicant stated that the fatigue analysis for Class 1 piping includes all operating temperatures above or below ambient. Even the ambient temperature is included as a load set with defined cycles. The stress-free state of a piping system is defined as a temperature of 21 degrees C (70 degrees F) for Class 1, 2, 3, or B31.1 piping. For Class 2, 3, or B31.1 piping, an explicit thermal expansion analysis is not required for piping with a system operating temperature of 65 degrees C (150 degrees F) or less. This temperature corresponds to typical industry practice, and the staff considers it reasonable and acceptable. GEH revised DCD, Tier 2, Section 3.9.3.1, to include these criteria. Therefore, RAI 3.12-28 was resolved.

3.12.6.19 *Intersystem Loss-of-Coolant Accident*

In SECY-90-016, "Evolutionary Light Water Reactor (LWR) Certification Issues and Their Relationship to Current Regulatory Requirements," dated January 12, 1990, the NRC staff recommended that the issue regarding intersystem loss-of-coolant accident (ISLOCA) for advanced light-water reactor plants be resolved by requiring that low-pressure piping systems that interface with the RCPB be designed to withstand full RCS pressure to the extent practicable. In its June 26, 1990, SRM, the Commission approved these staff recommendations, provided that all elements of the low-pressure systems are considered.

DCD, Tier 2, Appendix 3K, Section 3K.6, provides the guidelines for ultimate rupture strength compliance for the ESBWR piping. These include the requirement that the design pressure for the low-pressure piping systems that interface with the RCPB be equal to 0.4 times the normal operating RCPB pressure, and the minimum wall thickness of the low-pressure piping should be no less than that of a standard-weight pipe.

The staff evaluated the minimum pressure for which low-pressure systems should be designed to ensure reasonable protection against burst failure should the low-pressure system be subjected to full RCS pressure. The staff has concluded that the survival probability for low-pressure systems at normal RCS pressure is above 99 percent for both carbon and stainless steel piping under GEH-proposed guidelines established in DCD, Tier 2, Section 3K.6. Section 3.9.3.1.1 of NUREG-1503 documents the detailed evaluation.

DCD, Tier 2, Appendix 3K, Section 3K.7, provides the guidelines for ultimate rupture strength compliance for nonpiping components. These include a guideline that the remaining components in the low-pressure systems should also be designed to a design pressure of 0.4 times the normal reactor pressure and that a Class 300 valve is adequate for ensuring the pressure of the low-pressure piping system under full RCS pressure. The staff has concluded that the margins to burst for these remaining components are at least equivalent to that of the piping at its minimum wall thickness since these components typically have a wall thickness greater than that of the piping minimum wall thickness. Section 3.9.3.1.1 of NUREG-1503 also documents the detailed evaluation.

The staff finds that, for the ESBWR low-pressure piping systems that interface with the RCPB, using a design pressure equal to 0.4 times the normal RCS pressure and using a minimum wall thickness of the low-pressure piping no less than Schedule 40 provide an adequate basis for ensuring that these systems can withstand full reactor pressure and thus meet the Commission-approved staff recommendations in SECY-90-016 and its applicable regulation for designing against ISLOCAs.

Furthermore, the staff will continue to require periodic surveillance and leak testing of the pressure isolation valves according to the technical specification requirements, as a part of the inservice testing program. DCD, Tier 2, Section 3K.2, states that "The periodic surveillance and leak rate testing requirements for high pressure to low pressure isolation valves are not applicable to the ESBWR, because, as shown in this appendix, the ESBWR design does not contain a pressure isolation valve between the RCPB and a low pressure piping systems." The staff noted that the two normally closed valves between the RCPB and a low-pressure piping system are considered as pressure isolation valves. The staff asked GEH to explain why the ESBWR design does not contain a pressure isolation valve. GEH revised its DCD by deleting the above-quoted statement to continue the staff's requirements of periodic surveillance and leak rate testing of the pressure isolation valves for the ESBWR design. On this basis, the staff finds the applicant's response acceptable.

3.12.6.20 *Confirmatory Analysis of ESBWR Main Steam Piping*

A piping confirmatory analysis of the MS lines 2 and 3 and SRV lines connected from these two MS lines to the suppression pool of the ESBWR standard plant was performed to check the GEH PISYS computer code implementation of the piping analysis methods discussed in the DCD. BNL performed this confirmatory analysis using the PSAFE2 computer code developed previously at BNL in support of other NRC-sponsored studies. Using preliminary piping system design data provided by GEH, BNL developed the mathematical model of the MS piping system (including the SRV lines) for use with the PSAFE2 computer code. The analysis methods considered in the confirmatory analysis consist of static analyses for deadweight and thermal conditions, modal response spectrum analyses for seismic and hydrodynamic loads (e.g., LOCA—annulus pressurization (AP), SRV), and time-history analyses for SRV discharge and TSV closure loads on the MS piping.

