ACRONYMS

ABS	absolute sum
ABWR	advanced boiling-water reactor
ac/AC	alternating current
ACI	American Concrete Institute
ACRS	Advisory Committee on Reactor Safeguards
ADAMS	Agencywide Documents Access and Management System
ADS	automatic depressurization system
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
ALWR	advanced light water reactor
ANS	American Nuclear Society
ANSI	American National Standards Institute
AOO	anticipated operational occurrences
AOV	air operated valves
AP	annulus pressurization
APEX	Advanced Plant Experiment
ARI	alternate rod insertion
ASCE	American Society of Civil Engineers
ASIs	adverse systems interactions
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATWS	anticipated transient without scram
BE	best estimate
BNL	Brookhaven National Laboratory
BWR	boiling water reactor
CB	control building
CDF	core damage frequency
CFR	Code of Federal Regulations
COL	combined license
C&FS	condensate and feedwater system
CRGT	control rod guide tube
CS	core support
CS&TS	condensate storage and transfer system
CUF	cumulative usage factor
CV	check valve
CWS	chilled-water system
DBA	design-basis accident
DBPB	design-basis pipe break
DBT	design basis tornado
DCD	design control document
DCIS	distributed control and information system
DLF	dynamic load factor
DG	diesel generator
DHR	decay heat removal
DOE	U.S. Department of Energy
DOFs	degrees of freedom
EB	electrical building

EBAS	emergency breathing air system
ECCS	emergency core cooling system
EPRI’s	Electric Power Research Institute’s
EQD	equipment qualification document
ESBWR	Economic Simplified Boiling Water Reactor
ESP	early site permit
E-W	east-west
FAPCS	fuel and auxiliary pools cooling system
FB	fuel building
FE	finite element
FEM	finite element model
FIV	flow-induced vibration
FMCRD	fine-motion control rod drive
FPS	fire protection system
FRS	floor response spectra
FSAR	final safety analysis report
FSER	final safety evaluation report
FTS	fuel transfer system
FW	feedwater
GDC	general design criteria/criterion
GDCS	gravity-driven cooling system
GEH	GE Hitachi Nuclear Energy
GL	generic letter
HCU	hydraulic control unit
HELSA	high-energy line separation analysis
HVAC	heating, ventilation, and air conditioning
HWS	hot water system
IBC	International Building Code
IC	isolation condenser
ICMGT	incore monitor guide tube
ICMHs	in-core monitor housings
ICS	isolation condenser system
ISO	International Organization for Standardization
I&Cs	instrumentation and controls
IC/PCC	primary containment cooling pool cooling
IDS	Class 1E dc system
IEEE	Institute of Electrical and Electronics Engineers
IN	Information Notice
IOTs	infrequent operational transients
ISI	inservice inspection
ISM	independent support motion
IST	inservice testing
ITAAC	inspection, test, analyses, and acceptance criteria
KWU	Kraftwere Union Aktiengescellschaft
LB	lower bound
LOCA	loss-of-coolant accident
LOOP	loss of offsite power
LTR	Licensing Topical Report
MCR	main control room
mm	millimeters
MS	main steam

MSIV	main steam isolation valve
MSL	main steamline
MWS	main water system
NI	nuclear island
NRC	U.S. Nuclear Regulatory Commission
NS	non-seismic
N-S	north-south
NSSS	nuclear steam supply system
OBE	operating-basis earthquake
P&IDs	piping and instrumentation drawings
PCCS	passive containment cooling system
PCS	passive containment cooling system
PDA	piping dynamic analysis
PGA	peak ground acceleration
PMF	probable maximum flood
PMP	probable maximum precipitation
POVs	power-operated valves
PRA	probabilistic risk assessment
PSD	power spectral density
psf	per square foot
psi	per square inch
PSWS	plant service water system
PWR	pressurized-water reactor
QA	quality assurance
QG	quality group
RAI	request for additional information
RB	reactor building
RBV	reactor building vibration
RCCV	reinforced concrete containment vessel
RCCWS	reactor component cooling water system
RCPB	reactor coolant pressure boundary
RCS	reactor coolant system
RG	regulatory guide
RHR	residual heat removal
RIS	regulatory issue summary
RPV	reactor pressure vessel
RPVSB	reactor pressure vessel support bracket
RTNSS	regulatory treatment of non-safety systems
RWCU/SDC	Reactor Water Cleanup/Shutdown Cooling System
RW	radwaste building
SACF	single active component failure
SAR	safety analysis report
SAS	service air system
SB	service building
SER	safety evaluation report
SFPs	spent fuel pools
SFPC	spent fuel pool cooling
SLCS	standby liquid control system
SMACNA	Sheet Metal and Air Conditioning Contractor’s National Association
SOTs	system operation transients
SRM	staff requirements memorandum

SRP	standard review plan
SRSS	square root of the sum of squares
SRV	safety relief valve
SS	stainless steel
SSCs	structures, systems and components
SSE	safe-shutdown earthquake
SSI	soil-structure interaction
TB	turbine building
TEMA	Tubular Exchanger Manufacturers Association
TMSS	turbine main steam system
TRS	test response spectra
TSV	turbine stop valve
UD	upper drywell
USM	uniform support motion
VB	vacuum breaker
VLT	vent line clearing
VMG	Vibration Monitoring Group
VT	vertical
VW	vent wall
ZPA	zero period acceleration

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

3.1 Conformance with U.S. Nuclear Regulatory Commission General Design Criteria

3.1.1 Regulatory Criteria

The applicant should discuss the extent to which plant structures, systems, and components (SSCs) important to safety meet the United States (U.S.) Nuclear Regulatory Commission's (NRC) criteria in Appendix A, "General Design Criteria for Nuclear Power Plants," to Part 50, "Domestic Licensing of Production and Utilization Facilities," of Title 10 of the *Code of Federal Regulations* (10 CFR Part 50). For each applicable criterion, the applicant should provide a summary showing how the principal design features meet the general design criterion (GDC) and should identify and justify any exceptions to the GDC. The discussion of each criterion should 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 criterion.

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 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

In GDC 2, "Design Bases for Protection Against Natural Phenomena," of Appendix A of 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. Some of these functions are necessary to ensure the following:

- integrity of the reactor coolant pressure boundary (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 exposures requirements in 10 CFR 50.34(a)(1)

10 CFR Part 50, Appendix S, “Earthquake Engineering Criteria for Nuclear Power Plants,” 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 for the SSE; the SSCs are designed to remain functional through an earthquake that produces the maximum vibratory ground motion.

Regulatory Guide (RG) 1.29, “Seismic Design Classification,” Revision 3, 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 non-seismic (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.

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 to establish 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

In ESBWR DCD Tier 2, Revision 3, Section 3.2.1, Tables 3.2-1, 3.2-2, and 3.2-3 identify the ESBWR safety-related SSCs that are classified as seismic Category I, seismic Category II, or non-seismic (NS). These tables identify both pressure boundary components of fluid systems and nonpressure boundary items such as structures and supports. 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, Table 3.2-1, also identifies 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” indicates the QA requirements are applied commensurate with the importance of the safety function.

DCD Tier 2, 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 further states that the ESBWR meets the acceptance criteria of Section 3.2.1 of NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants" (hereafter referred to as the SRP), and the seismic classifications are consistent with the guidelines in RG 1.29. DCD Tier 2, Table 1.9-3, is consistent with SRP Section 3.2.1, and Table 1.9-21b of DCD Tier 2 shows that there are no exceptions to RG 1.29, Revision 3. Section 7.1.6.4 of DCD Tier 2 identifies that the instrument sensing lines are designed to satisfy the requirements of RG 1.151, "Instrument Sensing Lines," issued July 1983, and Section 7.7.7.3.1.2 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 reviewed the ESBWR DCD in accordance with SRP Section 3.2.1, Revision 2, and the guidance in RG 1.29, which is identified in SRP Section 3.2.1. The 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 Table 3.2-1. The staff required additional information to complete this review; the following sections include a summary of GE Nuclear Energy (GEH), responses to significant requests for additional information (RAIs) for each review topic. Section 3.2.2 of this safety evaluation report (SER) includes additional RAIs that address both seismic and quality group (QG) classification. Revision 3 of DCD Tier 2 includes changes that the applicant made in response to the RAIs.

3.2.1.3.1 Classification Criteria

The staff reviewed the criteria identified in DCD Tier 2, Section 3.2.1, that the applicant used to select the appropriate seismic classification in Table 3.2-1 for principal components. The staff determined that the classification criteria for seismic Category I, Category II, and NS are generally consistent with RG 1.29, Revision 3, and SRP Section 3.2.1 for seismic classification. One difference in terminology is that RG 1.29 does not use the term seismic Category II, but the basic methodology—that SSCs whose failure could adversely affect seismic Category I SSCs will be seismically analyzedCis consistent. Another difference is that certain components that may be important to safety, but which are not safety-related, are considered NS and are evaluated in accordance with the regulatory treatment of non-safety systems (RTNSS) discussed in DCD Chapter 19 and Chapter 22 of this SER.

Systems that provide post-72-hour cooling and postaccident monitoring are examples of RTNSS. Fire protection is another example of a non-safety-related system that may be important to safety. Revision 4 to RG 1.29, issued March 2007, changed this guidance to add Regulatory Position C.5 regarding reference to RG 1.189, "Fire Protection for Nuclear Power Plants," for seismic requirements applicable to fire protection systems (FPS). Although the applicant does not need to directly evaluate this revision in the DCD, this safety evaluation indirectly addresses this position's consistency with RG 1.189. Table 1.9-21b of DCD Revision 3 identifies no exceptions to RG 1.189 for FPS.

3.2.1.3.2 Use of Simplified Piping and Instrumentation Drawings

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 show the level of detail typically shown in P&IDs developed during the detailed design phase. Section 3.2.2.2.3.5 of this SER 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.

3.2.1.3.3 Seismic Classification for Restraints

In RAI 3.2-13, the staff requested the applicant to 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 that show 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 reference to seismic Category NS for safety-related pipe whip restraints. The staff finds that the changes made in Revision 3 of the DCD resolve its concerns with seismic categorization of restraints.

3.2.1.3.4 Seismic Category I

Based on its review of DCD Tier 2, Section 3.2.1; DCD Tier 2, Tables 3.2-1, 3.2-2, and 3.2-3; and the other sections and P&IDs as 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 Position C.1 of RG 1.29, including referenced RG 1.151. To make this finding, the staff requested that several SSCs with a potential safety function be designated 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. These components are identified as Seismic Category I in DCD Tier 2, Table 3.2-1. 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 non-safety-related and, therefore, the SSCs supporting these functions need not be seismic Category I. Non-safety-related SSCs that are risk significant are to be considered RTNSS candidates that are evaluated for seismic requirements under Chapter 22 of the SER. As explained in DCD Chapter 19A, certain RTNSS candidates require augmented seismic design criteria; the staff is evaluating 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 SER Chapter 22 and Section 3.2.1.3.9. RTNSS components with augmented seismic design criteria may require an appropriate seismic classification other than NS. With these clarifications and changes, the staff concludes that, pending the resolution of seismic requirements for RTNSS candidates and QA requirements for certain non-safety-related seismic Category I and Category II SSCs, the revised Table 3.2-1 is, in general, consistent with SRP Section 3.2.1 and RG 1.29 guidance for seismic Category I SSCs or the alternative classification in SRP 3.2.2 for the turbine main steam system (TMSS).

3.2.1.3.5 Seismic Category II

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, 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 will 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 turbine main steam 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. As identified in SRP Section 3.2.1, the staff concurs that this is an acceptable alternative to RG 1.29. In DCD Revision 4, the applicant revised Tables 1.9-21b and 17.0-1 to identify this as an exception to RG 1.29. Therefore, RAI 3.2-16 is closed. Regarding B21 Item 9, RAI 3.2-18 requested that the seismic category of pipe whip restraints be at least seismic Category II, and the RAI response stated that GEH 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 Section 3.7 and clarified that earthquake experience data is not the only basis for structural capability. The response to RAI 3.2-23 changed the seismic classification for alternate rod insertion (ARI) equipment from NS to seismic Category II. The response to RAI 3.2-40 modified the turbine bypass system 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 response to RAI 3.2-51, GEH revised the classification of the RB HVAC components in the U40 system from NS to seismic Category I or II. With these clarifications and changes, 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, Section 3.7, “Seismic Design,” discusses the design criteria for seismic Category II SSCs. In Position C.3 of RG 1.29, the NRC recommends guidelines for designing interfaces between seismic Category I and NS SSCs. DCD Tier 2, 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 SER discuss the staff’s evaluations of this information for structures and piping, respectively.

3.2.1.3.6 Quality Assurance Requirements

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, GEH 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 Appendix B to 10 CFR Part 50, QA program.
Section 3.2.2 of this SER 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 Category I SSCs, this information is consistent with item (1) above.

To satisfy 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 Position C2 and C3 of RG 1.29 defined by the applicant as seismic Category II. The staff reviewed the items listed in DCD 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 the applicant to 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, GEH explained in its response to RAI 3.2-6 that QA E is appropriate regardless of their seismic classification. In general, Table 3.2-1 shows that non-safety-related seismic Category II SSCs are identified as QA E. The staff concurs that, in general, there is no need to apply the 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. Contrary to the guidance in RG 1.29, several seismic Category II systems, such as the main steam (MS) drains, are QA E rather than QA B. Open Item 3.2-6, discussed in Section 3.2.2.3.4 of this SER, addresses the technical concerns pertaining to QA E requirements. Accordingly, except for the identified open item, the staff concludes that the inclusion of certain safety-significant SSCs under RTNSS is consistent with recent NRC policy and represents an acceptable position relevant to Item (2) above.

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 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 identified that the applicant will add a COL holder action item to DCD Section 10.3.7:

> A plant-specific walk-down of non-seismically 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 non-seismically designed systems, structures and components.

The staff concludes that, on the basis of this COL action item, there is reasonable assurance that any NS SSCs that could adversely impact the alternate MSL leakage path will be identified. 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 post-accident. 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 its 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 SER. Also, refer to the evaluation of RAI 3.2-63 in Section 3.2.1.3.9 and Chapter 22 of this SER for open items regarding the staff's concern about seismic qualification of systems that are RTNSS needed after 72 hours and RAI 3.2-6 in Section 3.2.2 of this SER relative to supplemental requirements for risk-significant RTNSS SSCs.

3.2.1.3.8 Structures

DCD Table 3.2-1 identifies the seismic designation of structures as seismic Category I, seismic Category II, or NS. Seismic analysis for SSE is necessary for both seismic Category I and seismic Category II structures. Structures designated as NS are designed for seismic requirements in accordance with requirements for Category IV of the International Building Code (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 (CB) structure are seismic Category I and that only those non-safety-related portions of the FB and CB structure that contain non-safety-related equipment have been classified as seismic Category II. The NRC staff concurs that seismic Category II is correct for portions of structures that do not support safety-related components but which could adversely affect seismic Category I components in the event of a structural failure resulting from an SSE. The RAI 3.8-2 response also clarified that the initially not-in-scope intake and discharge structures are to be classified as NS, and Revision 3 of the DCD identifies these non-safety-related structures as NS. The responses to RAIs 3.2-54 and 3.2-55 clarified that the plant service water system (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 classified as NS on the basis that they do not support or enclose any safety-related components and their failure in the event of an SSE could not adversely impact seismic Category I components. However, the PSWS has a long-term cooling function after 72 hours, and DCD Table 19A-2 includes the PSWS as B2 RTNSS to support post-72-hour cooling functions with seismic requirements for the structure consistent with the IBC. Seismic requirements for SSCs that support post-72-hour functions are considered to be a RTNSS issue, and such SSCs should be designed to withstand an SSE. Structures housing such equipment, if designed to the IBC provisions, are likely to suffer severe damage from an SSE to the extent that such an event could incapacitate the housed equipment. Acceptability of the application of the IBC to the seismic design of non-safety-related NS structures that support post-72-hour cooling functions is an RTNSS issue that the staff further evaluates under RAI 22.5-7 concerning the design of structures.

3.2.1.3.9 Electrical Systems

Open Item 3.2-63

In RAI 3.2-63, the staff questioned the NS classification of the R11, R12, and R21 systems that are used to recharge the safety-related batteries to support post-72-hour functions. In its response to RAI 3.2-63, GEH indicated that the medium-voltage distribution system, the low-voltage distribution system, and the standby alternating current (ac) power supply (diesel generators), designated in Table 3.2-1 of DCD Revision 3 as R11, R12, and R21, respectively, are classified as non-safety and NS and are designed and qualified to the seismic provisions of and the standards referenced in the IBC. In addition, 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 2500 years, which is further reduced by a factor of two-thirds 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 systems that are RTNSS may come 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, an SSE event is likely to severely damage the structures housing such equipment, if also designed to the IBC provisions, and could incapacitate the housed equipment.

In regard to RTNSS for passive plant designs, SECY-94-084 identified criteria to address SSC functions relied on to resolve long-term safety (beyond 72 hours) and seismic events. This document identifies that the designer will use probabilistic risk assessment (PRA) to determine the risk-significant non-safety SSCs. In addition, in SECY-96-128, "Policy and Key Technical Issues Pertaining to the Westinghouse AP600 Standardized Passive Reactor Design," dated June 12, 1996, the staff stated that "the equipment required after 72 hours need not to 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 in keeping with previous staff positions, the staff finds that the classification of the standby diesel generators (DGs) and their distribution systems as NS is inconsistent with staff positions regarding RTNSS using the IBC seismic provisions to ensure availability of DGs and their distribution systems when required. This finding considers that the DGs must 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 Uninterruptable Power Supply 120 VAC system beyond 72 hours during a loss of offsite power (LOOP). Therefore, the design of the standby DGs, the medium-voltage distribution system, and the low-voltage distribution system should be qualified to withstand the effects of the SSE. **RAI 3.2-63 is being tracked as an open item**. Chapter 22 of this SER will include resolution of this open item in the responses to RAIs 22.5-4, 22.5-6 and 22.5-7.

3.2.1.4 Conclusions

On the basis of its review of DCD Tier 2, Tables 3.2-1, 3.2-2, and 3.2-3; the applicable simplified P&IDs; and other supporting information in DCD Tier 2, the staff concludes that GEH properly classified the ESBWR safety-related SSCs, including their supports, as seismic Category I, in accordance with Position C.1 of RG 1.29 or alternatively to SRP 3.2.2 for TMSS. However, pending resolution of seismic and QA requirements for certain non-safety-related SSCs and RTNSS candidates, as discussed above, the staff is unable to finalize its conclusion regarding the degree of the applicant's conformance with RG 1.29 Positions C.2 and C.4 in meeting GDC 2.

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

The applicant has properly classified the MS and associated systems in accordance with the guidance in Appendix A to SRP Section 3.2.2 and is consistent with RG 1.29 Position C.3.

3.2.2 Quality Group Classification

3.2.2.1 Regulatory Criteria

In GDC 1, “Quality Standards and Records,” 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 systems important to safety. The plant will rely on these SSCs for the following functions:

- prevent or mitigate the consequences of accidents and malfunctions originating within the RCPB
- permit shutdown of the reactor and maintain it in a safe-shutdown condition
- retain radioactive material

10 CFR 50.55a, “Codes and Standards,” requires 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 Mechnical 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. QG A standards that are required for pressure-containing components of the RCPB are consistent with ASME Code, Section III, Class 1. In addition, 10 CFR 50.55a also identifies that QG B and QG C must meet the requirements for Class 2 and Class 3, respectively, in ASME Code, Section III. RG 1.26, “Quality Assurance Programs,” Revision 3, issued February 1976, 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 were 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

In DCD Tier 2, Section 3.2.2, “System Quality Group Classification,” Tables 3.2-1, 3.2-2, and 3.2-3 identify 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 identify ANS 58.14 safety class and QA requirements as either "B" or "E." DCD Tier 2, 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 also identify applicable codes and industry standards as well as quality and safety classifications for fluid systems.

DCD Tier 2, Section 3.1.1.1, identifies 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 identifies that applicable codes and standards are applied to equipment commensurate with their 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 ANS 58.14. DCD Tier 2, Section 3.2.2, states that the ESBWR meets the acceptance criteria of SRP Section 3.2.2. DCD Tier 2, Table 1.9-3, is consistent with SRP Section 3.2.2, and Table 1.9-21b of DCD Tier 2 identifies no exceptions to RG 1.26, Revision 3, for the ESBWR. DCD Tier 2, Section 7.1.6.4, identifies that the instrument sensing lines are designed to satisfy the requirements of RG 1.151, "Instrument Sensing Lines," 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 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 Table 3.2-1. The staff required additional information to complete this review; the following sections summarize the applicant's responses to significant RAIs under each review topic. Revision 3 of DCD Tier 2 included changes that GEH made in response to the RAIs.

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 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 are considered QA E rather than QA B. An evaluation of these RTNSS candidates appears under RAI 3.2-6 in SER Section 3.2.2.3.4 and under RTNSS in DCD Chapter 19 and Chapter 22 of this SER. 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 addresses the compliance with RG 1.143 for radwaste systems. Sections 11.2, 11.3, and 11.4 of DCD Tier 2 address the classification of radwaste systems relative to RG 1.143 guidance, and an evaluation appears in the corresponding sections of this SER. 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.

Confirmatory Item 3.2-1a

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. The staff asked GEH 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 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. The staff requested the applicant to review Tier 1 and 2 commitments relevant to 10 CFR 50.55a and modify its position or justify why such piping and components do not need an N stamp or an ASME-authorized inspection. The following information is necessary to the staff's evaluation of a proposed alternative position:

- The applicant should explain why it does not consider ASME N stamping and authorized inspection to be feasible. Any explanation should include factors such as hardship or unusual difficulty without compensating increase in the level of quality and safety, precedence, available N stamp suppliers, a cost-benefit analysis, and alternative stamping and inspection provisions.

- The applicant should demonstrate that the proposed alternative approach for stamping and inspection would provide an acceptable level of quality and safety equivalent to the certification activities required under the ASME Code.

- The applicant should confirm that, other than stamping and inspection, all other ASME Code required design, material, fabrication, inspection, testing, QA, and documentation are in conformance with ASME Code, Section III, Class 2 or equivalent alternative methods.

- The applicant should confirm that inservice inspection (ISI) and testing for these QG B piping and components will be consistent with ASME Code, Section XI, or equivalent alternative methods. If the applicant will not perform ISI according to ASME Code, Section XI, because of hardship or unusual difficulty, it should describe the hardship or unusual difficulty this presents and the alternative inspection approach, including the technical justification.

- If the applicant prefers to change Tier 1 and Tier 2 commitments and designate this non-safety-related piping as within the scope of RTNSS with augmented design, fabrication, inspection, and quality requirements, it should present for staff review all supporting information to technically justify such an alternative classification.

The applicant's response to RAI 3.2-1 S02, dated August 23, 2007, modified the applicable DCD Tier 1 and 2 sections to remove an exception from requirements for N stamping QG B MS piping. Confirmation that the applicant has revised Section 2.11.1 of DCD Tier 1 and Section 1.2.2.11.1 and Table 3.2-1 of DCD Tier 2 accordingly is Confirmatory Item 3.2-1a. RAI 3.2-1 is being tracked as a confirmatory item.

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 for controlling MSL leakage. To determine that these components are consistent with regulatory guidance, the staff requested 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 Subsection 3.2.1.3.7 of this SER 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 stated 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.

Position C.1.c in RG 1.26 specifies that those portions of the steam systems of boiling water-reactors (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. The staff requested the applicant to 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(b) are resolved.

The ESBWR design eliminates the main steam isolation valve (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 drain lines, 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 they 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 turbine stop valve (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 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 drain line 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 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 of this SER.

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 GEH 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 GEH to 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 roentgen equivalent man (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 and that 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. The staff requested the applicant to submit a revised DCD Figure 3.2-1 to show this normally closed valve in the MS drains. **RAI 3.2-19 is being tracked as an open item.**

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 B several items that are classified as either seismic Category I or II.

Open Item 3.2-6

Contrary to the guidance in RG 1.29, the response to RAI 3.2-6 indicated that QA E is appropriate for all non-safety-related SSCs regardless of their seismic classification. Note (5) to Table 3.2-1 identifies QA E as QA requirements commensurate with the importance of the item's function. Note (4) to Table 3.2-2 also states 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 of the general nature of this QA E definition, it is not clear what specific QA requirements apply to various components that are classified as QA E. For example, the DCD does not identify what supplemental requirements, if any, are applicable 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 do not appear to address graded supplemental requirements applicable to QA E for important non-safety systems such as the standby ac power system and the PSWS that have a defense-in-depth function. The staff asked GEH to clarify what graded requirements it applied to QA 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 not sufficiently defined at this time, this will be subject to further review at a later time when design requirements and a design-specific focused PRA are complete. **RAI 3.2-6 is being tracked as an open item.**

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 E that meet the guidelines of RG 1.143. The RAI response identified that GEH will revise DCD Table 3.2-1 to refer to the ESBWR QA program described in DCD Chapter 17. Table 3.2-1 in DCD Revision 3 identifies 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. RG 1.143 references American National Standards Institute (ANSI) ANS 55.6 for liquid radioactive waste processing systems. Therefore, the staff finds this change to be acceptable.

In RAI 3.2-41, the staff requested that GEH classify the main condenser and auxiliaries as QA 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. GEH will correct DCD Section 15.4.4.5.2.4 and Table 3.2-1 accordingly. In DCD Revision 3, Table 3.2-1 identifies 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. (Refer to Open Item 3.2-6 identified above for QA E components.)

In RAI 3.2-52, the staff requested the applicant to classify FPS components as QA 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 only apply to safety-related components. The staff concurs that typically the requirements of Appendix B only apply to safety-related or seismic Category II SSCs and, therefore, QA E supplemented by a QA program meeting the guidance of NRC BTP SPLB 9.5-1 is appropriate for the FPS.

In RAI 3.2-55, the staff requested the applicant to classify the intake and discharge structures as QA 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 B is generally not applicable to non-safety-related SSCs. However, RTNSS SSCs that support important safety functions may require special treatment. Open Item 3.2-6 addresses quality requirements applicable to QA E for items with a defense-in-depth function.

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 GEH 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, GEH 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. GEH 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. COL Information Item 3.9.9.4 requires the applicant to provide design specifications and reports for audit. Through this audit, the staff will have the opportunity to verify design finality. Because simplified diagrams are acceptable for the design certification and, through the COL information item, the staff will have the opportunity to review detailed design documents that support the final classification boundaries, the staff finds that the level of detail included with the simplified diagrams submitted in the DCD is acceptable.

3.2.2.3.6 Quality Group A

The staff reviewed DCD Tier 2, 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 SER 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 applicable 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, and are in conformance with GDC 1, and therefore are acceptable. To make this finding, the staff requested that GEH revise numerous designations in Table 3.2-1 to conform to the SRP Section 3.2.2 and RG 1.26 guidance. 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 GEH 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, GEH 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, GEH designated the gravity-driven cooling system (GDCS), which was previously classified as QG C, as QG B. However, the applicant did not revise Section 3.2.2.2 to include 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 GEH supplemental response resolved the staff's concern relative to 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, identifies that Safety Class 2 includes pressure-retaining portions of pipes 2.54 centimeters (1 in.) 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 include the exclusion criteria in Section 3.2.2 for quality class.

In its response to RAI 3.2-3, GEH identified the safety classifications based on ANS 58.14 and included them in Table 3.2-1. DCD Section 3.2.3.1 defines 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 requested GEH 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 submitted for endorsement, this remains an open item and safety class is subject to further review during the COL application. GEH has resolved the staff's concern with 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 in.) on the basis of reactor coolant makeup capability.

A supplemental response acknowledged that GEH is aware that ANS 58.14 is withdrawn and that the NRC has not endorsed this standard. Until this standard is revised and available for the NRC's endorsement, the NRC cannot approve the application of this document to the ESBWR. The applicant's supplemental response identified that it will remove the reference to ANS 58.14-1993, and it indicated that the GEH classification scheme is not dependent on ANS 58.14. The staff concurs that deleting the reference to the outdated and withdrawn

ANS 58.14-1993 will close this open item. The reference to ANS 58.14 is deleted in in DCD Revision 4. RAI 3.2-3b is closed.

The staff reviewed fluid systems that are important to safety to ensure that their classification is correct. The staff questioned the classification of various SSCs in Table 3.2-1 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, identifies that Safety Class 2 components include pressure-retaining portions of the control rod drive (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 identified 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. GEH 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 that the NRC has accepted 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. The staff requested GEH to confirm that this represents an exception to RG 1.26 and to submit a revision to DCD Section 1.9. Confirmation of an exception to RG 1.26 for the safety-related HCU assemblies is considered to be a confirmatory item. The response to RAI 3.2-21 S01 clarified that the classification of the HCU is an exception to RG 1.26 and that GEH will revise DCD Tier 2, Tables 1.9-21b and 17.0-1, accordingly. The staff confirmed that GEH 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, it requested the applicant to provide technical justification that this is 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, 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 identified 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, 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 are closed.

In RAI 3.2-22, the staff requested 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 identified that, as explained in the reply to RAI 4.6-1, the QG, QA, and seismic category are 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.

In RAI 3.2-23, the staff requested the applicant to classify DCD Table 3.2-1 C12 item 10 for the ARI equipment as QG B, QA B, and seismic Category I. The response identified that the seismic category classification is 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 the approved ABWR design and are in conformance with Licensing Topical Report (LTR) NEDE-31096-P-A, GEH 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.

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 GEH revised Table 3.2-1 in DCD Revision 3 accordingly.

G31 Reactor Water Cleanup/Shutdown Cooling System (RWCU/SDC)

In RAI 3.2-34, the staff asked the applicant to designate that the RWCU/SDC as safety-related QG B and QA B or to justify the 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 nonsafety-related SSCs with no safety function need not be QG B or QA B, provided that risk-significant systems are addressed under RTNSS. The RWCU/SDC 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. However, this nonsafety-related, risk-significant system is not included as a RTNSS system in DCD Table 19A-2. Refer to Section 22 of this report for an assessment of risk-significant systems relative to seismic requirements/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, ASME Code, Section III, Class 2 or 3, applies to QG B and C, respectively. The staff requested GEH 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 RWCU.

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 GEH 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. The staff asked the applicant to clarify if 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 what 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 further requested 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 is an open item.**

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 B, and seismic Category I. The RAI response identified that the service air system (SAS) and instrument air system have no safety-related functions 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 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 B, or seismic Category I; and that QG D and QA E are appropriate provided 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, 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 in conformance with GDC 1, and 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 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 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 the applicant to revise Section 3.2.2.3 to add important system functions, such as those that provide cooling water to systems for reactor shutdown, emergency core cooling, postaccident containment heat removal, or DHR or those containing radioactive waste, to the QG C description. 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 GEH classification scheme is not dependent on this standard. The applicant has identified that it will delete reference to ANS 58.14 for safety class.

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 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 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 QA Requirement E is appropriate, provided risk-significant systems are addressed under RTNSS. Open Item 3.2-6 addresses the issue of supplemental QA requirements for QA E applicable to important defense-in-depth functions, such as the fuel and auxiliary pools cooling system (FAPCS).

In RAI 3.2-31, the staff requested that G21 item 9 be safety-related QG C, QA B, and seismic Category I. The RAI response identified 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 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 QA Requirement E is appropriate, provided risk-significant systems are addressed under RTNSS. Open Item 3.2-6 addresses the issue of supplemental QA requirements for QA E applicable to important defense-in-depth functions such as the FAPCS.

In RAI 3.2-32, the staff requested that G21 item 10 be safety-related QG C, QA B, and seismic Category I. The RAI response identified that the auxiliary pool return lines do not have a safety-related function. The response explained that QA 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 QA Requirement E is appropriate, provided risk-significant systems are addressed under RTNSS. Open Item 3.2-6 addresses the issue of supplemental QA requirements for QA E applicable to important defense-in-depth functions such as the FAPCS.

G31 RWCU/SDC

In RAI 3.2-35, the staff requested that G31 item 8 be safety-related QG C and QA 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 is appropriate for a non-safety-related system provided risk significant systems are addressed under RTNSS. Open Item 3.2-6 addresses the issue of supplemental QA requirements for QA E applicable to non-safety-related SSCs that may be risk significant.

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 B, and seismic Category I. The RAI response identified 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 spent fuel pools (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 B, or seismic Category I and that classification as QG D and QA E is appropriate provided risk significant systems are addressed under RTNSS.

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 B, and seismic Category I. The RAI response identified 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 B, or seismic Category I and that classification as QG D and QA E is appropriate provided risk significant systems are addressed under RTNSS. Open Item 3.2-6 addresses the issue of supplemental QA requirements for QA E applicable to important defense-in-depth functions such as CWS.

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 identified 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 B, or seismic Category I and that classification as QG D and QA E is appropriate provided risk significant systems are addressed under RTNSS. Open Item 3.2-6 addresses the issue of supplemental QA requirements for QA E applicable to important defense-in-depth functions such as the PSWS.

P54 Nitrogen Supply System

In RAI 3.2-47, the staff requested that the applicant classify the P54 items 2 and 4 components as QG C, QA Requirement B, and seismic Category I. The RAI response identified 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 B, or seismic Category I and that classification as QG D and QA E is appropriate provided risk significant systems are addressed under RTNSS.

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 B. The RAI response identified that the station water system does not provide makeup water to any safety-related components and the station water system is classified appropriately in Table 3.2-1. The staff concurs that a system that performs no safety-related function need not be classified as QG C or QA B and that classification as QG D and QA E is appropriate provided 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 identified that the applicant would add the GDCS splash guard to Table 3.2-1 as item 5 for System E50; Revision 3 of the DCD correctly includes the splash guard as QG C and QA B.

In RAI 3.2-33, the staff requested the applicant to revise DCD Table 3.2-1 to include the FAPCS skimmer lines. The RAI response identified that the applicant would add skimmer lines to Table 3.2-1 as item 10 for System G21; Revision 3 of the DCD correctly includes the non-safety-related skimmer lines as QG D and QA E.

In RAI 3.2-48, the staff requested the addition to Table 3.2-1 of the vacuum breakers addressed in 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 QA B.

Because of omissions and other recent changes to Table 3.2-1, it is not evident that the applicant has 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 classification criteria in Section 3.2, the staff requested 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 the applicant to 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, GEH 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. In response to RAI 3.2-48 S02, the applicant submitted a minor revision to DCD Table 3.2-1 concerning the appropriate system assignment for the refueling bellows. The applicant confirmed that all safety-related systems are properly classified. In the RAI response, GEH 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 applicable to the design certification. RAI 3.2-7 identified a similar concern regarding the identification of applicable P&IDs and design finality. Section 3.2.2.3.5 of this SER 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.

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 B. The RAI response identified 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 E. Open Item 3.2-6 addresses the supplemental QA requirements for QA E applicable to important seismic Category I components with defense-in-depth functions such as the FTS.

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 identifies Systems K10, K20, and K30 as QG D and QA E with a QA program consistent with RG 1.143. 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, identifies that the radioactive waste management systems 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 identify compliance for liquid, gaseous, and solid radwaste systems, respectively.

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 identifies 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 GEH 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 identified that the applicant will insert reference to GEZ-4982A, "General Electric Steam Turbine-Generator Quality Control Program," and remove 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 SER review the acceptability of the 2004 ASME B31.1 code and other code and standard editions identified in Section 1.9.

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 GEH revise Table 3.2-3 to delete the Tubular Exchanger Manufacturers Association (TEMA) C reference or provide information that demonstrates the TEMA C standard meets or exceeds the requirements for QG A, B, C, and D components. The RAI response identified that the applicant would revise Table 3.2-3 to clarify that the requirements from both TEMA and the ASME Code must be taken into account. In DCD Revision 3, the applicant revised Table 3.2-3 accordingly. In RAI 3.2-59, the staff requested that GEH also revise Table 3.2-3 to include pumps. The RAI response identified that GEH would revise Table 3.2-3 to include pumps, and in DCD Revision 3, GEH revised Table 3.2-3 accordingly. In RAI 3.2-60, the staff requested that GEH 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 GEH 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 GEH revise Table 3.2-3 to refer to ASME Code, Section III, Subsection NC, for the design of ASME Code Class 2, pressure vessels and heat exchangers rather than Subsection NB. The RAI response revised the table accordingly. With these changes, the staff concludes that the revised table in DCD Revision 3 is consistent with the SRP Section 3.2.2 and RG 1.26 guidance.

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 these nonpressure-retaining items for application of the appropriate QG classification. 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 GEH revise the text in the DCD that states the component supports are not addressed by RG 1.26. In the RAI response, GEH agreed that component supports are included in the QG classifications; GEH revised the DCD to delete 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, ASME Code, Section III, Subsection NG, covers nonpressure-retaining core support structures. In RAI 3.2-10, the staff requested that GEH 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, GEH stated that it will revise Table 3.2-1 to add QG B to core support structures, and Revision 3 of the DCD shows the core support structures as QG B.

In RAI 3.2-11, the staff requested that GEH 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, GEH did not assign them a QG. Therefore, the response identified that giving these components a QG C and a QA Class B is not warranted. Open Item 3.2-6 addresses the supplemental QA requirements for non-safety-related seismic Category II components with QA E, such as steam dryers.

F16 Fuel Storage Facility

In RAI 3.2-28, the staff requested that GEH classify the fuel storage racks, F16 item 1, as at least QG D and QA B to be consistent with SRP Sections 3.2.1 and 3.2.2 and the guidance of 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,” 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 commensurate with the importance of the component’s function. Open Item 3.2-6 addresses the supplemental QA requirements for non-safety-related seismic Category I components with QA E, such as the fuel storage racks.

J11 and J12 Nuclear Fuel and Fuel Channel

In RAI 3.2-36, the staff requested that GEH classify the fuel and fuel channels as QG B. The RAI response identified that RG 1.26 only applies 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 only applies 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 identifies that nuclear fuel and fuel channels are designed in accordance with NRC-approved methodology as described in Chapters 4 and 15 and Reference 15.0-2. 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

Because of the open items that remain to be resolved for this section, the staff is unable to finalize its conclusion about the conformance with the applicable regulations related to the QG classifications of the pressure-retaining fluid systems and their supports 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.

3.3 Wind and Tornado Loadings

3.3.1 Wind Loadings

3.3.1.1 Regulatory Criteria

For structures that are important to safety and must withstand the effects of the design-basis wind load, their design must comply with the relevant requirements of GDC 2 of Appendix A of 10 CFR Part 50.

GDC 2 requires that the design of 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 for 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.

To ensure compliance with the requirements of GDC 2, the NRC staff reviews 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 windspeed 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 windspeed 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

GEH 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 Section 3.3.1 of NUREG-0800, 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 windspeed is 65.6 meters per second (m/s) (140 miles per hour (mph)) at an elevation of 9.14 meters (m) (30 feet (ft)) above grade. This basic windspeed 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 additional information was necessary to complete its review.

In RAI 3.3-1, the staff requested the applicant to 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 staff review, GE 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 windspeed (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 windspeed, 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, issued March 2007, 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 windspeed into equivalent pressure to be applied to structures and portions of structures. Accordingly, RAI 3.3-1 is considered resolved.

Based on its review, the staff determined that the GEH 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 2, issued July 1981. 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, 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 subject 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

3.3.2.1 Regulatory Criteria

For structures that are important to safety and must withstand the effects of the design-basis tornado (DBT), their design 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 for 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.

To ensure conmpliance with the requirements of GDC 2, the staff reviewed the following areas relating to the design of structures that have to 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

- 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 provided a description of 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 differential of 16.6 kilopascals (kPa) (2.4 pounds per square inch (psi)), a rate of pressure change 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 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 RB is 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 intake and exhaust openings. These dampers are designed to withstand the full negative pressure drop. GEH further indicated that all safety-related systems and components are protected within tornado-resistant structures.

With respect to the COL information items in DCD Tier 2, Revision 1, the applicant stated that site-specific design-basis wind and tornado and their recurrence intervals shall not exceed those defined in DCD Tier 2, Table 2.0-1. GEH further stated that the COL holder 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 adversely affect the ability of the seismic Category I ESBWR standard plant SSCs to perform their intended functions. The staff's evaluation provides further details on this issue.

3.3.2.3 Staff Evaluation

RG 1.76, "Design Basis Tornado for Nuclear Power Plants," 1974, provides the staff's position on DBTs. RG 1.76 delineates the maximum tornado windspeed as 579 kilometers per hour (km/h) (360 mph) for the contiguous U.S. The staff reevaluated the regulatory position in RG 1.76 for the standard design of ALWRs using tornado data that became available after development of the RG. Ramsdell J. V., and G. L. Andrews, 1986, "Tornado Climatology of the Contiguous United States," NUREG/CR-4461, discusses this reevaluation. A March 25, 1988, letter to Edwin A. Kintner, GPU Nuclear Corporation, "ALWR Design Basis Tornado," provided the staff's interim position related to RG 1.76. In this interim position, the staff concluded that the maximum tornado windspeed of 531 km/h (330 mph) is acceptable. However, in SECY-93-087, the staff recommended that the Commission approve its position that a DBT with a maximum tornado windspeed 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 its SRM dated July 21, 1993, the Commission approved the staff's position. The staff finds that by using the maximum windspeed of 147.5 m/s (330 mph), the ESBWR design meets the staff's position and the intent of SRP Section 3.3.2, Revision 2, issued in 1981. Therefore, the use of a maximum windspeed of 147.5 m/s (330 mph) by 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 requested 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 GE's basis for omitting the parameter in the Table.

In its response to RAI 3.3-2, dated June 16, 2006, the applicant stated that the rotational windspeed 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 windspeed used in the ESBWR standard plant design is acceptable, and the applicant 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 SER. By using BC-TOP-3-A, GEH 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 have to 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.

With respect to the COL information items provided in DCD Tier 2, Revision 1, the applicant stated that site-specific design-basis wind and tornado and their recurrence intervals shall not exceed those given in DCD Tier 2, Sections 2.3.1 and 2.3.2 and Table 2.0-1. GEH further stated 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.

In RAI 3.3-3, the staff requested 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 SSC's 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, 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 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 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 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 2, Section 3.3.2.3, however, the applicant stated that any NS structure (except the radwaste building (RW)) postulated to fail under tornado loading is located at least a distance of its height above grade from seismic Category I or II structures. In S01 to RAI 3.3-3, the staff requested 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 is being tracked as an open item.

3.3.2.4 Conclusions

Because an open item remains to be resolved for this section, the staff is unable to finalize its conclusion regarding the acceptability of the design for satisfying the requirements of GDC 2.

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 2, of NUREG-0800. The staff's acceptance of the design for flood protection is based on the design's conformance with the requirements of the following general design criteria (GDC), regulation, and guidance:

- GDC 2 of Appendix A of 10 CFR Part 50, which requires in part that SSCs important to safety shall be designed to withstand the effects of natural phenomena such as floods

- Section IV.C of 10 CFR Part 50, Appendix S, as it relates to protecting safety-related SSCs from the effects of floods, water waves, and other design conditions

- 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), as well as 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

The staff's acceptance of the design for flood protection also considers potential flooding of systems that are candidates for RTNSS from external and internal sources.

3.4.1.2 Summary of Technical Information

In DCD Tier 2, Revision 3, Chapter 2, GEH defined the envelope of site-related parameters that the ESBWR standard plant is designed to accommodate. DCD Tables 2.0-1 and 3.4-1 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, using figures)
- hazards in the site vicinity
- required stability of slopes
- meteorological dispersion (values at exclusion area boundary and low-population zone at appropriate short- and long-term time intervals)

Section 2.0 of this SER discusses the staff's evaluation of the site envelope parameters.

In DCD Tier 2, Revision 3, Section 3.4.1, GEH discussed the flood protection measures that are applicable to the ESBWR design for postulated external flooding resulting from natural phenomena, as well as for internal flooding from system and component failures. GEH conducted an analysis based on the site envelope parameters to identify the safety-related SSCs that require protection against flooding from both external and internal sources and 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). GEH also assessed 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 systems and components are located in seismic Category I structures that provide protection 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.

The applicant's internal flood analysis evaluated whether a single pipe failure, a firefighting event, or other flooding sources, as described in DCD Tier 2, Revision 3, 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 200 millimeters (mm) (8 in.) high, and leak detection systems.