To verify that the BNL model and GEH model match, BNL initially performed deadweight, thermal, and modal frequency analyses. Based on these analyses, the staff concluded that the GEH model and BNL model are sufficiently similar. The next series of analyses was performed for dynamic loads using response spectrum analysis. For the seismic and SRV loading cases, the ISM response spectrum analysis method was used, with five sets of response spectra corresponding to the five support groups. For the AP loading case, the USM response spectrum analysis method was used. Finally, the direct integration time-history method was used for both SRV discharge and TSV closure loads on the MS piping. In addition to the model parameter comparison of the static analysis results and the modal frequencies, a comparison of the PISYS pipe responses with PSAFE2 pipe responses was performed for each of the above piping analyses for a selected set of pipe displacements, pipe forces/moments, and pipe support forces.

Based on the comparison of analysis results from both PISYS and PSAFE2, the staff concludes that the piping analyses performed by GEH for deadweight and the piping analyses for SRV discharge and TSV loads (using the direct integration analysis method) are within acceptable limits. For thermal analysis, the results were not in good agreement at thermal transition regions where large differences in the nodal temperatures exist at both end nodes of a pipe element. The staff determined that this was attributable to the approach GEH used in applying the thermal load in containment penetration regions. GEH assumed that the containment penetration was at ambient temperature from the containment to the MS connection, whereas the BNL model accounted for a temperature gradient in the penetration from the MS connection to the containment. To alleviate this problem, GEH indicated that it will revise either the PISYS computer manual or other GEH ESBWR design specifications or guides to caution the user regarding the proper modeling of the temperature loading at the thermal transition regions of a piping model. The staff finds this resolution acceptable.

The BNL response spectra analyses calculated greater loads at several locations in the MS model. For both the USM and ISM response spectrum methods of analysis used for seismic, SRV discharge, and AP loads, the staff determined that the differences in the results are probably a result of the response combination methods used for groups, modes, and spatial directions, as well as their order of combinations. For example, when the seismic and SRV load cases used the ISM method, PISYS used the SRSS group combination and double sum modal combination, whereas PSAFE2 used the absolute sum group combination and SRSS modal combination without the closely spaced modal effect, consistent with current staff positions. The group combination procedure probably accounts for most of the differences in the ISM analyses. Section 3.12.4.3 of this report addresses GEH's criteria for ISM. GEH modified the criteria associated with the ISM method to increase loads and stresses by 10 percent to ensure a conservative result. The staff found this procedure acceptable because it was justified by sample analyses using multisupport time-history analyses. Multisupport time-history analysis is the most accurate method for performing the dynamic analysis because it retains the phase relationship between the group responses and is a method acceptable to the staff for performing dynamic analysis.

Both GEH and BNL programs used SRSS for spatial combination of piping responses. For the USM analyses, PSAFE2 used the RG 1.92 grouping method to account for closely spaced modes, whereas PISYS used the RG 1.92 double sum method. The RG 1.92 double sum method is not as conservative as the RG 1.92 grouping method. Because of limitations in its PSAFE2 program, BNL was not able to verify the PISYS implementation of the RG 1.92 double sum method. However, a PSAFE2 analysis using SRSS for the closely spaced modes resulted in a better match with the PISYS analysis. Section 3.12.5.1 of this report addresses GEH's implementation of RG 1.92.

Since BNL's PSAFE2 program did not have the capability to implement the RG 1.92 double sum grouping method, BNL performed a PSAFE2 analysis using SRSS for the closely spaced modes. This resulted in a better match with the GEH PISYS analysis. NUREG/CR-6645, "Reevaluation of Regulatory Guidance on Modal Combination Methods for Seismic Response Spectrum Analysis," issued December 1999, presents a comparison of RG 1.92 combination methods. The comparison includes the RG 1.92 grouping method, the RG 1.92 double sum method, and SRSS. The comparison shows that the support reactions and pipe moments from the RG 1.92 double sum method are comparable to the SRSS values, with RG 1.92 double sum responses only slightly greater than the SRSS values at the majority of the locations. The comparison also shows that the support reactions and pipe moments from the RG 1.92 grouping method are more conservative than the RG 1.92 double sum method values at most locations. Therefore, the staff concludes that the GEH PISYS USM analyses produced results that are reasonable when compared to the results reported in NUREG/CR-6645.

3.12.6.21 *Conclusions*

The staff finds that the ESBWR DCD adequately addresses the piping issues identified above and reflects the staff's position as indicated. Therefore, the staff concludes that the applicant has met the following requirements:

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

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

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

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

- GDC 15, with regard to the reactor coolant piping systems being designed with specific design and service limits to ensure a sufficient margin so that the design conditions are not exceeded

3.12.7 Pipe Support Design Criteria

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

3.12.7.1 *Applicable Codes*

The staff reviewed the methodology used in the design of ASME Code Class 1, 2, and 3 component supports as described in DCD, Tier 2, Section 3.9.3.7. Piping supports include hangers, snubbers, struts, spring hangers, frames, energy absorbers, and limit stops. ASME Code, Section III, Class 1, 2, and 3 component supports for the ESBWR standard plant will be designed, manufactured, installed, and tested in accordance with all applicable codes and standards, including ASME Code, Section III, Subsection NF.

DCD, Tier 2, Section 3.9.3.7.1, initially indicated that supports and their attachments for essential ASME Code Class 1, 2, and 3 piping are designed in accordance with Subsection NF up to the interface of the building structure, with jurisdictional boundaries as defined by Subsection NF. In addition, GEH stated the following:

> The building structure component supports are designed in accordance with ANSI/AISC N690, Nuclear Facilities—Steel Safety-Related Structures for Design, Fabrication and Erection (1994 edition) or the AISC specification for the Design, Fabrication, and Erection of Structural Steel for buildings correspond to those used for design of the supported pipe.

In RAI 3.12-30, the staff requested that GEH clarify whether all of the above industry codes are still applicable to the ESBWR pipe support design and to explain their application boundaries. In its response, the applicant deleted from DCD, Tier 2, Revision 2, all references to ASME Code Case N-476; U.S. Steel Manual Publication T114-2/83; and American National Standards Institute/American Institute of Steel Construction N690. Furthermore, GEH stated that supports and their attachments for ASME Code Class 1, 2, and 3 piping are designed in accordance with ASME Code, Subsection NF, up to the interface of the building structure, with jurisdiction boundaries as defined by Subsection NF. GEH also added new Tables 3.9-10, 3.9-11, and 3.9-12 for load combinations and their acceptance criteria to be used for the design of different support types (i.e., snubbers, struts, and anchors and guides) in the ESBWR piping system.

During the site audit at the GEH offices in San Jose, CA, on January 9–12, 2007, the staff reviewed the proposed load combinations detailed in DCD Table 3.9-10 for snubbers, Table 3.9-11 for struts, and Table 3.9-12 for anchors and guides. The staff identified several items, which are described in the Audit Trip Report issued May 3, 2007, that needed clarification regarding loads and load combinations applicable to pipe support types and their acceptance criteria. GEH provided changes to these tables in DCD, Tier 2, Revision 3.

The staff finds that these tables identify the applicable load combinations for the design of pipe supports and that the acceptance criteria for these load combinations are consistent with the ASME Code requirements. Therefore, the staff finds the resolution to RAI 3.12-30 acceptable.

The stress limits for pipe supports are consistent with ASME Code, Section III, Subsection NF and Appendix F. Supports are generally designed either by the load rating method in accordance with ASME Code, Subsection NF-3280, or by the stress limits for linear supports in accordance with ASME Code, Subsection NF-3143.

The staff finds that ASME Code, Section III, Subsection NF, provides an acceptable basis for the design of ASME Class 1, 2, and 3 pipe supports.

3.12.7.2 *Jurisdictional Boundaries*

DCD, Tier 2, Section 3.9.3.7, indicates that all piping supports are designed, fabricated, and assembled so that they cannot become disengaged by the movement of the supported pipe or equipment after they have been installed. As described in Section 3.12.7.1 of this report, all ASME Code Class 1, 2, and 3 piping supports are designed in accordance with Subsection NF of the ASME Code up to the building structure interface as defined by the jurisdictional boundaries in Subsection NF. The staff finds that Subsection NF of the ASME Code adequately addresses jurisdictional boundaries between the pipe supports and the building structure.

3.12.7.3 *Loads and Load Combinations*

DCD, Tier 2, Section 3.9.3.7, indicates that the load combinations for the design of piping supports correspond to those used for the design of the supported pipe. As discussed in Section 3.12.7.1 of this report, the staff requested in RAI 3.12-30 that GEH clarify how the load combinations for the piping supports correspond to those used for the design of the supported pipe. Instead of clarifying this information, GEH addressed the load combinations and their acceptance criteria for the design of pipe supports in new DCD Table 3.9-10 for snubbers, Table 3.9-11 for struts, and Table 3.9-12 for anchors and guides. Section 3.12.7.1 of this report reviews the adequacy of the loads and load combinations presented in these tables. The staff found the response acceptable; therefore, RAI 3.12-30 was closed.

3.12.7.4 *Pipe Support Base Plate and Anchor Bolt Design*

DCD, Tier 2, Section 3.9.3.7, initially stated that concrete anchor bolts used for pipe support base plates are designed to the applicable factors of safety, which are defined in IE Bulletin 79-02. Preferably, surface-mounted base plates will employ bearing-type anchor bolts and will not be used in the design and installation of seismic Category I and IIA pipe supports. The calculation of concrete anchor bolt loads will account for pipe support base plate flexibility, in accordance with IE Bulletin 79-02.