During the DCD review, the staff issued RAIs regarding external and internal flooding. These RAIs requested clarifications or more detailed descriptions of flood protection measures. In a letter dated January 30, 2007, GEH provided responses that addressed the staff's concerns. The staff finds these responses acceptable.

3.4.1.3 Staff Evaluation

3.4.1.3.1 External Flooding

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 stated in DCD Table 2.0-1. This is done by locating the plant grade elevation 0.3 meter (m) (1 foot (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 provides the following:

- wall thicknesses 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

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. Flood conditions typically develop relatively slowly, allowing ample time for operators to take appropriate measures to ensure that all facility flood protection measures are in place. 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 flood protection measures acceptable.

However, based on its evaluation of the information in the DCD and for the reasons stated below, the staff is not able to conclude that the applicant has provided adequate flood protection features for the ESBWR to protect safety-related and RTNSS equipment from external flood effects associated with the PMP, PMF, ground water seepage, and system and component failures.

- The ESBWR design for flood protection relies on plant personnel to take appropriate actions to ensure that all facility flood protection measures are in place as a flood condition develops. The staff determines that a COL holder should have emergency operating procedures directing plant personnel to take the appropriate actions as a flood condition develops. Therefore, the DCD needs a new COL action item. In RAI 3.4-12 the staff requested that GEH add this as a new COL action item. **This is being tracked as open RAI 3.4-12.**

  The site envelope parameters, as described and specified in DCD Tables 2.0-1 and 3.4-1, are used in the design of seismic Category I structures. Since the PMF results from site-specific events, such as river flooding, upstream dam failure, or other natural causes, the staff determines that every COL applicant should evaluate events leading to potential flooding and demonstrate that the design will fall within the values of the site parameters as described in DCD Tables 2.0-1 and 3.4-1.

In addition, the applicant has not addressed the protection of systems that are RTNSS from external flooding. Therefore, the staff is not able to conclude that RTNSS systems have been adequately protected from flood-related effects associated with both natural phenomena and system and component failures. This issue is discussed in RAI 22.5-5 in Section 22 of this SER. **This is an open item.**

3.4.1.3.2 Internal Flooding

All safety-related components that affect the safe shutdown of the plant are located in the RB and CB. Redundant systems and components are physically separated from each other, as well as from non-safety-related components. If a failure stem renders one division 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
- drainage systems

GEH 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 FPS
- flow from upper elevations and nearby areas

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

- The time to identify 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 (L/s) (125 gallons per minute (gal/min)) 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.

- The analysis reduced by at least 10 percent the free surface considered in each flooding zone to account for space utilization by components located in that zone.

The applicant used the criteria in DCD Tier 2, Revision 3, 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 nonseismically supported moderate-energy piping. The analysis assumed no breaks for piping with nominal diameters of 2.54 centimeters (cm) (1 in.) or less. In 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 (DBA) is qualified for loss-of-coolant accident (LOCA) environmental conditions. Flooding associated with the postulated failure of any moderate-energy pipe is within the bounds of the LOCA qualification. Consequently, no detailed evaluation of this less severe event is necessary to verify how moderate-energy piping failures in the containment would affect 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 takes into consideration the flowpaths 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.

Control Building

There are no tanks or high-energy piping in the CB, and the more relevant moderate-energy fluid system piping (i.e., FPS and CWS) is seismically qualified. The main source of floodwater is from the fire protection standpipe hose stations. The analysis assumed a nominal volume of 57 cubic meters (15,000 gal) for the FPS, with two fire hoses of 7.9 L/s (125 gal/min) capacity in service for 1 hour. This results in a flooding elevation in the lowest floor of the CB of 40 cm (16 in.) in the corridors, stair towers, and elevator rooms, assuming that the water propagates into these rooms by flowing through embedded drains and under the doors. This maximum water depth is below the distributed control and information system (DCIS) room floor elevation.

To prevent greater flooding in the lower elevation of the CB from pipe failures in the HVAC rooms, the water is retained in the HVAC rooms by the installation of 200-mm (8-in.) high curbs in the access doors, chases, and other floor openings, as well as by normally closed isolation valves in the drainlines. In addition, for further protection, the DCIS room access doors are watertight. Normally closed valves are installed in the drain pipes of the DCIS rooms. Moreover, the access doors from the access tunnel to the CB at El.-2000 are watertight. Therefore, the separation of electrical trains in independent zones, along with measures to direct the water to safe drain areas, maintains the safety function of the systems housed in the CB. There is no flooding hazard in the main control room.

Reactor Building

The potential sources of water in the RB include the following:

- reactor component cooling water system (RCCWS)
- CWS
- RWCU/SDC system
- CRD system, including the CRD pump suction from the condensate storage and transfer system (CS&TS)
- condensate and feedwater system (C&FS)
- FPS
- fuel auxiliary pools cooling system (FAPCS)
- hot water system (HWS)
- MWS
- standby liquid control system (SLCS)

The large number of pools in the ESBWR are contained within thick concrete walls designed for maximum hydrostatic loads combined with seismically induced hydrodynamic loads. GDCS pools inside containment are similarly contained within substantial structural members designed for hydrostatic loads combined with seismically induced hydrodynamic events. These pools are not considered as potential sources of floods.

The piping of the RCCWS, CWS, CRD pump suction (CS&TS/C&FS), MWS, and FPS is seismically analyzed. These are moderate-energy fluid systems; therefore, the flooding analysis only considers through-wall pipe cracks. The maximum expected flooding volume is from a through-wall pipe crack in the FPS or in the FAPCS suction lines from the suppression pool. The maximum volume of the suppression pool for flooding is limited to the difference between the maximum level and the antisiphoning provision in the suction line elevation. This results in a flood level of 20 cm (8 in.) in the RB lower elevation. This maximum flood level is lower than the CRD HCU room elevation. Other safety-related components in the lower elevation are located above the maximum flood level. Therefore, no flood in this RB elevation could affect the safety-related equipment or the plant's safe shutdown capability.

For further protection, the HCU room access doors and the access doors to the RB at El.-1000 are watertight. The SLCS accumulators for divisions 1 and 2 are located in fully independent rooms in El.-17,500 of the RB. Therefore, SLCS high-energy pipe break or tank failure flooding of one division cannot affect the other. Flooding in the electrical rooms is limited to the actuation of the FPS. The separation of the electrical trains in independent zones, along with measures to direct the water to safe drain areas, maintains the safety function of the systems housed in the RB. The MS tunnel contains the MS and main feedwater piping and their isolation valves. In the event of a feedwater pipe break or leak in the MS tunnel, water is drained to the turbine building (TB). The safety-related components in the MS tunnel are located above the maximum flood level or are designed to function when flooded.

Turbine Building

There are no components in the TB that could affect the safe shutdown of the reactor. The TB is subject to flooding from a variety of potential sources, including the circulating water system, C&FS, PSWS, RCCWS, turbine component cooling water system, CWS, and FPS. The bounding flooding source for the TB is a circulating water system pipe or expansion joint failure. Level switches are located in the TB to limit flooding in the TB in the event of a failure in the circulating water system. In any case, flooding in the TB could not affect the RB or CB because there is a 1.5-m (59-in.) high flooding barrier in the access tunnel to the RB and CB. A hypothetical massive flooding in the TB would run out of the building to the yard through relief panels.

Fuel Building

There are no safety-related components in the FB that flooding in the FB could affect. The FPS, CWS, RCCWS, HWS, FAPCS, MWS, and CS&TS (condensate storage tank) are the primary sources of flooding in the FB. In any case, flooding in the FB could not affect the RB because the connection points in the lower elevation are watertight.

Radwaste Building

The RW does not contain safety-related equipment. The radwaste tunnel and other connections with the CB and RB are designed to prevent floodwaters from spreading in the RW to the CB or RB. The primary sources of flooding in the RW are the liquid waste management system, the building drain systems, RWCU/SDC system, FAPCS, condensate purification system, CS&TS, CWS, HWS, and FPS. In case of flooding, the building substructure serves as a large sump that can collect and hold any leakage within the building.

Electrical Building

The electrical building (EB) has no safety-related components. The floodwater in a non-safety-related DG room is discharged outside via the equipment access door. The primary sources of flooding in the EB are the FPS, CWS, HWS, and RCCWS (non-safety-related DG rooms). The main source of potential floodwater is from an FPS piping failure. A flooding barrier is provided at the nuclear island (NI) access tunnel EB access door. In addition, for further protection, the access doors to the RB and CB are watertight.

Summary

Based on the above evaluation and information provided in DCD Tier 2, Revision 3, Section 3.4.1, the staff finds that GEH has identified all the internal flood sources for the ESBWR design. However, the staff is not able to verify the following GEH statements:

- The resulting flood level in the RB lower elevation is 20 cm (8 in.), and that maximum flood level is lower than the CRD HCU room elevation.
- Safety-related components in the lower elevation of the RB are located above the maximum flood level.
- The maximum water depth of 40 cm (16 in.) in the lowest floor of the CB is below the DCIS room floor elevation.
- Water in the lower elevation of the CB from pipe failures in the HVAC rooms is retained in the HVAC rooms by the installation of 200-mm (8-in) high curbs in the access doors, chases, and other floor openings, as well as by normally closed isolation valves in the drainlines.

In RAI 3.4-9 the staff requested that GEH should provide calculations to demonstrate the resulting flood level in each of the above areas. Also, the 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 is being tracked as an open item.**

In addition, the staff finds that the DCD has not addressed protection for systems that are RTNSS from potential internal flooding resulting from seismic events. Therefore, the staff is not able to conclude that systems that are RTNSS will be protected from flood-related effects associated with both high- and moderate-energy fluid piping and component failures inside and outside containment. This is further discussed in RAI 22.5-5 in Section 22 of this SER. **This is an open item.**

3.4.1.4 Conclusions

Because of the open RAIs that need the resolution as discussed above, the staff is not able to finalized its conclusion that the ESBWR has adequate flood protection features to guard safety-related SSCs in the CB and RB and to protect systems that are RTNSS systems from flood-related effects associated with both high- and moderate-energy fluid piping and component failures inside and outside containment.

3.4.2 Analysis Procedures

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 for 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.

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

- the data of the highest flood and ground water and the establishment of appropriate loading to account for flood and ground water on seismic Category I structures
- for plants where the flood level is higher than the proposed grade around the plant structures, considerations of the dynamic phenomena associated with flooding such as currents and flood waves, including their hydrodynamic effects
- 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 3.

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 as defined in Table 1.2-6 of Volume III of the Electric Power Research Institute's (EPRIs) "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 SER address the staff's review of the acceptability of the site parameters related to flood and ground water, respectively, while this section of the SER addresses the acceptability of the analysis procedures.

The staff reviewed the information provided by the applicant 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 requested the applicant to provide the necessary information. In the last paragraph of DCD Tier 2, Revision 3, Section 3.4.2, the applicant stated that the lateral hydrostatic pressure on the structures resulting from the design flood level as well as ground water and soil pressure are factored into the structural design in accordance with SRP Section 3.4.2. The applicant further referred to Appendix 3G, "Design Details and Evaluation Results of seismic Category I Structures," to the DCD for more specific design information. The staff requested the applicant to provide a discussion of the specific steps adopted in accounting for the lateral hydrostatic pressure resulting from the design flood level as well as ground water and soil pressure for the embedded areas of the RB and FB, including references to pertinent quantitative analysis results from DCD Appendix 3G. **RAI 3.4-10 is being tracked as an open item.**

In RAI 3.4-11, the staff requested the applicant to provide the following information:

- based on the information presented in DCD Revision 3, Table 3.4-1, a listing of penetrations below design flood level that go through the RB, FB, and CB, including the access openings in the CB

- typical sketches of the penetrations/access opening depicting how the leaktight function of the seals is ensured against the hydrostatic pressure head resulting from the design flood and ground water

- indication of whether bellows are used for large diameter penetrations to accommodate potential differential displacement effects

RAI 3.4-11 is being tracked as an open item.

3.4.2.4 Conclusions

Because of the open items that remain to be resolved, the staff is unable to finalize its conclusions regarding the acceptability of the ESBWR design for satisfying the requirements of GDC 2.

3.5 Missile Protection

GDC 4, "Environmental and Dynamic Effects Design Bases," of Appendix A, of 10 CFR Part 50, requires in part that SSCs important to safety must be protected against the effects of missiles that may result from equipment failures and from events and conditions outside the plant. GDC 2 requires that SSCs that are important to safety must be designed to withstand the effects of natural phenomena such as tornadoes without loss of capability to perform their safety functions. In addition, 10 CFR 100.21(d) requires an evaluation of the physical characteristics of the site, including meteorology, and the establishment of site parameters such that potential threats from such physical characteristics will pose no undue risk to the type of facility proposed to be located at the site.

3.5.1 Missile Selection and Description

Seismic Category I SSCs in the ESBWR standard design are required to be 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. In the ESBWR DCD Tier 2, Revision 3, Section 3.5.1, GEH, described the criteria for identifying missiles and protecting SSCs from their effects, as well as an assessment for determining if the protection requirements meet the NRC regulations. GEH stated that once a potential missile is identified, its statistical significance is determined in the following manner:

- If the probability of occurrence of a missile (P_1) is less than $1x10^{-7}$ per year, the missile is not considered significant.
- If P_1 is greater than $1x10^{-7}$ per year, the probability that the missile will impact a significant target (P_2) is determined.
- If the product of the above probabilities (P_1 x P_2) is less than $1x10^{-7}$ per year, the missile is not considered significant.
- If the product (P_1 x P_2) is greater than $1x10^{-7}$ per year, the probability of significant damage (P_3) is determined.
- If the combined probability (P_1 x P_2 x P_3 = P_4) is less than $1x10^{-7}$ per year, the missile is not considered significant.
- Finally, if the combined probability (P_4) is greater than $1x10^{-7}$ per year, protection of safety-related SSCs against the missile will be provided by one or more of the following methods:
    - locating the system or component in an individual missile-proof structure

- physically separating redundant systems or components of the system from the missile trajectory path or calculated range
- providing local shields or barriers for systems and components
- designing the particular structure or component to withstand the impact of the most damaging missiles with conservative design criteria
- providing design features on the potential missile source to prevent missile generation
- orientating a missile source to prevent unacceptable consequences caused by missile generation

GEH established the following criteria to provide an acceptable design basis for the plant's capability to withstand the statistically significant missiles postulated inside the RB and listed the safety systems requiring missile protection in DCD Tier 2, Revision 3, Table 3.2-1:

- No loss of containment function results from missiles generated internally in the containment.
- There is reasonable assurance that plant operators can achieve and maintain a plant safe-shutdown condition.
- Offgas exposure meets the 10 CFR 50.34(a) guidelines for those potential missile damage events resulting in radiation activity release.
- The failure of non-safety-related equipment, components, or structures whose failure could result in a missile does not cause failure of more than one division of safety-related equipment.
- No high-energy lines are located near offgas charcoal bed absorbers.

In addition, in DCD Tier 2, Revision 3, Section 3.5.1, GEH stated that many practices used in the fabrication, construction, and inspection of equipment, as well as conservative design criteria, resulted in very robust components making the design missile proof. The following general criteria are used in the design, manufacture, and inspection of components:

- All pressurized equipment and sections of piping that may periodically be isolated under pressure have pressure relief valves acceptable under the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (hereafter referred to as the ASME Code) to ensure that no pressure buildup in equipment or piping sections exceeds the design limits of the material involved.
- Components and equipment of various systems are designed and built to meet ASME Code or other equivalent industrial standards with a stringent quality control program.
- There is volumetric and ultrasonic testing where required by ASME code,

coupled with periodic ISIs of material used in components and equipment.

The staff finds the GEH approach to identify potential missiles, determine the statistical significance of potential missiles, and provide measures for SSCs requiring protection against the effects of missiles to be acceptable. However, during the review of DCD Tier 2, Revision 1, the staff found that the applicant did not address protection for RTNSS from potential missiles. Therefore, the staff issued a RAI as described below.

RAI 3.5-1

In Section 3.5.1, of DCD Tier 2, GEH 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, the staff requested GEH 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 RWCU/SDC system was not listed as requiring missile protection for its RCPB and SDC 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 dated May 10, 2006, to items (1) and (2) of the above RAI 3.5-1, GEH stated that it discussed RTNSS in DCD Section 19.6 and Appendix 1D, and the RWCU/SDC system was not identified as a candidate for RTNSS. The applicant's rationale was that the probabilistic risk analyses (PRAs) did not rely on the RWCU/SDC system to meet the staff's safety goal (a core damage frequency (CDF) less than $1x10^{-4}$ per year and large release frequency less than $1x10^{-6}$ 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, GEH stated that the design implemented for the system provided 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 GEH 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 issued RAI 19.1.0-2 regarding the determination of non-safety-related systems as candidates for RTNSS consideration.

By letter dated January 30, 2007, GEH responded to the staff's RAI 19.1.0-2. Section 22.0 of this SER 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, GEH 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.

Section 3.5.1.1 of this SER addresses the staff's evaluation of internally generated missiles (outside containment).

Section 3.5.1.2 of this SER addresses the staff's evaluation of internally generated missiles (inside containment).

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

Section 3.5.1.4 of this SER addresses the staff's evaluation of missiles generated by natural phenomena.

3.5.1.1 Internally Generated Missiles (Outside Containment)

3.5.1.1.1 Regulatory Criteria

The staff reviewed the ESBWR design's provisions for protecting SSCs important to safety against internally generated missiles (outside containment) in accordance with SRP Section 3.5.1.1, Revision 3, of NUREG-0800. The staff's acceptance of the ESBWR design is based on the design's compliance with the requirements of GDC 4. GDC 4 requires in part that SSCs important to safety shall be appropriately protected against the dynamic effects of internally generated missiles outside containment that may result from equipment failures.

3.5.1.1.2 Summary of Technical Information

GEH evaluated the potential internally generated missiles that could result from failure of the plant equipment located outside the 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—GEH evaluated the potential missiles that could result from in-plant rotating equipment overspeed failures and examined the equipment within the general categories of pumps, fans, blowers, DGs, compressors, and turbines for possible missile generation. Particularly, it examined components in the systems normally functioning during reactor power operation for any potential source of credible and significant missiles.

(2) Internally generated missiles resulting from in-plant high-pressure system ruptures—GEH evaluated the potential missiles that could result from high-pressure system ruptures against the design criteria. GEH 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. GEH categorized the potential missiles generated by these pressurized components as contained fluid energy missiles or stored-energy (elastic) missiles. GEH 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

GEH evaluated the rotating equipment within the general categories of electrically powered rotating equipment, such as pumps, blowers, DGs, and compressors, for any possible source of credible and significant missiles. GEH determined that no credible missiles meet the significant criteria of having a probability (P_4) greater than $1x10^{-7}$ per year. The applicant's rationale is that the equipment design and manufacturing criteria result in a probability (P_1) less than $1x10^{-7}$ per year, and sufficient physical separation of safety-related and redundant equipment exists so that the combined probability (P_1 x P_2) is less than $1x10^{-7}$ per year. In addition, since pumps, fans, and the like are powered by 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, GEH 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 SER addresses the staff's evaluation of turbine missiles.

GEH evaluated potential missiles that could result from the failure of pressurized components. GEH indicated that those valves rated ANSI 6.21 megapascals (MPa G) (900 pounds psig gauge) 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 ASME code requirements. Valves rated ANSI 4.14 MPa G (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 RCSs 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 1.9 MPa G (275 psig) are not credible missile sources as defined in DCD Section 3.6.2.1. The pneumatic system with pressures higher than 1.9 MPa G (275 psig), such as in air bottles, the emergency breathing air system (EBAS), and the standby liquid control accumulator tank, are not considered a credible source of missiles with 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.
- The bottles are strapped in a rack to prevent them from toppling over, and the rack is seismically designed.

During the review of DCD Tier 2, Revision 1, Section 3.5.1.1, regarding internally generated missiles outside the containment resulting from plant equipment and component failures within the NI, the staff identified areas in which additional information was necessary to complete its review. The following paragraphs discuss the staff's RAIs issued by letter dated March 22, 2006, and the applicant's responses.

RAI 3.5-2

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

In its response dated May 10, 2006, GEH 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 these types of components are not a potential missile source, 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 RCSs 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 1×10^{-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 in high-energy systems are not used.

The analysis did not consider instrumentation, such as pressure, level, and flow transmitters and associated piping and tubing, as credible missiles. The amount of high-energy fluid in these instruments is limited and will not result in the generation of missiles.

GEH 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 GEH response to RAI 3.5-2 acceptable and this RAI is resolved.

RAI 3.5-3

DCD Section 3.5.1.1.2.2 states that piping failures do not form missiles because the whipping section remains attached to the remainder of the pipe. However, a guillotine break of a high-energy line could cause piping attachments to become missile sources. DCD Section 3.6 discusses the dynamic effects related to jet impingement forces and pipe whipping, but does not consider missile generation. The staff asked GEH to discuss a postulated guillotine break of a high-energy line outside the containment that could become a potential missile source.

In its response dated May 10, 2006, GEH 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 BTP EMEB 3-1, as described in DCD Section 3.6.

In DCD Tier 2, Revision 3, Section 3.6.2.1.3, GEH provided the criteria for defining potential breaks of high-energy line systems outside the containment, stating that (1) circumferential (guillotine) breaks are only assumed 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 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's concern described in RAI 3.5-3 is resolved.

RAI 3.5-4

DCD Section 3.5.1.1.1.3 describes other missile analyses. However, this section does not address gravitational missiles. The staff asked GEH to 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 dated May 10, 2006, GEH 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 NI, 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 finds it acceptable. Because seismic Category I components are designed and protected to meet the spatial requirements of RTNSS and separation requirements of BTP 3-1, there should be no potential gravitational missiles that could be generated outside the containment. Therefore, the staff's concern described in RAI 3.5-4 is resolved.

RAI 3.5-5

DCD Section 3.5.1.1.2.2.6 states that blowout panels are hinged to prevent them from becoming missiles. The staff asked GEH to explain how it provides protection from external missiles for safety-related components located near the opening of the swing-type blowout panels.

In its response dated May 10, 2006, GEH 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's concern described in RAI 3.5-5 is resolved.

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

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 of SRP Section 3.5.1.1, Revision 2. However, the staff also finds that the applicant has not addressed protection for systems that are RTNSS against internally generated missiles outside containment. Therefore, the staff has not been able to conclude that systems that are RTNSS have been adequately protected from internally generated missiles outside containment. Chapter 22 of this SER addresses this item. **This is an open item.**

3.5.1.2 Internally Generated Missiles (Inside Containment)

3.5.1.2.1 Regulatory Criteria

The staff has 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's acceptance of the ESBWR design is based on the design's conformance with the requirements of GDC 4. GDC 4 requires in part that SSCs important to safety shall be appropriately protected against the dynamic effects of internally generated missiles inside containment that may result from equipment failures during power operation.

3.5.1.2.2 Summary of Technical Information

Internal missiles are those resulting from plant equipment failures within the containment. The potential internal missiles can be categorized into three groups:

(1) missiles generated by rotating equipment (e.g., pump impellers, compressors, and fan blades)

(2) missiles generated by pressurized components (e.g., valve bonnets, thermowells, nuts, bolts, studs, valve stems, and accumulators)

(3) gravitational missiles

Rotating Equipment

GEH stated that by an analysis similar to that described in DCD Tier 2, Revision 3, Section 3.5.1.1.1, it concluded that no items of rotating equipment inside the containment are capable of becoming potential missiles.

Pressurized Components

GEH stated that it specified and discussed the identification of potential missiles resulting from high-pressure system ruptures and their consequences outside containment in DCD Tier 2, Revision 3, Section 3.5.1.1.2. The same conclusions are drawn 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) mechanisms under the reactor vessel. The FMCRD mechanisms are not credible missiles, because the FMCRD 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, 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.

Gravitational Missiles

GEH stated that seismic Category I SSCs are not considered potential gravitational missile sources. NS items and systems inside containment are considered as follows:

- Cable trays—all cable trays for both Class 1E and non-Class 1E circuits are seismically supported whether or not a hazard potential is evident.

- Non-safety-related conduit and pipe—non-Class 1E 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, Revision 3, Section 3.7.3.8.

- 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

GEH evaluated the potential internal missiles resulting from plant equipment and component failures within the containment structure. GEH 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.

GEH 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. GEH justified its decision in DCD Tier 2, Revision 3, Section 3.5.1.2.2, with the following pressurized components:

- The accumulators of the ADS are moderate-energy vessels that are not a credible missile source.

- 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, there are internal restraints provided to support the FMCRD housing in the event of failure in the housing-to-nozzle weld or the housing.

GEH 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 based on the following design features:

- All cable trays for both Class 1E and non-Class 1E circuits are seismically supported whether or not a hazard potential is evident.

- The non-safety-related components are seismically supported to prevent their collapse during a SSE.

- The components that are identified as potential hazards to safety-related equipment, include all cable trays for both Class 1E and non-Class 1E circuits as well as non-Class 1E conduits and non-safety-related piping, are seismically analyzed.

- The non-Class 1E conduit is seismically supported if it is identified as a potential hazard to safety-related equipment.

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

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.

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. However, the COL holder needs to establish and provide procedures to require that equipment, such as a hoist that is required during maintenance, be either removed or seismically restrained following maintenance to prevent it from becoming a missile. In RAI 3.5-18, the staff requested GEH to include such requirements for COL holders. **RAI 3.5-18 is being tracked as an open item**.

In addition, in DCD Tier 2, Revision 3, Section 3.5.1.2.3, GEH justified that secondary missiles (concrete fragments) resulting from the impact of primary missiles on concrete structures will not be considered credible threats. Because all the containment structures are formed with steel, GEH considered no concrete fragments as secondary missiles. The staff agrees with GEH that concrete fragments need not be considered as secondary missiles.

During the review of DCD Tier 2, Revision 1, Section 3.5.1.2, regarding the internal missiles generated inside the containment, the staff identified areas in which additional information was necessary to complete its review. The following paragraphs discuss the staff's RAIs issued by letter dated March 22, 2006, and the applicant's responses.

RAI 3.5-6

Since operating nuclear plants seldom use squib valves, the reliability of the valve is not traceable through plant operation experiences. The staff asked GEH to discuss how it evaluated the failure of explosive squib valves, both as an initiating event and at 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 asked GEH 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 dated May 10, 2006, GEH stated that BWR SLCSs have used explosive valves in the past. Other systems also employ explosive valves in the ESBWR design, namely the 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. GEH 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 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 no missile can be generated by the explosive booster assembly because it is integrally built with the valve. Therefore, the staff's concern described in RAI 3.5-6 is resolved.

RAI 3.5-7

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. The staff asked GEH 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 safe shutdown.

In its response dated May 10, 2006, GEH stated that DCD Section 3.5.1.1.2.2 discusses the design characteristics of the SRVs that provide the basis to exclude 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. GEH noted that the remaining components that act as guides will prevent the larger diameter components in the shaft from becoming missiles. GEH provided a sketch showing relevant features for the SRV valves.

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's concern described in RAI 3.5-7 is resolved.

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 of SRP Section 3.5.1.2, Revision 2. However, the staff also finds that GEH has not addressed protection for systems that are RTNSS against internally generated missiles inside containment. Therefore, the staff is not able to conclude that GEH has adequately protected systems that are RTNSS from internally generated missiles inside containment. Chapter 22 of this SER addresses this item. **This is an open item.**

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 3, in accordance with the following regulations and guidance:

- GDC 4 requires that SSCs important to safety be protected against the effects of missiles that might 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, "Protection Against Low-Trajectory Turbine Missiles"; 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 the SER.

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 x P_3 can be reasonably taken to fall within the range of $1x10^{-4}$ to $1x10^{-3}$ per year for favorably oriented turbines, and (2) the NRC's criterion of $1x10^{-7}$ per reactor year for P_1 x P_2 x 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, Revision 3, 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 QA in design and fabrication, inspection and testing programs as provided in Section 10.2 of the DCD, and overspeed protection systems, provide an acceptable small risk from turbine missiles. Section 3.5.1.1.1.2 of DCD Tier 2, Revision 3, further states that the COL holder will provide an evaluation which 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.

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, 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, Revision 3, 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 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 states that the COL holder will provide an evaluation which concludes that the probability of turbine missile generation is less than $1x10^{-5}$ in accordance with Section 10.2.5 of the DCD. Because the turbine missile generation analysis would include an

ISI interval component that is needed to calculate the probability of turbine missile generation, the staff concludes that the ESBWR design satisfies SRP Section 3.5.1.3.II.4. Furthermore, the staff will review the COL holder's evaluation, which concludes that the probability of turbine missile generation is less than 1×10^{-5} in accordance with DCD Section 10.2.5. On that basis, 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's safety objectives.

SRP Section 3.5.1.3.II.5 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. Section 3.5.1.1.1.2 of DCD Tier 2, Revision 3, states that the COL holder will provide an evaluation which concludes that the probability of turbine missile generation (P_1) is less than 1×10^{-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, 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 a letter dated August 2, 2007, GEH 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. In addition, DCD Tier 1, Section 2.11.4, requires external turbine missile probability to be less than 1×10^{-4} per turbine year. DCD Tier 1, Table 2.11.4-1, inspection, test, analysis, and acceptance criterion (ITAAC) 5 also requires that "An analysis exists that documents that the probability of turbine material and overspeed related failures, resulting in external turbine missiles, is $<1 \times 10^{-4}$ per turbine year." Based on proposed turbine rotor designs that use integral forgings, the probability of turbine missile generation is less than 1×10^{-5} for the ESBWR, as stated in DCD Tier 2, Section 10.2.1. This probability is lower than that required by SRP Section 3.5.1.3, Table 3.5.1.3-1, for loading the turbine and bringing the plant (system) on line. 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 1×10^{-4} per turbine year.

Section 10.2.3 of this SER provides additional discussion of the staff's evaluation of the turbine ISI program. Section 10.2.2 of this SER 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 3, 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 which concludes that the probability of turbine missile generation (P_1) is less than 1×10^{-5} 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 design of the facility for protecting SSCs important to safety against the missiles generated by natural phenomena in accordance with the guidance of Section 3.5.1.4, "Missiles Generated by Natural Phenomena," of the SRP, Revision 3. The staff's acceptance of the ESBWR design of the facility for providing protection against missiles generated by natural phenomena is based on the design's compliance with the applicable requirements of GDC 2 and 4.

- 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.

The design is considered to be in compliance with GDC 2 and 4 if it meets Regulatory Positions C.1 and C.2 of RG 1.76.

3.5.1.4.2 Summary of Technical Information

Tornado-generated missiles, which have been determined to be the limiting natural phenomena hazard in the design of all structures required for the safe shutdown of the nuclear power plant, are used in the design basis for the ESBWR design. GEH used the Spectra 1 tornado missile spectrum, as identified in Section 3.5.1.4 of the SRP, Revision 3. In DCD Tier 2, Revision 3, Table 2.0-1, GEH specified the design parameters for the DBT and tornado missile spectrum as well as the site proximity missiles for the ESBWR design.

3.5.1.4.3 Staff Evaluation

In DCD Tier 2, Revision 3, Table 2.0-1, GEH provided the following parameters for the DBT:

- maximum tornado windspeed of 147.5 meters per second (m/s) (330 miles per hour (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 meters (m) (159 feet (ft))

- maximum atmospheric pressure differential of 16.6 kilopascals (kPa) (2.4 pounds psi)

- rate of pressure change of 11.7 kPa/s (1.7 psi/s)

The staff finds that these design parameters are more conservative than those specified in RG 1.76; therefore, the staff finds them acceptable. In addition, the staff finds that the tornado missile spectrum is acceptable and that it is properly selected for the ESBWR design and meets the requirements of GDC 2 and 4 with respect to protection for safety-related SSCs against natural phenomena.

Regarding a site proximity missile (except aircraft) for the ESBWR design, GEH specified the probability of occurrence to be less than $1x10^{-7}$ per year. This is consistent with the guidance of RG 1.76, Revision 1; therefore, the staff finds it acceptable. However, the COL applicant needs to confirm that the site has been selected such that the possible occurrence of the site proximity missile (except aircraft) is less than $1x10^{-7}$ per year. This is further discussed in Section 3.5.1.5 of this SER.

Section 3.5.2 of this SER addresses the staff’s evaluation of the protection provided for safety-related equipment from the identified tornado missiles, including conformance with RG 1.117.

Section 3.5.3 of this SER addresses the staff’s evaluation of the design of missile barriers and protective structures to withstand the effects of the identified tornado missiles.

During the review of DCD Tier 2, Revision 1, Section 3.5.1.4, the staff identified areas for which it needed additional information to complete its review. The following paragraphs discuss the staff’s RAIs issued by letter dated March 22, 2006, and the applicant’s responses.

RAI 3.5-8

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 design of seismic Category I buildings. In considering tornado-generated missile threats to plant safety-related SSCs, the staff asked GEH to explain whether the missile threat is considered concurrent with a LOOP.

In its response dated May 10, 2006, GEH 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 only take credit 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 (containment response) and 6.3.3 (RPV response).

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 against the missiles generated by natural phenomena, a DBT and tornado missile spectrum are bounded by the design-basis LOCA events with a concurrent LOOP. Therefore, the staff's concern described in RAI 3.5-8 is resolved.

RAI 3.5-9

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 were deemed to be credible. The staff asked GEH to address the potential for other extreme winds in more detail.

In its response dated May 10, 2006, GEH 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 tornados. Therefore, the design does not consider wind-driven missiles. GEH also provided a reference to James R. McDonald's "Rationale for Wind-Borne Missile Criteria for DOE Facilities" issued September 1999, to support its conclusion.

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

3.5.1.4.4 Conclusions

Based on its review, the staff concludes that GEH properly selected the tornado missile spectrum for the ESBWR design and that it meets the requirements of GDC 2 and 4 with respect to protection for safety-related SSCs against natural phenomena and missiles, meets the guidance of RGs 1.76 and 1.117 with respect to identification of missiles generated by natural phenomena, and is therefore acceptable.

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 human-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 (that is, if the probability of site proximity missiles (except aircraft) having the potential for radiological consequences greater than 10 CFR 50.34(a)(1) exposure guidelines as required by 10 CFR Part 100, is less than about $1x10^{-7}$ per year),

- 10 CFR 100.21(e), which states that potential hazards associated with nearby transportation routes and industrial or 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; the plant meets the relevant requirements of GDC 4 and is considered appropriately protected against site proximity missiles design if SSCs important to safety are capable of withstanding the effects of the postulated missiles without losing their safe shutdown capability and without causing a release of radioactivity that could exceed the 10 CFR Part 100 dose guidelines,

- 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,

- 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 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 $1x10^{-7}$ 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 $1x10^{-7}$ 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, GE has provided appropriate information that the COL applicant needs to address for 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 human-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 (that is, the probability of aircraft accidents having the potential for radiological consequences greater than the 10 CFR 50.34(a)(1) exposure guidelines as required by 10 CFR Part 100 is less than about 1×10^{-7} per year),

- 10 CFR 100.21(e), which states that potential hazards associated with nearby transportation routes and industrial or 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, which requires that SSCs important to safely have appropriate protection against the effects of fires,

- 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,

- 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 3.5.1.6 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 1×10^{-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 1×10^{-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 1×10^{-7} per year based on the COL applicant's address 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, GE 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 design of the facility for protecting SSCs on the plant site against externally generated missiles in accordance with the guidance of SRP Section 3.5.2, Revision 3, including all the safety-related SSCs and elements such as essential service water intakes, buried components (e.g., essential service water piping, storage tanks), and access openings and penetrations in structures. The staff's acceptance of the ESBWR facility design of the facility for providing protection against externally generated missiles is based on the design's conformance with the applicable requirements of GDC 2 and 4:

- GDC 2 requires in part that the design of 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.

The design is considered to be in compliance with GDC 2 and 4 if it meets the following guidelines:

- RG 1.13, “Spent Fuel Storage Facility Design Basis,” Revision 1, issued December 1975, as it relates to the capacity of the SFPC 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, issued July 1977, 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.

Section 3.5.1.3 of this SER discusses protection from low-trajectory turbine missiles, including compliance with RG 1.115.

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 have been provided to support the reactor facility. DCD Tier 2, Revision 3, Section 3.5.1, identifies the sources of external missiles that could affect the safety of a plant. Certain items in the plant are required to safely shut down the reactor and maintain it in a safe condition assuming an additional single failure. These are the safety-related items listed in DCD Table 3.2-1, which also gives their appropriate safety classes and equipment locations. These items, whether they are structures, systems or components, are protected from externally generated missiles. GEH stated in DCD Tier 2, Revision 3, Section 3.5.2, that 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 FAPCS that transport makeup water to the SFP and isolation and passive containment cooling (PCS) pools from the FPS against tornado missiles.

3.5.2.3 Staff Evaluation

GEH considered tornado-generated missiles as the limiting externally generated missiles on a plant site. The systems and equipment required to safely shut down the reactor and maintain it in a safe condition are necessary to meet the single-failure criteria. Section 3.5.1.4 of this SER discusses the tornado missile spectrum. In DCD Tier 2, Revision 3, Section 3.5.2, GEH stated that all the safety-related systems are located within the 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 FAPCS that transport makeup water to the SFP and isolation and PCC pools from the FPS against tornado missiles. On the basis of this review, the staff concludes that the ESBWR design meets the guidelines of RG 1.117. However, the COL applicant needs to evaluate all non-safety-related SSCs in a plant site (not housed in a tornado-protected structure) whose failure as a result of a DBT missile could adversely impact the safety function of safety-related systems. This item is further discussed in Section 3.5.3 of this SER.

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 SFP from externally generated missiles. Therefore, the staff concludes that the SFP meets the guidelines of RG 1.13.

The ESBWR design does not use an ultimate heat sink as it is 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 (ICS) 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 are protected 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.

The ESBWR design uses the passive containment cooling system (PCCS) as the safety-related ultimate heat sink for other design-basis events and shutdown. The PCCS removes the core decay heat rejected to the containment after a LOCA and maintains the containment within its pressure limits for DBAs. The PCCS pools are located inside the containment and are protected from tornado missiles. On the basis of this review, the staff concludes 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 indicated in DCD Tier 2, Revision 3, Section 3.5.1.1.1.2, and shown in DCD Figure 3.5-2, 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 concludes that the ESBWR design meets the guidelines of RG 1.115.

3.5.2.4 Conclusions

On the basis of the above review, 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 environment effects and missiles and that it meets the guidelines of SRP Section 3.5.2, Revision 2. However, the staff also found that the applicant has not addressed protection for systems that are RTNSS against externally generated missiles. Therefore, the staff has not been able to conclude that systems that are RTNSS have been adequately protected from externally generated missiles. Chapter 22 of this SER addresses this item. **This is an open item.**

3.5.3 Barrier Design Procedures

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 GDC 4 with respect to the capability of structures to withstand the effects of missile impacts and to provide protection 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 for 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. 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 relating 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

- 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 used Section C.7 of Appendix C to American Concrete Institute (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 II 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,” 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 requested the applicant to provide the following:

> 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 dated May 10, 2006, 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 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

DCD Tier 2, Section 3.5.3.3, states 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 on 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 satisfying the minimum concrete barrier thickness for Region II listed in Table 1 of SRP Section 3.5.3, Revision 1, issued July 1981, which is compatible with a maximum tornado windspeed of 300 mph in accordance with RG 1.76, Revision 0, issued April 1974. Since the maximum tornado windspeed for the ESBWR certified design is 330 mph, the staff considers Region II minimum barrier thickness to be not conservative. GEH revised DCD Tier 2, Revison 4, Section 3.5.3.1.1, by committing to satisfying the minimum concrete barrier thickness of Region I listed in Table 1 of SRP Section 3.5.3, Revision 1. These values are acceptable to the staff because they are compatible with a maximum tornado wind speed of 360 mph, which exceeds the ESBWR design parameters.

In its response to RAI 3.8-64, S02, dated June 26, 2007, GEH indicated that it 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. GEH also committed to revising DCD Section 3.5.3.2 in Revision 4 to include reference to the Bechtel topical report. 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 provide comparable results to those 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 missile shields and barriers induced by design-basis tornado missiles selected for the plant, provides 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 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 GDC 4.

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

Section 6.2 of this SER 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 NRC staff reviewed the ESBWR design as it relates to the protection of safety-related SSCs against postulated piping failures in fluid systems outside containment in accordance with the guidance in SRP Section 3.6.1 of NUREG-0800. The staff's acceptance of the design is based on the design's compliance with the requirements of GDC 4, "Environmental and Dynamic Effects Design Bases," of Appendix A of 10 CFR Part 50. GDC 4 requires in part that SSCs important to safety shall be designed to accommodate the dynamic effects of postulated pipe rupture, including the effects of pipe whipping and discharging fluids.

Compliance with GDC 4 is based on meeting the guidance of BTP SPLB 3-1, "Protection Against Postulated Piping Failures in Fluid Systems Outside Containment," with regard to high- and moderate-energy fluid systems outside containment and BTP EMEB (formerly the Mechanical Engineering Branch) 3-1, "Postulated Rupture Locations in Fluid System Piping Inside and Outside Containment."

In BTP SPLB 3-1, the staff specified that postulated piping failures in fluid systems outside containment should not cause a loss of function of essential safety-related systems. The BTP also specified that nuclear plants should be able to withstand postulated failures of any fluid system piping outside containment, taking into account the direct results of such failures and the further failure of any single active component, with acceptable offsite consequences. In BTP EMEB 3-1, the staff described the acceptable bases for selecting the design locations and orientations of postulated breaks and cracks in fluid systems piping.

3.6.1.2 Summary of Technical Information

The ESBWR plant is designed in accordance with the guidance described in SRP Section 3.6.1 for protection against piping failures outside containment, to ensure that such failures would not cause the loss of needed functions of safety-related systems or prevent the plant's safe shutdown capability. The design includes consideration 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 3, Section 3.6.1, GEH, provided the design basis and criteria for the analysis needed to demonstrate that safety-related systems are protected from pipe ruptures. This DCD section enumerates 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 systems and components. In DCD Tier 2, Revision 3, Section 3.6.2, "Determination of Break Locations and Dynamic Effects Associated with the Postulated Rupture of Piping," GEH provided criteria for postulated pipe rupture location and configuration. GEH conducted an analysis to identify those safety-related systems, components, and equipment that provide protective actions required to mitigate the consequences of the pipe break events postulated outside the containment to acceptable limits. DCD Table 3.6-2 identifies the safety-related systems, components, and equipment or portions thereof, and DCD Table 3.6-4 identifies the high- and moderate-energy fluid systems.

GEH stated that pipe break events involving high-energy fluid systems were evaluated for the effects of pipe whip, jet impingement, flooding, room pressurization, and other environmental effects such as temperature. GEH evaluated pipe break events involving moderate-energy fluid systems for wetting from spray, flooding, and other environmental effects.

GEH used the following assumptions to determine the protection requirements:

- Pipe break events might 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 might occur simultaneously with a seismic event; however, a seismic event does not initiate a pipe break event. This applied to seismic Category I and NS Category I piping (seismically analyzed).

- A single active component failure (SACF) was assumed in systems used to mitigate consequences of the postulated piping failure and to shut down the reactor, except as noted below. An SACF was the malfunction or loss of function of a component of electrical or fluid systems. The evaluation considered the failure of an active component of a fluid system to be a loss of component function as a result of mechanical, hydraulic, or electrical malfunction, but not the loss of component structural integrity. The direct consequences of an SACF were considered to be a part of the single active failure. The SACF was assumed to occur in addition to the postulated piping failure and any direct consequences of the piping failure.

- Where the postulated piping failure was 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), GEH did not assume a single active failure of components in the other train or trains of that system only, provided the system was designed to seismic Category I standards; was powered from both offsite and onsite sources; and was constructed, operated, and inspected to QA testing and ISI standards appropriate for nuclear safety-related systems.

- If a pipe break event involved 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 considering an SACF.

- If LOPP was a direct consequence of the pipe break event (e.g., trip of the turbine generator producing a power surge that, in turn, trips the main breaker), then a LOPP occurred in a mechanistic time sequence with an SACF. Otherwise, preferred power was assumed to be 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, were able to mitigate the consequences of a failure. In judging the availability of systems, GEH took into account the postulated failure and its direct consequences, such as unit trip and LOPP, and the assumed SACF and its direct consequences. GEH judged the feasibility of carrying out operator actions based on the availability of ample time and adequate access to equipment for the proposed actions.