In RAI 3.12-31, the staff asked GEH to address the following items: (1) GEH did not clarify that all aspects of the anchor bolt design (not just the factor of safety) follow IE Bulletin 79-02, Revision 2 (not Revision 1), (2) GEH did not indicate whether the design and installation of all anchor bolts will be performed in accordance with Appendix B to ACI 349-01, subject to the conditions and limitations specified in RG 1.199, and (3) GEH did not initially define the term “seismic Category IIA” used in DCD, Tier 2, Section 3.9.3.7.

GEH responded as follows:

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

(2) The design and installation of all anchor bolts will be performed in accordance with Appendix B to ACI 349-01 subject to the conditions and limitations specified in RG 1.199 and all applicable requirements of IE Bulletin 79-02, Revision 2, dated November 8, 1979.

(3) Seismic Category IIA does not exist.

GEH included these changes in DCD, Tier 2, Section 3.9.3.7. The staff found this resolution to RAI 3.12-31 acceptable, because the applicant followed the IE Bulletin 79-02 recommendations..

3.12.7.5 *Use of Energy Absorbers and Limit Stops*

DCD, Tier 2, Section 3.9.3.7, indicated that there may be instances in which special engineered pipe supports, such as energy absorbers and limit stops, will be used in lieu of struts or frame-type supports. Section 3.12.5.2 of this report addresses the staff evaluation of the use of energy absorbers and limit stops. GEH revised Section 3.7.3.3.3 of DCD Tier 2, to state that special engineered pipe supports will not be used for the ESBWR design.

3.12.7.6 *Use of Snubbers*

DCD, Tier 2, Section 3.9.3.7.1(3), indicates that the operating loads on snubbers are the loads caused by dynamic events (e.g., seismic, reactor building vibration caused by a LOCA, SRV and DPV discharge, discharge through a relief valve line or valve closure) during various operating conditions. Snubbers restrain piping against response to the dynamic excitation and to the associated differential movement of the piping system support anchor points. Snubbers are used in situations that require dynamic support because the thermal growth of the piping prohibits the use of rigid supports. The loads calculated in the piping dynamic analysis cannot exceed the snubber load capacity for design, normal, upset, emergency, and faulted conditions.

The pipe support design specification requires that snubbers be provided with position indicators to identify the rod position. This indicator facilitates the checking of hot and cold settings of the snubber, as specified in the installation manual, during plant preoperational and startup testing. DCD, Tier 2, Section 3.9.3.7.1(3), describes the inspection, testing, and repair or replacement criteria for snubbers. This section also includes the requirements for snubber design and testing specifications, snubber installation requirements, and snubber preservice examinations. The snubbers are constructed to the standards of ASME Code, Section III, Subsection NF.

The staff finds that construction of snubbers to the standards of ASME Code, Section III, Subsection NF, is consistent with the staff guidance in SRP Section 3.9.3.

3.12.7.7 *Pipe Support Stiffnesses*

DCD, Tier 2, Section 3.7.3.3.1, indicates that guides and snubbers are modeled by using representative stiffness values. DCD, Tier 2, Section 3.9.3.7.1, describes the procedures to ensure that the spring constant achieved by the snubber supplier matches the spring constant used in the piping system model. GEH did not describe how the representative stiffness values are developed for all supports other than snubbers. Therefore, in RAI 3.12-32, the staff requested that GEH describe (1) the approach used to develop the representative stiffness values, (2) the procedure that will be imposed to ensure that the final designed supports match the stiffness values assumed in the piping analysis, (3) the procedure used to consider the mass (along with the support stiffness) if the pipe support is not dynamically rigid, and (4) the same information asked for in (1), (2), and (3) above for the building steel/structure (i.e., beyond the ASME Code, Section III, Subsection NF, jurisdictional boundary) and for equipment to which the piping may be connected.

The applicant responded as follows:

(1) Standard stiffness values developed for an ABWR project will be used.

(2) Pipe supports will be designed and qualified to satisfy stiffness values used in the piping analysis. For struts and snubbers, the stiffness to consider is the combined stiffness of the strut, snubber, pipe clamp, and piping support steel.

(3)In general, the piping analysis considers pipe support component weights, which are directly attached to a pipe, such as a clamp, strut, snubber, and trapeze. Frame-type supports will be designed to carry their own mass and will be subjected to deflection requirements. A maximum deflection of 1/16 of an inch is used for normal operating conditions and 1/8 of an inch is used for abnormal conditions. For other types of supports, either the support will be shown to be dynamically rigid or it will be demonstrated that one-half of the support mass is less than 10 percent of the mass of the straight pipe segment of the span at the support location to preclude amplification. Otherwise, the contribution of the support weight amplification is added into the piping analysis.

(4) The stiffness for the building steel/structure (i.e., beyond the ASME Code, Section III, Subsection NF, jurisdictional boundary) is not considered in pipe support overall stiffness. Response spectra input to the piping system includes flexibility of the building structure. When attachment to a major building structure is not possible, the analysis of pipe support includes any intermediate structures.

DCD, Tier 2, Section 3.7.3.3.1, includes these criteria. The staff found that the modeling criteria are consistent with industry practice and were therefore acceptable. Thus, RAI 3.12-32 was resolved.

3.12.7.8 *Seismic and Other Dynamic Load Self-Weight Excitation*

DCD Sections 3.7.3 and 3.9.3 did not describe the analysis methods or design requirements needed to evaluate the effects of seismic and other dynamic (support) self-weight excitation for ESBWR pipe supports. Therefore, in RAI 3.12-33, the staff requested that GEH provide this information, which is especially important for the larger and more massive supports. The support evaluation should consider the effects of self-weight excitation on the support structure and its anchorage. In addition, the evaluation should consider all loads transmitted from the piping to the support and the support internal loads caused by self-weight, thermal, and inertial effects resulting from the support mass.

GEH provided a revised response:

> The ESBWR pipe supports will be designed to meet the stiffness values used in the piping analysis. (1) In general, pipe support weight, such as snubber clamp or strut clamp on the pipe, is considered in piping analysis. The larger and more massive type supports will be evaluated to include the impact of self-weight excitation on support structure and anchorage in detail along with piping analyzed loads, and (2) Pipe supports will be evaluated to include the impact of self-weighted excitation on support structure and anchorage in detail along with piping analyzed loads where this effect may be significant.

The staff reviewed DCD, Tier 2, Section 3.7.3.3.1, and confirmed that GEH had included the criteria as stated above. The staff found that the criteria are consistent with standard industry practice and therefore were acceptable. Thus, RAI 3.12-33 was resolved.

3.12.7.9 *Design of Supplementary Steel*

Supplementary steel includes structural steel within the jurisdictional boundary of ASME Code, Section III, Subsection NF (e.g., structural steel members connecting a snubber to the building structure). DCD, Tier 2, Section 3.9.3.7.1, provides design criteria for the design of pipe supports using supplementary steel. Supplementary steel for pipe supports is designed in accordance with ASME Code, Section III, Subsection NF. The use of Subsection NF is standard industry practice and is acceptable to the staff because it was developed by a professional society and voluntary consensus standards organization and has proven to provide adequate guidelines for the design of structural steel for use as pipe supports. The staff finds that the use of these criteria for the design of ESBWR supplementary steel provides reasonable assurance of the structural integrity of the supports and is, therefore, acceptable.

3.12.7.10 *Consideration of Friction Forces*

DCD, Tier 2, Section 3.9.3.7, initially described the criteria and design requirements for piping supports of ESBWR piping. However, it did not describe how the design would consider friction loads imparted on pipe supports caused by unrestrained thermal motion. Therefore, in RAI 3.12-34, the staff requested that GEH provide the criteria and design approach that will be used to calculate pipe support friction loads, in addition to the other externally and internally applied loads.

GEH responded that the friction loads that result from unrestricted motion of the piping caused by piping displacements are considered to act on the support with a friction coefficient of 0.3 in the case of steel-to-steel friction. For stainless steel, Teflon, and other materials, the friction coefficient could be less. The friction loads are not considered during seismic or dynamic loading evaluation of piping support structures.

GEH added these criteria to DCD, Tier 2, Section 3.9.3.7.1. The staff found this acceptable; therefore, RAI 3.12-34 was resolved.

3.12.7.11 *Pipe Support Gaps and Clearances*

Small gaps are always provided for frame-type supports built around a pipe. The gaps allow for radial thermal expansion of the pipe, as well as for pipe rotation. DCD, Tier 2, Section 3.9.3.7, described the criteria and design requirements for piping supports of ESBWR piping. However, it did not describe the development and specification of hot and cold gaps to be used between the pipe and the box-frame-type supports. Therefore, in RAI 3.12-35, the staff asked GEH to provide this information. GEH responded (MFN 06-119, Supplement 1) that current industry practice is to limit the total gap to 1/8 in. for frame-type pipe supports for loaded directions. In general, this gap will be adequate for the radial thermal expansion of the pipe to avoid any thermal binding. For large pipes with much higher temperature, this gap will be evaluated to ensure that thermal binding cannot occur. During the site audit at the GEH offices in San Jose, CA, on January 9–12, 2007, the staff indicated to GEH that the 1/8-in. gap may not be sufficient for some radial thermal growth of high-temperature, large pipes. As a result, GEH added a qualifying statement to DCD, Tier 2, Section 3.9.3.7.1: "The minimum total gap will be specified to ensure that it is adequate for the thermal radial expansion of the pipe to avoid any thermal binding." The proposed position meets the recommendation of SRP Section 3.12. The staff finds this resolution to RAI 3.12-35 acceptable.