- Although a pipe break event outside the containment might require a cold shutdown, the evaluation allowed 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 occurred in the plane determined by the piping geometry and caused movement in the direction of the jet reaction. If unrestrained, a whipping pipe with a constant energy source formed a plastic hinge and rotated 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) was not deemed capable of forming a plastic hinge and rotating about the hinge, provided its movement could be defined and evaluated.

- The fluid internal energy associated with the pipe break reaction could take into account 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 were designed to maintain their structural integrity after a postulated failure outside containment and within the RB. Divisional separation doors, penetration, and floors were not required to maintain their structural integrity.

In DCD Tier 2, Revision 3, Section 3.6.1, GEH stated that design features, such as separation, barriers, and pipe whip restraints, provided adequate protection against the effects of pipe break events for safety-related items to an extent that their ability to shut down the plant safely or mitigate the consequences of the postulated pipe failure would not be impaired. GEH further stated that non-safety-related systems and system components were not required for the safe shutdown of the reactor, nor were they necessary for the limitation of offsite releases in the event of a pipe rupture. However, while none of this equipment was needed during or following a pipe break event, GEH did consider pipe whip protection where a resulting failure of a non-safety-related system or component could initiate or escalate the pipe break event in a safety-related system or component, or in another non-safety-related system whose failure could affect a safety-related system.

General Protection Methods

In DCD Tier 2, Revision 3, Section 3.6.2, GEH described the break locations and direct effects associated with a particular postulated break or crack. GEH considered the actual pipe dimensions, piping layouts, material properties, and equipment arrangements in defining the following specific measures for protection against actual pipe movement and other associated consequences of postulated failures:

- Pipe whip restraints, equipment shields, and physical separation of piping, equipment, and instrumentation provide protection against the dynamic effects of pipe failures.

- The precise method chosen depends largely on limitations placed on the designer such as accessibility, maintenance, and proximity to other pipes.

The staff finds the above approach acceptable to provide protection against the effects of pipe break events for safety-related items to an extent that their ability to shut down the plant safely or mitigate the consequences of the postulated pipe failure would not be impaired.

Protection Methods by Separation

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. The paragraphs below discuss these methods of protection.

For other areas where physical separation is not practical, the following high-energy line separation analysis (HELSA) evaluation is conducted to determine which high-energy lines meet the spatial separation requirements and which lines require further protection:

- For the HELSA evaluation, no particular break points are identified. Cubicles or areas through which the high-energy lines pass are examined in total. Breaks are postulated at any point in the piping system.
- Safety-related systems, components, and equipment at a distance greater than 9.1 meters (m) (30 feet (ft)) from any high-energy piping are considered as meeting spatial separation requirements. No damage is assumed to occur on account of jet impingement, because the impingement force becomes negligible beyond 9.1 m (30 ft). Likewise, a 9.1-m (30-ft) evaluation zone is established for pipe breaks to ensure protection against potential damage from a whipping pipe. Assurance that 9.1 m (30 ft) represents the maximum free length is made in the piping layout.
- Safety-related systems, components, and equipment at a distance less than 9.1 m (30 ft) from any high-energy piping are evaluated to see if damage could occur to more than one safety-related division, preventing safe shutdown of the plant. If damage occurred to only one division of a redundant system, the requirement for redundant separation is met. Other redundant divisions are available for safe shutdown of the plant and no further evaluation is performed.
- If damage could occur to more than one division of a redundant safety-related system within 9.1 m (30 ft) of any high-energy piping, other protection in the form of barriers, shields, or enclosures is used. Pipe whip restraints are used if protection from whipping pipe is not possible by barriers and shields. The following paragraphs discuss these methods of protection.

Barriers, Shields, and Enclosures

Protection requirements are met through the protection afforded by the walls, floors, columns, abutments, and foundations in many cases. 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 MSIVs and the feedwater isolation and check valves located inside the tunnel will be designed for the effects of a line break. The COL applicant will provide the details of how the MSIVs and feedwater isolation and check valves functional capabilities are protected against the effects of these postulated pipe failures as specified in DCD Tier 2, Revision 3, Section 3.6.5. Barriers or shields that the HELSA evaluation identified as necessary (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.

Pipe Whip Restraints

Pipe whip restraints are used where pipe break protection requirements could not 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 3, 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, GEH used barriers, shields, or enclosures. DCD Tier 2, Revision 3, Section 3.6.2.3, gives the design criteria for restraints.

3.6.1.3 Staff Evaluation

The staff reviewed the ESBWR design as it relates to the protection of safety-related SSCs against postulated piping failures in fluid systems outside containment in accordance with the guidance described in Section 3.6.1 of the SRP, Revision 2, issued July 1981. Satisfaction of the SRP acceptance criteria ensures that the design meets the requirements of GDC 4.

The applicant has not made the ESBWR plant detailed layout and piping drawings available for the staff to review. In addition, the DCD does not address the protection for the RTNSS against postulated piping failures in fluid systems outside containment. **This is an open item.**

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

In DCD Tier 2, Revision 3, Section 3.6.5, regarding the details of pipe break analysis results and protection methods, GEH stated that the COL applicant shall provide the following (these are COL action items):

- a summary of the dynamic analyses applicable to high-energy piping systems in accordance with Section 3.6.2.5 of RG 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants," which shall 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, cumulative usage factors (CUFs), and stress ranges as delineated in BTP EMEB 3-1
- 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 measures to protect each of the systems listed in DCD Tables 3.6-1 and

3.6-2 against the effects of postulated pipe failures

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

The staff finds the above COL actions specified by GEH to be acceptable. The staff also finds that the applicant has not addressed the protection for systems that are RTNSS against postulated piping failures in fluid systems outside containment. **This is an open item.**

During the COL application review process, the staff will determine from the safety analysis report (SAR) whether the safety-related systems as well as the systems that are RTNSS are adequately protected against postulated piping failures in fluid systems outside containment by separation or enclosure in protective barriers. The staff will compare the design basis information given in the SAR with that described in item B.2 of BTP SPLB 3-1and BTP EMEB 3-1. By this comparison of individual design features, the staff will verify that the necessary measures have been provided.

3.6.1.4 Conclusions

Based on its evaluation of the information provided in the DCD and for the reasons stated above, the staff is not able to conclude that GEH has provided adequate protection features for the ESBWR to protect safety-related SSCs and systems that are RTNSS from the effects associated with postulated piping failures in fluid systems outside containment.

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, Draft Revision 2, April 1996, “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 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 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 LOCAs. These SSCs are to be protected against the effects of pipe whip and discharging fluids.

The NRC has established requirements in BTP MEB 3-1, 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.

In SECY-93-087, the staff recommended the elimination of the operating-basis earthquake (OBE) in the design process of a plant on the basis that it would not result in a significant decrease in the overall plant safety margin. In a SRM dated July 21, 1993, the Commission approved the staff's recommendations. The analyses for the maximum stresses, stress ranges, and usage factors to be used for determining postulated high- and moderate-energy pipe break and crack locations are based on loads that include the OBE. The staff concluded that no replacement earthquake loading should be used to establish the postulated pipe rupture and leakage crack locations once the OBE is eliminated from the design and 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 loads and operational transients. However, for establishing pipe breaks and leakage cracks from fatigue effects, the staff concluded that calculations of the CUF should continue to include seismic cyclic effects as discussed in Section 3.12.6.15 of this SER. Therefore, the staff based its evaluation of DCD Tier 2, Section 3.6.2, on the Commission-approved staff recommendations.

3.6.2.2 Summary of Technical Information

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

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

GEH listed the safety-related SSCs in DCD Tier 2, Table 3.6-1, for inside containment and Table 3.6-2 for outside containment. GEH 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, GEH 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, GEH 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 ASME Boiler and Pressure Vessel Code (ASME Code). For a structure separating a high-energy line from a safety-related component, GEH stated that the separating structure will be designed to withstand the consequences of the pipe break in the high-energy line at locations postulated based on these criteria. However, some structures that are identified as necessary by the HELSA, which is based on no specific pipe break locations, are designed for worst case loads. Section 3.6.2.1.2 provides criteria of 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, GEH 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. GEH stated that these forcing functions are determined for the ESBWR by the method specified in Appendix B to 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 EMEB 3-1, item B.3, to calculate the blowdown force acting on the ruptured pipe.

In DCD Tier 2, Section 3.6.2.2, GEH 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, GEH provided a procedure for performing the evaluation of 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 to be used for 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. Only U-bar-type whip restraints and simplified computer models of the piping and pipe whip restraints are included in the procedure. 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, GEH 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. Safety-related SSCs should be protected or designed to withstand the loads induced by the impingement of jets. In DCD Tier 2, Section 3.6.2.3.1, GEH discussed methods to be used to evaluate 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. The methods are commensurate with those given in Appendixes 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 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 two is applied to the static analysis results.

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, GEH 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. GEH 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, GEH 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 are in conformance with the requirements of paragraph 6.6 of ANS 58.2.

GEH 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 in the design selectively to ensure its safety-related function if ever needed. Other methods (i.e., testing) with a reliable database for design and sizing of whip restraints can 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, GEH 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 ABS. GEH 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, GEH stated that the ESBWR does not require guard pipes. However, in Section 3.6.2.1.1 for piping in containment penetration areas, GEH used sleeves for those portions of the piping in the containment penetration areas designed in accordance with BTP MEB 3-1, item B.1.b(6).

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

In DCD Tier 2, Section 3.6.4, GEH 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, GEH 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).

3.6.2.2.6 Combined License Information

In DCD Tier 2, Section 3.6.5, GEH stated that the COL applicant will provide the following:

- 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 MEB 3-1

- 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

- 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

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 GEH 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:

- defining 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

- guard pipe assembly design
- as-built inspection of high-energy pipe break mitigation features
- COL information

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, GEH 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 SPLB 3-1, which is attached to SRP Section 3.6.1. The operating temperature that separates the high-energy piping from moderate-energy piping is slightly different between that in Appendix A to BTP SPLB 3-1 and the DCD. Appendix A to BTP SPLB 3-1 defines this temperature to be 95 °C, while the DCD identifies it to be 93.3 °C. However, both have the same values when expressed in their corresponding Fahrenheit (F) values of 200 °F, and the DCD value in Centigrade (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 SPLB 3-1, 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, GEH identified high-energy piping systems inside and outside the containment that are subject to postulated pipe breaks. However, GEH 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 the applicant to identify moderate-energy systems that will be subject to postulated leakage cracks in accordance with SRP Section 3.6.1, BTP SPLB 3-1, and will be used by the COL applicant, or to provide reasons for not including them in the DCD for design certification. In a letter dated August 28, 2006 (MFN 06-299), GEH provided revised copies of DCD Section 3.6.1.2, Tables 3.6-3 and 3.6-4, which included the systems categorized as moderate-energy piping systems both inside and outside the containment. The staff verified that GEH revised DCD Tier 2, Revision 2, Section 3.6.1.2, and listed the moderate-energy piping systems subject to postulated leakage cracks in DCD Tier 2, Revision 2, Tables 3.6-3 and 3.6-4. Since DCD Tier 2, Revision 2, Tables 3.6-3 and 3.6-4, 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 the SRP Section 3.6.1, the staff finds this acceptable. Therefore, RAI 3.6-2 is resolved.

In DCD Tier 2, Section 3.6.2.1, GEH 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 exempted from consideration of postulated pipe breaks. GEH 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 exempted from consideration of pipe breaks. This is consistent with the requirements given in BTP MEB 3-1, item B.1; therefore, the staff finds this acceptable.

In DCD Tier 2, Section 3.6.2.1, GEH 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, GEH stated that the ESBWR design does not include the OBE load in the piping design. 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 performing explicit response or design analyses. The ESBWR OBE ground motion is one-third of the SSE ground motion. DCD Sections 3.7.3 and 3.7.4 address the effects of low-level earthquakes (lesser magnitude than the SSE) on fatigue evaluation and plant shutdown criteria, respectively.

In Section 3.1.1.3 of SECY 93-087, the staff included a Commission-approved staff recommendation to eliminate the OBE from the design of SSCs. 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 requested 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 a letter dated August 28, 2006 (MFN 06-299), GEH stated that DCD Section 3.7.3.2 will be used to define the seismic cycle requirements for fatigue analysis. Also, equations 9, 10, 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 0.1 to meet the no-postulated-pipe-break criteria. This is consistent with the guidelines given in BTP MEB 3-1, item B.1.b(1)(b). The staff finds this acceptable; therefore, RAI 3.6-1 is resolved.

Item B.1.c(5) in BTP MEB 3-1 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 the applicant to 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 a letter dated August 28, 2006 (MFN 06-299), GEH stated that the design bases for environmental qualification of safety-related equipment in an ESBWR plant includes the consideration of the environment resulting from pipe breaks or leakage cracks. GEH also suggested a revision of DCD Section 3.11.2.1 to state that there are no chemical sprays applicable to the ESBWR. The staff verified that GEH 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. 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 acceptable. Therefore, RAI 3.6-3 is resolved.

Item B.1.d in BTP MEB 3-1 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 requested the applicant to clarify if this criterion is applicable to the ESBWR for identifying pipe break locations. In a letter dated August 28, 2006 (MFN 06-299), GEH responded to RAI 3.6-4 that the criterion in BTP

MEB 3-1, 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 GEH has not provided the information requested, specifically whether DCD Section 3.6.2.1.1 is applicable to a complex piping system defined in BTP MEB 3-1, item B.1.d. GEH needs to address this RAI associated with complex systems, such as those containing arrangements of headers and parallel piping running between headers. The staff finds this issue unresolved. **RAI 3.6-4 is being tracked as an open item.**

In DCD Tier 2, Section 3.6.2.1.3, GEH discussed the reasons the 1.25-inch HCU fast scram lines do not require protection against pipe breaks. The second reason states that the total amount of energy contained in the 1.25-inch 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 the applicant to provide 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. In a letter dated August 28, 2006 (MFN 06-299), GEH responded to RAI 3.6-5 with the calculation of energy level for the 1.25-inch HCU fast scram lines at ambient temperature and operating pressure to be approximately 5.67 kilojoules per meter (kJ/m). GEH 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. GEH provided a markup of changes in DCD Section 3.6.2.1.3. The staff verified that GEH has 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-inch HCU fast scram lines. The staff also concurs with GEH that an energy level of 6 kJ/m in 1.25-inch 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 is resolved.

In BTP MEB 3-1, 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 MEB 3-1. The staff evaluated the information in DCD Tier 2, Section 3.6.2, to determine if GEH 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, GEH identified those portions of the ESBWR piping systems that qualify for break exclusion. GEH also provided additional design bases for these break exclusion areas which meet the guidelines in BTP MEB 3-1, and the staff finds them acceptable.

One important guideline 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 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 provided a requirement for such a program for all piping in the break exclusion zone. This commitment meets the applicable guidelines of SRP Section 3.6.2 and is acceptable.

On the basis of its review, the staff concludes that due to open RAI responses discussed above, the staff is unable to make a final conclusion about 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, GEH 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 Appendixes A and B of ANS 58.2 for calculation of fluid forces acting on a postulated ruptured pipe. It is 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, GEH did not provide any details on 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 does 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 requested 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 a letter dated August 28, 2006 (MFN 06-299), in Enclosure 2, GEH provided a sample calculation for a typical ABWR plant for the pipe break forcing functions for MS pipe break at terminal ends, RPV nozzle, and TSV. The sample calculation is a representative method to be used for the ESBWR plant. This sample calculation refers to GEH 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. The staff, as disussed in RAIs 3.6-11 through 3.6-19, requested the applicant to 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. GEH has not responded to these RAIs. Until these RAIs are satisfactorily resolved, the staff cannot resolve this RAI. **RAI 3.6-6 is being tracked as an open item.**

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, GEH provided details regarding assumptions in the piping dynamic analysis. In RAI 3.6-7(a) through (e), the staff asked the applicant to 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 asked the applicant to clarify whether this is applicable to all approaches used for the ESBWR. If it is not, then GEH should provide technical justification for the alternate initial conditions assumed in the analyses. In a letter dated August 28, 2006 (MFN 06-299), GEH provided an updated DCD Section 3.6.2.3.1 with the criterion of energy at hot standby or 102-percent power given in SRP Section 3.6.2.III.2.a applicable to the ESBWR. The staff verified that GEH has 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) is 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 asked the applicant to clarify whether any other analytical (nonlinear) methods and modeling techniques (discussed in the SRP and ANS 58.2) will be used for ESBWR plants. The applicant's response refers to Enclosure 4, which should be Enclosure 3. Enclosure 3 provides a sample calculation prepared for a typical ABWR plant for pipe break nonlinear method and modeling technique for MS pipe break at terminal end RPV nozzles, which claims to be the representative method to be used. However, the staff had asked whether any other methods discussed in the SRP and ANS 58.2 will be used for the ESBWR. GEH should address whether any other analytical (nonlinear) methods and modeling techniques (discussed in the SRP and ANS 58.2) will be used for ESBWR plants. The staff finds this issue unresolved. **RAI 3.6-7(b) is being tracked as an open item.**

(c) This part of the RAI relates to the question raised in paragraph (b) above. Specifically, the staff requested the applicant to discuss procedures and computer programs that will be used to calculate the pipe whip dynamic responses for all those methods not discussed in DCD Appendix 3J, if any. GEH, in its response, stated that computer programs PDA and ANSYS will be used to calculate the pipe whip dynamic responses. However, GEH did not identify the methods to be used. GEH should identify the methods to be used and then the computer programs to be used for each of these methods. The staff finds this response is incomplete**. RAI 3.6-7(c) is being tracked as an open item.**

(d) In RAI 3.6-7(d), the staff requested the applicant to 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 GEH to describe the computer programs for selecting the size and different types of whip restraints (i.e., crushable or rigid, if any). In its response, GEH 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, GEH 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) is resolved.

(e) In RAI 3.6-7(e), the staff requested the applicant to 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 included the analytical approach used for the two types of analyses presented in DCD Appendix 3J. However, GEH did not address the quality control of computer codes ANSYS and PDA, which these analyses used. In addition, the pipe break analysis in Enclosure 3 of the applicant's response includes 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. However, the staff has not yet approved the computer codes PDA and REDEP. GEH should address the quality control of all computer programs and the computer results to be used in the pipe break analysis. The staff finds this issue unresolved. **RAI 3.6-7(e) is being tracked as an open item**.

Because of the open items that remain to be resolved, the staff is unable to make final conclusions about the ESBWR design as it relates to the criteria for determining the dynamic responses of ruptured pipes to select the size of pipe whip restraints to meet the pertinent guidelines of SRP Section 3.6.2.

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 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 (Appendixes C and D) for estimating jet plume geometries and loads based on the fluid conditions internal and external to the piping, and to date ANS 58.2 has been accepted by the NRC's reviewers.

DCD Section 3.6.2.3.1 makes a reference to the use of Appendixes 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 Section 3.6.2 and Appendix J to DCD Tier 2. 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 15, 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, 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. The Wallis and Ransom critiques were cited in 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). Although the focus of the ACRS was on debris generation and sump blockage, its comments directly impact the assessments of 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 requested the applicant to address inaccuracies and omissions in ANS 58.2 discovered by ACRS, along with inconsistencies between ANS 58.2 and the applicant's approach.

Neglect of the Effects of Blast Waves

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 analyzed independently of any subsequent jet formation. Since the blast wave is not considered in ANS 58.2 or ESBWR DCD Section 3.6.2 for evaluating the dynamic effects associated with the postulated pipe rupture, omission of blast wave considerations is clearly nonconservative. In RAI 3.6-11, the staff requested the applicant to explain how it will account for the effects of blast loads on neighboring SSCs. GEH has not yet provided its response to this RAI. **RAI 3.6-11 is being tracked as an open item.**

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. 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, "Knowledge Base for Emergency Core Cooling System Recirculation Reliability," February 1996, http://www.nea.fr/html/nsd/docs/1995/csni-r1995-11.pdf).

In RAI 3.6-12, the staff requested the applicant to 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.

GEH has not yet provided its response to this RAI. **RAI 3.6-12 is being tracked as an open item.**

Nonphysical Pressure Distribution within Expanding Jet Model

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, GEH 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 Appendix D to ANS 58.2 is used, which defines variable (not uniform) pressures over the cross section of an expanding jet (see comments above regarding the inaccuracies of Appendix D to ANS 58.2). 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—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.

GEH has not yet provided its response to this RAI. **RAI 3.6-13 is being tracked as an open item.**

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, GEH 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 requested 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 two. 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, C.M. Ho and N.S. Nosseir, "Dynamics of an Impinging Jet. Part 1. The Feedback Phenomenon," Journal of Fluid Mechanics, Vol. 105, pp. 119–142, 1981). Some general observations by past investigators are that strong discrete frequency loads are observed 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 two to three increase in pressure fluctuations at the frequency of the resonance). In RAI 3.6-14, the staff requested the applicant to 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.

GEH has not yet provided its response to this RAI. **RAI 3.6-14 is being tracked as an open item.**

The applicant defined the limiting temperature (93.3 °C) and pressure (1.9 MPaG or 275 pounds (psig) 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 may 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. GEH has not yet provided its response to this RAI. **RAI 3.6-15 is being tracked as an open item.**

In DCD Tier 2, Section 3.6.2.3.1, GEH 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. GEH has not yet provided its response to this RAI. **RAI 3.6-16 is being tracked as an open item.**

In DCD Tier 2, Section 3.6.1.3, GEH 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. GEH has not yet provided its response to this RAI. **RAI 3.6-17 is being tracked as an open item.**

In DCD Tier 2, Section 3.6.2.3.1, GEH 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 GEH to justify this departure from ANS 58.2. GEH has not yet provided its response to this RAI. **RAI 3.6-18 is being tracked as an open item.**

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 the applicant to clarify how its jet load calculations will use target shape factors. GEH has not yet provided its response to this RAI. **RAI 3.6-19 is being tracked as an open item.**

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, GEH stated that components on 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 on what this particular criterion means. If it means that satisfying the ASME Code requirements for faulted conditions ensures meeting the required operability of the safety-related components, GEH did not provide the technical justification for this criterion. In RAI 3.6-8, the staff requested the applicant to provide the technical justification for operability criteria in DCD Section 3.6.2.3.2 for components on 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 (MFN 06-299), GEH did not entirely address this RAI. For a ruptured pipe, GEH claimed that for a MSL, the pipe stresses within the containment penetration region are required to be less than 2.25 S_m in accordance with BTP MEB 3-1 criteria. GEH referred to the statement in DCD Tier 2, Section 3.6.2.2, under Pipe Whip Dynamic Response Analysis, that says, "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," for the technical justification for this claim. This is acceptable to GEH because it meets the ASME Code requirement for faulted condition. However, GEH did not address the technical justification concerning the limits used to ensure the required operability of the safety-related components. GEH in its response stated that Appendix 3J contains further clarifications, which is not specific. In addition, in the last paragraph on MSIV operability, GEH stated that only satisfying the 2.25 S_m requirement in accordance with BTP MEB 3-1 criteria will ensure the operability of the MSIV installed within the containment penetration. However, the staff determined that only satisfying the code limit does not ensure the component's operability without meeting the operability assurance program specified in SRP Section 3.10. The staff finds this response incomplete and unacceptable. **RAI 3.6-8 is being tracked as an open item.**

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, GEH 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 a letter dated August 28, 2006 (MFN 06-299), GEH 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 is 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, for separating structure with high-energy lines," GEH 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 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, which is 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, GEH 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. GEH 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, the staff notes that recent German tests showed 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. The staff concludes that the HELSA criteria are acceptable, pending satisfactory resolution of RAI 3.6-12(b).

Because of the open items that need resolution, the staff is unable to finalize its conclusion that the ESBWR design as it relates to the criteria for pipe whip effects on safety-related SSCs and loading combinations for designing pipe whip restraints meets the pertinent guidelines of SRP Section 3.6.2.

3.6.2.3.4 Guard Pipe Assembly Design

BTP EMEB 3-1, 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, 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, GEH 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 a letter dated August 28, 2006 (MFN 06-299), GEH stated that the ESBWR plant design does not use guard pipe, 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. GEH 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 is resolved.

The staff's review finds that GEH adequately meets the guidelines for design, testing, and examination requirements for guard pipes described in SRP Section 3.6.2; therefore, the staff finds this acceptable.

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

In DCD Tier 2, Section 3.6.2.1.1, GEH 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, GEH 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 also be performed. This is consistent with the guidelines described in SRP Section 3.6.2; therefore, the staff finds this acceptable. 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 the inspection, test, analysis, and acceptance criteria process required by the regulation.

3.6.2.3.6 Combined License Information

In DCD Tier 2, Section 3.6.5, GEH appropriately listed the information that will be provided by the COL applicant for an ESBWR plant. The staff reviewed this list and finds it acceptable. **This is a COL action item.**

3.6.2.4 Conclusions

Because of the open items that need resolution, the staff is unable to finalize its conclusion 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 Sections 3.7.1 through 3.7.3, Revision 3, of NUREG-0800, as a basis, the staff reviewed Revision 3 of the ESBWR DCD, Sections 3.7, 3.7.1, 3.7.2, and 3.7.3, 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 GEH office in San Jose, California. 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 following summarizes the results of the staff’s technical review of DCD Sections 3.7, 3.7.1, 3.7.2, and 3.7.3.

In DCD Tier 2, Revision 3, Section 3.7, the applicant described the seismic classification of plant SSCs and the analysis criteria and methodology used to demonstrate seismic adequacy. In accordance with the SSC 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 (C-I), seismic Category II (C-II), and NS, as defined in DCD Section 3.2.

The applicant stated that for the seismic Category I and 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 of DCD addresses seismic aspects of design and analysis in accordance with RG 1.70, “Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants,” the applicant stated that the methods of this section are also applicable to RBV dynamic loadings, unless noted otherwise. **The method of combination of peak dynamic responses to seismic and RBV loads is the square root of the sum of the squares (SRSS), in accordance with NUREG-0484, “Methodology for Combining Dynamic Responses,” Revision 1, issued May 1980. For reinforced concrete structures, the section forces or stresses that result from each dynamic load are combined in the most conservative manner by systematically varying the sign (+ or -), equivalent to the absolute sum (ABS) method.**

In the review of DCD Section 3.8, the staff requested (in RAI 3.8-9) that the applicant describe the methods used to combine seismic and RBV loads. In response, the applicant added the bolded method described above to Section 3.7 in DCD Revision 2; however, the staff has not accepted this method. In RAI 3.7-61, Part (1), the staff asked the applicant to delete the bolded text above. The staff determined that appropriate text can be added to the DCD after RAI 3.8-9 has been resolved. By letter dated November 21, 2007, the applicant agreed to delete the text in question and provided acceptable changes to the DCD. **The staff considers RAI 3.7-61, Part (1) a confirmatory item**.

The applicant stated that the 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 RCPB
- the capability to shut down the reactor and maintain it in a safe condition
- the capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures comparable to the applicable guideline exposures given in Title 10, Part 100, “Reactor Site Criteria” of the *Code of Federal Regulations* (10 CFR Part 100).

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 for which structural integrity, not operational performance, is required. The methods of seismic analysis and design acceptance criteria for seismic Category II SSCs are the same as those for Category I; however, the procurement, fabrication, and construction requirements for Category II SSCs are in accordance with industry practices. Category II items are those corresponding to Regulatory Position C.2 of RG 1.29.

The applicant also 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 10 CFR Part 50, Appendix S. DCD Sections 3.7.3.2 and 3.7.4.4, respectively, address the effects of low-level (of lesser magnitude than the SSE) earthquakes on fatigue evaluation and plant shutdown criteria.

The staff evaluated the above information for consistency with NRC regulations and guidance and also determined that the applicant has properly addressed RAIs 3.7-1 through 3.7-4 posed by the staff on Revision 1 of DCD Section 3.7. With the exception of the confirmatory item noted above, the information contained in DCD Tier 2, Revision 3, Section 3.7, is consistent with NRC regulations and guidance.

3.7.1 Seismic Design Parameters

3.7.1.1 Regulatory Criteria Related to Seismic Design Parameters

The staff accepts the design of structures that are important to safety and that must withstand the effects of the earthquakes if the design complies with the relevant requirements of GDC 2 of Appendix A, of 10 CFR Part 50 and Appendix A, “Seismic and Geologic Siting Criteria for Nuclear Power Plants,” to 10 CFR Part 100 concerning natural phenomena. The following are the relevant requirements of GDC 2 and Appendix A to 10 CFR Part 100:

- GDC 2—The design basis shall 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.

  GDC 2 requires, in relevant part, that 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. 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. In accordance with SRP Section 3.7.1 the staff reviews 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. RG 1.60, “Design Response Spectra for Seismic Design of Nuclear Power Plants,” Revision 1, and RG 1.61, “Damping Values for Seismic Design of Nuclear Power Plants,” provide applicable guidance for implementing and complying with the requirements in GDC 2. RG 1.60 provides a procedure that is acceptable to the staff for defining response spectra for input into the seismic design analysis of nuclear power plants. RG 1.61 delineates damping values acceptable to the staff to be used in performing dynamic seismic analysis of seismic Category I SSCs. Meeting the requirements of GDC 2, in conjunction with the guidelines provided in RGs 1.60 and 1.61, 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.

- Section VI.(a) of Appendix A to 10 CFR Part 100—The design of the safety-related structures, components, and systems shall consider two earthquake levels, the SSE and the OBE.

  Appendix A to 10 CFR Part 100 requires that either a suitable dynamic analysis or an appropriate qualification test be used to demonstrate that all SSCs important to safety are capable of withstanding the seismic and other concurrent loads, except where it can be demonstrated that the use of an equivalent static load methodology provides adequate conservatism. The requirements of Appendix A to 10 CFR Part 100 ensure that the applicable levels of vibratory ground motion corresponding to the OBE and the SSE are properly defined and that adequate accuracy and conservatism are being applied in defining the parameter values being used for input into the seismic design analysis. Compliance with the requirements detailed in Appendix A to 10 CFR Part 100 in conjunction with implementation of the requirements provided in GDC 2, as discussed above, 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.

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 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 to satisfy paragraph IV.(a)(2)(i)(B)(I) of Appendix S to 10 CFR Part 50.

3.7.1.2 Technical Information in the DCD Related to Seismic Design Parameters

In DCD Tier 2, Revision 3, Section 3.7.1, the applicant stated that structures that are important to safety 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 also 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) = 0.3 g (acceleration of gravity)), and to three early site permit (ESP) sites. For the ESP sites (North Anna (DCD Reference 3.7-2), Clinton (DCD Reference 3.7-3), and Grand Gulf (DCD Reference 3.7-4)), the applicant's review of the three site conditions 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.

3.7.1.2.1 Design Ground Motion

In DCD Revision 3, 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 0.3 g. The high-frequency ground motion matches the North Anna ESP site-specific spectra as representative of most severe rock sites in the eastern U.S. 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) 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 meters (m) (66 feet (ft)) and 14.9 m (49 ft), respectively. The FB shares a common foundation mat with the RB.

In DCD Revision 3, 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 0.3 g and specified at the foundation level in the free field for generic sites. Figures 3.7-1 and 3.7-2 show the 0.3-g 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 0.3-g SSE acceleration time histories for two horizontal components (H1 and H2) and a 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 at three additional frequencies (40, 50, and 100 hertz (Hz)). The time histories of the two horizontal components also satisfy the power spectral density (PSD) requirement stipulated in Appendix A to SRP Section 3.7.1. Because this appendix 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 as recommended in the reference of RG 1.92, “Combining Modal Responses and Spatial Components in Seismic Response Analysis.” Thus, H1, H2, and VT acceleration time histories are mutually statistically independent.

In DCD Tier 2, Revision 3, 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. The ESBWR foundation elevations at the North Anna ESP site are 205 ft (62.484 m) for the RB/FB and 222 ft (67.666 m) for the CB. Since the low-frequency parts of North Anna SSE ground spectra are enveloped by the 0.3-g RG 1.60 generic site spectra with large margins, 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 and RB/FB foundation level. The PGA values, corresponding to the spectral acceleration at 100 Hz of the target spectra, are 0.492 g at the CB base and 0.469 g 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 it used the more stringent matching criteria of NUREG/CR-6728, a separate PSD check in accordance with SRP Section 3.7.1.II.1 is not required.

In DCD Tier 2, Revision 3, Section 3.7.1.1.3, the applicant stated that the single-envelope ground response spectra are constructed to envelop the low-frequency 0.3-g 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 0.3-g RG 1.60 spectra. At higher frequencies, the spectral values closely match that of the envelope of North Anna ESP spectra at the ESBWR RB/FB and CB foundations as a representative ground motion for eastern U.S. sites founded on rock. 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 considers this envelope to be very conservative in terms of energy content and useful in verifying 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 vertical components, respectively. Spectral matching for 5-percent damping is consistent with the recommendations of NUREG/CR-6728. Because a more stringent spectral matching criteria from NUREG/CR-6728 is used, a separate PSD check in accordance with SRP Section 3.7.1.II.1 is not required. The acceleration time histories are shown in DCD Figures 3.7-41 through 3.7-43, 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 vertical. 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 DAC3N and SASSI computer codes, respectively.

3.7.1.2.2 Percentage of Critical Damping Values

In DCD Tier 2, Revision 3, Section 3.7.1.2, the applicant stated that damping values for various structures and components are shown in DCD Table 3.7-1 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 2000 individual dynamic tests conducted by Bechtel/ANCO for a variety of raceway configurations (DCD Reference 3.7-5, P.Koss, “seismic Testing of Electrical Cable Support Systems, Structural Engineers of California Conference”) San Diego, September 1979.

The damping value for conduit systems (including supports) is 7 percent constant. For HVAC 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.

Alternative damping values specified in DCD Figure 3.7-37 may be used for piping systems covered by ASME Code, Section III, Division 1, Class 1, 2, and 3 and ASME B31.1, Piping.

The damping values shown in DCD 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 Revision 3, 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. Appendix 3A to the DCD describes the soil conditions considered for SSI analysis.

3.7.1.3 Staff Evaluation Related to Seismic Design Parameters

In DCD Tier 2, Revision 3, Section 3.7.1, the applicant stated that structures that are important to safety 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 also indicated that the 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, PGA = 0.3 g), and to three ESP sites. For the ESP sites (North Anna (DCD Reference 3.7-2), Clinton (DCD Reference 3.7-3), and Grand Gulf (DCD Reference 3.7-4)), the applicant's review of the three site conditions 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, it was not clear to the staff 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. The resolution of RAI 3.7-5 was that the applicant redefined the design-basis SSE 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-basis SSE. 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 within the ESBWR design envelope spectra is acceptable without further evaluation.

Based on DCD Revision 1, the staff also issued RAI 3.7-6, asking the applicant to 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 design-basis SSE 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 site-enveloping seismic design of the ESBWR standard plant. In RAI 3.7-7, the staff requested that the applicant 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 being used at the foundation depths of the CB and RB models with the surface response spectrum 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 spectrum, which the staff had noted. The staff finds the response to be acceptable on the basis that the reductions in the North Anna surface spectrum are consistent with the embedded foundation depths of the RB/FB and CB. Therefore, RAI 3.7-7 is resolved.

3.7.1.3.1 Design Ground Motion

In DCD Revision 3, 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 0.3 g. The high-frequency ground motion matches the North Anna ESP site-specific spectra and is representative of most severe rock sites in the eastern U.S. 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 a depth 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 dated June 30, 2006, the applicant stated that the use of the same 0.3-g 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, dated December 8, 2006, the applicant removed the reference to conservatism. The staff finds the applicant's use of the RG 1.60 ground response spectra applied 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. Therefore, RAI 3.7-8 is resolved.

In DCD Revision 3, 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 0.3 g and specified at the foundation level in the free field for generic sites. With one exception, the staff finds the applicant's methods to be acceptable, because they are consistent with the acceptance criteria in SRP Section 3.7.1. RAI 3.7-8 addressed this exception, and the issue has been resolved.

In DCD Revision 3, 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 the discussion of RAI 3.7-7 and has been resolved, the staff finds 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 Revision 3, Section 3.7.1.1.3, the applicant discussed the single-envelope ground response spectra constructed to envelop the low-frequency 0.3-g 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 finds 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 Revision 3, Section 3.7.1.1, is substantially different from the content of that same section in DCD Revision 1, which the staff initially reviewed and used to develop 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, Revision 3 reflects the resolution of the RAIs. The specific technical issues and their resolution are discussed below.

In DCD Revision 1, the applicant stated that the synthetic time histories developed to envelop the RG 1.60 spectra satisfy the spectrum-enveloping requirement stipulated 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 to judge 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 (1) the corresponding strong motion durations for the synthetic time history records and (2) 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 is resolved.

In DCD Revision 1, the applicant indicated that it developed a target PSD appropriate for the vertical RG 1.60 response spectrum by using the same process (Appendix A to SRP Section 3.7.2) 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 it used Appendix B to NUREG/CR-5347, "Recommendations for Resolution of Public Comments on USI (Unresolved Safety Issues) A-40, 'Seismic Design Criteria,'" dated June 1, 1989, to develop the target PSD for the vertical

RG 1.60 response spectrum. The applicant delineated the specific steps and committed to include this information in a future revision of 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 is resolved.

In DCD Revision 1, the applicant stated that the low-frequency part of North Anna SSE ground spectra is enveloped by the 0.3-g 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 the applicant's redefinition of the design-basis SSE to be the envelope of the two spectra automatically resolved this issue. Therefore, RAI 3.7-11 is resolved.

Based on its review of Revision 1, the staff concluded that the description of the North Anna ESP design ground motion (e.g., 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) provided in the DCD was insufficient for the staff to reach a safety conclusion regarding the design adequacy of the RB/FB and CB for the North Anna spectra. In RAI 3.7-12, the staff requested that the applicant include the following information in the DCD:

(1) identification of which ESP ground response spectra (target spectra or spectra /1/10 or spectra x 1.30) are used for the seismic analysis and design

(2) the ESP response spectra for 2-, 3-, 4-, and 7-percent damping ratios

(3) definition of the "modified" ground motion time histories

(4) demonstration that the response spectra calculated from the modified ground motion time histories envelop the design ESP ground response spectra for all damping ratios to be used in the analyses

(5) demonstration 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 that "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. The staff had applied this position for other design certification reviews, such as the AP600 and AP1000.)

In its response, 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 SRP 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 item (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 to show clearly 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 address only 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 all have been found to 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 the cross-correlations and performed both of these checks with the CARES code. The staff found that both spectral matching and cross-correlation SRP criteria were 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 is resolved. The staff notes that, subsequent to the resolution of RAI 3.7-12, SRP Section 3.7.1.II.1.B, Revision 3, issued March 2007, incorporated spectral matching for 5-percent damping, following the approach in NUREG/CR-6728.

3.7.1.3.2 Percentage of Critical Damping Values

In DCD Tier 2, Revision 3, Section 3.7.1.2, the applicant indicated that DCD Table 3.7-1 shows the damping values for use in SSE dynamic analysis for the various structures and components and that these damping values are consistent with RG 1.61 SSE damping, except for cable trays and conduits.

In response to RAI 3.7-13 on DCD Revision 1, the applicant had made a number of changes to DCD Table 3.7-1. The staff noted that, with the exception of several footnotes related to cable tray and conduit damping, DCD Table 3.7-1 is now either consistent with RG 1.61, Revision 1, issued March 2007, or conservative in comparison to the RG. Therefore, with this one exception, the proposed damping values are acceptable to the staff.

The staff requested supplemental information under RAI 3.7-13 to resolve the remaining issue concerning cable tray and conduit SSE damping values. Table 4 of RG 1.61, Revision 1, delineates the damping values currently acceptable to the staff. Note 1 to Table 4 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." DCD Revision 3, Table 3.7-1 lists the same SSE damping values as in Table 4 of RG 1.61, Revision 1. However, footnote 2c to DCD Table 3.7-1 implies that a cable tray need be only one-third full. In addition, DCD Table 3.7-1 does not address cable fill for conduits. The staff asked the applicant to concur with note 1 to Table 4 of RG 1.61, Revision 1, or to provide its technical basis for the one-third fill level criterion for cable trays and no fill level criterion for conduits.

By response dated December 3, 2007, the applicant agreed to concur with note 1 to Table 4 of RG 1.61, Revision 1, and provided an acceptable revision to the DCD. **RAI 3.7-13 is being tracked as a confirmatory item.**

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 this change 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.
Section 3.7.2.3.13 of this report contains the staff's evaluation of composite modal damping.

3.7.1.3.3 Supporting Media for Category I Structures

In DCD Revision 3, 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 Appendix 3A to the DCD gives the soil conditions considered for SSI analysis.

Section 3.7.2.3.4 of this report contains the staff's assessment of the soil conditions considered for the SSI analysis, as described in Appendix 3A to the DCD.

3.7.1.4 Conclusions

The staff finds that with the exception of one confirmatory item, 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 Related to Seismic System Analysis

The staff accepts the design of SSCs that are important to safety and must withstand the effects of earthquakes if the design complies with the relevant requirements of GDC 2, contained in Appendix A to 10 CFR Part 50, and Appendix A to 10 CFR Part 100 concerning natural phenomena. The following are the relevant requirements of GDC 2 and Appendix A to 10 CFR Part 100:

- GDC 2—The design basis shall 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.

  GDC 2 requires, in relevant part, that 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. GDC 2 also 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. SRP Section 3.7.2 reviews 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. RG 1.92 and RG 1.122, "Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components," Revision 1, issued February 1978, provide appropriate guidance for implementing and complying 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 to be used 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 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.

- Section VI(a) of Appendix A to 10 CFR Part 100 defines the OBE and the SSE and requires that the engineering methods used to ensure that the required safety functions are maintained during and after the vibratory ground motion associated with the SSE and OBE shall involve the use of either a suitable dynamic analysis methodology or an appropriate qualification test to demonstrate that all SSCs important to safety are capable of withstanding the seismic and other concurrent loads, including postulated accident loads, except where it can be demonstrated that the use of an equivalent static load analysis methodology provides adequate conservatism. The requirements of Appendix A to 10 CFR Part 100 ensure that the applicable levels of vibratory ground motion corresponding to the OBE and the SSE are properly defined and that adequate accuracy and/or conservatism is applied in defining the system data used for input into the seismic design analysis. Compliance with the requirements in Appendix A to 10 CFR Part 100, in conjunction with meeting the requirements in GDC 2, as discussed above, 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.

For design certification, Appendix S, Part IV.(a)(2)(i)(A), to 10 CFR Part 50, provides an option for specification of the OBE. If the OBE is designated as less than or equal to one-third of the SSE ground motion, it is not necessary to conduct explicit response or design analyses in order to satisfy paragraph IV.(a)(2)(i)(B)(I) of Appendix S to 10 CFR Part 50.

3.7.2.2 Technical Information in the DCD Related to Seismic System Analysis

In DCD Revision 3, 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 Tier 2, Table 3.7-3 summarizes the methods of seismic analysis for primary building structures.

3.7.2.2.1 Seismic Analysis Methods

In DCD Revision 3, 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 or multi-supported 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 Tier 2, Revision 3, Section 3.7.2.1.1, the applicant presented the basic equations of motion for dynamic analysis of multiple-degree-of-freedom (DOF) linear systems subjected to external forces and/or uniform support excitations and indicated that the 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 convergence of the solution up to the highest frequency (or shortest period) of significance. The approach for selecting the time step, Δt, is that the Δt used shall be small enough so that the use of one-half of Δt does not change the response by more than 10 percent. 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. 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 also 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-DOF, 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 this section, 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 Tier 2, 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 USMs, 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 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 response spectrum method, and (3) DCD Section 3.7.3.9 discusses 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 Tier 2, Revision 3, Section 3.7.2.1.3, the applicant stated that the static coefficient method is an alternative method of analysis that allows a simpler technique in return for added conservatism. This method does not require determination of natural frequencies. The response loads are determined statically by multiplying the mass value by a static coefficient equal to 1.5 times the maximum spectral acceleration at 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 (DCD References 3.7-13 and 3.7-14). A factor of less than 1.5 may be used if justified. If the fundamental frequency of the structure is known, the 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-DOF 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 Tier 2, 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’s evaluation of the natural frequencies and SSE responses of Category I buildings appears 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 (FEM). 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 is less than 0.01, decoupling can be done for any R_f.
- If 0.01 is less than or equal to R_m less than or equal to 0.1, decoupling can be done if R_f is less than or equal to 0.8 or R_f is greater than or equal to 1.25.
- If R_m is greater than 0.1, a subsystem model should be included in the primary system model.