3.12.7.12 *Instrumentation Line Support Criteria*

DCD, Tier 2, Section 3.9.3.7, initially described the criteria and design requirements for piping supports of ESBWR piping. However, it did not describe the analysis and design criteria for instrumentation line supports. Therefore, in RAI 3.12-36, the staff requested that GEH provide this information. GEH responded (MFN 06-119, Supplement 1) that the small-bore lines (e.g., small branch and instrumentation lines) will be supported, taking into account the flexibility and thermal and dynamic motion requirements of the pipe to which they connect. DCD, Tier 2, Section 3.7.3.16, details the support design and criteria for instrumentation lines 50 mm and smaller. The criteria allow the use of a small-bore piping handbook to qualify the design in lieu of specific calculations. The use of the piping handbook methodology for the design small-bore piping is standard industry practice and thus acceptable to the staff. GEH needs to maintain sufficient documentation to demonstrate that the piping designed using the small-bore piping handbook satisfies the applicable ASME Code requirements.

DCD, Tier 2, Section 3.9.3.7.1, includes a discussion of the above criteria. The staff found this acceptable; therefore, RAI 3.12-36 was resolved.

3.12.7.13 *Pipe Deflection Limits*

DCD, Tier 2, Section 3.9.3.7, initially described the criteria and design requirements for piping supports of ESBWR piping. In this section, GEH indicated that the maximum calculated static and dynamic deflections of the piping at support locations do not exceed the allowable limits identified in the "suspension design specification." The purpose of the allowable limits is to preclude failure of the pipe supports because of piping deflections. In RAI 3.12-37, the staff requested that GEH adequately describe the suspension design specification and the ways in which the deflection limits are developed. GEH responded that the ESBWR design of piping supports considers a deflection limit of 1.6 mm for erection and operation loadings, based on Welding Research Council Bulletin 353, paragraph 2.3.2. For the consideration of loads caused by SSE and in the case of springs, the deflection limit is increased to 3.2 mm. GEH also stated that it will change "suspension design specification" to "piping design specification."

GEH revised Section 3.9.3.7.1 of DCD Tier 2 to include the criteria discussed above. The staff finds these criteria acceptable because they are compatible with the design assumptions, thus ensuring functionality of the pipe supports under design loading conditions. Since the DCD criteria will ensure that the support deflections resulting from combined loads will not exceed the deflection limits, the staff finds the resolution to RAI 3.12-37 acceptable.

3.12.7.14 *Conclusions*

On the basis of these discussions and the evaluation of DCD, Tier 2, Sections 3.7.3.3 and 3.9.3.7, the staff concludes that the supports of piping systems important to safety are designed to quality standards commensurate with their importance to safety. The staff's conclusion is based on the following:

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

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

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

- GEH satisfies the requirements of 10 CFR Part 52 by providing reasonable assurance that the piping systems will be designed and built in accordance with the certified design. Through the performance of the ITAAC, the COL holder will verify the implementation of these preapproved methods and satisfaction of the acceptance criteria. This will ensure that the as-built piping systems conform to the certified design for their safety functions.

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

3.13 Threaded Fasteners for ASME Code Class 1, 2, and 3 Components

3.13.1 Regulatory Criteria

The following regulatory requirements provide the basis for the acceptance criteria for the staff's review:

- GDC 1 require that SSCs important to safety be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed.

- 10 CFR 50.55a, “Codes and Standards,” relates to the design, fabrication, erection, construction, testing, and inspection of components and systems. It requires the systems and components of both boiling- and pressurized-water-cooled nuclear power reactors to meet the requirements of the ASME Boiler and Pressure Vessel Code (referred to as the ASME Code), and SSCs must be designed, fabricated, erected, constructed, tested, and inspected to quality standards commensurate with the importance of the safety functions to be performed;

- GDC 4 requires that SSCs important to safety be designed to accommodate the effects of, and be compatible with, the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including LOCAs.

- GDC 14 require that components that are part of the reactor coolant pressure boundary be designed, fabricated, erected, and tested to ensure an extremely low probability of abnormal leakage, rapidly propagating failure, and gross rupture;

- GDC 30 requires that components which are part of the reactor coolant pressure boundary shell be designed, fabricate, erected, and tested to the highest quality standards practical. Means shell be provided for detecting and, to the extent practical, identifying the location of the source of reactor coolant leakage.

- 10 CFR Part 50, Appendix B, requires that measures be established to control the handling, storage, shipping, cleaning, and preservation of material and equipment to prevent damage or deterioration; and,

- 10 CFR Part 50, Appendix G, “Fracture Toughness Requirements,” specifies fracture toughness requirements for ferritic materials of pressure-retaining components of the reactor pressure boundary of light-water nuclear power reactors to provide adequate margins of safety during any condition of normal operation, including anticipated operational occurrences and system hydrostatic tests, to which the pressure boundary may be subjected over its service lifetime.

3.13.2 Summary of Technical Information

DCD, Tier 2, Revision 6, Section 3.9.3.9, provides information that is needed for the staff to perform its review using the guidance provided in SRP Section 3.13. Specifically, the DCD describes the use of threaded fasteners (e.g., threaded bolts, studs) and specifies requirements pertaining to selection of materials, design, inspection, and testing prior to and during service.