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

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

R_f = fundamental frequency of the supported subsystem/dominant frequency of the support motion

The applicant also 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 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 Tier 2, Revision 3, 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. DCD Reference 3.7-6 gives the details of the hydrodynamic mass derivation. In the vertical excitation, the hydrodynamic coupling effects are assumed to be negligible, and the fluid masses are combined for the appropriate structural locations.

3.7.2.2.4 Soil-Structure Interaction

In DCD Revision 3, Section 3.7.2.4, the applicant stated that Appendix 3A to the DCD presents the seismic SSI analyses of the Category I buildings performed for a range of soil conditions. This appendix 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, and CB of the ESBWR standard plant under SSE excitation. (This document occasionally refers to the RB and FB, which are integrated and founded on a common basemat, as the “RB/FB.”) DCD Tier 2 Section 3.7.1 describes the SSE design ground motion at the foundation level for both site conditions. The SSI analysis results are presented here in the form of site-enveloped seismic responses at key locations in the RB/FB and CB. Appendix 3G to the DCD shows the structural adequacy calculations for the RB, FB, and CB.

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, the study considers the North Anna ESP site-specific condition. When actual sites for these facilities are selected, site-specific geotechnical data will be developed and submitted to the NRC to demonstrate compatibility with the site-enveloping parameters considered in the standard design.

Appendix 3A to DCD Tier 2 details the basis for selecting the site conditions and analysis cases and the method of the seismic SSI analysis. The appendix also describes the input motion and damping values, the structural model, and the soil model. It presents the parametric study SSI results, as well as the enveloping seismic responses. To demonstrate the seismic adequacy of the standard ESBWR design, 27 RB/FB cases and 11 CB cases are analyzed for the uniform site cases using the sway-rocking stick model for the SSE condition. In addition, 11 RB/FB cases and 6 CB cases are analyzed for the layered site cases using the SASSI SSI model. The enveloped results reported in this appendix form the design SSE loads.

3.7.2.2.5 Development of Floor Response Spectra

In DCD Revision 3, Section 3.7.2.5, the applicant stated that Floor Response Spectra (FRS) are developed from the primary structural dynamic analysis using the time history method. The applicant also stated that a direct spectra generation without resorting to time history, in accordance with the method referenced in DCD Reference 3.7-7 or the equivalent, 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 SRSS method to obtain the combined spectrum in that direction. An alternative approach to obtaining 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, plus additional frequencies corresponding to the natural frequencies of the supporting structures. 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 can be used.

3.7.2.2.6 Three Components of Earthquake Motion

In DCD Tier 2, Revision 3, 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 also identified the 100-40-40 method of combination, as described in ASCE 4-98, “Seismic Analysis of Safety-Related Nuclear Structures” (DCD Reference 3.7-8), as an alternative to the SRSS method and stated that the use of the 100-40-40 method of combination will be consistent with the requirements of RG 1.92.

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. The total response may alternatively 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 Revision 3, 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. 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 (Rev. 1) is applicable for the combination of modal responses.

The applicant indicated that for modal combination involving high-frequency modes, the procedure of Appendix A (1989) to SRP Section 3.7.2 applies. The total combined response to high-frequency modes is combined by the SRSS method with the total combined response from lower frequency modes to determine the overall peak responses. As stated in Appendix A to SRP Section 3.7.2, this procedure requires the computation of individual modal responses only for lower frequency modes (below the ZPA); the more difficult higher frequency modes need not be determined, and the procedure ensures inclusion of all modes of the structural model and proper representation of DOF masses.

The applicant stated that the methods of combining modal responses described above meet the requirements in RG 1.92 (Rev. 1).

3.7.2.2.8 Interaction of Non-Category I Structures with Seismic Category I Structures

In DCD Tier 2, Revision 3, Section 3.7.2.8, the applicant stated that the interactions between seismic Category I and NS 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 shall meet any one of the following requirements:

(1) The collapse of any non-Category I SSC does not cause the NS 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.

3.7.2.2.9 Effects of Parameter Variations on Floor Response Spectra

In DCD Revision 3, 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 by plus or minus 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 $1/(1 \pm 0.15)$ so as to change the frequency content of the time history within plus or minus 15 percent. Alternatively, the analysis may use a synthetic time history that is compatible with the broadened FRS.

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 Tier 2, Revision 3, Section 3.7.2.10, the applicant stated that equivalent vertical static factors are used when the requirements for the static coefficient method in Section 3.7.2.1.3 are satisfied.

The applicant 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 Revision 3, 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 that have negligible coupling of lateral and torsional motions, a two-dimensional model without the torsional DOFs can be used for the dynamic analysis. The torsional effects are accounted for by first calculating the locations of the center of mass for each floor. The centers of rigidity and torsional stiffness are determined for each story. Torsional effects are then 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 elements in proportion to each individual stiffness.

The applicant stated that the seismic analysis for the primary building structure is performed using a three-dimensional model, including the torsional DOFs.

3.7.2.2.12 Comparison of Responses

In DCD Revision 3, 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 Revision 3, 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 account for SSI by the lumped soil-spring approach, stiffness-weighting is acceptable. For a fixed-base model, either stiffness-weighting or mass-weighting may be used. This section also presents other approaches applicable to frequency domain analysis and direct integration time history analysis.

3.7.2.2.14 Determination of Seismic Category I Structure Overturning Moments

In DCD Tier 2, Revision 3, 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 Related to Seismic System Analysis

In DCD Tier 2, Revision 1, the applicant stated that Section 3.7.2 applies to building structures that constitute primary structural systems and further stated that the RPV is not a primary structural component but is considered another part of the primary system of the RB for the purpose of dynamic analysis, because of its dynamic interaction with the supporting structure.

In RAI 3.7-15, the staff asked the applicant to 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 which sections of the DCD present the details and results of the design-basis seismic analyses. In its response, the applicant stated that the building structures covered by DCD Section 3.7.2 are the RB, FB, CB, and EBAS building. DCD Table 3.2-1 for Structures and Servicing Systems (U) describes the seismic classification of building structures. The applicant has completed the design-basis seismic analyses for the RB, FB, and CB. The details and results of the design-basis seismic analyses appear in DCD Section 3A. The staff finds the applicant’s response to be acceptable. The applicant included additional information in Revision 2 of DCD Section 3.7.2. Therefore, RAI 3.7-15 is 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 or multi-supported 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 the 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.

With respect to the applicant's formulation of the equations of motion, in terms of undamped eigenvalues and mode shapes, with solutions obtained by integration in the time domain, in RAI 3.7-16, the staff requested that the applicant address the limitations of this formulation, particularly for the case of frequency-dependent SSI stiffness and damping coefficients.

In its response dated August 18, 2006, 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 ASCE 4-98, Section 3.3.4.2.2. The applicant also stated that the effects of frequency-dependent SSI stiffness and damping coefficients were evaluated for four additional layered sites and referred the staff 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 them 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 the basemat from its confirmatory analysis against the applicant's design response spectra at the top of the CB and at the top of the 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 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 the foundation mat and to increase frequency points around the locations of numerical instabilities.

In its supplementary response dated December 11, 2006, the applicant provided the SASSI transfer functions for the RB. 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 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 is slightly different than 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 finds the applicant's response for the RB/FB to be acceptable.

Further review by the staff indicated that the applicant and the staff need to address a number of issues to resolve the differences between the applicant's results and the staff's confirmatory analysis results for the CB. The staff asked the applicant to provide a supplemental response to RAI 3.7-16 to resolve the differences.

The GEH analyses and the staff's confirmatory analyses both use the same single-stick, beam-mass model of the CB. GEH conducted analyses for a number of uniform site conditions using DAC-3N and four assumed layered site conditions using SASSI. The staff conducted SASSI confirmatory analyses for nine assumed layered site conditions to assess whether GEH had considered an adequate number of layered site conditions. The staff presented its confirmatory analysis results for the CB to GEH at the October 30–November 2, 2006, audit. As stated in the GEH S01 response to RAI 3.7-16, dated December 11, 2006, "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 the GEH 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 GEH. The FRS generated by the staff at the CB basemat exceed the GEH design spectra provided at the audit in the 15 to 20 Hz range. To date, this difference in results has not been reconciled. The staff requested that GEH address the following:

(1) The staff noted that, in comparing the GEH design spectrum at the basemat to the GEH 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.

The staff asked GEH to submit the individual FRS results at both the basemat and at the 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. The staff also noted that it cannot correlate the design spectrum at the top of stick, provided to the staff at the October 30–November 2, 2006, audit, with the comparable design spectrum in Appendix 3A to DCD Revision 3. The staff asked GEH to explain this apparent discrepancy.

The staff also has concern about the accuracy of the GEH design spectrum for the CB basemat, provided to the staff at the October 30–November 2, 2006, audit. This location is not included in Appendix 3A to DCD Revision 3. Assuming there are no plotting or analysis errors, the staff requested that GEH provide a detailed technical explanation of why the amplification factor in the 10-Hz range is 6. The staff also requested that the applicant include the design spectrum for the CB basemat in the next revision of Appendix 3A to the DCD.

(2) 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 GEH to address whether its approach to developing the surface motion is consistent with the latest update to SRP Section 3.7.1, issued March 2007. If there are any differences, the applicant should provide the technical basis for the acceptability of each difference. The staff also requested that GEH 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. **RAI 3.7-16 is being tracked as an open item.**

The staff noted that in DCD Revision 3, the applicant added the highlighted 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 convergence of the solution up to the highest frequency (or shortest period) of significance. **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.** 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 reviewing DCD Section 3.7 found the added sentence to be unacceptable in its present form and location in the discussion. In RAI 3.7-61, part (2), the staff proposed the following alternate wording:

> For the time domain solution, the numerical integration time step is sufficiently small to accurately define the dynamic excitation and to render stability and convergence 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 percent.

By letter dated November 21, 2007, the applicant agreed to the staff’s proposed wording and provided acceptable changes to the DCD. **RAI 3.7-61, part (2), is being tracked as a confirmatory item.**

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 for the following Information:

- For each building structure covered by DCD Section 3.7.2, the applicant should 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.

- If modal superposition time history analysis was employed, the applicant should 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, the applicant should explain why it was used instead of the more accurate missing mass method; define the cutoff frequency; and explain how it was determined. The staff noted that RG 1.92, Revision 2 (DG-1127 at the time the RAI was originally written), does not accept the alternative procedure.

In its response dated May 23, 2006, the applicant stated the following:

> 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 percent change in response for the representative hard site. For the usage of analysis results, please see the response to RAI 3.7-6.
>
> 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 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 and computer codes used, and the use of the analysis output. In its supplemental response dated October 17, 2006, the applicant stated that it had developed DCD Table 3.7-3 to supply this information and that it would revise DCD Section 3.7.2 to include a reference to this new DCD table. The staff reviewed new DCD Table 3.7-3 and found that it satisfied the staff's request. The applicant included the 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). 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 referencing RG 1.92, Revision 2, for the treatment of missing mass in DCD Section 3.7.2.7.

The applicant revised DCD Tier 2, Section 3.7.2.7, in Revision 4 for consistency with RG 1.92, Revision 2. The staff considers this RAI resolved.

The staff raised concerns regarding the adequacy of computer codes used for design and analysis of the ESBWR seismic Category I structures to produce reasonable seismic responses. In RAI 3.7-55, the staff requested that the applicant submit validation packages, translated into English, for the following computer codes listed in Appendix 3C to the DCD:

- SSDP-2D—concrete element cracking analysis
- TEMCOM2—heat transfer analysis
- 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 any problem size limitation that may exist. The applicant agreed to provide a supplemental response to include a more realistic benchmark problem. The staff also requested that the applicant update Appendix 3C to the DCD to include validation information for computer codes that were not originally used 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's review of DCD Section 3.8, because these codes are used for detailed design calculations, not for the seismic analysis.

In its supplemental response dated December 8, 2006, the applicant stated that the revised validation report S/VTR-D3N, 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, the 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 for accurately addressing SSI. The applicant's reanalysis of SSI using SASSI provides a more recognized, state-of-the-art approach. The staff compared its confirmatory analyses to the applicant's SASSI results.

DCD Revision 3 contains the necessary changes to Appendix 3C. Therefore, RAI 3.7-55 is resolved.

3.7.2.3.1.2 Response Spectrum Method

In DCD Tier 2, 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 asked the applicant to identify, for each seismic Category I building structure, whether it used the response spectrum analysis method and, if it used the method, to describe the implementation of the method, including the method used to account for the contribution of modes with frequencies above f_{ZPA}, and to discuss how the analysis results were used. In its response, the applicant stated that it did not use response spectrum methods for the design-basis seismic analyses of the building structures documented in Appendix 3A to the DCD. 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 Appendix 3A. In Revision 2 of DCD Section 3.7.2.1.2, the applicant incorporated this additional information. Therefore, RAI 3.7-18 is 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 stated that it is an alternative method of analysis that allows a simpler technique in return for added conservatism. The applicant's description of the method and its range of applicability follows standard practice in the nuclear industry, is consistent with SRP Section 3.7.2, and is acceptable to the staff.

However, from the information provided in DCD Section 3.7.2.1.3, 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 asked the applicant to identify, for each seismic Category I building structure, whether it used the static coefficient method, and if it did use the method, to describe the implementation of the method and the technical basis for its use and to discuss how the results were used. In its response, the applicant stated that it did not use the static coefficient method 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 requested that the applicant revise the DCD to state that it did not use the static coefficient method 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 it did not use the static coefficient method for primary building structures. Therefore, RAI 3.7-19 is resolved.

3.7.2.3.2 Natural Frequencies and Responses

In DCD Section 3.7.2.2, the applicant stated that Appendix 3A presents the natural frequencies and SSE responses of Category I buildings. (See Section 3.7.2.3.4 of this report for the staff's 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 FEM. 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 asked the applicant to describe in detail in the DCD the development of the stick models and FEMs 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 FEM, 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 the stick 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 finds this clarification to be acceptable. Therefore, RAI 3.7-20 is resolved.

The applicant described the subsystem decoupling criteria. The staff finds this description consistent with SRP Section 3.7.2.II.3.b and therefore 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 requested that the applicant describe in detail in the DCD how it has implemented the general criteria in the third paragraph of DCD Section 3.7.2.3 in the seismic design/analysis of the primary structural systems covered by DCD Section 3.7.2 (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 its response, the applicant stated that, as described in DCD Section 3A.7, the three-dimensional stick model of the primary building structures explicitly considers rotary inertia, torsional DOFs, and eccentricities. Rotary inertia of the RPV and internals is neglected because its contributions to both the total plant response and the RPV and internals response are small. The small response contributions follow from the fact that 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 NS 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 NS suppression pool hydrodynamic loads. Therefore, the analytical models can neglect the RPV and internals torsional rotary inertia.

The applicant further stated that the analytical models also neglect RPV and internals rotary inertia about each of two horizontal, orthogonal axes. Sensitivity studies completed during the initial development of GEH BWR RPV and internals analytical models illustrated that the model responses were essentially the same whether or not the horizontal rotary inertia components were included. This is because the natural frequencies of the pure rotational modes tend to be well above the ZPA frequencies of both the seismic and NS excitations. Consequently, the pure rotational modes contributed essentially zero to the overall response of both the RPV and internals, as well as that of the primary structure.

During the June 5–8, 2006, audit, the staff reviewed the method for modeling rotary inertia described in GEH report 26A6647, “Seismic Analysis of RB/FB Complex,” Revision 1, 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 Appendix 3A to the DCD. Therefore, RAI 3.7-21 is 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 asked the applicant to describe in the DCD the live loads and snow loads that are included in the seismic models. The staff position 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 the fourth paragraph of DCD Section 3.7.2.3 and the fifth paragraph of DCD Section 3A.7.1 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 is resolved.

The third sentence in the second paragraph on page 3.7-10 of 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 (PCC pool and isolation condenser pool at 88.58 ft, GDCS pool at 15.26 ft, and suppression pool at -3.28 ft). Based on the staff’s review experience, 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 provide in the DCD a detailed description of pool geometry, total height of water, location of free board, procedure for modeling 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 stick model includes the water masses in the pools and conservatively considers the entire water mass as impulsive mass rigidly attached to the wall/slab nodes for the purpose of calculating 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 is resolved.

The last two sentences in the second paragraph on page 3.7-10 of DCD Section 3.7.2.3 state 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 applicant has implemented the criteria in the development of the seismic structural models. In RAI 3.7-24, the staff asked the applicant to include in the DCD specific information on how each seismic structural model satisfied these criteria. 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 staff found that 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.

In response to a staff audit comment during the review of RAI 3.7-36, 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 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, confirming 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 audit of October 31–November 2, 2006, 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 so that the staff can assess 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, “Mode Shapes of RB/FB Seismic Stick Model,” Revision 0. The applicant also noted the good comparison of the stick and NASTRAN FEMs provided in the RAI 3.7-59 response 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 is resolved.

For the development of the RB/FB seismic model, in RAI 3.7-25, the staff requested that the applicant 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 should be identified as an interface item for the COL applicant. In its response, the applicant stated that the developers of the RB/FB seismic model assumed that the heavy crane (with trolley) is 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 for various crane locations. The sensitivity analysis considers a worst location. The centers of gravity moved only 25 centimeters (cm) maximum. Comparison of eigenvalue analysis results for the RB/FB model in the fixed base case found that the difference of frequencies resulting from the crane location is negligibly small. Hence, there is no need to identify crane location as an interface item for the COL applicant. During its 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. GEH 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., 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. Because the applicant has adequately considered the parked location of the crane in both the dynamic seismic analysis and the detailed stress analysis, the staff finds the response to be acceptable. Therefore, RAI 3.7-25 is resolved.

For seismic subsystem analysis, accurate in-structure response spectra are needed at the subsystem support points. In RAI 3.7-26, the staff asked the applicant to 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, it used a FEM 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 walls that support subsystems designed using in-structure response spectra show very high out-of-plane vibration frequencies. 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 effects of out-of-plane vibration of walls are not considered in the seismic structural models.

During the October 31–November 2, 2006, 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 it had reviewed the out-of-plane vibration frequencies of walls. 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 FEM, in the same way that the slab frequencies are evaluated. To obtain design loads of these walls and design FRS for the components attached to these walls, seismic analysis will be performed using wall oscillators calculated by the above analysis, in the same way that the floor oscillators are calculated. The analysis would address the cracked concrete effect by reducing the oscillator's spring values by 50 percent. The applicant stated that it would revise Appendix 3A to the DCD 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 Appendix 3A to DCD Revision 3 confirmed that the applicant has adequately addressed the treatment of flexible walls, in accordance with its commitment. Therefore, RAI 3.7-26 is 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 asked the applicant to include these dimensions in the above figures.

In its response, the applicant stated that Figures 3G.1-1, 3G.1-6, and 3G.1-7 of DCD Revision 1 provide the foundation dimensions of the RB/FB. These figures also show the distance from the RPV center to the edge of the RB/FB foundation. Figures 3G.2-1 and 3G.2-3 of DCD Revision 1 provide the CB foundation dimensions. The applicant stated that 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 in the next DCD revision.

The staff’s review of the applicant’s response found that the dimensions of the foundation mat provided in Figures 3G.1-1, 3G.1-6, and 3G-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 has included the dimensions in the appropriate Tier 1 and Tier 2 figures. Therefore, RAI 3.7-27 is resolved.

In the fifth paragraph of DCD Section 3.7.2.3, the applicant stated that the RPV and its major internal components are analyzed together with the primary structure using a coupled RPV/supporting structure model. The applicant also stated that, for the RPV, (1) the presence of fluid and other structural components introduces a dynamic coupling effect, (2) hydrodynamic coupling effects caused by horizontal excitation are considered by including coupling fluid masses lumped to appropriate structural nodes at the same elevations, (3) the details of the hydrodynamic mass derivation are given in DCD Reference 3.7-6, and (4) the hydrodynamic coupling effects are assumed to be negligible in the vertical excitation and fluid masses are lumped to appropriate structural locations. In RAI 3.7-28, the staff asked the applicant to include in the DCD the following additional information related to modeling of the RPV and modeling of hydrodynamic coupling effects:

a. Describe how the seismic analysis results for the RPV and its major internal components, obtained from the coupled RPV/supporting structure model, were used in design of the RPV.

b. Describe how direct fluid loading on the major internal components was considered. Was the fluid load transferred from these internal components to the locations of attachment to/contact with the RPV?

c. Describe the methodology in DCD Reference 3.7-6 to derive the hydrodynamic mass, and include the results of implementing the method for the RPV model.

d. Provide the technical basis for the assumption that hydrodynamic coupling effects are negligible in the vertical excitation.

In its response, the applicant stated the following:

a. Maximum member end forces and moments and accelerations and response spectra at each nodal location from the seismic time history analysis of the primary structure (i.e., coupled RPV/supporting structure) model were used in the design of the RPV and the RPV internal components.

b. Fluid loads at internals nodal locations and RPV nodal locations were calculated using hydrodynamic loads calculation method described in response c below and added to RPV contact and attachment locations (i.e., at the appropriate nodal locations).

c. To determine the dynamic response of RPV and internals, the inclusion of the hydrodynamic mass is mandatory. The hydrodynamic mass effect comes from the force (due to the change in momentum of the fluid) which an accelerating solid object immersed in a fluid must impart to the fluid in order to cause fluid acceleration. Using the methodology described in DCD Reference 3.7-6, the hydrodynamic mass in the RPV and internals system can be idealized as being that of concentric cylinders. Hydrodynamic mass calculation is based on two or three concentric cylinders. Based on this method diagonal and off-diagonal hydrodynamic masses were calculated for RPV and internal components and used in the RPV and internals model. Leakage effects in the core, guide tubes and steam separators are accounted for in the calculation.

d. In the vertical model the predominant effects of the water in the vessel is to load the bottom head. Based on geometry and modeling in the vertical direction, there are no compartmental regions with leakage, which will have coupling effect for the vertical RPV and internals model. Note that the core support plate and top guide are both represented as single nodes in the RPV and internal part of the primary structure model. Based on this and consistent with the all GE BWR vertical model, the hydrodynamic mass coupling between model nodes is assumed negligible.

During the audit on June 5–8, 2006, the staff discussed the RPV model with the applicant. Subsequently, the staff determined that the detailed review of the RPV modeling is not necessary and judged the applicant’s response to be acceptable, with respect to the staff’s review of DCD Section 3.7. Therefore, RAI 3.7-28 is 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 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 Section 3.4.1 of ASCE 43-05, "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities." 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, SEA-ESB-033, "Parametric Evaluation of Effects on SSI Response," Revision 0, contains details. The applicant stated that it will revise DCD Section 3A in the next update to include this information. The staff confirmed that Appendix 3A to DCD Revision 3 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 is 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 Appendix 3A to the DCD, can transmit frequencies up to 50 Hz and are 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 concluded that the mode shapes up to 50 Hz are adequate for use in the seismic stick model analysis. Therefore, RAI 3.7-57 is resolved.

Based on its review and audit of ESBWR DCD Sections 3.7 and 3.8, the staff determined that GEH developed the seismic stick models for the RB/FB and CB and the static NASTRAN FEMs for the RB/FB and CB directly from design information, without conducting any comparison/correlation of the static and dynamic responses of these models. The staff concluded that it needed this comparison/correlation to complete its assessment of the adequacy of the stick models and the static NASTRAN FEMs.

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 in order to assess the adequacy of the stick models and the static NASTRAN FEMs, it performed static and dynamic comparative analyses for both the RB/FB and the CB. The following documents contain details of the analyses:

- Attachment SEA-ESB-043, “Comparative Analysis between Seismic Stick Model and Static Finite Element Model for RB/FB,” Revision 0
- Attachment SEA-ESB-044, “Comparative Analysis between Seismic Stick Model and Static Finite Element Model for CB,” Revision 0

The applicant stated that the stick model is consistent with the FEM in predicting static and dynamic responses. The stick model adequacy is therefore confirmed.

During the audit of October 31–November 2, 2006, the staff reviewed the two cited reports and identified the following two areas where it needed additional information to confirm 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 FEM for RB/FB, Revision 1.
- Attachment SEA-ESB-044, Comparative Analysis between Seismic Stick Model and Static FEM 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 properly addressed. On the basis of this review, the staff concludes that the applicant has demonstrated sufficient equivalency between the dynamic seismic stick model and the static NASTRAN model. The staff further concludes, 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 is resolved.

3.7.2.3.4 Soil-Structure Interaction

In DCD Section 3.7.2.4, the applicant stated that Appendix 3A to the DCD presents the seismic SSI analyses of the Category I buildings performed for a range of soil conditions. The staff's review of Appendix 3A identified a need for additional information for the staff to complete its evaluation.

The first sentence of Appendix 3A, Section 3A.1, states that this appendix presents SSI analysis 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, and CB of the ESBWR standard plant under SSE excitation. It was not clear to the staff whether the SSE is defined as both the 0.3-g RG 1.60 ground motion response spectra and the North Anna ESP ground motion response spectra, or as the combination (envelope) of these two spectra. In RAI 3.7-29, the staff requested that the applicant 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 finds the applicant's response to RAI 3.7-5 acceptable, RAI 3.7-29 is resolved.

The last part of the second paragraph on page 3A-4 of 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 provided 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 have significant variation of shear wave velocity with depth, leading to potentially significant impedance mismatches between layers. Such profiles can have effective impedance functions that are significantly different from those associated with a uniform half-space (see, for example, "Handbook of Impedance Functions" by Sieffert and 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 significantly different computed responses. The behavior (or response) of a massive structure (such as the RB/FB or CB) may be significantly influenced by these variations that result from 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 asked the applicant to include this information in the DCD and also identify it as a COL interface item.

In its response dated August 17, 2006, the applicant stated that, to enhance the applicability of the ESBWR design, it used the SASSI computer code to evaluate four cases of layered sites for the RB/FB and the CB. These cases cover a wide range of variation of shear wave velocity with depth to capture the effect of impedance mismatches between layers. Enclosure 2, SEA-ESB-033, contains details. Since the results of layered sites are considered in the site-envelope design loads, 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.

In August 17, 2006, 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.5 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. The staff based its assessment on comparison of the results of its confirmatory SSI analysis (which used the same structural models and ground response spectra) to the applicant's results.

During the October 31–November 2, 2006, staff audit, the staff discussed with the applicant 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 to address this under RAI 3.7-16. **RAI 3.7-30 is being tracked as an open item,** pending the resolution of RAI 3.7-16.

The staff noted that the minimum shear wave velocity specified in Table 3A.3-1 of Appendix 3A to the DCD for the generic site is 1000 ft/s. However, the staff could not determine whether this is a best estimate (BE) value or a lower bound (LB) value after considering potential variations (BE divided by the square root of 2). If the table values are BE, then the LB shear wave velocity would be 707 ft/s. The staff position is that competent material should have an LB shear wave velocity of 1000 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 of 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 asked the applicant to (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) to revise the DCD to specify the LB 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 LB 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 LB iterated shear velocity profile at any site will be no less than 300 m/s, 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 is resolved.

However, the staff 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 was in response to 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. At that time, the staff did not evaluate the acceptability of completely deleting DCD Section 3.7.5.1.

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 that had previously been 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 is retained. The second condition was stipulated based on review of DCD Tier 2, Revision 3, Table 2.0-1, related to the minimum shear wave velocity. The very specific wording previously accepted by the staff and incorporated by the applicant in DCD Revision 2, Section 3.7.5.1, was modified and may be subject to misinterpretation

In its response dated November 21, 2007, the applicant revised the DCD, but the staff had additional comments regarding the information included in Tier 1. **RAI 3.7-61 (part 5) is being tracked as an open item.**

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 1000 ft/s in order to confirm 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 BE to an LB value, defined as the BE 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 1000 ft/s is an LB velocity and not a BE velocity, or, as an alternative, the minimum acceptable BE 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 what degree of variation from the uniform velocity profile 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 indicated that the LB velocity profile is no less than 1000 ft/s (300 m/s). Therefore, RAI 3.7-54 is resolved, based on the resolution of RAI 3.7-31.

In Appendix 3A to the DCD, 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 did not explain 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 asked the applicant to clarify in the DCD how the SSI calculations considered these properties (material damping and radiation damping).

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 the 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 the SSI calculations deal with these properties.

On the basis that the soil material damping values were conservatively neglected in the uniform-site SSI analyses that use soil springs, the staff finds the response acceptable. Since the applicant is using the SASSI computer code (frequency domain solution) to perform additional SSI analyses for layered sites, the staff's concern about soil damping is resolved. RAI 3.7-16 addresses the remaining issue, 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 Appendix 3A to DCD Revision 2, the applicant stated that the soil material damping was conservatively neglected in the uniform-site SSI analyses that use soil springs. Therefore, RAI 3.7-32 is 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, the staff knows 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 asked the applicant to 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 should be incorporated into the acceptable site profile characteristics to restrict the actual dynamic pressures anticipated. In its response dated

August 17, 2006, the applicant stated that, to confirm that the ASCE 4-98 approach is conservative, it performed an additional evaluation 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 of the response provides details. The applicant committed to revising DCD Section 3A in the next update to include this information.

During the October 31–November 2, 2006, audit, the staff requested that the applicant clarify the RAI response to include 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 SASSI analysis or ASCE 4-98 methodology. The staff finds that the applicant’s supplemental response adequately addresses the enveloping issue and is acceptable. The staff confirmed that Appendix 3A to the DCD, Revision 3, includes the identified change. Therefore, RAI 3.7-33 is 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 response to RAIs 3.7-5 and 3.7-8 for part (a) and its response to 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 why the NUREG does not require spectrally matched time histories to satisfy PSD enveloping guidelines. The applicant proposed modifications to DCD Tier 2, Section 3.7.1.1.3, to include the above technical basis for not satisfying the SRP PSD enveloping guidelines.

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 changes as discussed above. On this basis, RAI 3.7-34 is resolved.

In Appendix 3A to the DCD, Section 3A.7, the applicant indicated 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 two issues in need of clarification—(1) the soil damping (material damping and energy loss resulting from wave propagation) that was assigned for the SSI analyses and (2) how the analysis considered embedment effects (especially at relatively soft soil sites). In RAI 3.7-35, the staff asked the applicant to supply these clarifications and also to describe how the elastic half-space theory was applied to the North Anna site in the DCD.

In its August 17, 2006, response, for part (1) the applicant referenced its answers 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 embedment works to reduce basemat reaction shear forces. Enclosure 2 of the response contains details. The foundation properties considered in the SSI analysis for the North Anna site shown in DCD Table 3A.3-2 are applied as uniform half-space soil. As stated in DCD Section 3A.3.2, they are determined based on the North Anna ESP site-specific conditions. (See the response to RAI 3.7-7 for further details.) The applicant stated that it will revise DCD Section 3A in the next update to provide the requested clarifications.

The staff determined that the acceptability of the response submitted depends on the resolution of RAI 3.7-16. On this basis, **RAI 3.7-35 is being tracked as an open item.**

In Tables 3A.7-1 through 3A.7-14 of Appendix 3A to the DCD, the applicant presented the eigenvalue analysis results. Based on the data presented, it appears 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% 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 finds 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 was 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 second 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 SASSI-2000 computer code to perform SSI analyses, when using the 0.005-second time step for the artificial input motions. The version of SASSI-2000 available to the applicant has a limitation of 4096 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 8192 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 requested that the applicant provide the frequencies and modes 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 by using a reduced model in which the three sticks representing the RPV were removed. Based on its 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 will 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 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 SASSI-2000 capability to handle 8192 input steps. The applicant also revised the RB/FB stick model to include coupling in the vertical direction between the RB and RCCV. The applicant provided the revised model to the NRC in a letter dated August 22, 2006.

The staff finds that the applicant's supplemental response adequately addresses the two technical issues raised by the staff during the June 5–8, 2006, audit. The applicant increased the capability of SASSI-2000 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 is resolved.

In the third paragraph of Appendix 3A to the DCD, 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.5.2 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 asked the applicant to 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) appears in the response to RAI 3.7-49, which describes the procedure used to convert these frequency-dependent soil impedances to frequency-independent soil stiffness and damping ratios. 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 staff review of the example, the staff finds the response to be acceptable. The applicant made the requested changes in Revision 2 of Appendix 3A to the DCD. Therefore, RAI 3.7-37 is resolved.

In Appendix 3A to the DCD, the applicant stated that the shear wave velocities and material damping ratios are strain compatible. In RAI 3.7-38, the staff asked the applicant to 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

(3) a clear description 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 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 stated that it will revise DCD Section 3A.3 in the next update.

The staff finds 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 the use of material damping are accepted methods for incorporating the nonlinear behavior of soil, 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.

During the October 31–November 2, 2006, staff audit, the staff asked the applicant to confirm that using an envelope of soil sites that includes a fixed base condition resolves the staff's concern about radiation damping. In its supplemental response, the applicant stated that, as shown in Table 6-1 of Enclosure 2 (SEA-ESB-033), it has been confirmed that the design-basis envelope forces and FRS include the results of fixed-basis analysis, in which radiation damping is zero. The staff finds 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 considers RAI 3.7-38 to be resolved but has determined that the applicant needs to identify a COL information item, specifying that the COL applicant will verify that the iterated soil properties at the site fall in the range of those considered in the generic SSI analysis. The staff requested that the applicant address this as part of RAI 3.7-62.

For the SSI analyses that were performed, the staff, in RAI 3.7-39, 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 August 17, 2006, 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 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 structure-to-structure interaction effect are bounded by the broadened envelope responses of uniform site cases in the entire frequency range. Enclosure 2 contains 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 asked the applicant to 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 Enclosure 2 (SEA-ESB-033).

Because the applicant confirmed that the design FRS bounds the FRS both with and without structure-structure interaction effects, the staff finds the supplemental response to be acceptable. The applicant incorporated the change identified in the initial response into Revision 3 of the DCD. Therefore, RAI 3.7-39 is resolved.

In addition to the evaluation of the issues discussed above, the staff's review of DCD Section 3.7.2 and Appendix 3A found that the applicant performed its SSI analyses based on two assumptions—(1) soil sites with uniform properties and (2) soil stiffness presented 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 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 soft generic soil site (one of the four uniform site conditions used by the applicant) as the supporting media. The purpose of these analyses is 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 is 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:

- detailed finite element RB/FB model (e.g., including figures showing mesh plots, node numbering) used for the development of the lumped-mass stick model

- detailed fixed-base (fixed at the top of the foundation mat) lumped-mass stick model used in the applicant's SSI analyses

- large-size structural design drawings of the RB/FB, and specifically, drawings showing the detailed foundation mat and embedded side walls

- soil information used to develop soil springs and soil damping for the SSI analyses of the RB/FB supported by the soft soil condition

- description of the computer code DAC3N used by the applicant for the SSI analyses

- input ground motion time history text files in digitized form

- description of the SSI analytical formulation and digitized response computation results

In its response, the applicant provided the information requested by the staff. 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 the 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 finalized. 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 is 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, in accordance with the method of DCD Reference 3.7-7 or its equivalent, is an acceptable alternative method.

The staff noted that 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 those obtained by 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 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 (RRS) 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 Eigen data set (obtained from the subsystem Eigen analysis) 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. The staff requested the validation package for the ERSIN computer code in RAI 3.7-56. The staff included the resolution of RAI 3.7-56 with 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 (regarding seismic and dynamic qualification of seismic Category I mechanical and electrical equipment) that its use is for the development of equipment RRS. 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 are 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:

(4) 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.

(5) An alternative approach to obtaining codirectional FRS is to perform dynamic analysis with simultaneous input of the three excitation components, if those components are statistically independent of each other.

(6) 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 finds 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 the 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. These methods are (1) 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; and (2) to choose a set of frequencies such that each frequency is within 5 percent of the previous one.

The staff finds all three methods for selecting frequency intervals to be acceptable, on the basis that they are consistent with the acceptance criteria in SRP Section 3.7.2.5.

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 the acceptance criteria in SRP Section 3.7.2.6.

The applicant also identified the 100-40-40 method of combination, as described in ASCE 4-98 (DCD Reference 3.7-8) 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 the use of the 100-40-40 method of combination.

In its 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.

The staff initially found the applicant's response to be acceptable, pending review of the formal DCD revision and review of the implementation of the 100-40-40 method for the structural design of buildings. However, the staff's subsequent review of DCD Sections 3.8.1.3.6, 3.8.4.3.1.2, and 3.8.4.3.1.3 identified that the 100-40-40 method was implemented in accordance with ASCE 4-98, not in accordance with RG 1.92, Revision 2, Regulatory Position 2.1, Equation 13.

The staff has requested that the applicant either (1) implement the 100-40-40 rule in full compliance with RG 1.92, Revision 2, Regulatory Position 2.1, Equation 13 or (2) revise DCD Section 3.7.2.6 accordingly to describe the actual implementation of the 100-40-40 rule. **RAI 3.7-41 is being tracked as an open item,** pending review of the response provided by the applicant on December 3, 2007.

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. The total response may alternatively 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 finds this acceptable because it is consistent with the acceptance criteria in SRP Section 3.7.2.6.

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 asked the applicant to specifically identify in the DCD which of the spatial combination methods delineated in DCD Section 3.7.2.6 it used for seismic analysis of the building structures. In its response, the applicant referred to the response to RAI 3.7-41. The staff finds 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 finds 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 is 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 (Rev. 1) is applicable for the combination of modal responses. The applicant indicated that for modal combination involving high-frequency modes, the procedure of Appendix A (1989) to SRP Section 3.7.2 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 their 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 explains its rationale for not accepting this alternative method in RAI 3.7-17. In RAI 3.7-43, the staff asked the applicant to state whether it had used the alternative method, 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. The applicant's response to RAI 3.7-17 indicated that it would delete the alternative method from the DCD. Therefore, the staff finds 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 is resolved.

The staff 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 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 staff determined that the added sentences are unacceptable in their present form and location in the discussion and requested in RAI 3.7-61 (part 3) that the applicant change the wording.

In its response dated November 21, 2007, the applicant stated that it will revise DCD Tier 2, Section 3.7.2.7, step 1, to read as follows:

> Determine the modal responses only for those modes with 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.

The staff finds the proposed changes in wording and the changes in the DCD acceptable. **RAI 3.7-61 (part 3) is being tracked as a confirmatory item.**

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-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:

(7) The collapse of any non-Category I SSC does not cause the non-Category I SSC to strike a seismic Category I SSC.

(8) 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 a tornado, including missiles).

(9) 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 finds 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.

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 plus or minus 15 percent. If a detailed parametric variation study is made, the minimum peak-broadening ratio is plus or minus 10 percent. In lieu of peak broadening, the peak-shifting method of ASME Code, Section III, “Rules for Construction of Nuclear Power Plant Components,“ Appendix N, as permitted by RG 1.84, “Design, Fabrication, and Materials Code Case Acceptability, ASME Section III,” can be used.

The staff finds the methods identified by the applicant to be consistent with the acceptance criteria in SRP Section 3.7.2.9.

To complete its review, in RAI 3.7-44, the staff asked the applicant to 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 to 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 plus or minus 15 percent and agreed to revise DCD Section 3.7.2.9. The staff noted that RG 1.122 accepts the plus or minus 15 percent technique for broadening FRS peaks. In Revision 2 of DCD Section 3.7, the applicant made the identified change. On this basis, RAI 3.7-44 is resolved.

However, during the June 5–8, 2006, audit, the staff noted that the applicant had used the ASCE 4-98 incoherence reduction factors to reduce the spectral peaks of the raw FRS calculated from the time history analysis before the application of peak broadening. At that time, the staff was reviewing the use of the ASCE 4-98 incoherence reduction factors, and the use of the factors was not then acceptable. 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 finds the applicant's response acceptable, because the reduction factor in question is no longer used. In Revision 2 of Appendix 3A to the DCD, the applicant made the identified changes. On this basis, RAI 3.7-58 is resolved.

The staff noted that, in DCD Revision 3, the applicant revised Section 3.7.2.9, paragraph 1, in response to RAI 3.12-6, by adding the following sentences:

> 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 staff 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 needs additional description. In RAI 3.7-61 (part 4), the staff asked the applicant to provide additional clarifications. In its response dated November 21, 2007, the applicant stated that it will delete the second and third sentences in the first paragraph of DCD Tier 2, Section 3.7.2.9, and replace them with a new paragraph to read as follows:

> 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 percent. 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.

The staff finds the proposed changes and the marked up DCD acceptable. **RAI 3.7-61 (part 4) is being tracked as a confirmatory item**.

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. Section 3.7.2.3.1.3 of this report contains the staff's review of DCD Section 3.7.2.1.3.

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 finds the methods identified by the applicant to be consistent with SRP Section 3.7.2.11 acceptance criteria, and therefore they are acceptable.

To complete its review, the staff, in RAI 3.7-45, asked the applicant to 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 for the building structures and to describe the specific applications of each method. In its response, the applicant stated that, as described in Appendix 3A.7.2, a dynamic analysis that incorporates the torsional DOFs was performed to treat the torsional effects in the dynamic analysis. The applicant indicated that it would revise DCD Section 3.7.2.11 accordingly to clarify this issue. The staff finds the applicant's response acceptable. In Revision 2 of DCD Section 3.7.2.11, the applicant made the identified change. On this basis, RAI 3.7-45 is 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 finds 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. The applicant also presented additional approaches applicable to frequency domain analysis and direct integration time history analysis. The staff finds the description of composite modal damping in DCD Section 3.7.2.13 to be consistent with the acceptance criteria in SRP Section 3.7.2.13, with one exception.

From its review of DCD Section 3.7.2.13, the staff noted that the section does not address the limitation imposed on the use of composite modal damping in SRP Section 3.7.2.II.13. This limitation, as described in SRP Section 3.7.2.II.13, states that for models that account for SSI 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 it has considered this limitation in the applications of composite modal damping, and, if it did not consider the limitation, 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. The third paragraph of page 3.7-16 of the DCD 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 also 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 finds 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 is resolved.

In RAI 3.7-47, the staff asked the applicant 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 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 finds that the applicant's response to RAI 3.7-46 adequately addresses RAI 3.7-47, which is thus 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, "Seismic Analyses of Structures and Equipment for Nuclear Power Plants," Revision 3, 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 (letter from R.W. Klecker, U.S. 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 Equation 4-17 of the Bechtel report contains an error. The staff asked the applicant to submit its results. Following the June 5–8, 2006, audit, the staff conducted its own study of the equation in question and also concluded that the equation contains an error.

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 to permit the use of the SRSS method. The applicant referred to the Bechtel topical report as its source.

In a supplemental RAI response, the applicant provided the following:

(1) the corrected equation: Wb = (zb-za) [B(zb) - B(za)]/ 2 + B(za)(zb - za)

(2) 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 there is insufficient basis for using the SRSS combination. The applicant agreed to submit a second supplemental response and stated that it would use the absolute summation.

In a second supplemental RAI response, the applicant stated that it would use the ABS method instead of the SRSS method for combining the velocity terms V_h and V_v, that it will 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 revision.

The staff finds the applicant's second supplemental response to be acceptable, because ABS method is more conservative than 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 is resolved.

3.7.2.4 Conclusions

Because of open RAIs that need resolution, the staff is unable to finalize its conclusion regarding the acceptability of the seismic system analysis, in accordance with the acceptance criteria delineated in SRP Section 3.7.2.

3.7.3 Seismic Subsystem Analysis

3.7.3.1 Regulatory Criteria Related to Seismic Subsystem Analysis

The staff accepts the design of subsystems that are important to safety and must withstand the effects of earthquakes if the design complies with the relevant requirements of GDC 2, contained in Appendix A to 10 CFR Part 50, and Appendix A to 10 CFR Part 100 concerning natural phenomena. The relevant requirements of GDC 2 and Appendix A to 10 CFR Part 100 are the following:

- GDC 2—The design basis shall 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.

  GDC 2 requires, in relevant part, that 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. GDC 2 also 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. In accordance with SRP Section 3.7.3, the staff reviews methods for seismic analysis and modeling of piping systems and components to ensure that they accurately and/or conservatively represent the behavior of SSCs during postulated seismic events, thus assuring that GDC 2 is met. Meeting the requirements of GDC 2 ensures that fundamental safety functions, such as core cooling, are adequately protected, so that the plant can be safely brought to a shutdown condition following a seismic event.

- Section VI(a) of Appendix A to 10 CFR Part 100 defines the OBE and the SSE and requires that the engineering methods used to ensure that the required safety functions are maintained during and after the vibratory ground motion associated with the SSE shall involve the use of either a suitable dynamic analysis or an appropriate qualification test methodology to demonstrate that all SSCs important to safety are capable of withstanding the seismic and other concurrent loads, including postulated accident loads, except where it can be demonstrated that the use of an equivalent static load analysis methodology provides adequate conservatism. The requirements of Appendix A to 10 CFR Part 100 ensure that the applicable levels of vibratory ground motion corresponding to the OBE and the SSE are properly defined and that adequate accuracy and/or conservatism are applied in defining the system data used for input into the seismic subsystem analysis. SRP Section 3.7.3 reviews the methods utilized for seismic subsystem analysis and thereby ensures that the Appendix A requirements are being met. Compliance with the requirements detailed in Appendix A to 10 CFR Part 100, in conjunction with meeting the requirements in GDC 2, as discussed above, ensures that the plant can be operated without undue risk to the health and safety of the public and that it can be safely brought to a shutdown condition, with its fundamental safety functions intact, following a seismic event.

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 the OBE is defined as being less than or equal to one-third of the SSE ground motion, it is not necessary to conduct explicit response or design analyses in order to satisfy paragraph IV.(a)(2)(i)(B)(I) of Appendix S to 10 CFR Part 50.

In the final safety evaluation report for the ABWR and the System 80+ design certifications, the staff accepted an exemption from the requirement of Appendix A to 10 CFR Part 100 that all safety-related SSCs be designed to remain functional and within applicable stress and deformation limits when subjected to an OBE. This exemption was based on the licensees' alternative analyses performed for the SSE and procedural requirements to inspect the plant following an earthquake at or above one-third of the SSE. The licensees' alternative analyses met one or both of the following approaches in determining the number of earthquake cycles to be used in the fatigue analysis of piping systems:

(1) Use two SSE events with 10 maximum stress cycles per event (20 full cycles of the maximum SSE stress range).

(2) Use the number of fractional vibratory cycles equivalent to that of 20 full SSE vibratory cycles (but with an amplitude not less than one-third of the maximum SSE amplitude) when derived in accordance with Appendix D to Institute of Electrical and Electronics Engineers (IEEE) 344-1987, “Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations.”

These alternative analyses accomplish the design objectives of the OBE design analyses and meet the Commission-approved staff recommendations in SECY-93-087.

3.7.3.2 Technical Information in the DCD Related to Seismic Subsystem Analysis

In DCD Revision 3, Section 3.7.3, the applicant stated that this section applies to seismic Category I (C-I) and seismic Category II (C-II) subsystems (equipment and piping) that are qualified to satisfy the performance requirements according to their C-I or C-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 data from experience, the applicant stated that this section of the DCD addresses the aspects related to analysis only.

3.7.3.2.1 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 apply equally to equipment and piping systems and that 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 details additional considerations associated with the ISM response spectrum method of analysis. For equipment analysis, the applicant referenced the requirements of step 1 of Section 3.7.2.7 for ZPA cutoff frequency determination.

3.7.3.2.2 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 smaller 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 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 also 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,” Revision 2, issued June 1988, 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 may be 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 generally 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 seven rules:

(1) 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.

(2) 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.

(3) 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 Section 3.7.2.1.1.

(4) 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 stipulated in DCD Section 3.7.2.1.1, when calculated as a simply supported beam with uniformly distributed mass.

(5) The analytical model includes the torsional effects of valve operators and other equipment with offset center of gravity with respect to the piping centerline.

(6) All pipe guides and snubbers are modeled so as to produce representative stiffness.

(7) The equivalent linear stiffness of the snubbers is based on certified test results 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 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 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, to preclude amplification, analysis should demonstrate 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. Otherwise, the contribution of the support weight amplification is added into the piping analysis. Piping supports will be evaluated in detail to include the impact of self-weight excitation on support structure and anchorage, along with piping analyzed loads where this effect may be significant.

The stiffness of the building steel/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.

3.7.3.2.3.2 Equipment 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 the following 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 whose flexibility is significant 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 FEM, 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 mid-span 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 process described above, 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 will not be 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/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 also 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 Tier 2, Section 3.7.3.5, the applicant stated that DCD Table 3.7-1 shows damping values for equipment and piping, and these values are consistent with RG 1.61. For ASME Code, Section III, Division 1, Class 1, 2, and 3, and ASME B31.1 piping systems, the alternative damping values specified in Figure 3.7-37 may be used. For systems comprising 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 resulting 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 NS) system is designed to be isolated from any seismic Category I system by either a constraint or barrier or is remotely located with regard to the seismic Category I system. If it is not feasible or practical to isolate the seismic Category I system, adjacent non-Category I systems are analyzed according to the same seismic criteria that apply 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, which are typically supports located on the same floor, or portions of a floor, of a structure. The responses caused by motions of supports in two or more different groups are combined by the SRSS procedure.

In addition to the inertial response discussed above, the analysis considers the effects of relative support displacements. 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 $S_d = S_a$ x $g/ù^2$, where S_a is the spectral acceleration in g's at the high-frequency end of the spectrum curve (which, in turn, is equal to the maximum floor acceleration), g is the gravity constant, and 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 (i.e., most unfavorable combination) manner, 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 resulting from seismic anchor motion are included in Service Level D load combinations.

The applicant also identified that the ISM time history method of analysis may be 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 induce forces and moments in 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.

3.7.3.2.13 Seismic Category I Buried Piping, Conduits, and Tunnels

In DCD Section 3.7.3.13, the applicant indicated that for seismic Category I buried conduits, tunnels, and auxiliary systems, the analysis considers the following items:

- Two types of loadings induced by ground shaking 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 analysis considers effects caused by local soil settlements, soil arching, and other similar factors.

The applicant also stated that for the ESBWR, there is no buried seismic Category I piping.

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 there are no seismic Category I concrete dams in the ESBWR design.

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:

- The analysis includes at least two horizontal modes of combined fluid-tank vibration and at least one vertical mode of fluid vibration. The horizontal response analysis includes at least one impulsive mode in which the response of the tank shell and roof is combined 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 with due consideration given 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, S_a1, 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, "Recommended Revisions to Nuclear Regulatory Commission Seismic Design Criteria," issued May 1980. Alternatively, the maximum spectral acceleration corresponding to the relevant damping may be used.

- Damping values used to determine the spectral acceleration in the impulsive mode are based on the system damping associated with the tank shell material, as well as with the 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 DCD Tier 2.

- In determining the spectral acceleration in the horizontal convective mode, S_a2, the fluid damping ratio is 0.5 percent of critical damping unless experimental results can substantiate a higher value.

- The maximum overturning moment, M_o, at the base of the tank is obtained by the modal and spatial combination methods discussed in Sections 3.7.2.7 and 3.7.2.6, respectively. The uplift tension resulting from M_o is resisted either by tying the tank to the foundation with anchor bolts or other fasteners or by mobilizing enough fluid weight on a thickened base skirt plate. The latter method of resisting M_o, 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 Sections 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 SSI result in higher response, then an appropriate SSI method of analysis comparable to that described in DCD Tier 2, Reference 3.7-16 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 M_o.

- In addition to the above, consideration is given to preventing the buckling of tank walls and roof, failure of connecting piping, and sliding of the tank.

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 shall 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. 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 will 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 Standard B31.1, whenever the following conditions 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 detailed stress analysis for all applied loads and load combinations using static and dynamic analysis methods defined in Section 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 CUFs, (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 may be 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 the following options:

(1) Specify and design a structural anchor at the seismic Category I valve and analyze the seismic Category I subsystem.

(3) 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.

(3) Design the interface anchor between the seismic and NS category piping for the maximum load using piping reactions from both sides.

The applicant also stated that where small seismic Category II piping is directly attached to seismic Category I piping, it can be decoupled from seismic Category I piping.

3.7.3.3 Staff Evaluation Related to Seismic Subsystem Analysis

At the beginning of DCD Tier 2, Revision 3, 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 the aspects related to analysis only.

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 apply equally to equipment and piping systems and that the response spectrum method is used most often. DCD Section 3.7.3.9 describes special considerations associated with the ISM response spectrum method of analysis.

The staff's review of the analysis methods described in DCD Section 3.7.2.1 appears in Section 3.7.2.3.1 of this report. Section 3.7.3.3.9 of this report contains 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, a 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 also 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, in accordance with Appendix D to IEEE 344, a number of fractional peak cycles equivalent to the maximum peak cycles for five 0.5-SSE events may be used, when followed by one full SSE.

The staff finds the applicant's approach for 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.

The staff's review of DCD Section 3.7.2.3 appears in Section 3.7.2.3.3 of this report.

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.

The staff's review of DCD Section 3.7.3.3.1 appears in Sections 3.12.5.2 and 3.12.7.7 of this report.

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. In that section, the applicant presented its criteria for selecting the location and the number of lumped masses.

The staff's review of these criteria identified several areas where additional information was needed. In RAI 3.7-51, the staff asked the applicant to address the following issues:

(a) The alternate criterion in DCD Section 3.7.3.3.2 for ensuring a sufficient number of mass DOFs 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 that the applicant define "cutoff frequency," as it relates to ensuring a sufficient number of mass DOFs, and explain in detail how it is determined for SSCs.

(b) The staff asks the applicant to clarify its criterion in DCD Section 3.7.3.3.2 related to location of lumped masses 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 (see response to RAI 3.12-20). 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 that 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 also stated 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 case 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 finds the applicant's response to part (a) acceptable. During the June 5–8, 2006, audit, the staff discussed the proposed DCD revision for part (b) with the applicant. The staff noted that, in some cases, 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 by more clearly describing its approach for 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 finds this acceptable. In Revision 2 of DCD Section 3.7, the applicant incorporated the requested changes. Therefore, RAI 3.7-51 is resolved.

3.7.3.3.3.3 Modeling of Special Engineered Pipe Supports.

In DCD Revision 3, Section 3.7.3.3.3, the applicant stated that special engineered pipe supports shall not be used. For this reason, the staff concludes that it is not necessary to address the 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/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.

The staff finds the approach discussed in DCD Section 3.7.3.4 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 the damping values for equipment and piping shown in DCD Table 3.7-1 are consistent with RG 1.61. For ASME Section III, Division 1, Class 1, 2, and 3, and ASME/ANSI B31.1 piping systems, the alternative damping values specified in Figure 3.7-37 may be used. For systems comprising subsystems with different damping properties, the analysis procedures described in DCD Section 3.7.2.13 apply.

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.

Section 3.12.4.8 of this report contains the staff's review of DCD Section 3.7.3.8, specifically for interactions with piping. The staff determined that the review is also applicable 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.

Section 3.7.2.3.1.3 of this report presents the staff's review of DCD Section 3.7.2.1.3.

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 to occur.

Section 3.12.4.2 of this report presents the staff's review of DCD Section 3.7.3.12, specifically for piping. 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/analysis of seismic Category I or II buried piping, conduits, tunnels, and auxiliary systems considers 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 stated in DCD Tier 2, Revision 3, that the ESBWR has no buried seismic Category I piping.

The staff noted that the applicant's considerations are consistent with SRP Section 3.7.3.II.12. However, the applicant 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" is not defined. In RAI 3.7-52, the staff requested that the applicant submit additional clarifying information.

Since its initial review of DCD Revision 1, Section 3.7.3.13, the staff has been attempting to gain an understanding of the scope of buried components and the methods to be used for their seismic analysis. Although the applicant has submitted several responses to RAI 3.7-52, the scope of buried components and the seismic analysis methods to be employed remain unclear. Consequently, the staff has been unable to resolve RAI 3.7-52.

From its review of DCD Revision 3, Section 3.7.3.13, and previous responses to RAI 3.7-52, the staff has noted 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 GEH 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 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 Section 3.5.2 and the commentary of ASCE 4-98. The staff's understanding is that the GEH 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) GEH 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 GEH has specifically identified and described all buried seismic Category I systems and components.

Consequently, the staff has asked the applicant to provide the following additional information as a followup to RAI 3.7-52:

(1) 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.

RAI 3.7-52 is being tracked as an open item.

3.7.3.3.14 Methods for Seismic Analysis of Seismic Category I Concrete Dams

In DCD Revision 3, Section 3.7.3.14, the applicant stated that the ESBWR design has no seismic Category I concrete dams. On this basis, the staff concludes that it is not necessary to address 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 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 these items are in accordance with the guidance presented in SRP Section 3.7.3.II.14 and therefore are acceptable to the staff. However, several items in the analysis method for the aboveground tanks need clarification. DCD Section 3.7.3.15 indicates that the evaluation may consider the beneficial effects of SSI. However, no discussion is provided for the case where SSI effects may lead to a higher response (i.e., the effects are not beneficial). If SSI effects are important, then the analysis must consider them. In addition, the applicant should describe or refer to an appropriate SSI method of analysis, comparable to those identified in SRP Section 3.7.3.II.14. Regarding damping, it was not clear how the damping value in the impulsive mode is determined. In RAI 3.7-53, the staff asked the applicant to address the following:

(c) DCD Section 3.7.3.15 indicates that the beneficial effects of 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.

(d) 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:

(e) DCD Section 3.7.3.15, 6th bullet, 3rd sentence will be revised to read: "If the effects of SSI results 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, BNL 52361, "Seismic Design and Evaluation Guidelines for the Department of Energy High-Level Waste Storage Tanks and Appurtenances." October 1995.

(f) 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 finds the applicant's response to part (a) acceptable. During the June 5–8, 2006, audit, the staff asked the applicant to clarify its response to part (b) to discuss 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 the tank analysis includes SSI effects.

In its supplemental response, the applicant stated that it would revise DCD Tier 2 to further clarify how the soil damping is determined and used in the analysis when SSI effects are 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. In Revision 2 of DCD Section 3.7, the applicant incorporated the requested changes. On this basis, RAI 3.7-53 is 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 section 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 at 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 staff's review of DCD Section 3.7.3.17 appears in Sections 3.12.4.8 and 3.12.5.4 of this report.

3.7.3.4 Conclusions

Because of open RAIs identified in Sections 3.7.1.3, 3.7.2.3, 3.7.3.3, 3.12.4.3, 3.12.5.4, and 3.12.6.13 of this report, the staff is unable to finalize its conclusion regarding the acceptability of the applicant's seismic subsystem analysis.

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, 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 regulatory guides.

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 list of regulatory guides and the description provided in DCD Tier 2, Section 3.7.4, 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 provided 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, and FB. In Tier 2, Section 3.8, of the DCD, General Electric Hitachi Nuclear America, LLC (GEH or the applicant) described the design, analysis, testing, and ISI of these structures following the standard FSAR format under the sections noted below:

Section 3.8.1—Concrete Containment
Section 3.8.2—Steel Components of Concrete Containment
Section 3.8.3—Containment Internal Structures
Section 3.8.4—Other Seismic Category I Structures
Section 3.8.5—Foundations

In addition, the applicant provided design details and evaluation results for seismic Category I structures in Appendix 3G. The applicant also included other pertinent information used for the analysis and design of seismic Category I structures in Appendices 3B, 3C, and 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 NUREG-0800. The following sections discuss the results of the staff review.

3.8.1 Concrete Containment

The 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 RCCV is totally enclosed by the RB. The concrete containment consists of the RPV pedestal, containment cylindrical wall, top slab, suppression pool slab, and foundation mat. This section of the SER discusses the concrete elements and steel liner of the containment structure. SER Section 3.8.2 discusses the steel components of the containment that resist pressure and are not backed by structural concrete.

3.8.1.1 Regulatory Criteria Related to Concrete Containment

The staff reviewed DCD Tier 2, Section 3.8.1, "Concrete Containment," and DCD Tier 2, Appendix 3G, "Design Details and Evaluation Results of Seismic Category I Structures." The staff will consider 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. Meeting the guidance of this SRP section will ensure that the relevant requirements of Title 10, Section 50.55a, "Codes and Standards," of the *Code of Federal Regulations* (10 CFR 50.55a) and GDC 1, 2, 4, 16, "Containment Design"; and 50, "Containment Design Basis," of Appendix A, of 10 CFR Part 50, are met. 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 shall 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 shall 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 shall withstand the dynamic effects of equipment failures including missiles and blowdown loads associated with the LOCA.

- GDC 16 requires that the concrete containment shall act as a leaktight membrane to prevent the uncontrolled release of radioactive effluents to the environment.

- GDC 50 requires that the concrete containment shall 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," which contains material specifications, design criteria, fabrication and construction requirements, construction testing and examination techniques, and structural integrity testing (SIT) of the concrete containment per 10 CFR 50.55a.

The staff evaluated the design, materials, fabrication, erection, inspection, testing, and inservice surveillance of the reinforced concrete containment based on the 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, “Materials, Construction and Testing of Concrete Containments,” issued June 1981

For design certification, Section IV.(a)(2)(i)(A) of 10 CFR Part 50, Appendix S, 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 in order to satisfy the requirements of Section IV.(a)(2)(i)(B)(I) of Appendix S to 10 CFR Part 50.

3.8.1.2 Technical Information in the DCD Related to Concrete Containment

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/PCC pools and the service pools for storage of the dryer/moisture separator and other uses.

The containment wall is 2 meters (m) (6 feet (ft) 7 in.) thick with an inside radius of 18 m (59 ft) and height of 19.95 m (65 ft 6 in.). The containment design pressure is 310.3 kilopascals gauge (kPag) (45 pounds per square inch guage (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 containment are in accordance with Subsection CC of the 2004 Edition of ASME Code, Section III, Division 2. The materials, construction, and testing of the concrete containment are in accordance with the guidance in RG 1.136. In addition, the applicant used industry standards, such as ACI 349-01, and standards published by the American Society for Testing and Materials (ASTM) and the 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 kilopascals (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 suppression pool 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 and/or conditions.

SRV loads—Oscillatory dynamic pressure loadings resulting from discharge of SRVs into the suppression pool.

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 Section 3.3, DCD Tier 2.

Extreme Environmental Loads

E′—SSE loads as defined in Section 3.7, DCD Tier 2, including pool-sloshing loads.

W′—Loads indirectly transmitted by the tornado specified in Section 3.3, DCD Tier 2.

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 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_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 suppression pool 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 suppression pool 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—PS bubble pressure on the suppression pool 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. 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 ASCE Standard 4-98.

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) utilizes the linear elastic finite-element 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. The SSI analysis is described in Appendix 3A to the DCD. The finite-element model 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 suppression pool boundaries are simulated as equivalent static pressure loads equal to the dynamic peak value times the DLF. The model includes major penetrations, including the drywell head, upper and lower drywell equipment and personnel hatches, suppression chamber access hatch, and MS and feedwater pipe penetrations.

The liner plate and its anchorage system are analyzed 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 of 4.41 megapascals (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 the SIT will be conducted in accordance with ASME Code, Section III, Article CC-6000, and RG 1.136. Deflection and concrete crack measurements are made to 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 Subarticle CC-6370 of ASME Code Section III, Division 2.

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 Section XI, edition and addenda specified, in accordance with 10 CFR 50.55a. The containment structure is designed to provide 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 specified 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 Related to Concrete Containment

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. 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 containment internal wall (such as pipe restraints); containment external supports, if any, attached to the wall to support external structures/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 which are not shown. These elements include the shield wall, RPV stabilizer, RPV skirt, RPV 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 suppression pool).

In its response dated June 28, 2006, 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 dated October 31, 2006, to provide the NRC with the details of reinforcement around MS/feedwater penetrations and a representative hatch through the RCCV. This information would be representative of the detailed structural design.

The applicant further stated that DCD Figure 3.8-1 is intended 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. Details for the RPV insulation and the major equipment platforms are developed in the detailed design phase.

During its onsite audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, California, the staff discussed the initial response with the applicant. The staff noted that even if "construction level design details" have not been performed, additional information should be provided 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 second part of the RAI was aimed at obtaining a single figure that would show all of the various structural elements and attachments. The GEH 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 will 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 will be confirmed by the COL holder.

In a supplemental response dated September 14, 2006, 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 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 ACI 349 Appendix B.
>
> 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 -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 Appendix B for the embedded anchors.

In a second supplemental response dated November 7, 2006, 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 a third supplemental response dated January 24, 2007, the applicant stated that it will update the descriptions and sketch details of representative containment structural components provided in the Supplement 1 and 2 responses in the next revision to DCD Tier 2. 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 finds 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 the proposed revisions are included in DCD Revision 3. RAI 3.8-3 is 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 dated August 31, 2006, 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. 12 (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 of 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 specified 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 be applicable for all loads.

Analogous to the jurisdictional boundary definition provided in Interpretation No. 12, the RAI response stated that structural components (e.g., RB floor slabs, fuel pool girders), which are integral with the containment, are treated the same as the containment only so far as loads and loading combinations are concerned in the design. The applicant indicated that this is consistent with the NRC position provided in RG 1.142, on the design code (ANSI/ACI 349-97) and the requirements for the DF slab in the 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, California, the staff requested further clarification. The applicant explained that the loads and load combinations for the entire RB are checked 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 "Code Requirements for Nuclear Safety-Related Concrete Structures." The staff asked the applicant to provide the technical basis for this conclusion.

In a supplemental response dated January 29, 2007, 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 the supplemental response, the applicant also presented a comparison of acceptance criteria between ACI 349-01 and the 2004 edition of ASME Code, Section III, Division 2.

The staff reviewed the supplemental response and finds that additional clarification is needed. 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 is not clear as to why there is 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 a supplement to RAI 3.8-4 the staff requested applicant to explain the purpose of the comparison and clarify how ASME Code, Section III, Division 2, Subsection CC and the ACI 349-01 code were used for the design of the RB. **RAI 3.8-4 is being tracked as an open item**.

To understand how structural attachments are made to the ESBWR containment, the staff asked, in RAI 3.8-27, the applicant 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 the thickened liner plate and anchorage was modeled 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 and/or Appendix 3G.

In its response dated June 28, 2006, 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 identified that DCD Table 3G.1-35 provides the analysis results. The anchorage itself is not modeled; however, the reaction forces are evaluated and the results are shown 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 GEH Report DC-OG-0052, Revision 1, “Structural Design Report for Containment Metal Components,” issued September 2005, which contains the evaluation method and results for 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, California, 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. Details of the major structural attachments are shown in Figures 3G.1-48, 3G.1-49, and 3G.1-51 for the liner; in Figures 3G.1-55 and 3G.1-56 for the DF; Figure 3G.1-57 for the reactor pressure vessell support bracket (RPVSB) and VW; and Figure 3G.1-59 for the GDCS pool. At the staff’s request, the applicant agreed to provide a sketch of the RPV stabilizer and address the design of anchorage at the penetrations in a supplemental RAI response.

In a supplemental response dated September 14, 2006, 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 finite-element model 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. The applicant agreed to provide a more detailed description and revised sketch of the RPV stabilizer, which shows the tangential restraint while allowing free radial and vertical movement, in a second supplemental RAI response. The applicant also agreed to include the description and sketch of the RPV stabilizer in the DCD.

In a supplemental response dated January 24, 2007, 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. The staff reviewed the applicant's proposed change to DCD Section 3G.1.4.1 and confirmed that it was incorporated into Revision 3 of the DCD.

The staff found that the applicant provided sufficient information for the anchorage of containment penetrations and hot piping penetrations in the first supplemental response to this RAI. 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 third supplemental response, dated March 26, 2007. 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 it was incorporated into Revision 4 to 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 the original questions posed by this RAI to be adequately addressed. Therefore, RAI 3.8-27 is resolved.

During its review of DCD Figures 3G.1-48 and 3G.1-49 (referenced in the response), the staff noted that some liner plate thicknesses and the size of the stiffeners were reduced 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 these figures were revised. 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 is being tracked as an open item.

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, the 1989 edition was reviewed and accepted 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 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 the provisions of ANSI N45.2.5 and RG 1.94 are incorporated into the referenced codes and standards.

In its response dated August 31, 2006, 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 a supplemental RAI response.

In a supplemental response dated January 29, 2007, 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, is 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 finds 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 it was incorporated into Revision 3 of the DCD. Parts (b) and (c) of RAI 3.8-5 are resolved.

The staff notes that Revision 3 of RG 1.136 was officially issued 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 needs to 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 response dated August 13, 2007, 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 original and S01 responses to RAI 3.8-5. 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. The applicant provided the latest revised comparisons in its S01 response to RAI 3.8-5, 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), which 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 recording 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 utilized 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 needs to confirm that the regulatory positions in RG 1.136, Revision 3, which endorse the ASME Code through the 2003 Addenda, are also met. **Part (a) of RAI 3.8-5 is being tracked as an open item.**

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 dated August 31, 2006, the applicant stated that the containment design meets all applicable subarticles and paragraphs of the 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. RAI 3.8-11 is 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 description of live load used inside containment given in DCD Section 3.8.1.3.1 needs to be expanded, 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 utilized for seismic and hydrodynamic effects, then a justification is needed for the reduced live load magnitude.

In its response dated June 28, 2006, 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 suppression pool 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. Design of individual members is based 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, California, the staff discussed the requested information in further detail with the applicant. 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 inquired as to why 25 percent was included 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 the effect of using the 25-percent value in the hydrodynamic loads analysis was found to be negligible. The applicant agreed to submit a supplemental RAI response, including the additional information discussed at the audit.

In a supplemental response dated January 24, 2007, the applicant provided the results of eigenvalue analyses performed for the VW, RSW, and DF considering 25 percent of live load (9.6 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 thereby would also have a very small effect on the seismic structural response. For hydrodynamic load analyses, the applicant utilized 25 percent of the live load, which is 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. RAI 3.8-6 is 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 dated August 31, 2006, 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 the LRT pressures could not be identified 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 a supplemental response dated January 29, 2007, 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 provided a markup of the proposed change.

The staff finds the applicant's supplemental 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 it was incorporated into Revision 3 of the DCD. RAI 3.8-7 is 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 the requirements contained in 10 CFR 50.34(f)(3)(v) regarding loads, loading combinations, and design for the ESBWR containment are addressed, 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 dated August 31, 2006, 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. 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 requirements in 10 CFR 50.34(f)(3)(v)(A) are being evaluated under the review of DCD Section 6.2.5.4.2. 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. The applicant's response to part (b) did not address the postflooding load combination (which includes OBE) defined by SRP Section 3.8.1.

The staff discussed this omission with the applicant during the December 2006 onsite audit. The applicant agreed to submit a supplemental response to the RAI to demonstrate that the accident pressure + SSE + flooding during LOCA (used in design) bounds the post-LOCA flooding event with OBE; therefore, the post-LOCA flooding load combination with OBE does not need to be considered explicitly.

The applicant submitted its supplemental response to RAI 3.8-8 on March 26, 2007. Based on the staff's review of the supplemental information, the applicant adequately demonstrated that the accident pressure + SSE + flooding during LOCA (used in design) bounds the post-LOCA flooding event with OBE; therefore, the post-LOCA flooding load combination with OBE does not need to be explicitly considered. RAI 3.8-8 is 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 LOCA (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 of the dynamic loads.

In its response dated August 31, 2006, the applicant stated that LOCA (large, intermediate, and small break) and SRV discharges (single valve first actuation, single valve subsequent actuation, and multiple valves) are discussed in the Containment Load Definition - NEDE-33261P. 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 areas in need of further clarification:

a) If NEDE-33261P indicates that 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 (CHUG, CO, pool swell (PS), annulus pressurization (AP), vent clearing, etc.).

d) Since this is done for generation of FRS throughout the building (not just local containment response), aren't 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 RBV loads for reinforced concrete structures varies the sign (+ or -), equivalent to 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, Revision 1. 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, CH, vent clearing, etc) are not clearly defined. According to NUREG-0484, Revision 1, the use of SRSS for the other loads would require demonstrating that a non-exceedance probability (NEP) of 84 percent or higher is achieved. This criterion should be clearly specified and addressed in the DCD.

The staff discussed the above items with the applicant during the December 2006 onsite audit. During the audit, the applicant presented a draft supplemental response to this RAI. Based on the additional information provided during the audit, the staff concluded that parts (a) through (d) are adequately addressed. For part (e), the staff informed the applicant that justification for the use of the SRSS method is still needed. The applicant indicated that a supplemental response would be formally submitted to address parts (a) through (e).

In a supplemental response dated January 29, 2007, 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 finds 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, the applicant needs to provide additional information demonstrating that the combination of the ESBWR hydrodynamic loads (other than LOCA) satisfy the 84-percentile NEP requirement of NUREG-0484.

In its response dated August 13, 2007, the applicant stated that the ESBWR hydrodynamic load definitions and bases are described in the ESBWR Containmnet Load Definition- NEDE-33261P. These include the SRV loads, LOCA CO loads, and LOCA CHUG loads. The ESBWR load definitions are developed 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 (e.g., SRV and individual LOCA loads (e.g., AP, PS, CO, CHUG, vent clearing, etc)) are not clearly defined. According to NUREG-0484, Revision 1, the use of SRSS (rather than the absolute sum (ABS) method) for combining the other loads would require demonstrating that an NEP of 84 percent or greater is achieved 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 is being tracked as an open item.

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 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 dated August 31, 2006, the applicant referred to RAI 3.7-41 for the same issue and stated that the 100/40/40 method used is consistent with the DG-1127 guidance.

During 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 a supplemental response dated January 29, 2007, the applicant stated referneced its response to RAI 3.8-107, S01. This issue will be resolved under RAI 3.8-107 in Section 3.8.5.3.4 of this report. RAI 3.8-10 is closed.

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 dated November 19, 2007, the applicant stated that it will 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 a markup of the proposed revision to DCD Table 3.8-2 to the staff. 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. RAI 3.8-115 is being tracked as a confirmatory item. .

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 finite-element model described in DCD Sections 3.8.1.4.1.1 and 3G.1.4. The finite-element model includes the entire RB, the RCCV, the containment internal structures, and the FB. The model utilizes quadrilateral, triangular, and beam elements to represent the various structural components. Beam elements are used to represent the columns and beams. Springs are also used in the model to represent the foundation soil. The various loads are applied 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 July 11–14, 2006, onsite audit, 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 dated August 31, 2006, 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. 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 its 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 has 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. Since there are no other outstanding issues, RAI 3.8-12 is 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 dated June 28, 2006, 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, California, 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 in which comparisons of the basemat deformation and basemat moments for soft soil and hard rock springs, for the load combination of D + LOCA (accident pressure) + SSE, were performed. 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.

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 will 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 supplemental response dated September 14, 2006, 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 those 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 supplemental response also provided the results of the followup study to address the issue of vertical soil springs in tension. An iterative approach was used whereby any springs in tension were released in a subsequent iterative analysis until no soil springs remain 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 supplemental response.

In a second supplemental response dated November 7, 2006, 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 supplemental responses submitted on September 14, 2006, and November 7, 2006, 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 a third supplemental response dated January 24, 2007, the applicant submitted proposed changes to the DCD which describe the study and results for the soft soil versus hard rock conditions and for 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 addresses this issue. Therefore, RAI 3.8-13 is 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 dated June 28, 2006, 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 DCD Appendix 3G.1.5.2.1.6 would be revised in the next DCD update, and provided a mark-up of the proposed change.

During its onsite audit, conducted July 11–14, 2006, at the applicant’s offices in San Jose, California, 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 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 for evaluation of LOCA thermal load effects does consider the actual nonlinear temperature distribution (see the discussion associated with RAI 3.8-19).

In its supplemental response dated September 14, 2006, 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 supplemental 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 a second supplemental response dated January 24, 2007, the applicant described a study that evaluated two cases consisting of material properties based on the average uniform temperature and a case that utilized 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 second supplementary response adequately addressed its questions on part (b) and is acceptable. The staff reached this conclusion based 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 is resolved.

DCD Section 3.8.1.4.1.1, Appendix 3B, and Appendix 3G provide a description of 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 axisymmetric and nonaxisymmetric loads are applied and how variations in pressure definition parameters (e.g., phasing of maximum pressure on different pool boundary locations, DLF, variation in loading function frequencies) are considered. The description should include pressures associated with normal operating, accident pressures, and SRV actuations. The staff asked the applicant to explain whether negative pressure loads on the containment can occur and whether upward pressure loading on the DF can develop under any conditions. Appendix 3B, "Hydrodynamic Load Definitions," needs to be expanded to include this information. Some information is presented in Appendix 3B, however it appears that much of the description is applicable to response spectra generation using a different model than the NASTRAN finite-element model.

In its response dated August 31, 2006, 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 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 information for hydrodynamic loads presented in DCD Figures 3G.1-21 through 3G.1-23, and DLF=2, is used 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 kPad (–3.0 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 35 psid. The DF slab is also subjected to an upward pressure of 3 psid as shown in Figure 3.8-15(3). It is not controlling the design of the DF slab.

Regarding the vent wall 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 wetwell in Figure 3.8-15(1) should continue up until 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 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 the second item is addressed under RAI 3.8-46.

In its supplemental response dated January 29, 2007, 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 NRC 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 supplemental response to RAI 3.8-15 provides the additional technical information needed to describe the hydrodynamic pressure loadings and is acceptable. The staff also reviewed the applicant's supplemental response to RAI 3.8-46 and found it acceptable to justify that the axisymmetric loads are controlling. Therefore, RAI 3.8-15 is resolved.

DCD Section 3G.1.5.4.2 provides some information for how water in the various pools is considered in the seismic analysis. In RAI 3.8-16, the staff requested that the applicant provide additional information by describing how the dynamic fluid effects (water mass, fluid-structure interaction, sloshing) associated with the suppression pool, other pools, and water above the drywell head are considered in the model development, analysis, and design of the containment and RB, subjected to the various dynamic loading events.

In its response dated August 31, 2006, the applicant stated that the design of the containment and buildings considers two kinds of dynamic fluid effects. One is hydrodynamic loads of the suppression pool water, and the other is sloshing loads resulting from earthquakes. The approach described in ASCE 4-98, together with the discussions given in Brookhaven National Laboratory (BNL) Report 52361, is followed. (See also 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, 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, North Carolina on May 16–17, 2007, the staff reviewed GEH Report No. DC-OG-0053, Revision 3, "Structural Design Report for Containment Internal Structures," dated March 30, 2007, and Report No. 26A6651, Revision 2, "Reactor Building Structural Design Report," dated March 27, 2007. These reports describe how the water fluid effects were included in the analytical models. The description covers how the water mass and fluid-sloshing pressure loads were considered for the various pools. The staff concluded that the approach utilized is technically acceptable and consistent with the criteria presented in DCD Revision 3, Sections 3.7.3.15, 3.8.1.4.1, and Appendix 3G. Therefore, RAI 3.8-16 is 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 finite-element 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 finite-element models, identification of the loading conditions, the types of analyses conducted, a summary of the results of the analyses, and comparison to ASME Code acceptance criteria. The staff requested that this information be included in DCD Section 3.8 and/or Appendix 3G.

In its response dated November 8, 2006, 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 finite-element analysis model, which includes the local area around the opening, (2) in the local model finite-element analyses, displacements that are obtained from the RB/FB global model stress analyses are prescribed to the boundary nodes in order to consider the constraints of items not included in the model, and (3) local loads which 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 are installed to 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 some of the information requested in the RAI was not provided, particularly those figures showing the finite-element models used, a summary of the types of analyses, a summary of results of the analyses, and comparison to 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 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 supplemental response dated February 1, 2007, the applicant stated that detailed design calculations of the containment around the UD personnel airlock opening were performed 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 supplemental response, which present the element forces and moments in the local finite-element model, show, in some cases, a sudden change in response. 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 MNm/m over a change in elevation from about 16.5 to 17 to 17.5 m. The applicant needs to explain this sudden change in element forces and determine whether it indicates a modeling error or insufficient refinement of the finite-element 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 finite-element model, and figure(s) showing the reinforcement details, as provided in the applicant's RAI response. **RAI 3.8-17 is being tracked as an open item**.

In RAI 3.8-18, the staff requested that the applicant describe how the reinforced concrete containment shell and basemat material and stiffness properties are represented in the shell finite-element NASTRAN model (e.g., monolithic concrete properties with Young's modulus, thickness, Poisson's ratio, and density corresponding to 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 dated June 28, 2006, 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 cracking of concrete. However, the design of the cross section utilizing the SSDP-2D 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, California, the staff discussed the requested information in further detail with the applicant. 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 cracking of concrete 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 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 as compared to the seismic stick model. The applicant presented limited results from the Lungmen project (related to ABWR), which compared the natural frequencies between the seismic stick model and the finite-element model. The frequency comparison table from the Lungmen project shows that the fundamental frequencies in the N-S and E-W directions are comparable between the seismic stick model and the finite-element model.

In its supplemental response dated September 14, 2006, the applicant referred to its response to RAI 3.7-59, where it addresd 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 consideration of internal force and moment redistribution caused by concrete cracking, the NASTRAN results for the SIT condition were examined. 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 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 supplemental 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. ASCE 4-98 notes that nominal shear stresses are usually shown to be below 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," February 1994, refers to concrete cracking under SSE with shear stresses below 150 psi. As discussed in the ASCE report on the stiffness of low-rise reinforced concrete shear walls, variation in concrete properties are often used to account for potential concrete cracking.

In a second supplemental response dated January 24, 2007, the applicant stated that, to address the effect of redistribution of loads caused by concrete cracking, SSE dynamic analysis using the RB/FB global finite-element model was performed. The analysis method is the same as that used in response to RAI 3.7-59 for comparing the stick and finite-element models, except that the stiffness of RCCV elements in the finite-element model 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 second supplemental response and concluded that the applicant had verified the adequacy of the NASTRAN finite-element model against the seismic stick model in its response to RAI 3.7-59, which is 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 finite-element model 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 significant redistribution of loads for the ESBWR design.

The applicant's response given in RAI 3.8-18, Supplement 1, also addressed the potential effect of concrete cracking. This response showed that for the SIT the tensile stresses in the principal membrane force and principal bending moment directions do no exceed the tensile strength of concrete, with very few localized exceptions. Therefore, RAI 3.8-18 is resolved.

DCD Section 3.8.1.4.1.3 describes how concrete cracking is considered 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 three-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 dated June 28, 2006, the applicant stated that Figure 3.8-19(1) illustrates the three-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, a transient thermal analysis is conducted 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. Analyses are conducted for conditions representing both winter and summer conditions. The stress analyses are then conducted using the three-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 °C (60 °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 section forces and moments at the specified sections are calculated for both the linear stress analyses and the nonlinear concrete-cracking analyses at each of the specified time snapshots. The thermal ratios or scale factors are then computed 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. These ratios are then used 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 three-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 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 reviewed GEH Report 26A6625, Revision 1, at the May 16–17, 2007, audit at the applicant's offices in Wilmington, North Carolina. Before the audit, the staff reviewed a limited set of data that used the thermal load factor approach, which was submitted in response to a request for information under RAI 3.8-107. Based on its limited preaudit review, the staff noted that very significant cracking and load redistribution was indicated by the thermal load factors and 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 has 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 is closed.**

Based on the information contained in DCD Section 3G.1.5.2.1.13, it was not clear to the staff how seismic member forces for each section are obtained 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 dated June 28, 2006, the applicant stated that seismic loads used for the structural design are obtained 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.

In its supplemental response dated January 24, 2007, the applicant referred to its RAI 3.7-59, S01, response for a comparison of NASTRAN dynamic and static analysis results.

The staff found that the applicant’s initial response to the RAI clarified how the seismic forces from the stick model were applied to the finite-element 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 DCD 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 finite-element model. The staff reviewed the results obtained from these two approaches and observed that they are very similar. Therefore, RAI 3.8-20 is 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 dated August 31, 2006, 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 revise DCD Table 3G.1-35 in the next update and provided a markup of the change.

The staff confirmed that the correction noted in the applicant response is included in DCD Revision 3. RAI 3.8-21 is 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 dated August 31, 2006, 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 posed because it provided the basis for the assumed corrosion rate and described how the corrosion allowance was calculated. Therefore, RAI 3.8-22 is resolved.

The staff reviewed DCD Tier 2, Chapter 1, for information of potential significance to the ESBWR containment design and identified several areas in need of 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 this hydrostatic loading on the adjacent pool walls, the top slab and the drywell head in greater detail, including the height of the pool, and the pressure gradient. Describe how this loading is included in the load combinations defined in DCD Section 3.8.1 and 3.8.2 and describe the external pressure loading analysis of the drywell head and the results of the analysis; and include the above requested information in DCD Section 3.8.1, Section 3.8.2, and/or Appendix 3G, as applicable.

(2) DCD Tier 2 Table 1.3-3 states that the design temperature of the drywell is 171 °C (340 °F). Describe how this design temperature was utilized in defining the concrete and steel properties used in the drywell structural analyses; explain how the concrete temperature limits in ASME Code, Section III, Subsection CC (150 °F general, 200 °F local) are satisfied;

and include the requested information in DCD Section 3.8.1, Section 3.8.2, and/or Appendix 3G, as applicable.

In its response dated June 28, 2006, 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, thermal analyses have been carried out 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 °C (200 °F) for normal operation and lower than 177 °C (350 °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 proposed DCD change is included in DCD Revision 3.

During its onsite audit, conducted July 11–14, 2006, at the applicant’s offices in San Jose, California, the staff discussed the requested information for part (1) in further detail with the applicant. The staff noted that the information provided is incomplete. The pool above the drywell head is not identified. 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 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.

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 analysis and results for the external pressure loading on the drywell head are contained in a GEH calculation. The applicant indicated that this calculation was being revised to be consistent with ASME Code Case 284-1 and the NRC staff positions found 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 water sloshing and inertia effects were considered.

During the December 2006 onsite audit, the applicant indicated that GEH Design Report DE-ES-0003 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, North Carolina. 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 has 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 has been resolved. Therefore, RAI 3.8-23 is 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 due to fabrication and erection tolerances. Describe the treatment of fabrication/erection tolerances in the evaluation of the liner plate. Explain whether the potential for buckling of the liner plate was considered (convex curvature due to fabrication tolerances/concrete shrinkage), and include this information in DCD Section 3.8.1 and/or Appendix 3G.

(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/erection tolerances are considered in this analysis. Include this information in DCD Section 3.8.1 and/or Appendix 3G.

In its response dated November 8, 2006, 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.

Fabrication/erection tolerances are considered for liner anchor design. The applicant's RAI response provided the minimum, maximum, and nominal values for liner thickness, liner anchor spacing, and anchor stiffness. Considering these fabrication/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/pullout. GEH 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 additional clarification was needed. 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 by Subarticle CC-3720 of the ASME Code.

In its supplemental response dated February 1, 2007, 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 will 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. GEH 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/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, and, therefore, is acceptable. The applicant's proposed revision to the DCD to clarify this information is acceptable, and the staff confirmed that the applicant implemented this change in DCD Revision 3. The staff audited the applicant's two design reports referenced in the RAI response at the GEH offices in Wilmington, North Carolina, 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 is 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 the analysis of a typical liner plate-to-RCCV attachment is performed using the NASTRAN model results The applicant should include this information in DCD Section 3.8.1 and/or Appendix 3G.

In its response dated June 28, 2006, 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, rigid bar elements are placed in the radial direction for the liners of the RCCV cylinder wall and the RPV pedestal. They are placed vertically for the basemat, the suppression pool slab, and the top slab. Using this modeling technique, the design forces of liner plates are obtained from the analysis directly, and the anchorage design is performed in accordance with Appendix B,1.199 “Anchoring to Concrete,” to ACI 349-01. 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, California, 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/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/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/shell element, the presence of significant bending moments in the liner plate elements under a uniform pressure loading would be indicative that the liner plate is under constrained. The staff also inquired whether the finite-element 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 for evaluation of 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/standard, as well as referencing RG 1.199, “Anchoring Components and Structural Supports in Concrete,” issued November 2003, and RG 1.142. The applicant also indicated that it used the Bechtel Topical Report BC-TOP-1 approach to design the liner.

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.

In its first supplemental RAI response dated September 14, 2006, 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 second supplemental response dated November 7, 2006, 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 the liner grid spacing versus the actual spacing. The applicant also explained how the forces on the anchors are determined if 1/10,000 E is used for the liner in the NASTRAN model.