3.13.3 Staff Evaluation

The staff reviewed the information included in the DCD, Tier 2, Section 3.9.3.9, Revision 6, in accordance with the guidance provided in SRP Section 3.13, issued March 2007. The purpose of the review was to determine the adequacy of threaded fasteners (e.g., threaded bolts, studs) with respect to the selection of materials, design, inspection, and testing prior to and during anticipated service. The staff notes that DCD Table 1.9.3, which summarizes the differences between the DCD application and SRP Chapter 3, did not include a reference to SRP Section 3.13 since the application was submitted before this new SRP section was finished. However, DCD Section 3.9.3.9 provided sufficient information for the staff to confirm that the applicant is following the recommendations of SRP Section 3.13 and that the issues identified in

New Generic Issue (NGI) 29 “Bolting Degradation of Failure in Nuclear Power plants” and GL 91-017 “Bolting Degradation of Failure in Nuclear Power plants” has been have been considered in the ESBWR DCD. The staff’s review of DCD Section 3.9.3.9 follows.

DCD, Tier 2, Section 3.9.3.9, states that material used for threaded fasteners complies with the requirements of ASME Code, Section III, Articles NB-2000, NC-2000, ND-2000, or NF-2000, as appropriate. DCD, Tier 2, Section 3.9.3.9, also states that the criteria of ASME Code, Section III, Subarticles NB-2200, NC-2200 or ND-2200, rather than the material specification criteria applicable to the mechanical testing, should be applied if there is a conflict between the two sets of criteria. For safety-related threaded fasteners, documentation related to fracture toughness (as applicable) and certified material test reports are part of the ASME Code records that are provided when the parts are shipped and are part of the required records that are maintained at the site. The staff finds these requirements acceptable because the ASME Code, Section III, imposes additional requirements over and above those included in the materials specifications.

Fracture toughness testing is performed in accordance with ASME Code, Section III, Subarticles NB-2300, NC-2300, or ND-2300, as appropriate. For verification of conformance to the applicable Code requirements, a chemical analysis is required for each heat of material. Additionally, testing for mechanical properties is required on samples representing each heat of material and, where applicable, each heat treat lot. Inspection of the threaded fastener materials complies with ASME Code Section III, NB-2500, NC-2500, or ND-2500, as applicable. The staff finds these requirements acceptable because the selection of threaded fastener materials and their inspection, testing, and certification are in accordance with ASME Code, Section III, criteria for Code Class 1, 2 and 3.

DCD, Tier 2, Section 3.9.3.9, states that the design of threaded fasteners complies with ASME Code, Section III, NB-3000, NC-3000, or ND-3000, as appropriate. Fabrication of threaded fasteners complies with ASME Code Section III, NB-4000, NC-4000, or ND-4000, as appropriate. The staff finds these requirements acceptable because the design and fabrication of threaded fasteners are in accordance with ASME Code, Section III, criteria for Code Class 1, 2, and 3.

DCD, Tier 2, Section 3.9.3.9, states that preservice and inservice inspections of threaded fasteners are performed in accordance with ASME Code, Section XI. The requirements for pressure-retaining Class 1 bolting are addressed as Category B-G-1 for bolting greater than 2 in. in diameter and B-G-2 for bolting with diameters 2 in. and less. The Class 1 pressure-retaining bolting sample is limited to the bolting on the heat exchangers, piping, pumps, and valves that are selected for examination in the ISI program. Category B-G-1 requires volumetric examination of the selected bolting. Category B-G-2 requires visual, VT-1, examination of the selected bolting. For Class 1, 2, and 3 systems, the bolted connections are examined for leakage (VT-2) during the system pressure tests required by ASME Code, Section XI. For safety-related threaded fasteners, documentation related to preservice inspection is part of the ASME Code records that are provided at the time the parts are shipped and are part of the required records that are maintained at the site. The staff finds these requirements acceptable because threaded fasteners must meet the requirements of ASME Code, Section XI. Compliance with the requirements of ASME Code, Section XI, also satisfies the regulatory requirements of 10 CFR 50.55a. In addition to ASME Code, Section III and Section XI, requirements discussed above, the reactor vessel closure studs also follows the guidance provided in RG 1.65, “Materials and Inspections for Reactor Vessel Closure Studs,” without exceptions, as noted in DCD, Tier 2, Chapter 1, Table 1.9-21, “NRC Regulatory Guides

Applicability to ESBWR." Following the guidance provided in RG 1.65 ensures that the reactor vessel studs will perform as designed.

The NRC staff also reviewed two ASME Code cases that relate to ISI of threaded fasteners during the operational phase of the nuclear power plant. DCD, Tier 2, Table 5.2-1, includes Code Cases N-307-2 and N-457 as alternatives to the requirements of ASME Code, Section XI. Section 5.2.1.2.3 of this report documents the results of that review.