The applicant stated that in the NASTRAN analysis of the RB/FB global finite-element model, Young's modulus for the RCCV steel liners is set to a small value (i.e., 1/10000 of the normal value for non thermal loads) so that they do not bear any stresses. For thermal loads, the normal Young's modulus for the liner is used in the model to account for the effect of differential thermal expansion between steel and concrete. The liner is modeled in the global finite-element model with rigid bar elements placed between RCCV wall element and 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 in order 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. Two simple models are developed 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 further detailed review to fully understand the analysis study performed and to identify specific areas of the description, figures, and tables (in the Supplement No. 2 response) that require further clarification. As an example, the response indicated that Case 1 is provided to simulate 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 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.

In its third supplemental response dated January 24, 2007, 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 revised the word "glued" (used in the response to RAI 3.8-25 S02) to read "DCD," as shown in the attached "FEM Analysis for Liner Plates" analysis.

Following the December 2006 onsite audit and receipt of the third supplemental RAI response, the staff conducted a more detailed review of this technical issue. From the information submitted, it is not clear to the staff that the comparative analysis between the small "DCD model" and the "contact model" actually addresses the displacement compatibility issue. The two models appear to be basically 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 also needs to 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 whether this model represents the most critical location (e.g., where spacings between rigid links are large). Also, from the information provided, it was not clear 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 also 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 is being tracked as an open item**.

Originally, RAI 3.8-25 dealt with how the analysis of the liner plate-to-RCCV attachment is performed 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 and/or Appendix 3G. The staff also requested that the applicant 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.

In its response dated June 28, 2006, 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, CH 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, California, the staff and the applicant discussed RAI 3.8-26 in conjunction with the information provided in RAI 3.8-25. In a supplemental RAI response dated January 24, 2007, 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. **RAI 3.8-26 is being tracked as an open item**.

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. No special construction techniques were identified. 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.

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 SRP Section 3.8.1.II.6 review criteria.

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 inspection 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. A test pressure of 52 psig, which is 115 percent of the design pressure, is used for the SIT. This pressure is also utilized for the differential pressure test 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 provided 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 SRP Section 3.8.1.II.7 review criteria.

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 ISIs of the containment components. The staff noted that, while it is understandable that the COL applicants will develop plans for preservice and inservice inspection, the DCD should provide additional preoperational inspection requirements (per IWE-2000) specifically pertinent to the ESBWR containment. In addition, the IWE-1220 exclusions cited in DCD Section 3.8.1.7.3.2 should be revisited to minimize the inaccessible areas in the containment. Also, because of the high radiation areas in the containment, the DCD should discuss remote means of monitoring certain structures and components inside the containment.

In its response dated August 31, 2006, 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, GEH indicated that the DCD would state that the use of remote tooling for inspections will be done in high radiation areas where feasible.

In its supplemental RAI response dated January 29, 2007, 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 change and found it acceptable. The staff confirmed that GEH implemented this change in DCD Revision 3.

With the above noted revisions made in the DCD, the staff finds that the preservice and ISIs 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 SRP Section 3.8.1.II.7 review criteria. RAI 3.8-1 is resolved.

3.8.1.4 Conclusion

Because of the open items that remain to be resolved for this section, the staff is unable to finalize its conclusions on acceptability of the ESBWR concrete containment design.

3.8.2 Steel Components of Concrete Containment

In DCD Revision 3, the steel components of the ESBWR RCCV are identified as (1) personnel air locks, (2) equipment hatches, (3) penetrations, and (4) the drywell head.

3.8.2.1 Regulatory Criteria Related to Steel Components of Concrete Containment

The staff reviewed Revision 3 of DCD Section 3.8.2, "Steel Components of the Reinforced Concrete Containment," and DCD 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 3.8.2, Revision 2. This will ensure that the relevant requirements of 10 CFR 50.55a and GDC 1, 2, 4, 16, and 50 of Appendix A to 10 CFR Part 50 are met. 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 shall 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 shall 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 shall withstand the dynamic effects of equipment failures including missiles and blowdown loads associated with the LOCA.

- GDC 16 requires that the steel containment shall 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 shall be designed with sufficient margin of safety to accommodate appropriate design loads.

- ASME Code, Section III, Division 1, "Nuclear Power Plant Components," Subsection NE, Class MC, which 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 per 10CFR 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, "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, " Material Construction and Testing of Containments"

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 in order to satisfy the requirements of paragraph IV(a)(2)(i)(B)(I) of Appendix S to 10 CFR Part 50.

3.8.2.2 Technical Information in the DCD Related to Steel Components of Concrete Containment

3.8.2.2.1 Description of the Steel Components of Concrete Containment

In Revision 3 of 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, and the drywell head. These components are designed for the same loads and load combinations as those 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 feedwater lines. These hot penetrations are provided with 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 hot and cold mechanical penetrations and the containment 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 drywell head is designed 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. Provisions are made 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 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 ASME Code, Section NB-3122.3 requirements 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, a structural seal plate with an attached compressible bellows sealing mechanism is utilized between the reactor vessel and 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 Revision 3 of 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 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 Revision 3 of DCD Section 3.8.2.3, the applicant stated that the applicable loads are defined 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 Revision 3 of DCD Section 3.8.2.4, the applicant stated that the steel components of the concrete containment are designed 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, a fatigue evaluation is performed. The nonpressure-resisting components are designed in accordance with the practices given in AISC-N690, “Manual of Steel Construction.”

The personnel air lock consists of four main sections—doors, bulkheads, main barrel, and reinforcing barrel with collar. The personnel air locks are supported entirely by the RCCV wall. The lock barrel is welded directly to the containment liner penetration through the RCCV wall. The personnel lock and penetration through the RCCV wall is analyzed using a finite-element computer program and/or manual calculation based on handbook formulas and tables. The discontinuity stresses induced by the combination of external, dead, and live loads, including the effects of earthquake loadings, are evaluated. 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. A finite-element analysis model and/or manual calculation are used 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 hatch cover with the bolted flange is designed in accordance with Subarticle NE-3326 of ASME Code, Section III.

Piping penetrations and electrical penetrations are subjected to various combinations of piping reactions and mechanical, thermal, and seismic loads transmitted through the RCCV wall structure. The forces resulting from various load combinations are combined 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.

MS and feedwater penetrations are analyzed using the finite-element 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 drywell head, consisting of shell, flanged closure, and drywell-head anchor system, is analyzed using a finite-element stress analysis computer program or manual calculation. The stresses, including discontinuity stresses induced by the combination of external pressure or internal pressure, dead load, live load, thermal effects, and seismic loads are evaluated. 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.

3.8.2.2.5 Structural Acceptance Criteria

In Revision 3 of DCD Section 3.8.2.5, the applicant stated that the structural acceptance criteria for the steel components with regards to allowable stress values, deformation limits, and factors of safety are based on ASME Code, Section III, Subsection NE. 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 levels A, B, C and D conditions. The stability against buckling is assured by an adequate factor of safety. The allowable stress limits for nonpressure-resisting components are in accordance with ANSI/AISC-N690-1994s2 (2004), “Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities.”

3.8.2.2.6 Material and Quality Control and Special Construction Techniques

In Revision 3 of 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-516 grade 70, SA-240 type 304L, SA-516 grade 60 or 70 purchased to SA-264)
- 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-350 grade LFI or LF2 or SA-182F 304L/316L)

- Bolting (SA-320-L43 or SA-193-B7 bolts with SA-194-7 or A325 or A490 nuts)

- Castings (SA-216, grade WCB or SA-352, grade LCB, A27, or 7036)

- Cold finished steel (A108 grade 1018 to 1050)

- Bar and machine steel (A576, carbon content not less than 0.3%)

- Clad (SA-240 type 304L)

The structural steel materials located beyond the containment vessel boundaries are as follows:

- Carbon steel (A36 or SA-36)
- SS extruded shapes (SA-479)

The materials used for ESBWR steel components of the containment meet requirements as specified in Subarticle NE-2000 of ASME Code, Section III.

3.8.2.2.7 Testing and Inservice Inspection Requirements

In Revision 3 of DCD Section 3.8.2.7, the applicant stated that testing and ISI requirements of the containment vessel, including the steel components, are described in Section 3.8.1.7. Welding activities conform to the requirements of Section III of the ASME Code. Table 3.8-5 provides the required nondestructive examination 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 Related to Steel Components of Concrete Containment

3.8.2.3.1 Description of the Steel Components of Concrete Containment

DCD Tier 2, Section 3.8.2.1, provides descriptive information of 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 miscellaneous mechanical and electrical penetrations. The staff also asked whether the design for all penetrations had been finalized or if the applicant considers it to be a COL applicant responsibility. The staff further requested that this information be included in DCD Section 3.8.2 and/or Appendix 3G.

In its initial response, dated November 8, 2006, the applicant stated that details for the containment 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 these containment penetrations will be designed to meet the ASME Code. The applicant indicated that it would revise Section 3.8.2.4.1.3 in the next DCD update.

The applicant submitted a supplemental response to RAI 3.8-28, dated February 1, 2007, in response to a staff followup question during the December 2006 onsite audit. The applicant stated that it would add typical details for the containment mechanical and electrical penetrations to DCD Section 3.8 in new Figures 3.8-6 through 3.8-11.

The staff confirmed that the proposed changes were incorporated into Revision 3 of the DCD. However, the staff is unclear how the typical design details will be implemented at the COL application stage. The staff submitted a supplemental information request for RAI 3.8-28 in June 2007, which asked the applicant to identify in the DCD a COL action item that will ensure implementation of the typical mechanical and electrical penetration design details. **RAI 3.8-28 is being tracked as an open item.**

The staff noted that DCD Figure 3G.1-51 indicates a 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, 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 the stress of cladding is classified as peak stress in ASME Table NE-3217-1, only fatigue analysis is required for the cladding, and fatigue analysis will be performed 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 cladding thickness will be determined in the detailed design in accordance with ASME Code, Subsection NB-3122.3, requirements 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 additional information was needed. The clad thickness had not been specified. In a supplemental response, the applicant stated that the stainless clad thickness for the drywell head is determined 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. The staff confirmed that the applicant had incorporated the proposed changes into Revision 3 of the DCD. RAI 3.8-30 is 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 (stiffening effect is local and active only during refueling when the head is in its stored position). They are not considered 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 brackets. However, GEH did not analyze the effects on local stresses in the drywell head when subjected to accident pressure and temperature. In a supplemental 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 supplemental 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 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 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. RAI 3.8-31 is 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 identify any relaxations in the 2004 edition, as compared to RG 1.57, Revision 1, including the regulatory positions, and provide a technical justification for each relaxation.

In its response dated June 29, 2007, the applicant stated that the ESBWR design certification is based 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. 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 regulatory positions in the current RG 1.57, Revision 1, which endorses the 2001 edition through the 2003 addenda of the ASME Code, are also met.
RAI 3.8-110 is being tracked as an open item.

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′, Ro, Ra, 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 and/or Appendix 3G.

In its response, the applicant stated that these loads do not act on the drywell head directly. The indirect effect under these loads is evaluated 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, issued September 2005, 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 W, W′, Ro, Ra, Y, SRV, and LOCA can be neglected for the drywell head. The staff found the applicant’s proposed DCD change to be acceptable and confirmed that it was incorporated into Revision 3 of the DCD. RAI 3.8-39 is 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 steel components are analyzed using a computerized finite-element stress analysis or manual calculations. The forces from the various load combinations are considered and evaluated 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 feedwater penetration analyses for both stress and buckling (if applicable), including a description of all pressure and thermal conditions applicable to the MS and feedwater 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, the applicant stated that three-dimensional finite-element models have been developed to analyze MS and feedwater penetrations. Calculations consider pressure and temperature for the process piping inside and outside of the RCCV. The reaction loads obtained from the pipe stress analysis of the MS lines are used in the design of MS penetrations. For feedwater penetrations, a set of enveloping mechanical loads is developed 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. Hand calculations are used to demonstrate that buckling stress values are much higher than the values obtained in the finite-element 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 penetrations and feedwater 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 concluded that the applicant had appropriately analyzed the MS and feedwater penetrations for both stress and buckling. The staff found the applicant's proposed DCD change to be acceptable and confirmed that it was incorporated into Revision 3 of the DCD. RAI 3.8-35 is 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 pressure and thermal conditions applicable to the personnel air locks. 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, the applicant stated that stress and buckling analyses for the upper and lower personnel airlocks are performed 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 stress and buckling analysis results. The applicant referenced GEH Report DE-ES-0010, Revision 0, "Stress Analysis Report for Personnel Airlock," issued October 2006, and GEH Report DE-ES-0023, Revision 0, "Buckling Evaluation for Personnel Airlock," 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. The staff concluded that the applicant had appropriately analyzed the two personnel airlocks for both stress and buckling. The staff found the applicant's proposed DCD change to be acceptable and confirmed that it was incorporated into Revision 3 of the DCD. RAI 3.8-36 is 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, the applicant stated that stress and buckling analyses for the wetwell hatch and upper/lower equipment hatches are performed 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," issued October 2006; GEH Report DE-ES-0009, Revision 0, “Stress Analysis Report for Wetwell Hatch,” issued October 2006; GEH Report DE-ES-0020, Revision 0, “Buckling Evaluation for Equipment Hatch,” issued October 2006; and GEH Report DE-ES-0019, Revision 0, “Buckling Evaluation for Wetwell Hatch,” 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. The staff concluded that the applicant had appropriately analyzed the three equipment hatches for both stress and buckling. The staff found the applicant’s proposed DCD change to be acceptable and confirmed that it was incorporated into Revision 3 of the DCD. RAI 3.8-37 is 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, the applicant stated that stress and buckling analyses for the drywell head are performed 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 stress and buckling analysis results. The applicant referenced GEH Report DC-OG-0052, Revision 2, “Structural Design Report for Containment Metal Components”, issued October 2006, 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,” issued October 2006; GEH Report DE-ES-0001, Revision 0, “Stress Analysis Report for Drywell Head,” issued October 2006; and GEH Report DE-ES-0003, Revision 0, “Buckling Evaluation for Drywell Head,” 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. 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 was incorporated into Revision 3 of the DCD. RAI 3.8-38 is resolved.

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

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/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 implementing a design modification to alleviate the high secondary stress.

In its response, the applicant stated that the high stress value results from thermal loads from the LOCA condition. 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 permits a simplified elastoplastic analysis in Subsection NE-3228.3. The applicant referenced GEH Report DC-OG-0052, Revision 1, issued September 2005, which contains the evaluation method and results for 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 in the next DCD revision and provided a markup of the proposed change.

The staff determined that it needed additional information to resolve this issue. The staff asked the applicant to (1) provide a comparison to 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 °C (340 °F) and compare it to the computer results for this thermal condition. In a supplemental response, 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 Pm is not evaluated 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. The staff concluded that the applicant's technical approach, in accordance with ASME Code, Subsection, NE-3228.3, 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. RAI 3.8-29 is 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 GEH include information about fatigue analysis of the drywell head in

DCD Section 3.8.2 and/or Appendix 3G. In its response, the applicant stated that fatigue evaluation is performed 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 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. At the audit, the staff requested that the applicant include a brief description of the fatigue evaluation in the DCD. The staff confirmed that this information was added to Section 3G.1.5.4.1.4 in Revision 3 of the DCD. RAI 3.8-32 is resolved.

The staff noted that the DCD did not address fatigue failure for the MS, feedwater, and other hot penetrations. In RAI 3.8-33, the staff requested that GEH include information about fatigue analysis of the MS, feedwater, and other hot penetrations in DCD Section 3.8.2 and/or Appendix 3G. In its response, the applicant stated that fatigue evaluation was performed for the MS penetrations using the same three-dimensional finite-element model that was developed for the stress analysis (see GEH response to RAI 3.8-35). In addition to pressure and temperature loads, the cyclic dynamic loads were taken into account when calculating the total stress intensity (including peak stress) for each event. The maximum cumulative usage factor was found 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, detailed fatigue evaluation for the feedwater 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, "Main Steam and Feedwater RCCV Penetrations Design Report," 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, feedwater, and other hot penetrations. The staff found the applicant's proposed DCD change to be acceptable and confirmed that it was incorporated into Revision 3 of the DCD. RAI 3.8-33 is 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 fatigue analysis of the cold penetrations, equipment hatches, and personnel airlocks in DCD Section 3.8.2 and/or Appendix 3G. In its response, the applicant stated that fatigue evaluation for cold penetrations will be performed in the detailed design in accordance with the acceptance criteria stated in the DCD. 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 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 fatigue evaluation for cold penetrations will not be performed until the detailed design stage because only typical design details have been developed 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 applicant's proposed DCD change to be acceptable and confirmed that it was incorporated into DCD Revision 3. RAI 3.8-34 is resolved.

3.8.2.3.6 Material and Quality Control and Special Construction Techniques

The staff reviewed the information in the DCD. Steel materials conforming to the requirements of Article NE-2000 of ASME Code, Section III, are specified for the steel components of the RCCV. The staff considers this acceptable.

3.8.2.3.7 Testing and Inservice Inspection Requirements

The staff reviewed the information in the DCD. This section of the DCD 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.

3.8.2.4 Conclusion

Because of the open items that remain to be resolved for this section, the staff is unable to finalize its conclusions on acceptability of the steel components of the concrete containment.

3.8.3 Containment Internal Structures

The ESBWR containment internal structures are constructed of reinforced concrete and structural steel and include the (1) diaphragm floor (DF), (2) vent wall,(VW) (3) GDCS pool walls, (4) reactor shield wall (RSW), (5) RPV support brackets, 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 Related to Containment Internal Structures

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 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 3.8.3, Revision 2. This will ensure that the relevant requirements of 10 CFR 50.55a and GDC 1, 2, 4, 5, "Sharing of Structures, Systems, and Components," and 50 are met. These relevant regulatory requirements are discussed below.

- 10 CFR 50.55a and GDC 1 require that the containment internal structures shall 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 shall 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 shall 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 shall be designed with sufficient margin of safety to accommodate appropriate design loads.

The staff evaluated the design, materials, fabrication, erection, inspection, testing, and inservice surveillance of components of the containment internal structures based on the following industry codes and standards, materials specifications, and RGs:

- ACI 349

- ASME Code, Section III, Division 2, Subsection CC

- ASME Code, Section III, Subsection NE

- ANSI/AISC N690

- ANSI N45.2.5, “Supplementary Quality Assurance Requirements for Installation, Inspection and Testing of Structural Concrete and Structural Steel During the Construction Phase of Nuclear Power Plants”

- RG 1.57, “Design Limits and Loading Combinations for Metal Primary Reactor Containment System Components”

- 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 1.142, “Safety-Related Concrete Structures for Nuclear Power Plants”

For design certification, Section 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 in order to satisfy the requirements of Section IV(a)(2)(i)(B)(I) of Appendix S to 10 CFR Part 50.

3.8.3.2 Technical Information in the DCD Related to Containment Internal Structures

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 ESBWR containment internal structures inside the containment include the DF slab, VW, GDCS pool walls, RSW, and the RPVSBs. 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 suppression pool.

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. For cable trays, conduits, and HVAC ducts and their supports, the applicant referred to DCD Sections 3.8.4.1.6 and 3.8.4.1.7.

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 anchorage of steel internal structures use 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 the steel containment internal structure components are designed in accordance with the practices given in ANSI/AISC-N690, including Supplement No. 2. Reference is made 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 finite-element model described in Section 3.8.1.4.1.1 includes the DF, RPVSB, RSW, VW, and GDCS pool wall. The design and analysis using this model are based on the elastic method. The miscellaneous platforms are considered as additional mass in the finite-element model.

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 testing and ISI of the DF and VW are directly related to the functioning of the containment system and are discussed in DCD Section 3.8.1.7.

A formal program of testing and ISI 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 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, “Monitoring the Effectiveness of Maintenance at Nuclear Power Plants,” and in accordance with Section 1.5 of RG 1.160.

Space control is exercised in the ESBWR by means of a three-dimensional model. It is the means by which interference checking and space control is accomplished. 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 criticality to the plant and construction sequence of the item. Accessibility to equipment, valves, instrumentation, welds, supports, and the like for operation, inspection, or removal is characterized by sufficient space to allow unobstructed access and reach of site personnel. Therefore, aisles, platforms, ladders, and handrails, for example, are reviewed as the layout of the components is planned. Interferences with access ways, doorways, walkways, truck ways, lifting wells, and similar spaces are constantly monitored. This method of configuration control is maintained and documented during the plant layout process. Remote tooling is considered 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 welding activities are performed 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.”

3.8.3.3 Staff Evaluation Related to Containment Internal Structures

3.8.3.3.1 Description of the Containment Internal Structures

DCD Tier 2, Section 3.8.3.1, provides descriptive information about the containment internal structures. The staff found the descriptive information, including figures and details of the containment internal structures, 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 of the applicant:

a. Provide information (description, plans, and sections) for several structures inside containment that are not presented in the DCD. These structures include the RPV stabilizer, quenchers, 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 a description of how the quenchers are anchored to the suppression pool.

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 length of anchor bars embedded in the containment that connect to the RPVSB.

In its response dated June 28, 2006, 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, California, 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 (1) that the RPV stabilizer is addressed separately in RAI 3.8-3, (2) insulation attached to the shield wall is not considered a structural element, (3) the SRV quenchers are considered mechanical components and are not described in DCD Section 3.8, and (4) SRV quencher attachments to the pool floor and the RPV insulation details are considered to be COL action items.

In the staff's subsequent detailed evaluation of the applicant's RAI response and the July 2006 audit discussions, the staff noted the following:

a. RPV stabilizer is in the load path and should be included in the global structural analysis. Details of the RPV stabilizer have been provided under RAI 3.8-27. If anchorage for quenchers is to be done in the next design phase, has it been identified as a COL Action Item in the DCD? If RPV insulation will be developed in the detailed design phase, has it been identified as a COL Action Item in the DCD? Information for connection of DF to VW is acceptable.

b. Some design details for RPVSB, VW, shield wall, GDCS pool wall, DF, and platforms, are not shown in the DCD (e.g., weld sizes/lengths, anchorage, some plate thicknesses). If these are considered to be local design details and will be determined in the detail design phase, has it been identified as a COL Action Item in the DCD?

The staff discussed these issues with the applicant during the December 2006 onsite audit. During the audit, the applicant presented a draft supplemental RAI response. 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. The applicant presented a sketch depicting the details of the quencher anchorage which will be included 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 this response, the staff requested 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.

In its supplemental response dated March 26, 2007, 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 supplemental 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. GEH has added typical details for the SRV quencher anchorage to Revision 3 of the DCD and the RAI response indicates that the anchorage design is performed 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. RAI 3.8-40 is 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 the infill concrete is considered in the analysis and design of these structures and how the mass, stiffness, and strength are considered 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 the infill concrete was modeled in the heat transfer analyses and how the constraint to thermal growth/contraction of the steel plates was considered in the thermal-stress analyses.

In its response dated June 28, 2006, the applicant stated that concrete strength and stiffness are conservatively neglected in both the structural analysis model and the seismic analysis model. The mass of concrete is considered in the seismic analysis model and in the structural analysis model.

For the linear thermal analysis, concrete strength and stiffness are neglected and thus the constraint to thermal expansion or contraction of the steel plates from the infill concrete is not considered. However, for the nonlinear analyses, the infill concrete in the VW and DF is explicitly included 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 via thermal ratios. Concrete-cracking effects from thermal loads are obtained 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 heat transfer coefficient of concrete is neglected in the DF and the wetwell for the linear analysis, but concrete is included 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.

Therefore, for the nonthermal and NS loads, neglecting the strength of the infill concrete in the design of the VW and DF structures is conservative, because the steel sections must then resist all of these type of loads (under the bending of the VW or DF, the concrete could resist significant load in compression, if not neglected). For seismic load, neglecting the strength and stiffness of the concrete, but including the mass, is conservative because the mass can add significant dynamic load without the benefit of any stiffness or strength to resist this load. For the thermal loads, the nonlinear modeling includes the stiffness, strength, and associated constraint from thermal expansion or contraction of the infill concrete. In addition, concrete cracking from thermal-induced stress and the associated reduction and redistribution of thermal load is also included. The effect of concrete expansion or contraction and cracking of the infill concrete in the steel composite structures (VW, DF) associated with thermal loads is incorporated into the design through the use of thermal ratios which scale results of the design-basis model that employ linear thermal-stress analysis neglecting the infill concrete.

During its onsite audit, conducted July 11–14, 2006, at the applicant’s offices in San Jose, California, 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 needs to 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 and/or hydrodynamic loads. This phenomenon may also be important for models that develop FRS (seismic and hydrodynamic loads). Since concrete properties were not used in the stick model for the VW and DF, the applicant needs to determine the effect of a frequency shift when considering the concrete, even if it is cracked, in generating FRS for qualification of equipment and piping. For thermal analyses other than LOCA, the issue of neglecting the infill concrete still needs to be addressed.

In its supplemental response dated November 7, 2006, the applicant indicated that, to address the effect of infill concrete on the fundamental frequency of the VW and DF, the stiffness properties of the two structures in the seismic model were adjusted to include contribution of concrete stiffness. Since the infill concrete is unreinforced, it would likely crack under the SSE. An effective concrete stiffness equal to 50 percent of the nominal uncracked stiffness was thus assumed. 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 effect of the frequency shift on the FRS was evaluated by additional parametric SSI analysis for generic uniform sites with single envelope ground motion input. The results were compared 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 the applicant’s letter, MFN 06-274. 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 an additional parametric seismic analysis is being performed to address the effect of containment LOCA flooding (see GEH 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 supplemental 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 75 percent or 100 percent of the uncracked concrete stiffness had been used, 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 supplemental response only discussed seismic loading. The applicant needs to 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 all thermal loading conditions analyzed using NASTRAN (including normal operating conditions) have been adjusted to account for the presence of the concrete infill, using thermal ratios obtained from the ABAQUS/ANACAP thermal-stress analyses.

In a second supplemental response dated January 24, 2007, 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. The effect of infill concrete stiffness on hydrodynamic response has been evaluated 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. Normal operating temperature is much lower than the DBA, and GEH did not consider any thermal ratios for normal operating conditions, which is conservative.

For the ABAQUS/ANACAP DBA thermal analyses, the applicant indicated that separate models are used for both a linear solution and a cracking analysis solution as a basis for developing the thermal ratios for the redistribution of internal section forces resulting from concrete cracking under the DBA thermal loads. The only difference in the modeling between the linear analysis and the cracking analysis is in the treatment of the infill concrete in the VW and DF. The structural design of these components is based on assuming that the steel will carry all the loads, that is, no credit is taken for the loads that will be carried by the infill concrete. Thus, the design-based NASTRAN models ignore the infill concrete in the linear analyses for section stresses under the required combination of loads. However, since the cracking analyses are intended to provide the actual internal section force distributions under the thermal loads, these models must include the effect of the infill concrete. Thus, for this ABAQUS/ANACAP study, the linear analysis model does not include the infill concrete. In the cracking analysis model, this infill concrete is included and modeled with 20-node brick elements with strain compatibility enforced at the connections of the plate-bending elements used for the steel plates in the VW and DF.

The applicant stated that it will revise Appendix 3F to DCD Tier 2 in the next update.

Based on its review of the latest supplemental response, the staff determined that the following additional information is needed before it can resolve the technical issues raised in RAI 3.8-41:

(1) When 50 percent of the concrete stiffness was considered, the natural frequencies of the VW and the DF increased 113 percent and 26 percent, respectively, compared to the original values. When 100 percent of the concrete stiffness was considered, the natural frequencies only increased an additional 8 to 10 percent. Based on the results obtained from considering 50 percent of the concrete stiffness, the applicant needs to explain how the natural frequencies could rise only 8 to 10 percent when 100 percent of the concrete stiffness values were utilized. For seismic loadings, the applicant indicated that differences were noted in the FRS at certain locations when 50 percent of the concrete stiffness values were included. Therefore, the applicant stated that the results of the infill concrete stiffness parametric evaluation will be included in the site-envelope seismic design loads. In addition, the applicant indicated that additional parametric seismic analysis is being performed to address containment LOCA flooding and the effect of updated modeling properties of the containment internal structures. From a review of DCD Revision 3, it is not clear whether the enveloping and updates of the modeling properties discussed above have been incorporated for the seismic loading.

(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 loads) for the VW and diaphragm walls are affected by a shift in the natural frequencies of these two structures (i.e., could the accelerations increase due to a shift in frequency).

(4) For the thermal loading condition, the applicant indicated that the normal operating temperature is much lower than DBA and no thermal ratios were used for normal operating conditions, which is conservative. Does this imply that the DBA thermal loading is used for all load combinations, even those that specify the normal operating condition? If not, then the applicant needs to explain why neglecting the thermal ratios is conservative.

RAI 3.8-41 is being tracked as an open item.

DCD Section 3.8.3.1.6 discusses platforms that are classified as seismic Category I and seismic Category II. However, no description is provided regarding 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 [safe shutdown earthquake] 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 C-II SSCs.

b. Describe any other SSCs that are seismic Category II inside containment.

In its response dated August 31, 2006, 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 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 a supplemental response dated January 29, 2007, the applicant noted that the inconsistency between the criteria would be corrected, as stated in the NRC assessment, and committed to revise the fourth paragraph of DCD Tier 2, Section 3.7, accordingly, in the next DCD update. The staff confirmed that the change has been implemented in DCD Revision 3. The staff finds that the resolution for this RAI is technically acceptable on the basis that the DCD has been revised to be consistent with the criteria in SRP Section 3.7.2.II.8 for seismic Category II SSCs. Therefore, RAI 3.8-42 is 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 though, the staff needed 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). The staff notes that the recent update to SRP Section 3.8.3 and 3.8.4 (March 2007) accepts ANSI/AISC N690-1994, including S02 (2004). The applicant identified an exception in the DCD to ANSI/AISC N690-1994, including S02 (2004), regarding ductility ratios, in order 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. The staff identified two items that may 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 RG1.54, “Service Level I, II, and III Protective Coatings Applied to Nuclear Power Plants.” The applicant noted that both items were addressed in its proposed DCD change. The staff confirmed that the changes are included in Revision 3 of the DCD. Therefore, the staff finds 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. RAI 3.8-43 is 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 additions and modifications as 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 dated November 8, 2006, 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 a supplemental response dated February 1, 2007, 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 the change has been implemented in Revision 3 of the DCD. Therefore, RAI 3.8-44 is 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 ASME Code, 2004 Edition, is identified in this table. In its response dated August 31, 2006, the applicant stated that ASME Code, 2004

Edition, would be deleted 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 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 is 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 for design of 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 the sequence of occurrence is given in Appendix 3B. A description of VLC loads is not provided in Appendix 3B 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 dated June 28, 2006, the applicant stated the following:

a. LOCA (large, intermediate, and small break) are described in Containment Load Definition 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 Pa 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 Pa 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 Pa (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, California, 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 needed to 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/components and components above the suppression pool surface. The applicant indicated it would submit a supplemental RAI response and revise the DCD to incorporate all of the additional information provided to the staff at the audit.

In a supplemental response dated September 14, 2006, 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 nonaxisymmeric 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 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 resulting forces or stresses from one dynamic load were combined 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 ABS method was used 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 those above suppression pool water surface, the applicant stated that a footnote would be added 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 a second supplemental response dated January 24, 2007, the applicant stated that for steel structures, DCD Revision 2, Tables 3.8-4 and 3.8-7, permit the use of SRSS for combination of peak dynamic responses. However, GEH indicated that it would clarify Appendix 3G to the DCD to indicate that the ABS method is actually used for analysis of steel structures, except for the GDCS pool, for 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 response dated June 28, 2006, 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. GEH provided additional information requested by the staff about the various SRV and LOCA loads, and how they are treated in the load combinations, in its supplemental responses. GEH is separately addressing the adequacy of the combination method (i.e., varying + and - or ABS versus SRSS) for dynamic loads of SSCs under RAI 3.8-9. 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 need 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 to implement this requirement. This table also refers to the methodology for calculation of 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 identifies 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 implement this clarification. Based on the above, RAI 3.8-46 is 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 RWS caused by a rupture of a pipe within the reactor vessel shield wall annulus region. 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 reactor vessel shield wall, 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 need to be considered in the analysis and design of other SSCs.

In its response dated June 28, 2006, the applicant stated that AP loads and effects are considered 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 containment, but the reactions are considered in the RSW design. RPV insulation is not a part of the steel internal structures of 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, North Carolina, on May 16–17, 2007, the staff reviewed GEH Report No. DC-OG-0053, Revision 3. This report demonstrates that the effects of AP loads as well as the other hydrodynamic loads (e.g., CO, CH, PS, and SRV) were applied to the various containment internal structures such as the DF, VW, RSW, and RPVSB. To address the question concerning generation of displacements and FRS, the staff reviewed two reports, GEH Report No. 092-134-F-C-00009, Issue 2, "SRVD, LOCA Hydrodynamic & AP Dynamic Responses in RBFB and RCCV," dated January 29, 2007, and GEH Report No. 092-134-F-C-00008, Issue 1, "SRVD, LOCA & AP Dynamic Responses in RPV and RSW," dated June 20, 2007. GEH Report No. 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 loads, SRV loads, and pipe break loads). GEH Report No. 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. 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 review of these reports, the staff concludes that the applicant provided the additional information requested in the RAI, and the methods of analysis described are considered to be acceptable because they are consistent with the criteria presented in SRP Section 3.8.3.II. Therefore, RAI 3.8-47 is resolved.

From the information provided in DCD Section 3.8.3 and Appendix 3G, it was not clear to the staff whether there are any other pipe rupture loads acting on containment internal structures other than the feedwater and RWCU breaks which 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 dated August 31, 2006, 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 AP pressure time histories were generated for the feedwater and RWCU breaks in the annulus between the RPV and the RSW.

A steamline break occurring outside of the annulus does not induce AP pressure. The time histories of the nozzle jet, impingement jet, and pipe whip restraint loads induced by steamline, feedwater, and RWCU breaks were calculated. These breaks were considered 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 of 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 description of the loads, models, analysis, and design approach for assessment of containment internal structures caused by other pipe breaks (other than AP). During the audit, the resolution of this RAI was addressed under the first part of RAI 3.8-51.

In a supplemental response dated January 29, 2007, 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 feedwater, RWCU, and MSLs. Some of these breaks lead to AP loads. In addition, the analysis also considers nozzle jet, jet impingement, and pipe whip restraint loads resulting from these pipe breaks. The staff found the applicant's description of the various pipe break loads and analysis approach to be acceptable based on the information provided in the RAI responses and the staff's evaluation of RAI 3.8-51. Therefore, RAI 3.8-53 is 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 various steel structures consisting of the DF, RPVSB, RSW, VW, and GDCS pool are included in the finite-element model described in DCD Sections 3.8.1.4.1.1 and 3G.1.4. The finite-element model 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 analysis, the infill concrete is neglected in the model. For the GDCS pool, a detailed stress evaluation is performed using a local model. The design of the containment internal structures is based 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 (Response of Structures to Containment Loads) 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 dynamic effects of the hydrodynamic loadings were analyzed and how the results were included in the design calculations for the affected structures. In RAI 3.8-48, the staff requested that the applicant provide the following information:

a 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 4 locations. What is the significance of these 4 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 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/will be utilized 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 dated June 28, 2006, 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. Response 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 CH 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 CH 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, California, 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 (suppression pool) 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 hertz (Hz), (e) provide examples of system and equipment design specifications, explain whether this is a COL applicant responsibility, and explain how compliance/adequacy is 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 in order 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 for 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 the details of the pressure distributions are provided in Appendix 3B to the DCD. During the audit, the applicant indicated that it would provide a supplemental RAI response to 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 a supplemental response dated September 14, 2006, the applicant stated that for the analysis of the asymmetric loads, only the first two terms in the Fourier series were considered ($F(\theta) = A0 + A1 \cos \theta$). 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 asymmetric load with 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 item (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 item (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 a second supplemental response dated November 7, 2006, 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 suppression pool 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 for analysis and/or testing of 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 staff’s December 2006 onsite audit, the staff requested that the applicant explain a contradiction that appears between supplemental responses 1 and 2 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.

In a third supplemental response dated January 24, 2007, 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 supplemental response and has incorporated these markups into DCD Tier 2.

The staff reviewed the applicant’s use of the computer code ANSYS for performing 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 suppression pool 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 provided a technical basis for ending the FRS at 100 Hz for hydrodynamic loadings, 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 hydrodynamic response spectra are utilized in the ESBWR detailed design and how the design evaluation of the affected structures subjected to the hydrodynamic loads was performed. 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 is resolved.

From the finite-element NASTRAN model shown in various figures in Appendix 3G to the DCD, it was not clear to the staff 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/component, then the applicant should discuss how its mass and stiffness have been represented in the overall NASTRAN model.

In its response dated June 28, 2006, 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 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, California, the staff discussed the requested information in greater detail with the applicant. 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 location and the RPV stabilizer location. 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 concludes 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, North Carolina, 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 reviewed several other reports which were more suited to answer the questions raised by this RAI (GEH Report No. 092-134-F-C-00009, Issue 2, and GEH Report No. 092-134-F-C-00008, Issue 1). GEH Report No. 092-134-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 finite-element model of the RB/FB including the RPV detailed model. GEH Report No. 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 No. 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 analysis of 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 analysis methods prescribed in SRP Section 3.8.3.II.4. Therefore, RAI 3.8-49 is 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 could potentially induce thermal expansion loads during radial thermal growth of the RPV, in RAI 3.8-50, the staff requested that the applicant provide the following information:

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 dated August 31, 2006, 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 resists and transmits 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 is resolved.

From the information presented in DCD Section 3.8.3.4 and Appendix 3G, it was not clear to the staff how the individual member forces from thermal, seismic, hydrodynamic, and other loads are obtained from the finite-element model. In RAI 3.8-51, the staff requested that the applicant do the following:

a. Provide a description of what type of analyses (static, response spectra, time history, etc.) are used with the FEM for each of the applicable loads in order to obtain individual member forces for design.

b. For thermal loading consideration, define the transient and steady state Ta, nonlinear temperature distributions, analysis approach, model, and design approach utilized for the major containment internal structures.

In its response dated June 28, 2006, 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 (Po and Pa) applied to DF and VW.

    (iii) Thermal load—Static analysis was performed for the thermal load (To and Ta) 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, CH 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, California, the staff discussed the response in greater detail with the applicant. The applicant indicated that the impulsive (rigid) portion of the water in all pools was included in the models as dead weight. The convective (sloshing) effect of the water was considered for all pools except for the GDCS pool. In the case of the GDCS pool, calculations were provided that demonstrate that the convective (sloshing) pressures are much smaller than the impulsive pressures. In addition, the convective and impulsive pressures are combined by the SRSS method which further diminishes the effect of the sloshing pressures for this pool. The applicant also clarified 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 temperature and the wetwell temperature. 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.

In a supplemental response dated November 7, 2006, the applicant stated that the water mass in all pools was treated as 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 suppression pool, the seismic-induced hydrodynamic pressures were calculated for impulsive and convective components separately and the results then combined by the SRSS method. For the GDCS and suppression pools, 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 the staff's December 2006 onsite audit, the staff asked the applicant to explain why the supplemental response for item a)(vi) above does not include pipe break loads associated with pipe breaks other than AP. In addition, the applicant was informed 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 (because of MS, feedwater, 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 a draft supplemental response which 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.

In a second supplemental response dated January 24, 2007, the applicant stated that AP loads include all high-energy line breaks (MS, feedwater, 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 impulsive response for the total mass of the pool water. (See Tables 3.8-51(1) through 3.8-51(4).)

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 clarified that these loads consist of pipe breaks associated with the MS, feedwater, and RWCU lines based on the information contained in DCD Section 3.6. Also, the applicant provided the technical basis demonstrating that its treatment of convective and impulsive modes for water sloshing under a seismic event in the ESBWR design 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 being addressed separately under RAI 3.8-41. Therefore, RAI 3.8-51 is 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. 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 containment.

In its response dated August 31, 2006, 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. These commodities are designed to the loads, loading combinations, and allowable stresses in accordance with applicable codes, standards, and regulations consistent with 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, it is necessary to describe in the DCD whether the analysis methods will follow those presented in DCD Tier 2, Sections 3.7 and 3.8. If cold-formed sections are used, 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). During the audit, the applicant indicated that it would revise Section 3.8.3 to provide criteria similar to, or reference the criteria in, Section 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.

In a supplemental response dated January 29, 2007, 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-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 and 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 is 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 response dated June 28, 2006, 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 with 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 a supplemental response dated January 24, 2007, 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 finds 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 is 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, 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 response dated August 31, 2006, the applicant stated that invoking the structural acceptance criteria for each of the containment internal structures to be in accordance with ANSI/AISC N690 means the same as in DCD Table 3.8-7. 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 a supplemental response dated January 29, 2007, 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 finds the text of the proposed revision, which clarifies the design and analysis procedures, as well as acceptance criteria, to be acceptable. 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 is 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 evaluation of quality control was based 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, several material types are listed (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 dated August 31, 2006, 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 multiple materials are specified 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 is 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.

3.8.3.3.7 Testing and Inservice Inspection Requirements

DCD Section 3.8.3.7 indicates that a formal program of testing and ISI is not planned 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 diaphragm and VW.

The staff noted that although DCD Section 3.8.3.7 states that Section 3.8.1.7 discusses testing and ISI of the DF and VW, 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 dated August 31, 2006, 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 this examination requirement is in accordance with the ASME Code, Section XI, Subsection IWE, and therefore, is acceptable. The staff confirmed that DCD Revision 3 includes the applicable change to Section 3.8.1.7. Therefore, RAI 3.8-55 is resolved.

The staff noted that DCD Section 3.8.3.7 indicates that no testing or inspection is performed for 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 for structures monitoring in RG 1.160 and 10 CFR 50.65 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 dated August 31, 2006, 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 structures monitoring apply to the ESBWR containment internal structures. If they are not applicable, the applicant needed to include a technical basis in DCD Section 3.8.3.7. During the audit, the applicant that containment internal structures are monitored per 10 CFR 50.65, as clarified by RG 1.160.

In a supplemental response dated January 29, 2007, 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 also 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 is resolved.

The staff noted that GDC 53, "Provisions for Containment Testing and Inspection," 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 identification of conditions in inaccessible areas that can lead to degradation, remote visual monitoring of high-radiation areas) to accommodate 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 applicant was informed that it needed to provide the technical basis for concluding that they are not necessary.

In its response dated November 8, 2006, 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, except that the applicant should include in the DCD the information provided in its response. During the December 2006 onsite audit, the applicant presented a draft supplemental response, which included 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.

In a supplemental response dated February 1, 2007, 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 ISI of containment internal structures. The staff confirmed that DCD Revision 3 includes the applicable changes to Sections 3.8.3.4 and 3.8.3.7. Therefore, RAI 3.8-59 is 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 the 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 the 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 N690-1994 (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 it is consistent with industry practice and SRP Section 3.8.3.II.

3.8.3.4 Conclusion

Because of open items that remain to be resolved for this section, the staff is unable to finalize its conclusions as to acceptability of the containment internal structures design.

3.8.4 Other Seismic Category I Structures

Other ESBWR seismic Category I structures include the RB, the CB, and the FB. Although the radwaste (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 Related to Other Seismic Category I Structures

The staff reviewed DCD Tier 2, Section 3.8.4, “Other Seismic Category I Structures,” 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 3.8.4, Revision 2. This will ensure that the applicant 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, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants,” to 10 CFR Part 50. The relavent regulatory requirements are discussed below.

- 10 CFR 50.55a and GDC 1 require that the safety-related structures shall 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 shall 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 shall 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 shall 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
- 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 1.94, “Quality Assurance Requirements for Installation, Inspection and Testing of Structural Concrete and Structural Steel during the Construction Phase of Nuclear Power Plants”

- RG 1.115, “Protection Against Low Trajectory Turbine Missiles”

- RG 1.142, “Safety-Related Concrete Structures for Nuclear Power Plants”

- RG 1.143, “Design Guidance for Radioactive Waste Management Systems, Structures, and Components Installed in LWR Plants”

For design certification, Appendix S, Section IV(a)(2)(i)(A), to 10 CFR Part 50, provides an option for specification of the OBE. If the OBE is chosen to be less than or equal to ⅓ of the SSE ground motion, the applicant need not conduct explicit response or design analyses to satisfy Section IV(a)(2)(i)(B)(I) of Appendix S to 10 CFR Part 50.

3.8.4.2 Technical Information in the DCD Related to Other Seismic Category I Structures

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 the service pools for storage of the dryer/separator on the top of the concrete containment. MS and feedwater 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 and supported on a foundation mat, houses the essential electrical and control and instrumentation equipment. Similar in construction, the FB is integral to the RB. The FB houses the 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 other building similar in construction is the RW building, which houses the equipment and floor drain tanks, sludge phase separators, resin holdup tanks, detergent drain tanks, a concentrated waste tank, chemical drain collection tank, associated pumps, and mobile systems for the radioactive liquid and solid waste treatment systems. This building is a 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 nondestructive examination method is used. Liquid penetrant examinations are conducted on all liner plate butt, fillet, corner, and tee welds in accordance with the ASME Code, Section V, Article 6, requirements. The acceptance criteria are in accordance with the requirements of the ASME Code, Section III, NE 5352. Helium sniffer tests or vacuum box techniques meeting the requirements of the ASME Code, Section V, Article 10, are also conducted. Any evidence of leakage is unacceptable. After construction is finished, each isolated pool is leak tested. The liner welds for all pools outside of the RCCV, including the SFP, are backed by leak chase channels and a leak detection system to monitor any leakage during plant operation. The leak chase channels are grouped according to the different pool areas and direct any leakage to area drains. This allows both leak detection and determination of the origin of the leaks. The functioning of the leak chase channels is 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 load.
>
> 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.
>
> Ro = Pipe reactions during normal operating or shutdown conditions based on the most critical transient or steady-state condition.
>
> Ra = Pipe reactions under thermal conditions generated by the postulated break and including Ro.
>
> Yr = 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.
>
> Yj = 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.

Ym = 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)

Wt = 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.)

Pa = 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.

To = 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 ^{o}C.

Ta = Thermal effects (including To) which may occur during a design basis accident.

H = Loads caused by static or seismic earth pressures.

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 the RB, CB, and FB are analyzed using linear elastic finite-element analysis methods and the computer program NASTRAN. Since the RB and FB are integrated into one building, these structures are analyzed using a common finite-element model which includes the RB, FB, and the concrete containment. The CB is analyzed using a separate finite-element model. Appendix 3G to the DCD discusses the details of these analysis models.

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 accord with item 32 in DCD Table 3.8-9 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 34.5 MPa (5000 psi), and 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 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. For welding of reinforcing bars, inspection and documentation requirements conform to ASME Code, Section III, Division 2.

The applicant also stated that composite construction is used for other seismic Category I structures. Some of the components, such as rebar cages, are preassembled and lifted into place. As described in DCD Section 3.8.4.1.1, the RB floor slabs are composed of reinforcing bars, steel plates, and concrete. Floor slab steel plates, which are reinforced by welded shapes, are assembled in discrete segments that are lifted into place. The steel plates are also used as form work for concrete fill.

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 per NUREG-1801, “Generic Aging Lessons Learned (GALL) Report,” and 10 CFR 50.65, as clarified in Section 1.5 of RG 1.160.

3.8.4.3 Staff Evaluation Related to Other Seismic Category I Structures

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 that “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 clarify that 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 clarify this discrepancy and identify where the DCD discusses criteria for the design of any guard pipes used in the ESBWR design.

In its response dated August 31, 2006, the applicant stated that no guard pipes are provided in the ESBWR because the MS and feedwater 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, per BTP MEB 3-1 of SRP Section 3.6.2, Revision 1. Therefore, the RB walls of the MS tunnel are designed to accommodate the penetrations and pipe support forces as well as the postulated pipe break Pa. DCD Section 3.6.2.1 discusses the postulated pipe break locations and configuration general criteria.

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.” The staff noted the need for a definition of the “environmental conditions” for which the tunnel is being designed.

In a supplemental response dated January 29, 2007, the applicant stated that according to SRP Section 3.6.2, longitudinal breaks (of at least 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 qualification of safety-related equipment. Outside of 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 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 they were incorporated in a formally submitted revision to the DCD. RAI 3.8-60 is resolved.

In an earlier version of the DCD, the staff noted that Section 3.8.4 stated that seismic Category I masonry walls are not used in the design. In RAI 3.8-61, the staff asked the applicant to explain if there are any non-safety-related masonry walls used in the ESBWR design. If so, 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 dated August 31, 2006, the applicant stated that masonry wall construction is not used in the ESBWR design. 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. In the next DCD revision, the applicant stated that it would also update Figures 1.2-1 and 1.2-3 by changing “Concrete Block” to “Shield Block.”

The staff determined that the applicant needed to 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 a steel frame retainer structure will be designed to seismic Category II requirements to prevent sliding or overturning under the SSE event and agreed to submit a supplemental response to the RAI.

In the supplemental response dated January 29, 2007, the applicant stated that removable shield blocks typically consist of metallic forms filled with grout or concrete. They will be designed as seismic Category II components, as stated in the original RAI 3.8-61 response. They will be provided with 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 finds the applicant's supplemental 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 they were incorporated in a formally submitted revision to the DCD. RAI 3.8-61 is 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 the three criteria presented in SRP Section 3.7.2.II.8 for all Category II SSCs.

In its response dated November 8, 2006, 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 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 SRP Section 3.7.2. II.8 criteria and are not postulated to fail. The applicant also referenced its response to RAI 3.8-42.

The staff determined that, in the applicant's supplemental response to RAI 3.8-42, dated January 29, 2007, 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 they were incorporated in a formally submitted revision to the DCD. RAI 3.8-62 is 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 dated June 28, 2006, 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 clarify that a minimum 100-mm gap will be provided 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 all reanalyses based on single-envelope ground spectrum curve are completed.

In a supplemental response dated September 14, 2006, the applicant stated that seismic gaps capable of a minimum 100-mm free movement are provided between independent NI (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 finds the applicant's supplemental 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 they were incorporated in a formally submitted revision to the DCD. RAI 3.8-63 is 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. A similar statement appears in Section 3.8.4.1.3 for the FB. Such a statement also appeared in Section 3.8.4.1.4 for the 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 dated June 28, 2006, 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, California, 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 structural design of reinforced concrete frame members is performed in accordance with ACI 349-01, and the steel frame members are designed in accordance with ANSI/AISC N690-1994s2 (2004). In the supplemental information provided at the audit, the applicant indicated that evaluations for 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, more information is needed to conclude that the applicant's approach is 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 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 this missile was evaluated for the structures and that it would provide more information on this subject. Following the audit, the staff also asked the applicant to provide an evaluation of the RB/FB exterior walls for the automobile tornado missile.

In a supplemental response dated September 14, 2006, the applicant proposed DCD changes to address the EBAS building. These changes were subsequently deleted from the DCD, since the EBAS building was deleted from the ESBWR.

In the same supplemental response dated September 14, 2006, 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 performed 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 also 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 also 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 other analyses are not needed. 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 frame members are explicitly included in the three-dimensional NASTRAN model, are designed in accordance with ACI-349 and ANSI/AISC N690, and the deformations are very small, the staff finds the response to the RAI regarding the design of frame members to be acceptable.

In a second supplemental response dated November 7, 2006, the applicant provided additional information on the evaluation of the RB/FB exterior walls for the automobile tornado missile. The applicant stated that the evaluation of the automobile tornado missile was performed 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 the impact load generated by an automobile missile was estimated 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, evaluations for punching shear and bending were performed. As 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 finite-element model analyses, in which the impact loads were applied to several critical elements, evaluated bending moments resulting from the automobile missile. The applicant reported that the resulting bending moments in critical elements were combined with moments resulting from other loads, including the tornado wind pressure, and confirmed that 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, California, the staff discussed the applicant’s evaluation of the automobile tornado missile. The staff stated that the applicant needs to 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 large concrete wall (approximately 18 m x 48 m x 1 m thick) in the FB has been checked for missile impact loads. The applicant stated that it has evaluated the large concrete wall for missile impact loads, and GEH Report SER-ESB-041 contains the summary of this evaluation.

In a third supplemental response dated January 24, 2007, 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 BC-TOP-9A has been added as Reference 3.5-9 in DCD Section 3.5.5, there is no reference to it in DCD Section 3.5.3. If BC-TOP-9A is used for the evaluation of the RB/FB exterior walls for the automobile tornado missile, DCD Section 3.5.3 needs to be revised accordingly. If not accepted, the applicant needs to provide an evaluation of the RB/FB exterior walls for the automobile tornado missile using the procedures currently referenced in DCD Section 3.5.3.

In a supplemental response dated June 26, 2007, 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 will revise the DCD in the next update.

The staff’s evaluated the applicant’s response and 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 a letter dated November 9, 2007, the applicant provided a supplemental response to RAI 3.8-64 to address the staff’s request. Section 3.5.3 of this report presents further evaluation of this supplemental response. In Section 3.5.3 of this report, the staff has documented acceptance of use of BC-TOP-9A for evaluation of overall damage prediction resulting from missile impact. In RAI 3.5-19, the staff asked the applicant to clearly state in the DCD that BC-TOP-9A was used for evaluation of missile impacts or provide justification if it used any other similar method. This issue is addressed by the staff under RAI 3.5-19 in Section 3.5.3 of this report. Therefore, RAI 3.8-64 is resolved.

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The staff noted that the TB, service building (SB), and RW building are in proximity to Category I structures. In RAI 3.8-79, the staff requested that the applicant confirm that these structures are designed to seismic Category II requirements or provide justifications for using different design requirements.

In its response dated November 8, 2006, the applicant stated that DCD Tier 2, Table 3.2-1, shows the TB, SB, and RW building seismic category classifications. 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 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 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 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 response dated February 1, 2007, the applicant stated that an exception to the requirement that any NS structure be located at least a distance of its height above grade from Category I or II structures was taken for the RW building in DCD Tier 2, Revision 2, Section 3.5.3.3, 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 has a height of 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, potential failure of the RW building under full SSE will have negligible impact on Category I or II structures.

The staff determined that this exception was not identified in DCD Tier 2, Section 3.7, and has not been reviewed by the staff for acceptability. Given the possibility that the RB may be impacted by collapse of the RW building, in a supplement to RAI 3.8-79 the staff requested a detailed technical evaluation to support the conclusion that there would be no unacceptable damage to the RB. This information needs to be documented in the DCD. **RAI 3.8-79 is being tracked as an open item.**

The staff noted that the RB, FB, and CB have been designed and evaluated to applicable acceptance criteria. In RAI 3.8-80, the staff asked the applicant to identify other buildings that have 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 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 dated November 8, 2006, 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 done. The RW design had not started. DCD Tier 2, Section 3.8.6, addresses the COL applicant responsibilities.

The staff found the applicant’s response to be incomplete for the EBAS building and the RW building. It was unclear whether the designs would be completed in sufficient time for staff review, before issuance of the staff’s SER, 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 a draft supplemental response to address the questions related to DCD Section 3.8.6.

In a supplemental response dated February 1, 2007, the applicant referred to the response to RAI 3.8-65, S01, for EBAS status and stated that the RW building is a non-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 is 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. The staff asked the applicant to clearly define the design responsibility for this essential building in accordance with RG 1.143. This information needs to be documented in the DCD. **RAI 3.8-80 is being tracked as an open item.**

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 the design/analysis of the entire CB has been completed in accordance with seismic Category I design criteria or discuss when it will be completed and by whom. Also, the the staff requested that information in Section 3G.2 of DCD Tier 2, Revision 3, be updated to completely 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 4650 and the floor slabs at elevation 9060 and elevation 13500. **RAI 3.8-112 is being tracked as an open item.**

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 though, the staff required additional clarification about their use, 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 the SER include the staff’s evaluation.

For each item in Table 3.8-9, the staff requested, in RAI 3.8-66, that the applicant identify and explain any exceptions to the codes and standards used for the ESBWR design.

In its response dated August 31, 2006, the applicant stated that in the title of DCD Table 3.8-9, it would change “Regulations” to “Regulatory Guides.” Regarding item 2 of DCD Table 3.8-9, ANSI/AISC N690-1994s2 (2004), in order to comply with Appendix G, to NUREG-1503 issued July 1994, for impact and impulsive loads, the ductility factors in Table Q1.5.8.1 are replaced with the ductility factors in Appendix A to SRP Section 3.5.3. 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 they were incorporated in a formally submitted revision to the DCD. RAI 3.8-66 is resolved.

The staff noted that DCD Section 3.8.4.2.1 states that the applicable documents for the RB design are shown in Table 3.8-9, 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 dated August 31, 2006, 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 as in the design, insofar as loads and loading combinations are concerned. Since item 3 (ASME 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. RAI 3.8-67 is resolved.

The staff noted that for design loading and acceptance criteria for the SFP racks and associated structures, the applicant referenced DCD Section 9.1, which references 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 a supplemental response dated February 1, 2007, the applicant stated that loads and load combinations in DCD Tier 2, Section 9.1.2.4, have been reconciled with Appendix D to SRP Section 3.8.4. The applicant stated that it would revise DCD Tier 2, Section 9.1.2.4 (page 9.1-5), in the next update. The applicant provided a markup of the proposed DCD change.

The staff finds the response to this RAI to be acceptable since the criteria for the design of the spent fuel racks and associated structures meet the staff technical position described in Appendix D to SRP Section 3.8.4. The staff reviewed the applicant's proposed DCD change and confirmed that it was incorporated in a formally submitted revision to the DCD. RAI 3.8-69 is resolved.

The staff noted that DCD Section 3.8.4.2.5 discusses the welding and subsequent inspections of pool liners during construction. The staff requested, in RAI 3.8-70, that the applicant clarify that 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 dated August 31, 2006, the applicant stated that liner welds of SFPs are backed by leak chase channels. The leak chase channels are grouped according to the different pool areas and direct 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 are 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 holder 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.

In a supplemental response dated January 29, 2007, the applicant stated that leak chase channels collect potential SFP or other pool leakage. The leak chase channels are grouped by different areas of a pool and direct 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, or 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 revision to the DCD. 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 finds the applicant’s supplemental response to be partially acceptable, since it clarifies the inspections to be performed on all pool liner welds and how the SFP and other pools outside the RCCV can be monitored for leakage during the plant operating life. However, the applicant’s response also stated that no COL action is needed. The staff considered the question of whether the applicant should define in the DCD a COL action to monitor the leakage of all pools during the plant operating life to be unresolved. This issue, however, is closely related to RAI 3.8-81. As a result of the applicant’s supplemental response to RAI 3.8-81, DCD Tier 2, Section 3.8.4.7, has been revised 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 is 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 accept ANSI/AISC N690-1994s2 (2004) without exception. Therefore, this is acceptable.

DCD Section 3.8.4.2 indicated that the design of other 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 additions and modifications as 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 dated November 8, 2006, the applicant proposed 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 a supplemental response dated February 1, 2007, the applicant stated that it has 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 was incorporated in a formally submitted revision to the DCD. RAI 3.8-84 is 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 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 dated November 8, 2006, 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 make the comparison between the staff's current position (ACI 349-97, supplemented by RG 1.142) and the unreviewed ACI 349-01, with consideration of 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 that are being 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 acceptance of the provisions.

In its supplemental response dated March 26, 2007, the applicant stated that there are two main changes in the ACI 349-01 edition versus the ACI 349-97 edition. First, ACI 349-01 is based on ACI 318-95 (except for Chapter 12, which is based on ACI 318-99), while ACI 349-97 is based on ACI 318-89 (revised in 1992), except for Chapter 12, which is based on ACI 318-95. 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 ACI 318-95 (except for Chapter 12 which is based on ACI 318-99). ACI 318 has long been the basis for the design of concrete buildings in the U.S., 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 design for torsion, the provisions in ACI 349-01 are in accordance with the guidance in RG 1.142 and are acceptable. For anchorage requirements to concrete, the provisions in Appendix B to ACI 349-01 accord 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 is 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 and RG 1.142 for concrete structures and ANSI/AISC N690-1994 including S02 (2004) for steel structures, which is 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. Pa is defined as the accident pressure at the MS tunnel resulting from a high-energy line break. Ta is defined as the thermal effects (including To) which 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 Ra, Ta, Pa, 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 dated August 31, 2006, 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 applied to the RCCV only but have some effect on the RB structures because of a common foundation mat, such as Pa and Ta. The applicant referred to DCD Table 3G.1-11 for an example of 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 Pa and Ta are considered in the RB design, noted that all loads included in the RB design need to 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 will add a footnote in DCD Tables 3.8-15 and 3.8-16, that the effects of SRV and LOCA dynamic loads originating inside the containment will be considered applicable.

In a letter dated January 29, 2007, 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 finds 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 was incorporated in a formally submitted revision to the DCD. RAI 3.8-71 is 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 state that the maximum co-directional 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. If not, the applicant should provide the technical basis for the differences.

In its response dated August 31, 2006, 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 (currently issued as RG 1.92, Revision 2).

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 the staff’s confirmatory analysis, that the applicant’s implementation of the 100/40/40 method is not consistent with DG 1127. During the audit, the staff and the applicant agreed to pursue the resolution of this issue under RAI 3.8-107.

In a letter dated January 29, 2007, the applicant referred to RAI 3.8-107, S01, for information on the implementation of the 100/40/40 method for combination of responses resulting from three directions of seismic loading. The staff addresses this technical issue under RAI 3.8-107 in Section 3.8.5.3.4 of this report.

The staff noted that DCD Section 3.8.4.3.2 states that accident pressure loads (Pa) do not exist for the CB. Section 3G.2.5.2.1.6 states that thermal loads (Ta) 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 why the dynamic effects of LOCA, SRV discharge, CO, and CHUG are not applicable to the design of the CB.

In its response dated November 8, 2006, the applicant stated that Ta 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 LOOP and delivers the maximum thermal load, Ta, 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. 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 was incorporated in a formally submitted revision to the DCD. RAI 3.8-73 is resolved.

The staff noted that DCD Section 3.8.4.3.3 states that accident pressure loads (Pa) 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 also supported on the same foundation as the RB. Therefore, the staff requested in RAI 3.8-74 that the applicant explain why the FB is not designed for the effects of Ra, Ta, Pa, 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 the dynamic effects of the above loads are not considered in the design of the entire FB. The staff also noted that DCD Section 3G.3.5.2.1.1 does not define either Pa or Ta for the FB, but Table 3G.3-4 includes Pa and Ta in two of the three selected load combinations (LOCA (1.5 Pa) 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 dated August 31, 2006, 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 Pa and Ta, 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 besides Pa and Ta are considered in the FB design, noted that all loads included in the FB design need to 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 in the DCD, by the addition of a footnote in Tables 3.8-15 and 3.8-16, that the effects of SRV and LOCA dynamic loads originating inside the containment will be considered as applicable.

In a supplemental response dated January 29, 2007, the applicant referred to its supplemental response to RAI 3.8-71, which addressed the same issues for the RB. The staff finds this response to be acceptable since it confirms that the FB 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 to address RAI 3.8-71 and concluded that it also addresses RAI 3.8-74. The staff confirmed that the change was incorporated in a formally submitted revision to the DCD. RAI 3.8-74 is 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 dated June 28, 2006, the applicant stated that design calculations were performed for all load combinations in DCD Table 3.8-15, excluding those that are obviously not critical or whose loads are negligibly small. Among the combinations, the ones that are controlling in critical sections were selected, and the DCD describes their results. Design calculations for the load combinations including tornado loads were performed but were found 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, California, 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 (Wt) 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/FB for load combinations including tornado, wind, seismic, and thermal loads..

In its supplemental response dated September 14, 2006, 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 response to the staff’s request at the audit, the applicant 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 Ta), 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/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, North Carolina, 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 a supplemental response to RAI 3.8-82.

In its response dated June 26, 2007, the applicant described how the penthouse is analyzed and designed for seismic and other loads. The RB/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 stiffness of the penthouse external walls is also included in the stick model. The penthouse effective mass in the vertical direction is considered in the slab oscillators at elevation 22500 of the seismic stick model. For design, the loads resulting from the FB penthouse are applied to the global NASTRAN model. The dead load, live load, and seismic loads are applied as nodal forces to the model. 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 load combinations, stress analysis, and section design calculations are performed by the same methodologies as the seismic Category I portions. The staff finds that the approach described above for the analysis and design of the penthouse structure are in accordance with industry methods and with those described in SRP Sections 3.7 and 3.8 and thus are acceptable. RAI 3.8-82 is resolved.

The staff noted that DCD Section 3G.1.5.3 does not include the load combinations for wind (W) and tornado loads (Wt), as defined in DCD Table 3.8-14. The staff requested, in RAI 3.8-83, that the applicant explain why Appendix 3G to the DCD does not include these load combinations.

In its response dated June 28, 2006, 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 Wt. 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, California, 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," April 28, 2006. The report discussed the procedures for determining the factors of safety for seismic loads and flotation. The procedures for determining the factors of safety for seismic loads will be evaluated under the DCD Tier 2, Section 3.7 review. 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 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 revision to the DCD. RAI 3.8-83 is resolved.

The staff review of the SFPCS 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 temperature effects were considered in the design of the SFP structure, to account for boiling of the pool water for up to 72 hours at 212 °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. This information should be documented in the DCD. **RAI 3.8-113 is being tracked as an open item.**

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 RB, CB, and FB are analyzed using the linear elastic finite-element 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 finite-element model, which is described in DCD Section 3G.1.4.1. The model also includes the concrete containment and utilizes quadrilateral, triangular, and beam elements to represent the various structural components. DCD Section 3G.2.4.1 describes the finite-element analysis model of the CB, which includes the entire structure. The design of the other seismic Category I structures is based 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 dated November 8, 2006, 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.

In a supplemental response dated February 1, 2007, 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. (See further discussion and staff evaluation for RAI 3.8-52 in Section 3.8.3.3.4 of this SER.) RAI 3-8-77 is resolved.

The staff noted a large disparity in element sizes in the NASTRAN model of the RB/FB structure. The staff requested, in RAI 3.8-104, that the applicant explain how the numerical stability of the solution was checked and verified. 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 dated June 28, 2006, the applicant stated that the large disparity in element sizes and triangular elements which have large height-to-base aspect ratios is mainly found in the areas around the RCCV openings in the NASTRAN model. However, the RCCV wall around large penetrations is designed using refined local finite-element models 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 stresses in triangular elements of large aspect ratios in other locations are compared 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, California, the staff discussed the requested information in greater detail with the applicant. 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 stresses. For this structure, the applicant also presented a local finite-element model that will be created using rectangular elements. The applicant also presented figures depicting the refined local finite-element models that will be used to design the RCCV wall around large penetrations. The triangular elements that have large height-to-base aspect ratios in the global model are eliminated. The applicant stated that it would include the information discussed during the audit in a supplement to its initial RAI response.

In its supplemental response dated September 14, 2006, 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/feedwater 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 member design. Figure 3.8-104(5) shows the application of drywell wall unit pressure.

The applicant also stated that the RCCV wall around large penetrations is designed using refined local finite-element models 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 supplemental response, the staff concludes that the applicant has adequately addressed the issue raised in this RAI. RAI 3.8-104 is resolved.

The staff noted that the desirable mesh shown in DCD Figure 3G.1-13 for the suppression pool 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. The staff requested, in RAI 3.8-105, that the applicant explain these observations.

In its response dated June 28, 2006, the applicant stated that the suppression pool 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 be established considering connections with these walls. This is why the mesh for the top slab is different from that of the suppression pool slab. The pool girders running along the 0–180 degree direction and the location of the pool walls are not symmetrical with respect to the 90–270 degree plane. Therefore, an asymmetrical mesh with respect to the 90–270 degree plane is developed. 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 finite-element model mesh patterns used. RAI 3.8-105 is 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. The staff requested, in RAI 3.8-106, that the applicant explain these movements.

In its response dated June 28, 2006, the applicant stated that because of the weight imbalance between 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 symmetric, both ends of the basemat would tend to equally deform upwards. However, the RB/FB foundation mat is not symmetric 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, California, 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.

In its supplemental response dated September 14, 2006, the applicant stated that 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 1017.9 MN.

The staff finds the applicant's supplemental response to be acceptable, because it confirms that there is no net vertical force resulting from drywell pressure. RAI 3.8-106 is 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 the structural acceptance criteria given in SRP Section 3.8.4.II.5. However, one clarification was needed, as discussed below.

In an earlier version of the DCD, the staff noted that DCD Section 3.8.4.5.1 references "SRP 3.8.1 Section II.3." This reference appeared to be incorrect, and the staff requested, in RAI 3.8-75, that the applicant check this section number and correct it as needed. In its response dated August 31, 2006, the applicant stated that it would revise "SRP Section 3.8.1 Section II.3" to read "SRP Section 3.8.4 Section II.3." The staff confirmed that the reference to SRP Section 3.8.4, Section II.3, is correct and that the proposed DCD change was incorporated in a formally submitted revision to the DCD. RAI 3.8-75 is resolved.

3.8.4.3.6 Material, Quality Control, and Special Construction Techniques

ESBWR DCD, Revision 1, did not provide information on materials, quality control, and 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 dated November 8, 2006, 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 welding of reinforcing bars (splices) comply with the applicable sections of the 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.

In its supplemental response dated February 1, 2007, the applicant stated that welded bar splices are not intended 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 will 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 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 the 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 needs to revise DCD Sections 3.8.3 and 3.8.4 to address this position. **RAI 3.8-76 is being tracked as an open item**.

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 ESBWR other 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 dated November 8, 2006, the applicant stated that it would refer to RG 1.160 in a new DCD Tier 2, Section 3.8.4.7, for monitoring of 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 of 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 10 CFR 50.65 should be referenced, along with RG 1.160, and that ESBWR seismic Category II structures also are 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 and/or inservice surveillance programs for other 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/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. The applicant 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 applicant stated that it would submit a supplemental response to RAI 3.8-81.

In its supplemental response dated March 26, 2007, the applicant stated that it has 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 Category I buried tanks, piping, and 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 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 proposed DCD changes have been incorporated in a formally submitted revision to the DCD. RAI 3.8-81 is 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 Category I structures is essential for plant safety. However, DCD Section 3.8.4 does not address any special design provisions (e.g., providing sufficient physical access, providing alternative means for identification of conditions in inaccessible areas that can lead to degradation, and remote visual monitoring of high-radiation areas) to accommodate ISI of other Category I structures. Therefore, in RAI 3.8-86, the staff asked the applicant to describe any special design provisions for other Category I structures in a new DCD Section 3.8.4.7. 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 dated November 8, 2006, the applicant stated that, in support of the monitoring of the seismic Category I structures of the ESBWR 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. In the ESBWR, interference checking and space control are accomplished through a three-dimensional model. 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 criticality to the plant and construction sequence of the item. 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 and 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 supplemental response. The staff noted that, when received, the supplemental response to RAI 3.8-86 needed to be consistent with the responses to RAIs 3.8-58, 3.8-59, and 3.8-81.

In its supplemental response dated March 26, 2007, the applicant referenced its supplemental responses to RAI 3.8-59, Supplement 1, and RAI 3.8-81, S01. The staff finds this acceptable; changes have been made to the DCD as a result of the supplemental responses to RAIs 3.8-59 and 3.8-81. 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 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 ISI of all safety-related and non-safety-related SSCs. Therefore, RAI 3.8-86 is resolved.

3.8.4.4 Conclusion

Because of open items that remain to be resolved for this section, the staff is unable to finalize its conclusions regarding the acceptability of other seismic Category I structures.

3.8.5 Foundations

The ESBWR RB, including the containment structure, and FB are built on a common foundation mat. The foundation of the CB is separated from the foundation of the RB and FB.

3.8.5.1 Regulatory Criteria Related to Foundations

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. The relavent regulatory requirements are discussed below:

- 10 CFR Part 50.55a and GDC 1 require that the foundations shall 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 shall 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 shall 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.

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 SER.

For design certification, Appendix S, Section IV(a)(2)(i)(A), to 10 CFR Part 50 provides an option for specification of the OBE. If it is chosen to be less than or equal to ⅓ of the SSE ground motion, it is not necessary to conduct explicit response or design analyses in order to satisfy Section IV(a)(2)(i)(B)(I) of Appendix S to 10 CFR Part 50.

3.8.5.2 Technical Information in the DCD Related to Foundations

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 × 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 the containment foundation 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 × 23.8 m rectangular reinforced concrete foundation, which is 3.0 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 the applicable codes, standards, specifications and regulations are discussed in DCD Section 3.8.1.2 for the containment foundation and in Section 3.8.4.2 for 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 and 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 the foundations of seismic Category I structures are analyzed 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 finite-element computer program NASTRAN, as described in DCD Sections 3.8.1.4.1.1 and 3.8.4.4.1. 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 involves primarily 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 sliding of the structure when subjected to lateral loads.

To evaluate the effect of 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. No membrane waterproofing is used under the foundations in the ESBWR.

The standard ESBWR design is developed 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 (i.e., piping, conduit, and others) are designed for the calculated settlement of the foundations. The effect of the site-specific subgrade stiffness and calculated settlement on the design of the seismic Category I structures and foundations is evaluated.

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 referred to DCD Section 3.8.1.5. DCD Section 3.8.4.5 describes the structural acceptance criteria for the RB, CB, and FB foundations.

DCD Table 3.8-14 lists the required factors of safety applicable to the ESBWR structures for overturning, sliding, and flotation. The calculated factors of safety are shown in Appendix 3G to the DCD. 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:

$$FS = (Fs + Fp)/(Fd + Fh)$$

where Fs is the shearing and sliding resistance, and Fp is the passive soil pressure resistance. Fd is the maximum lateral seismic force including any dynamic active earth pressure, and Fh is the maximum lateral force from loads other than seismic loads.

The factor of safety against flotation is defined as the following:

$$FS = F_{DL} / F_B$$

where F_{DL} is the downward force from dead load and F_B is the upward force from buoyancy.

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 Section 3.8.1.6 provides 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 per 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 Related to Foundations

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, some information was lacking or required clarification of certain details of the structures, including the foundations. These issues are discussed and evaluated in details in Sections 3.8.1.3 and 3.8.4.3 of this SER 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 accord 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 about the use of several items as discussed and evaluated in Sections 3.8.1.3 and 3.8.4.3 of this SER and below.

The staff noted that DCD Section 3.8.5.2 implies that two separate sets of codes, standards, and specifications were used for the common RCCV/RB/FB foundation. The staff requested, in RAI 3.8-101, that the applicant explain whether the common foundation supporting the RCCV, RB, and FB was actually designed to two different sets of codes, standards, and specifications, as indicated, or whether a uniform design basis was employed. If two different design bases were used, the staff asked the applicant to explain how this was implemented and to justify the jurisdictional boundary.

In its response dated November 8, 2006, the applicant stated that portions included in the RCCV are designed in accordance with the ASME Code and other portions outside of containment are designed in accordance with ACI 349. The loads and load combinations that cover both codes are considered for the whole basemat for conservatism. 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 had questions about (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.

RAI 3.8-101 relates to the jurisdictional boundary between the containment and other Category I structures. This issue is discussed under RAI 3.8-4, which is currently unresolved. When resolved, DCD Section 3.8.5.2 will require revision to reflect this resolution. **RAI 3.8-101 is being tracked as an open item.**

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 for the evaluation of sliding and overturning resulting from earthquakes, winds, and tornadoes and 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 in Sections 3.8.1.3 and 3.8.4.3 of this SER and below.

The staff noted that DCD Section 3.8.5.3 implies that two different sets of loads and load combinations were used 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 dated November 8, 2006, the applicant referred to the response to RAI 3.8-101. (See the staff's assessment of the response to RAI 3.8-101 in the preceding section.)

During the December 2006 audit, the staff and the applicant agreed to address this issue 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.

RAI 3.8-102 relates to the jurisdictional boundary between the containment and other Category I structures. This issue is discussed under RAI 3.8-4, which is currently unresolved. When the issue is resolved, the applicant will need to revise DCD Section 3.8.5.3 to reflect the resolution. **RAI 3.8-102 is being tracked as an open item.**

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 finite-element model 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 finite elements. Similarly, the foundation of the CB is included in the separate finite-element model of the CB which is described in DCD Section 3G.2.4.1. The soil foundation of the CB is also represented by soil springs using spring constants acting in the three global directions. All of the loads are applied statically to the finite-element models and analyzed using the linear elastic method with the NASTRAN computer code. The vertical structural loads are transferred to the foundation through bearing walls and columns. 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 the design and analysis procedures 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 dynamic analyses are performed using simplified frequency-independent impedance functions, which implies that the dynamic analyses are performed using rigid base assumptions. In RAI 3.8-87, the staff requested that the applicant describe the procedures that are 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 dated June 28, 2006, the applicant stated that bending moments induced in the foundation mat are calculated by 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. Bending moments in the foundation mat are evaluated 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, California, 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. Results of the staff's review of the base mat design are discussed under RAIs 3.8-90, 3.8-91, and 3.8-100 in this section of the report.

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 a supplemental response dated September 14, 2006, 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 explain the basis for this statement and to explain how it determined and applied the seismic stick model loads to the NASTRAN model.

In a second supplemental response dated January 24, 2007, the applicant stated that the design shear forces applied to the NASTRAN model are taken directly from SSI analysis results using the stick model. Additional shear forces shown in the RAI 3.8-87, S01, response are obtained 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 input moments are adjusted in NASTRAN to match the moments from the stick model results. The overturning moment applied to each story is determined 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 moment is adjusted 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, a compatible set of shears and moments for both models is maintained.

The staff finds 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 they are included in DCD Revision 3. RAI 3.8-87 is 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 sliding of the structure when subjected to lateral loads. However, the DCD did not indicate how the analysis will be performed and how lift-off effects, if appropriate, are 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 1000 feet per second, to hard rock sites.

In its responses dated November 8, 2006, and March 26, 2007, 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. Thus, RAI 3.8.-88 is 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 dated November 8, 2006, 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. It forms a waterproof barrier. No membrane waterproofing is used under the foundations in the ESBWR. However, membrane waterproofing is applied to the outer walls. The friction at sidewalls is not evaluated 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 they are included in a formally submitted revision to the DCD. The staff discusses its review of the mud mat under RAI 3.8-96. RAI 3.8-89 is 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 the procedures used to evaluate the worst conditions in DCD Section 3.8.5.4.

In its response dated June 28, 2006, the applicant stated that the worst-case scenario for 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 done for 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, California, 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 the basemat design is considered to be performed under the worst 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 is not possible. RAI 3.8-13 covers this uplift concern about soil springs in tension.

The staff also requested that the applicant consider nonuniform soil conditions under the mat and noted that such studies were done for design certification of the NI for another advanced reactor.

In a supplemental response dated September 14, 2006, 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 of 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 is 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. The issue regarding the effect of nonuniform soil conditions on the design of the basemat is being addressed under RAIs 3.8-93 and 3.8-94 which are discussed below. Therefore, RAI 3.8-90 is 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 with the requirements of SRP Section 3.8.5.

In its response dated June 28, 2006, the applicant stated that, as described in DCD Section 3.8.1.4.1.1, the linear elastic finite-element model is used for the analyses of the building structures, including the foundation mat, and the foundation soil is modeled with elastic springs in the finite-element model. The modeling method is the same as the ABWR standard design which the NRC has 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, California, 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 explain the transition from radial and hoop reinforcement to orthogonal reinforcement and whether sufficient development length was provided 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, assuring the required development length. N-S and E-W bars are either continuous or are terminated at the end of the transition region, assuring the required development length. The applicant explained that in section design calculations, both cases of orthogonal rebars and radial-circumferential rebars are evaluated 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. This information was not included in the GEH Report 26A6651, Revision 1. The staff asked the applicant to demonstrate how the individual load cases are combined to arrive at the total loads and how these total loads are applied to critical sections. The applicant provided a table of maximum stress ratios that included the three locations in the basemat.

The staff determined that the following additional information was needed from the applicant in a supplemental response to RAI 3.8-91:

(1) describe the details of the mat reinforcement beneath the RCCV where the reinforcement transitions from a circumferential/radial pattern to an orthogonal pattern, and demonstrate that adequate development length for the reinforcement is provided;

(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 a supplemental response dated September 14, 2006, 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 is 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 a second supplemental response letter dated November 7, 2006, the applicant provided supplemental information in response to item (1) above. The applicant stated that in the basemat around the cylindrical wall below the RCCV wall, rebars in two coordinate systems (i.e., orthogonal and cylindrical coordinates) are installed. Circumferential rebars are continuous. Other rebars are terminated at the end after assuring the required development length. In section design calculations, orthogonal rebars and radial rebars are evaluated for adequate development length.

The staff determined that the applicant’s supplemental responses address the questions raised by the staff during the audit. However, to demonstrate the adequacy of the design approach, additional information is needed 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 needs 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 is being tracked as an open item.**

The staff noted that the applicant carried out elastic analyses of the complete NI structure, including the RCCV for separate load conditions using a static NASTRAN finite-element model. Internal element loads for all the finite elements in the complete structure for a specific applied load are stored in a computer file. For each applied load, a specific file is produced. These computer files are used as input files, along with the rules for combining the individual load files to a postprocessor software called 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 finite element. In the postprocessing phase, SSDP checks demand against available reinforcement areas. It was unclear to the staff how the SSDP package treats the tangential shear reinforcement. In addition, during the staff audit in July 2006, the staff reviewed the SSDP validation package and found that the validation package did not contain several items of interest to the staff. Therefore, in RAI 3.8-107, the staff requested that the applicant provide the following information:

a. How does SSDP flag instances where reinforcement provided is less than the demand?

b. How does SSDP identify governing load combinations and the corresponding loads on a given finite element?

c. How does SSDP apply the reinforced concrete codes used in the U.S., such as ACI 349, ASME Section III, Div 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 dated November 7, 2006, 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 a detailed review of the validation report was needed 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. The staff asked the applicant to provide additional information regarding the input data and equations used in the SSDP postprocessor software.

In a supplemental response dated March 22, 2007, 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 the applicant's 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 March 22, 2007, supplemental response and the revised validation report for SSDP-2D are 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 3 directions of motion. The staff determined that the applicant needs to address the following questions:

  (1) From review of the Fot values (member forces due to other loads plus temperature loads) in Tables 3.8-107(2) and 3.8-107(7), both listed as element 1824, 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. Of particular note is Nx, listed as 4.096 in Table 3.8-107(2) and 0.946 in Table 3.8-107(7). The staff requires an explanation for this apparent discrepancy, which would tend to show the DCD method is conservative. If this is an error, re-calculate the combined loading results using the correct Fot loads, and provide the revised comparison results.

  (2) All comparisons presented in Figures 3.8-107(1) thru (12) show that the predicted stress does not exceed the allowable stress limit, for all 3 methods of spatial combination. The data presented is based on a limited subset of locations and two (2) load combinations that include SSE. Identify any locations and load combinations where the allowable stress limit is exceeded by any of the 3 spatial combination methods. Quantify the degree of exceedance.

(3) Figures 3.8-107(6)(b) and (10)(b) show one point where the SRSS and RG 1.92 100/40/40 methods of spatial combination produce results significantly higher (factor of 2.5 to 3) 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 RG 1.92, Revision 2, acceptable procedure for implementation of the 100/40/40 rule was intended to produce the most conservative estimates of response components due to 3 directions of seismic loading. Since the calculated response components are absolute values and seismic response is oscillatory, both the positive and negative sign must be considered when combining with response components due to other loads. This is completely analogous to implementation of the SRSS combination method. Studies conducted by the staff demonstrated the conservatism of this approach, compared to SRSS. The staff requires clarification why, 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) Table 7 and Table 8 present the transverse shear analysis and code check for ASME 2004 and ACI 349-01, respectively. Table 7 lists the stress units as “MPa.” Table 8 lists some units as “MPa” and some units as “psi.” The correct units need to be identified in these tables.

(2) The results presented in Tables 7 and 8 each show excellent correlation with hand calculations. However, comparing the results in Table 7 to the results in Table 8, row 1 and row 5 show differences, while the remaining rows show consistency. These differences need to be explained.

(3) The applicant referenced journal article utilized for the membrane section force calculation in Section 4.1 of the validation report; the staff is not familiar with this paper. For Section 4.2 of the validation report, the applicant should identify the source of the equations utilized for the axial force and bending moment calculation. In addition, it is unclear whether the hand calculations solve the same set of equations utilized in the SSDP computer code, or whether the hand calculations use an independent approach. If the hand calculations use an

independent approach, the method used in the SSDP computer code should be described.

(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 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 above ratios were obtained 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 if it is appropriate to combine the nonlinear thermal stress analysis results with the elastically calculated results for other loads. In the presence of significant nonlinear behavior, linear superposition of results attributable to different applied load sets may lead to significant errors in the final combined loading response. In a supplement to RAI 3.8-107 the staff requested the applicant to a detailed technical basis for the acceptability of its approach using several examples, including element 1824. **RAI 3.8-107 is being tracked as an open item.**

The staff noted that DCD Section 3.8.5.4 indicates that the standard design is developed 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 if any potential effects of static or dynamic differential settlement have been incorporated into the design of the standard plant nor does it give the magnitude of settlement that was 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 settlement issues are incorporated into the generic design of the standard plant and identify limitations on the magnitude of settlements. Specifically, the applicant should (a) explain how the potential for settlement was considered in the ESBWR standard plant design and (b) provide the allowable settlement that can be accommodated by the ESBWR foundations/structures.

In its response dated November 8, 2006, the applicant stated that three types of soil conditions are considered in the DCD (soft, medium, and hard) as uniform subgrades and referred to the response to RAI 3.8-93 for clarification of settlement issues.

The staff decided to address this issue under RAI 3.8-93 which is addressed below.

The staff noted that Section 3.8.5.4 states that total and differential settlements of the foundations must be considered but refers 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 settlement issues are incorporated 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 applicant was asked to define the COL applicant actions required to confirm that the predicted site-specific settlement meets the standard plant design assumptions.

In its response dated November 8, 2006, the applicant stated that it will incorporate the stipulated settlements into the total plant design as a requirement. The applicant provided an evaluation entitled, “Settlement Effect on Basemat Design,” to clarify the settlement issues. 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 such a program would not be necessary.

The applicant further stated that confirmation of the settlement effect on basemat design is provided by parametric analysis considering a variety of soil conditions and construction sequences as shown in the evaluation, “Settlement Effect on Basemat Design.” 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 this response, the staff noted that DCD Section 3.8.6.2 (identifying COL information) has been deleted from the DCD. The applicant needs to identify where it will be documented in the DCD 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 needs to (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 if 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.

During the December 2006 audit, the applicant discussed the issues identified above. Then, in a supplementary response dated March 26, 2007, the applicant stated that DCD Tier 2, Section 3.8.6.2, has been deleted since an analysis of the settlement issue is performed 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 I buildings will be quantified in the next DCD Tier 2 revision. The evaluation, “Assessment of Building Settlement,” included as part of the 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 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 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," 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. 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 of 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 NRC RAI 3.8-93 in MFN 06-407. 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. Figure 3.8-93(24) shows the relative displacement normalized to the basemat displacement at the centerline position of the RB. 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. The applicant included the revised pages (2.0-4, 2.0-6, 3G-16, 3G-17, and 3G-194) in DCD Tier 2, Revision 3, with the response.

Based on its review of this response, the staff identified the need for additional information:

(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 requires 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 needs to clarify 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 that may vary by a factor of 3 from the basemat center to the basemat edge, and describe how such a variation in shear wave velocity over the mat foundation was considered in the seismic analysis of the RB/FB and CB buildings. If this variation was not considered in the seismic SSI analysis, then appropriate criteria for the permissible variation in shear wave velocity to be used by the COL applicant needs to be specified and the technical bases for the criteria explained. The criteria in DCD Tier 1 Table 5.1-1 and DCD Tier 2 Table 2.0-1 should be revised accordingly.

(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 than 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 needs to address why these higher moments are acceptable.

(5) As stated by the applicant in the response, Figure 3.8-93(16)-c indicates that the Softx3 case exceeds the base case (DCD) under the "Hard Spot" condition. The applicant states that for the design allowable, slightly less than 3x soft or hard conditions is used. However, Figure 3.8-93(16)-d indicates that the Softx2 case exceeds the base case (DCD) under the "Hard Spot" condition with results that appear to be identical to those in Figure 3.8-93(16)-c. The applicant needs to clarify what is meant by "slightly less than 3x soft or hard conditions is used," compare the moments shown in these two figures 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 needs additional information to complete its assessment of RAI 3.8-93. **RAI 3.8-93 is being tracked as an open item.**

The staff noted that DCD Section 3.8.5.4 indicates 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 dated November 8, 2007, 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 SSE, and determined that the applicant should clarify that the values in Table 3G.1-58 represent the maximum soil-bearing stress for all load combinations The applicant needs to explain 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. The staff indicated that the applicant needed to 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 also needed to 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 a supplemental response dated March 26, 2007, 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. Note that the values obtained by the Energy Balance Method shown in Table 3.8-94(2) are the updated values for DCD Tier 2 Table 3G.1-58, due to the changes in seismic design loads, which have been included in DCD Tier 2 Revision 3.