The applicant also addressed the use of lubricants and/or surface treatments in mechanical connections secured by threaded fasteners and the compatibility of these materials with the threaded fasteners. As stated in DCD, Tier 2, Section 3.9.3.9, lubricants with deliberately added halogens, sulfur, or lead are not used for any reactor coolant pressure boundary components or other components in contact with reactor water. Additionally, lubricants containing molybdenum sulfide (disulfide or polysulfide) will not be used for any safety-related application. For ferritic steel threaded fasteners, conversion coatings, such as the Parkerizing process, are suitable and may be used. If fasteners are plated, low melting point materials, such as zinc, tin, and cadmium, will not be used. The staff finds these requirements acceptable because lubricants are specified to be free of halogens, sulfur, lead, and molybdenum sulfide, which are known to cause cracking in threaded fasteners. In addition, DCD, Tier 2, Table 1.9-21b, "ESBWR Compliance with Quality Related Regulatory Guides," indicates that the ESBWR will comply with the recommendations of RG 1.37, "Quality Assurance Requirements for Cleaning of Fluid Systems and Associated Components of Water-Cooled Nuclear Power Plants." DCD, Tier 2, Table 1.9-22, "Industrial Codes and Standards Applicable to ESBWR," incorporates the ANSI standard N45.2.1-1980, "Cleaning of Fluid Systems and Associated Components for Nuclear Power Plants." The staff had endorsed N45.2.1 in RG 1.37 for use in nuclear power plant components. Based on compliance with this ANSI standard and the RG, the staff finds that controls imposed on threaded fasteners satisfy the requirements of 10 CFR Part 50, Appendix B, Criterion XIII, "Handling, Storage and Shipping," with respect to controls for cleaning of materials and components. Additionally, the lubricants and sealants are compatible with the threaded fastener materials.

In the ASME Code, Section III, paragraphs NB-2160, NC-2160, and ND-2160 require consideration of material degradation in service to ensure that the threaded fasteners will perform in service as designed. However, because the ASME Code, paragraph NB-2160, does not clearly specify how the owner should consider service conditions for bolting, DCD, Tier 2, Section 3.9.3.9, needed to be revised to state that the threaded fasteners will be selected for compatibility with the materials of the components being joined and with the piping system fluids. This was tracked as an open item in the SER with Open Items. Revision 5 of DCD, Tier 2, Section 3.9.3.9, states that fasteners are also selected for compatibility with the materials of the component being joined and with the piping system fluids. On that basis, Open Item 3.0-1 S02 is closed. The staff, therefore, concludes that threaded fasteners meet the requirements of ASME Code, Section III, paragraphs NB-2160, NC-2160, and ND-2160, which ensure that the threaded fasteners will perform in service as designed.

3.13.4 Conclusions

The staff concludes that the selection of materials, design, inspection, testing and recording are in accordance with ASME Code, Section III, criteria for Code Class 1, 2, and 3 threaded fasteners and ensure application of quality standards commensurate with the importance of the safety functions to be performed. Application of these ASME Code criteria also provides assurance of an extremely low probability of abnormal leakage, rapidly propagating failure, or gross rupture. The ESBWR DCD conforms to these ASME Code requirements, addresses the concerns identified in NGI 29 and GL 91-07,and, therefore, satisfies 10 CFR Part 50, Appendix A, GDC 1, 14, and 30.

The fracture toughness tests specified in the ASME Code, as augmented by the requirements of Appendix G to 10 CFR Part 50, provide reasonable assurance that adequate safety margins against nonductile behavior or rapidly propagating fracture will be provided for threaded fastener materials used in ASME Code Class 1, 2, and 3 systems. The ESBWR DCD conforms to these criteria and, therefore, meets the requirements of 10 CFR 50.55a(c), (d), and (e) and GDC 31, "Fracture Prevention of Reactor Coolant Pressure Boundary."

The ESBWR DCD has identified special processes used for threaded fasteners. Since the ESBWR DCD has certified compliance with the materials and fabrication criteria of Section III of the ASME Code, the staff considers the special processes used to be acceptable.

The threaded fastener materials need to be compatible with the materials of the components being joined. Lubricants and sealants need to be compatible with the materials of the components being joined and with the piping system fluids. Following the criteria of the ASME Code, Section III, ensures that the level of general corrosion of threaded fasteners will be acceptable. The threaded fasteners are also compatible with the materials being joined and with the piping system fluids as discussed above, and therefore, the ESBWR DCD meets the requirements of GDC 4 relative to compatibility of components with the environmental conditions.

The ESBWR DCD controls to avoid contamination that could lead to stress-corrosion cracking conform to the recommendations of RG 1.37. These controls satisfy the requirements of 10 CFR Part 50, Appendix B, Criterion XIII, with respect to the cleaning of materials and components.

The staff concludes that the preservice and inservice programs for threaded fasteners specified in the ESBWR DCD are acceptable and meet the criteria of ASME Code, Section XI, and the requirements of 10 CFR 50.55a.