(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. Note that 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.

(3) DCD Tier 2 Subsections 3G.1.5.5, 3G.1.6, Table 3G.1-58 and Table 3G.2-27 have been revised. The pages (pp. 3G-16, 3G-18, 3G-123 and 3G-215) revised in DCD Tier 2 Revision 3 for this response were included with the response.

Based on the review of this response, the staff identified the following needs for additional information:

(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 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 needs to explain how the COL applicant will satisfy this criteria, 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) Footnote 7 to DCD Tier 2 Table 2.0-1 references DCD Tier 2 Subsections 3G.1.5.5, 3G2.5.5 and 3G.3.5.5 for the minimum dynamic bearing capacities for the Reactor, Control and FB, respectively. However, Footnote 7 to the corresponding DCD Tier 1 Table 5.1-1 only states "At foundation level of Seismic Category I structures." The minimum dynamic bearing capacities need to be clearly specified as Tier 1 information.

(4) The response to RAI 3.8-94 states that variations in the horizontal soil spring were considered and concludes that the maximum soil bearing pressures of the nonuniform soil condition are similar to those of the uniform soil condition. Results for maximum bearing pressure under non-uniform soil conditions are presented in Table 3.8-94(3). For the non-uniform soil conditions considered in Table 3.8-94(3), 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, need to be included.

As discussed above, the staff needs additional information to complete its assessment of RAI 3.8-94. **RAI 3.8-94 is being tracked as an open item**.

The staff noted that DCD Section 3.8.5.4 indicates that site-specific allowable bearing capacities are no less than the calculated static and dynamic bearing pressures and refers 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 back 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 dated November 8, 2006, the applicant stated that it will delete the statement, "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," from DCD Tier 2, Section 3.8.5.4. 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 the applicant 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.

In its supplemental response dated February 1, 2007, 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 Table 2.0-2 for COL actions for site-related parameter criteria. The staff reviewed the applicant's proposed DCD changes and confirmed that they are included in DCD Revision 3. RAI 3.8-95 is resolved.

DCD Figure 3G.1-9 shows the finite-element model of the RB/FB foundation mat. From the information provided, it was not evident what type of elements were 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 the transition between the 5.1-m thick portion of the mat and the 4-m thick portion of the mat is modeled. Given that the thickness of the foundation mat identified in Table 3.8-13 is 5.1 m and 4 m, the applicant should supply the technical basis for using plate/shell-type elements.

In its response dated June 28, 2006, the applicant stated that the type of finite elements used to model the foundation mat is the thick-shell-type 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 set to 4.0 m uniformly. 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 as compared to the total mat. Furthermore, this extra thickness is treated as a non-load-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 on-site audit, conducted July 11–14, 2006, at the applicant's offices in San Jose, California, the staff discussed the response in greater detail with the applicant. The staff noted that it has 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 plans 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 SER discusses the staff's confirmatory analysis of the basemat, which utilizes three-dimensional solid finite elements and considers the basemat thickness variation.

During the audit, 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 a supplemental response dated September 14, 2006, 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 supplemental response and the results which show that the bending moments increase almost 30 percent at the center because of the larger basemat thickness. 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. The staff determined that the applicant should clarify the bases for the reinforcement design, in the light of its study, and should explain the technical bases for the procedure used to determine the size of the reinforcing bars in the top surface of the thickened portion to prevent the development of concrete cracking.

In its supplemental response dated January 24, 2007, the applicant stated that the NASTRAN model was revised 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, 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 they are included in DCD Revision 3. RAI 3.8-100 is 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, and FB 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 the structural acceptance criteria 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 DCD Section 3.8.5.5 presents two specifications of appropriate safety factors for foundation design. The safety factors against sliding indicate 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 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 basemat friction capacity. In RAI 3.8-96, the staff requested that the applicant clearly describe in DCD Section 3.8.5.5 how these effects are incorporated into the standard plant design for the range of acceptable site conditions considered.

In its response dated November 8, 2006, the applicant stated that in the response to RAI 3.7-35, SASSI analyses were performed to address 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 needed to 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. The applicant also needed (1) to 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) to clarify whether both base shear and passive pressures are relied on for lateral restraint, (3) to explain the friction coefficient used in the analysis and its technical bases, (4) to show how the sliding analysis captures lift-off effects, (5) to address the capacity of the mud mat to resist applied loads, and (6) to clarify the effect of the chemical crystalline powder in the mud mat on the assumed structural properties. Potential leaching of the mud mat by ground water is being reviewed under RAI 3.8-81.

In a supplemental response dated March 26, 2007, 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. For the RB/FB and CB, the gap between the building and excavated soil is filled with concrete up to the top level of the basemat or higher. Since the basemat is constrained by rigid concrete backfill, the passive soil pressure is mobilized for the region.

- Passive soil pressure on walls. The passive soil pressures considered are the envelope lateral soil pressures obtained from the elastic solution based on ASCE 4-98, Section 3.5.3.2 and SASSI analysis results, which are used in the wall design.

(3) Only the static coefficient of friction is used for stability evaluation. Coefficient of friction, μ, is calculated by the following equation: $\mu = \min(\tan \varphi, 0.75)$ 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 as shown in Table 3.8-96(1). 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.

The applicant stated that it has revised DCD Tier 2, Table 2.0-1, Sections 3G.1.5.5 and 3G.2.5.5, and Tables 3G.1-57 and 3G.2-26. Figures 3G.1-65 and 3G.2-15 have been added to DCD Tier 2. The applicant included the revised pages (2.0-3, 3G-16, 3G-123, 3G-189, 3G-194, 3G-215, and 3G-230) with the response.

Based on the review of this supplemental response, the staff concluded that the applicant has not used a consistent set of criteria to determine the safety factor against sliding and also needs to provide the technical bases for some of the parameters used in the analysis results. The staff identified the need for the following additional information:

(1) The fourth bullet in the list of items that comprise the sliding resistance is identified as “passive soil pressure on walls.” This terminology is misleading since the information included under this item is the elastic lateral soil pressure. If passive soil pressures are being credited to provide sliding resistance, explain how these pressures are calculated and confirm that the walls are designed to resist these forces. If elastic lateral soil pressures on the walls are being credited to provide sliding resistance, it is not consistent to use these elastic soil pressures with the

passive soil pressures at the basemat side surface. Also, explain how the passive soil pressures are calculated for the basemat side surface.

(2) Passive soil pressure at the basemat side surface is being credited to provide sliding resistance, which means that the static friction resistance at the bottom of the basemat is overcome. Explain why a dynamic coefficient of friction is not used to calculate the friction force at the basemat bottom surface.

(3) How has the applicant determined that there are sufficient soil sites that would have an angle of internal friction of 30 degrees or greater? What would a COL applicant be required to do if a site has a soil friction angle of less than 30 degrees?

(4) Provide a description of the formulations used to calculate the cohesion resisting forces and discuss how the material properties were determined for the analysis.

(5) Provide the technical basis for assuming that medium soils with an angle of internal friction of 30 degrees would also have the effective cohesion resisting forces reported in the analysis results in Table 3.8-96(1). Why is the cohesion value in Table 3.8-96(1) equal to zero for soft soils?

(6) Provide the technical basis for assuming that the hard soil/rock conditions have the effective cohesion resisting forces reported in the analysis results in Table 3.8-96(1).

(7) Why does the response indicate that the cohesion force contribution to total force is small when Table 3.8-96(1) shows that it is quite large for hard soils? For the RB/FB medium soil condition, a small change in the cohesion force could result in a factor of safety of less than 1.1. In the light of these observations, further justification is needed to support the statement that “the reduction of the cohesion due to uplift has little impact on the total resistance.”

(8) Describe the COL requirements for the backfill material for the gap shown in Figures 3G.1-65 and 3G.2-15. Will the backfill material be required to have a stiffness defined by its shear wave velocity which is at least equal to the shear wave velocity of the surrounding insitu soil? If not, explain why not. Also, clarify that the backfill material will completely fill the gap above the concrete backfill to the grade level.

(9) The footnote in Table 3.8-96(1) implies that the 100-40-40 three directional combination method was used for the sliding evaluation. The data in the tables above the footnote, however, indicate that a two dimensional (one horizontal and one vertical) check was made for calculating the factor of safety. In this evaluation the bottom friction force is derived based on the total vertical load consisting of dead weight minus the buoyancy effect minus 0.40 times the vertical seismic force. Since a simplified two dimensional approach (i.e., N-S & Vertical and then E-W & Vertical) is being used to demonstrate the factors of safety against sliding

> and overturning, the 100-40-40 rule is not considered to be appropriate. The typical approach that is utilized for checking sliding and overturning in accordance with the SRP Section 3.8.5 requirements is to use the dead load minus the buoyancy effect and then subtract the full vertical seismic load for the N-S & Vertical check and the E-W & Vertical check. If any other method is utilized, then the applicant needs to provide the technical justification for the approach. Note that 90 percent of the dead load (including the buoyancy effect) should be utilized as specified in footnote 1 of DCD Table 3.8-15, which is also in accordance with ACI 349 requirements.

The staff needs significant additional information to complete its assessment of RAI 3.8-96. **RAI 3.8-96 is being tracked as an open item.**

The staff noted that DCD Section 3.8.5.5 presents two specifications of appropriate safety factors for foundation design. The safety factor against uplift indicates that the full calculated dead load will be used 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 BE 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 the dead load will be defined for this uplift evaluation, including the treatment of the stored volume of water in the pools.

In its response dated November 8, 2006, the applicant stated that the full dead load was considered 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 for checking overturning. For flotation, the RAI response provided a table which 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 the dead load was defined 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 applicant presented a draft supplemental response addressing this request.

In a supplemental response dated February 1, 2007, the applicant stated that, as described in the original response to RAI 3.8-97, the full dead load was used. 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. RAI 3.8-97 is resolved.

The staff noted that DCD Section 3.8.5.5 refers to DCD Section 3.7.2.14 for a description of the overturning analysis methodology. The staff had previously requested additional information on this subject in RAI 3.7-48. In RAI 3.8-98, the staff requested that the applicant revise DCD Section 3.8.5.5 if needed as a result of any changes made to Section 3.7.2.14, in response to RAI 3.7-48.

In its response dated August 31, 2006, the applicant referred to the response to RAI 3.7-48. In a supplemental response dated January 29, 2007, the applicant provided the markup of DCD

Tier 2, Section 3.7.2.14, submitted with its RAI 3.7-48, S02, response. The applicant demonstrated that the markup of DCD Tier 2, Section 3.7.2.14, has no impact on DCD Tier 2, Section 3.8.5.5. Therefore, RAI 3.8-98 is resolved.

The staff noted that DCD Section 3.8.5.5 describes the structural acceptance criteria for foundations and states that the containment portion follows DCD Section 3.8.1.5 and 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 the common foundation supporting the RCCV, RB, and FB was actually designed to two different sets of structural acceptance criteria, as indicated, or whether uniform structural acceptance criteria were employed. If two different structural acceptance criteria were used, the applicant should explain how this was done and justify the jurisdictional boundary.

In its response dated November 8, 2006, the applicant referred to the response to RAI 3.8-101. (See the staff's assessment of the response to RAI 3.8-101 in Section 3.8.5.3.2 of this SER.)

During the December 2006 audit, the staff and applicant agreed to address this issue under RAI 3.8-4. In a supplemental response dated February 1, 2007, the applicant referred to the response to RAI 3.8-4, S01, for further clarification of jurisdictional boundaries.

RAI 3.8-103 relates to the jurisdictional boundary between the containment and other Category I structures. This issue is discussed under RAI 3.8-4, which is currently unresolved. When resolved, the applicant will need to revise DCD Section 3.8.5.5 to reflect the resolution.
RAI 3.8-103 is being tracked as an open item.

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 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 SER 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 of structures to meet the requirements of 10 CFR 50.65. If there was such a commitment, then the applicant needed to modify DCD Section 3.8.5.7 to indicate this. If not, the applicant needed to provide the technical basis in DCD Section 3.8.5.7.

In its response dated November 8, 2006, the applicant stated that it would reference RG 1.160 in a revised DCD Tier 2, Section 3.8.5.7, for monitoring of the seismic Category I structures of the ESBWR listed in DCD Tier 2, Table 19.2-4, and 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 will address structures covered by DCD Sections 3.8.4 and 3.8.5.

In a supplemental response dated March 26, 2007, the applicant stated that it has 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 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 proposed DCD changes have been incorporated in a formally submitted revision to the DCD. RAI 3.8-99 is 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, California, 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 utilize three-dimensional solid finite elements, 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, 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 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 to be resolved.

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 results comparison in the confirmatory analysis. During the audit, the NRC staff discussed with the applicant's staff 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.

At the audit, 12 post-audit actions were identified. 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 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 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) is 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 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 will 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 needs to program ANSYS macros to calculate Qz and Nz in order 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 CC at this intersection is 6.2 MN-m/m; the out-of-plane moment Mz (My, in NASTRAN terminology) in 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 requests 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 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 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 ANSYS results. Because the staff was able to make the necessary sign corrections, item (5) is resolved.

(6) The applicant's internal forces and moments in the walls were taken at the center of the first row of shell elements in the walls (-11.0 m). The staff's corresponding results were taken 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/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/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 can explain the cause of the differences and address them, item (7) is 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 provided a reasonable explanation 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) is 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 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) is 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 is a sufficient number of 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 has 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 generated by the staff, 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.

Once the applicant submits new results that resolve the other open items in this list, the staff can then complete the review of this item. Item (12) is open.

Five items from the December 2006 audit have not been resolved. **RAI 3.8-114 is being tracked as an open item.**

3.8.5.4 Conclusion

Because of open items that remain to be resolved for this section, the staff is unable to finalize its conclusions regarding the acceptability of the foundation of seismic Category I structures design.

3.9 Mechanical Systems and Components

3.9.1 Special Topics for Mechanical Components

In accordance with the guidelines in NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants" (hereafter referred to as the 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

3.9.1.1 Regulatory Criteria

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

- GDC 1, "Quality Standards and Records," in Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10, Part 50, "Domestic Licensing of Production and Utilization Facilities," of the *Code of Federal Regulations* (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, "Design Bases for Protection Against Natural Phenomena," 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, "Reactor Coolant Pressure Boundary," 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, “Reactor Coolant System Design,” 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, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants,” to 10 CFR Part 50, as it relates to design quality control

- Appendix S, “Earthquake Engineering Criteria for Nuclear Power Plants,” to 10 CFR Part 50, as it relates to the structures, systems, and components important to safety to withstand the effects of the 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, 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, Section 3.9.1.1, “Design Transients,” 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 LOCA transient for ASME Code, Section III, Service Level D conditions.

DCD Tier 2, Table 3.9-2, shows the loads combinations and acceptance criteria for safety-related ASME Code Class 1, 2, and 3 components, component supports, and CS structures. DCD Tier 2, 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. DCD Tier 2, Section 3.9.1.2, “Computer Programs Used in Analysis,” refers to Appendix 3D to DCD Tier 2 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, Section 3.9.1.3, “Experimental Stress Analysis,” 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 FMCRD.

3.9.1.2.4 Considerations for the Evaluation of Faulted Conditions—Inelastic Analyses

In DCD Tier 2, 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 control rod drive (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, 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, 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, "Licenses, Certifications, and Approvals for Nuclear Power Plants," the applicable criteria appear in Appendix S, "Earthquake Engineering Criteria for Nuclear Power Plants," 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 dated March 22, 2007, 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 finds this response acceptable, and RAI 3.9-3 is 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, 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 dated November 11, 2006, 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 finds this response acceptable, and RAI 3.9-4 is 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 dated November 11, 2006, the applicant stated that the ESBWR events are basically the same as the events specified for all earlier BWRs, including the advanced boiling-water reactor (ABWR). The number of cycles specified over the 60-year life of the reactor is based on earlier BWR experience. The staff agrees that it is reasonable to use previous experience as a basis for specifying design transients and considers 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 dated November 11, 2006, the applicant stated that the 180 startup cycles correspond to 172 shutdown cycles, specified for Event 9, plus 8 SRV or single depressurization valve (DPV) actuation cycles, specified for Event 15, after which the reactor is also shut down. The staff finds this response reasonable and acceptable and considers 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 Table 3.9-1. In its response dated November 11, 2006, 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 an additional response dated May 1, 2007, 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 finds this response reasonable and acceptable and considers RAI 3.9-7 closed.

In RAI 3.9-8, the staff requested that the applicant discuss the basis of the statement "2 events/10 cycles per event" for Event 13 in Table 3.9-1. In its response dated November 11, 2006, 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." The applicant specifically quoted Section 3.12.5.14, which states that "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 finds this response reasonable and acceptable and considers 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 dated November 11, 2006, the applicant stated that a single Level D SSE and LOCA events are very low probability events, and each is therefore postulated to occur only once during the life of the plant. The staff finds this response acceptable because it conforms with previously accepted nuclear power plant design practice, and it considers 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 dated November 11, 2006, the applicant stated that it will add a footnote to the table indicating that plant events are for 60 years. The staff finds this response reasonable and acceptable and considers RAI 3.9-11 closed.

On the basis of this evaluation and the evaluation of the responses to RAI 3.9-2 through RAI 3.9-11, the staff finds that the information pertaining to the ESBWR design transients in DCD Tier 2, 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 the DCD Tier 2 Section 3.9.1 for computer programs. Appendix 3D to DCD Tier 2, describes these programs. To complete its review, the staff requested additional information.

In RAI 3.9-12, the staff requested 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 dated April 18, 2007, 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 has reviewed the response to this RAI and finds it acceptable because it conforms with current industry practice for verifying computer programs used in nuclear industry structural analysis, and it considers 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 dated April 18, 2007, the applicant listed the computer programs ANSYS, EVAST, and ANS17 as having the capability for 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 is being tracked as an open item.**

Because of the open RAI that needs resolution, the staff will defer its conclusion regarding the computer code qualification methods described in this section.

3.9.1.3.4 Experimental Stress Analysis

In accordance with the guidance in SRP Section 3.9.1.III, the staff finds that the experimental stress analysis methods used in the design of ESBWR components are in compliance with the provisions of Appendix II to ASME Code, Section III, and are 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 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 ASME Code, Section III, have been met. In its response dated April 18, 2007, 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 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. The staff has 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 is being tracked as an open item.**

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 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 finds it acceptable because it conforms with current industry practice, and it considers 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 dated April 18, 2007, 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 finds this response reasonable and acceptable and considers RAI 3.9-16 closed.

Because of the open RAI that needs resolution; the staff will defer its conclusion regarding the application of elastic and inelastic analyses.

3.9.1.4 Conclusions

Because of open RAIs that need resolution, the staff is unable to finalize its conclusion about the acceptability of the ESBWR design applications.

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:

- 10 CFR Part 50 and 10 CFR 50.55a, “Codes and Standards,” as they relate to NRC codes and standards

- 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 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

- GDC 14, “Reactor Coolant Pressure Boundary,” 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

- Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants,” to 10 CFR Part 50, as it relates to design quality control

- Appendix A to 10 CFR Part 100, as it relates to the suitability of the plant design bases for mechanical components established in consideration of site seismic characteristics

- RG 1.124, “Design Limits and Loading Combinations for Class 1 Linear-Type Component Supports”

- ASME Code, Section III

- 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

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/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, "Piping Vibration, Thermal Expansion, and Dynamic Effects," Section 14.2.8.1.42, "Expansion Vibration and Dynamic Effects Pre-operational Test," Section 14.2.8.2.9, "System Expansion," and Section 14.2.8.2.10, "System Vibration." 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 effect testing should be conducted during startup testing. The staff 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 SER 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. Thus, it is not clear whether the applicant intends to monitor all 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. 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 dated November 22, 2006, 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 is 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/recorded measurements. The technique used depends on such factors as the safety significance of the particular system, the expected mode and/or magnitude 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/recorded measurements) will be used on each piping system covered by the vibration and dynamic effects testing program.

In its response dated November 22, 2006, the applicant responded as follows:

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/recorded measurements) will be used on each piping system. Therefore RAI 3.9-18 is 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 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 dated January 20, 2007, 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 (27.5MPa) 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, 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 is closed.

The applicant stated the following in DCD Tier 2, Section 3.9.2.1.1, "Reconciliation and Corrective Actions":

> 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, and/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 directed 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/analyzers used for such monitoring. Alternately, the staff asked the applicant to provide a reference document that describes the vibration/condition monitoring program.

In its response, GEH 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. Therefore, RAI 3.9-20 is 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/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 finds 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 dated January 20, 2007, 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 GE 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.

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 SER 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 steamflow 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 dated November 22, 2006, 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, 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.

However, DCD Tier 2, 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 GEH 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 dated November 22, 2006, 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 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 are 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/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 dated February 16, 2007, the applicant stated that it will revise DCD Tier 2, Section 3.9.3.7.1(3)c, to acknowledge that this is an action item for the COL applicant. The DCD has since been revised accordingly. Therefore, RAI 3.9-24 is 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, 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.

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, and/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 dated November 22, 2006, 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.

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 provides a description to address the identified discrepancies in snubber motion, as requested.

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. GEH 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:

- 10 CFR Part 50 and 10 CFR 50.55a, as they relate to NRC codes and standards
- 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 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
- 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

- Appendix B to 10 CFR Part 50, as it relates to design quality control
- Appendix A to 10 CFR Part 100, as it relates to the suitability of the plant design bases for mechanical components established in consideration of site seismic characteristics

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/or analysis applicable to the major components on a component-by-component basis. Seismic and other events that may induce 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, equipment, and their supports (including supports for conduit and 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.

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 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 RG 1.60, “Design Response Spectra for Seismic Design of Nuclear Power Plants,” response spectrum anchored to a PGA of 0.3g, both in the horizontal and vertical directions. In DCD Tier 2, Section 3.7.5.1, the application 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 horizontal and vertical direction, respectively. Section 3.7.1 of this SER 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 floor response spectra and displacements obtained from the primary system dynamic analysis. Dynamic qualification can be performed by analysis, testing, 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, and/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 and/or static bend testing is also used to show that there are no natural frequencies below the 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.

In addition, 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 upon 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, are 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 SER 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, 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 requirements of SRP Section 3.9.2.

By letter dated November 22, 2006, the applicant stated that 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, will be revised 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, Revision 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, Revision 2. In addition, DCD Tier 2, Revision 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, Revision 2, the applicant stated that conduit and cable trays, 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, Revision 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, 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 adequate design methodologies and criteria are in place for the cable trays and conduits, HVAC ducts, and their supports. Therefore, RAI 3.9-27 is 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 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 $1/(1 \pm 0.15)$ 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 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-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 combined by the SRSS rule if the modes are not closely spaced. Closely spaced modes (two modes having frequencies within 10 percent of each other) were combined using the criteria of RG 1.92. The applicant also considered the residual rigid response caused by the missing mass in accordance with the methods described in DCD Tier 2, Section 3.7.2.7. This procedure ensures inclusion of all modes of the structural model and proper incorporation of the responses associated with high-frequency modes. Responses associated with the high-frequency modes are combined algebraically (i.e., retain signs) with each other. The total combined response to high-frequency modes is combined by the SRSS method with the total combined response from lower frequency (i.e., less than or equal to 100 Hz) modes to determine the overall peak responses.

The staff determined that the methods of combining modal responses described above meet the requirements in RG 1.92, Revision 1, and SRP Section 3.7.2 and, therefore, are acceptable for use in the calculation of seismic and dynamic responses of seismic Category I piping systems and components.

The applicant stated that the mathematical modeling of primary piping systems is generally developed according to the 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 degrees of freedom 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 degrees of freedom is considered adequate when additional degrees of freedom do not result in more than a 10-percent increase in response. Alternatively, the number of dynamic degrees of freedom 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 is closed.

In DCD Tier 2, Revision 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 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 in order 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 for the adequacy of the applicant's frame-type support design.

The applicant stated that the stiffness of the building steel/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.

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, 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 and housings, spargers, and their supply heaters, but their masses are considered. To ensure that the RPV and its internals are properly modeled in the coupled dynamic analysis, 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/or 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., having sufficient dynamic degrees of freedom) to amplify high-frequency inputs at 33 Hz to as high as 100 Hz, considering that projected SSE ground motion estimates in several future sites in the U.S. 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.

By letter dated November 30, 2006, 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 degrees of freedom 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 degrees of freedom 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 (FEM) 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. 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 concern regarding the dynamic modeling of the RPV and its internals. The staff determined that the modeling approach proposed by the applicant 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. RAI 3.9-30 is, therefore, closed.

In DCD Tier 2, Section 3.7.3.3.3, the applicant 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 dated February 16, 2007, the applicant referred to its earlier response to RAI 3.12-13, dated

December 11, 2006, and to the revision made to DCD Tier 2, Revision 2, Section 3.7.3.3.3. The applicant stated that the need to use these supports during the detailed design phase is not foreseen. If their use should be essential at any point during the development of detailed engineering, the modeling and analytical methodology would be based on applicable design codes and allowables approved by the NRC. By letter dated April 24, 2007, the applicant provided a supplemental response stating 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 applicant also notes this in DCD Tier 2, Revision 3, Sections 3.7.3.3.3 and 3.9.3.7.1(6). Therefore, the original response to this RAI is no longer applicable, and no further action is necessary. The staff reviewed DCD Tier 2, Revision 3, Sections 3.7.3.3.3 and 3.9.3.7.1(6), and confirmed that the applicant has revised these two sections by noting that “special engineered pipe supports shall not be used.” The staff finds this acceptable, and RAI 3.9-31 is 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. By letter dated November 22, 2006, 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, and RAI 3.9-32 is 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 floor response spectrum 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 floor response spectrum for all supports. By letter dated February 16, 2007, 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 requirements of SRP Section 3.9.2.II.2.g. RAI 3.9-45 is 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 $S_d = S_a g/\omega^2$, where S_a is the spectral acceleration in “g’s” at the high-frequency end of the spectrum curve (which, in turn, is equal to the maximum floor acceleration), “g” is the gravity constant, and ω is 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 require that the support displacements be imposed on the supported item in the “most unfavorable combination” using static analysis procedures. By letter dated February 16, 2007, the applicant clarified that by “conservative” it meant the “most unfavorable combination.” This is consistent with the requirements of SRP Section 3.7.3.II.9. RAI 3.9-33 is 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 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 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 latter reference requires group responses to be combined by the ABS method. Section 3.12.4.3 of this SER 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. This issue of the response calculation of multiple-supported piping systems in a building will be discussed further in the staff safety evaluation provided in Sections 3.12.6.13 and 3.12.4.3.

In 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 the applicant to further clarify how such a piping system will be analyzed for both inertial response and the response caused by differential anchor movements. By letter dated November 22, 2006, 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 concurred with the applicant's assertion that, for the effect of differential building movements, SRSS combination of the system responses caused by the peak inertial effect and the peak anchor displacement effect is adequate. This is because the response from the inertial effect and the response from the anchor displacements are both dynamic in nature and are not expected to reach their peak values at the same time. RAI 3.9-34 is, therefore, 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. By letter dated November 22, 2006, 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.

The applicant has not provided the requested supplemental information. **RAI 3.9-35 S01 is being tracked as an open item.**

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 flexibility and masses of equipment attached to the piping are to be incorporated into the analytical model. By letter dated November 22, 2006, 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 is, 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.

By letter dated January 31, 2007, 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. This is acceptable to the staff. RAI 3.9-37 is 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 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 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 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, GEH 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. By letter dated November 22, 2006, 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. Based on its 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 is closed.

The applicant stated that damping values for equipment and piping are shown in Table 3.7-1 of DCD Tier 2, Revision 2, and are consistent with RG 1.61. For ASME Code, Section III, Division I, Class 1, 2, and 3, and ASME/ANSI B31.1 piping systems, the alternative damping values specified in DCD Tier 2, Figure 3.7-37, may be used, provided all the conditions described in the notes attached to the figure are met. The staff finds the above proposed damping values to be consistent with the regulatory requirements for 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. SRP Sections 3.7.2 and 3.9.2 provide guidelines for equipment and component damping values. 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. By letter dated November 22, 2006, the applicant stated that, as described in its responses to RAI 3.7-13 and RAI 3.7-13, S01, DCD Tier 2, Revision 2, Figure 3.7-36, has been deleted and Table 3.7-1 has been revised. In DCD Tier 2, Revision 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 2000 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 systems and supports to be acceptable. RAI 3.9-40 is 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 letters dated January 31, 2007, and December 11, 2006, 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 ESBWR design does not include buried seismic Category I piping. Based on the information provided, RAI 3.9-41 is closed.

DCD Tier 2, Section 3.9.2.2.1, states that equipment that is large, simple, and/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.

By letter dated November 30, 2006, 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/or 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/or analysis records of equipment qualification for staff audit acceptable. However, the applicant should include this commitment in its revised DCD as a COL action item.

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/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 applicant was asked to provide a summary description of how the qualification will be performed for each of these equipment items.

By letter dated August 24, 2007, 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 and/or isolation is subject to testing under the seismic and dynamic equipment qualification program 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/or analysis records of equipment qualification for staff audit. In Tier 1, Section 1, the scope of the system basic 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 is closed.

In DCD Tier 2, Section 3.9.2.2.2, "Qualification of Safety-Related Mechanical Equipment," 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. The applicant has not responded to the staff's request. **RAI 3.9-43 is being tracked as an open item.**

3.9.2.2.4 Conclusions

Because of the open RAIs that need resolution as identified in this section, as well as in Sections 3.12.4.3 and 3.12.6.13 of the SER, the staff is unable to finalize its conclusions regarding the design adequacy of all safety-related mechanical equipment and piping and their 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

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

- 10 CFR Part 50 and 10 CFR 50.55a, as they relate to codes and standards
- 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 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
- 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
- Appendix B to 10 CFR Part 50, as it relates to design quality control
- Appendix A to 10 CFR Part 100, as it relates to the suitability of the plant design bases for mechanical components established in consideration of site seismic characteristics
- RG 1.92, "Combining Modal Responses and Spatial Components in Seismic Response Analysis," Revision 2, July 2006
- ASME Code, Section III

3.9.2.3.2 Summary of Technical Information

The applicant states 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. GEH 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.

GEH Letter MFN 05-116, DCD Tier 2, Appendix 3L, Section 3L.5.5.1, “Finite Element Models,” supplements this section of the DCD by providing some 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.

GEH Letter MFN 05-116, DCD Tier 2, Appendix 3L, Section 3L.3, “Chimney Partition Assembly Evaluation,” 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.

GEH Letter MFN 05-116, DCD Tier 2, Appendix 3L, Section 3L.4, “Steam Dryer Evaluation Program,” presents 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 safety evaluation.

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 the applicant 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 SER.

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, GEH did not provide a complete listing of the major components. Therefore, in RAI 3.9-46, the staff requested that the applicant provide this listing of the major reactor internal components within the vessel that would be subjected to FIV testing.

In its response to RAI 3.9-46 dated November 22, 2006, the applicant stated the following:

> DCD Tier 2 Appendix 3L.2 “Reactor Internal Components FIV Evaluation,” 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.

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 dated November 22, 2006, 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 the supplemental RAI 3.9-47, the staff requested that the applicant include this information in the ESBWR DCD.

In its response dated August 7, 2007, GEH proposed modifications to DCD Tier 2, Section 3.9.2.3, to reflect its answer to RAI 3.9-47. The staff found the proposed modifications of the DCD acceptable. **RAI 3.9-47 is being tracked as a confirmatory item.**

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 dated November 22, 2006, 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 is identified are 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. By letter dated August 7, 2007, the applicant proposed revisions to the DCD that were acceptable to the staff. **RAI 3.9-48 is being tracked as a confirmatory item**.

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, GEH 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 GEH 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 dated November 22, 2006, 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 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 the LTR, NEDE-33259P, "ESBWR Reactor Internals Flow Induced Vibration Program—Part I," January 2006.

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 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 applicant was requested in RAI 3.9-49 S01 to provide additional information, comparing the components and flow conditions of ESBWR and other reactors so that reliable FIV evaluation could be made

In the GE response to RAI 3.9-49 S01, the dynamic structural analysis method used to calculate ESBWR response was provided in detail. The forced response equation, based on modal analysis was provided, tables from which the structural parameters of ABWR and ESBWR components could be determined were provided, selected measured responses of the ABWR were given, and the fluid forcing function F(t,x) was assumed to be the same in the ESBWR and ABWR except that differences in local flow velocities must be taken into account.

After evaluation of 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 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 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, 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 GE’s response to RAI 3.9-49 S01, but GE did address the potentials in Licensing Topical Report, NEDE-33259P Revision 1, “ESBWR Reactor Internals Flow Induced Vibration Program,” dated December 2007 and in response to RAI 3.9-79 S01, from GEH on February 4, 2008. 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.

Therefore RAI 3.9-49 is 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 dated November 22, 2006, 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 provides a satisfactory explanation of 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.

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 dated November 22, 2006, 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, GEH did not provide response amplitudes for other major components. In a supplement to RAI 3.9-51 the staff requested that the applicant should 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 is being tracked as an open item.**

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 dated November 22, 2006, 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 MSIV and 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 MSIV's and TSV's. 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 the applicant in RAI 3.9-52 S01 to 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, in a letter dated August 7, 2007, GEH replied 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 phase of each mode is different from 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.

GEH 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 vane-passing frequency 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, GEH 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 finds 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 requested GEH to discuss how its FIV analysis and testing programs considered deterministic excitation mechanisms, like acoustic and vortex shedding excitation, as well as on the importance of the phasing of the forcing functions. In its response, GEH has provided additional information and proposed changes to the DCD, discussed in RAI 3.9-79 later in this section, which the staff found acceptable. **RAI 3.9-52 is being tracked as a confirmatory item.**

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 dated November 22, 2006, 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 the applicant to 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 S 01, the applicant referred to its response to RAI 3.9-49 S 01 and LTR NEDE-33259P Rev 1. Based on its review of the applicable portion's of LTR NEDE-33259P Rev 1, and RAI 3.9-49 S 01, 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. Therefore RAI 3.9-53 is 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 dated November 22, 2006, 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 NRC 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 finds 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.

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 dated November 22, 2006, 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 finds 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.

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 dated August 1, 2007, the applicant provided the requested test data and proposed modifications to DCD which the staff finds acceptable. The applicant included these changes in the formal revision of the DCD. RAI 3.9-56 is 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 dated April 2, 2007, 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: General Electric Company, "Steam Dryer—Acoustic Load Definition," NEDC-33312P, Class III (Proprietary), and NEDO-33312, Class I (Non-Proprietary).
>
> 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: General Electric Company, "Steam Dryer—Structural Evaluation," NEDC-33313P, Class III (Proprietary), and NEDO-33313, Class I (Non-Proprietary).

> The steam dryer instrumentation and startup testing process is described in Subsection 3L.4.6 of DCD, Tier 2, Appendix 3L. Details regarding the confirmation of the steam dryer load definition and stress analysis during initial power ascension will be provided in a future reference report: General Electric Company, “Steam Dryer—Instrumentation and Power Ascension Monitoring,” NEDC-33314P, Class III (Proprietary), and NEDO-33314, Class I (Non-Proprietary). Computational fluid dynamic analyses are not used in the steam dryer acoustic load definition.

Based on its review, the staff finds that the applicant has 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 is being tracked as an open item.**

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 dated November 22, 2006, 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:
>
> Shroud and Chimney
>
> 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 GE acceptance criteria require that this maximum stress is below a threshold value of 68.9 MPa.

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 per cent will be used where required. The GEH acceptance criteria require that this maximum stress be below a threshold value of 68.9 MPa.

In response to RAI 3.9-59, the applicant provided descriptions of two 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, as requested. The staff found the applicant's response acceptable for the components reported. However in a supplement to RAI 3.9-59, the staff requested the following information:

(1) The applicant's 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.

Responses to RAI 3.9-59 S01, as well as the referenced RAI 3.9-76 S01, RAI 3.9-56, RAI 3.9-77 S01, RAI 3.9-78, pertinent sections of LTR NEDE-33259P Revision 1 were evaluated because supplementary details are provided for all the components covered in this RAI. In general, the information in LTR NEDE-33259P Revision 1 supersedes the information provided in this RAI.

The RAI 3.9-59 S01 is closed because (1) the applicant has identified the components that are sufficiently different from the earlier BWRs and the ABWR and they will be will be instrumented and analytically evaluated for FIV, (2) remaining components in the ESBWR are considered to have characteristics sufficiently similar to the ABWR so that detailed FIV testing and analyses are unnecessary, and (3) smaller torsional fluid forces and the torsional restraint at the top of the chimney will result in an ESBWR torsional responsethat is less than the comparable ABWR response. Therefore RAI 3.9-59 is resolved.

3.9.2.3.4 Conclusions

Because of the open RAIs that need resolution, the staff is unable to finalize its conclusions regarding the acceptability of the applicant’s evaluation for dynamic responses of reactor internals under operational flow transients and steady-state conditions.

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

A. 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

- 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 50.34, “Contents of Construction Permit and Operating License Applications; Technical Information,” as relates to specifying the margin of safety associated with normal operation and anticipated operating transients

- RG 1.20, “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.

GEH will conduct inspections before and following startup testing to identify any damage, excessive wear, or loose parts. Posttesting 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, “Reactor Internals Vibration Analysis, Measurement and Inspection Program,” identifies the information to be provided to the NRC regarding the startup FIV program.

Section 3L.5, “Startup Test Program,” of Appendix 3L (GEH report MFN 05-116) 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/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

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 dated November 22, 2006, 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 finds the applicant's response reasonable and acceptable because it provides the steady-state and transient conditions that are to be evaluated, as requested.

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 dated April 2, 2007, 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 concerns. **RAI 3.9-61 is being tracked as an open item.**

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 response dated April 2, 2007, 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, as well as additional reference reports. In addition, in its response to RAI 3.9-73, the applicant committed to instrument several regions of the steam dryer which the staff finds acceptable. However the applicant did not provide specific instrumentation and testing plans, deferring those to the COL applicant. COL Information Item 14.2-2-H requires the COL Holder to provide the test procedures. Therefore, RAI 3.9-62 is 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 in order 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 in order 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 response dated April 2, 2007, 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 3.9-63 is being tracked as an open item.**

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 dated April 2, 2007, 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 submitted additional information on April 7, 2008, discussed in detail in response to RAI 3.9-79, which addresses the staff's concerns and the staff finds it acceptable. Therefore, RAI 3.9-64 is 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, GEH 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 GEH 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 is 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 response dated April 2, 2007, 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. However, this information does not adequately address the staff's concerns. **RAI 3.9-66 is being tracked as an open item.**

The discussion provided in DCD Tier 2, Section 3.9.2.4, does not specifically state that the startup test procedure will include specific hold points 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 hold points 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 hold points will be of sufficient duration to accomplish those activities.

In its response to RAI 3.9-67 dated November 22, 2006, 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 the applicant has committed to provide the requested information on startup testing to the NRC at the time of 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 hold points 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 hold points with respect to the steam, FW, and condensate systems and components.

In its response, GEH 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 finds that the applicant adequately identified the plant parameters that will be monitored during the hold points with respect to the steam, FW, and condensate systems and components, as requested. Therefore, RAI 3.9-68 is 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 dated January 31, 2007, the applicant identified DCD Tier 2, Section 3.9.2.1.1, “Vibration and Dynamic Effects Testing,” 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 is 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, GEH 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 provided an adequate discussion of 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 is 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 dated April 2, 2007, 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. However, this information does not adequately address the staff concerns. **RAI 3.9-71 is being tracked as an open item.**

The GEH 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 cannot 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 dated November 22, 2006, 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 the review of the applicant's response, in a supplement to RAI 3.9-72 the staff requested the applicant to provide the revised LTR NEDE-33259P with the completed analyses for staff review. LTR NEDE-33259P, Revision 1, submitted by the applicant contains the information requested by the staff.

Based on its review of the applicant's response, in pertinent sections of this report as well as the applicant's response to RAI 3.9-59 S01 the staff finds the applicant's response acceptable because LTR NEDE-33259P Rev 1, includes the completed analyses of the components that are different from ABWR,and the revised Appendix 3L that is consistent with the revised report. Therefore RAI 3.9-72 is 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.

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 and SRP Section 3.9.2. 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 dated November 22, 2006, 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 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 in to 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 micro-strains. 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 500Hz. 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. The applicant also committed to 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. Since the applicant has deferred this information to the COL submittal, COL Information Item 14.2-2-H requires the COL Holder to provide the test procedure. The applicant was requested in RAI 3.9-73 S01 to justify why the components below the core (i.e., control rod guide tubes, in-core guide tubes and stabilizers, and non-pressure boundary portion of control rod housing and in-core housings) are not being instrumented for testing. In particular, a discussion was requested of potential FIV excitation mechanisms associated with the upstream core support structures, which were also identified in RAI 3.9-79. The response to RAI 3.9-79 S01, explains why the components below the core do not need to be tested. The staff has found the response to RAI 3.9-79 S01 acceptable as discussed in RAI 3.9-79 below. Therefore RAI 3.9-73 is resolved.

The use of the terms “prototype” and “non-prototype” in DCD Tier 2, Section 3.9.9.1, and GEH LTR, 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 dated November 22, 2006, 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 action 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 dated August 7, 2007, the applicant generally agreed with the staff. However, the applicant is expected to provide further clarification to its response. **RAI 3.9-75 S01 is being tracked as an open item.**

For the ESBWR FW sparger and the chimney head and steam dryer guide rod, the applicant implied that valid prototype structures and flow conditions provide evidence that those differences between the prototype and the ESBWR will have no 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 rod, and 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 dated November 22, 2006, 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 LTR 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 needed clarification. Therefore in RAI 3.9-76 S01, the applicant was requested 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, clarification was requested 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, dated February 4, 2008, GE responded as follows:

> 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 Licensing Topical Report, NEDE-33259P, Revision 1, “ESBWR Reactor Internals Flow Induced Vibration Program,” December 2007, which was transmitted to the NRC via letter Number MFN 07-635 dated December 7, 2007.
>
> As in the ABWR, the ESBWR feed-water (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 is no leakage-flow induced instabilities. Thus, even though the FW flow in the ESBWR is about 10% higher than that in the ABWR, there is no possibility of leakage flow induced instabilities.

After review of the pertinent sections of LTR NEDE-33259P, the staff found acceptable that an FIV analysis of the Chimney Head/Steam Separator Assembly due to flow in the annuli had been made and instrumentation is to be included on start up testing to verify the analysis. Also based on the review of the LTR NEDE-33259P, the staff found the reported welded-in design does eliminate the possibility of leakage flow instabilities in the Feedwater Sparger. Therefore concerns related to RAI 3.9-76 are considered resolved and this RAI is closed.

In accordance with RG 1.20 and SRP Section 3.9.2 guidelines, differences between the valid prototype and the nonprototype reactors will 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 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 due to the structural differences with 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 response, in Enclosure 1 to MFN 07-207, 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 does 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 2, and SRP Section 3.9.2, Revision 3, in RAI 3.9-77 S0 1 the staff asked the applicant 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 S01 is being tracked as an open item.**

GEH report NEDE-33259P, Rev. 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. GEH report NEDE-33259P Rev 1, includes the above requested information. Based on a review of this information, the staff finds that the concerns related to the core plate are resolved. RAI 3.9-78 is closed because the ESBWR core plate design is similar to that of ABWR core plate and its stresses are well below the allowable stresses.

Comparing the ESBWR DCD Tier 2, Figure 3.9-3, to the ABWR DCD Tier 2, Figure 3.9-2, 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 a discussion of the potential effects of organized wake flows downstream of the shroud supports.

In its response to RAI 3.9-79 dated November 22, 2006, 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 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 explained 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. Therefore in RAI 3.9-79 S01 the staff requested 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 the applicant to 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, dated February 4, 2008, the applicant provided information which addressed the staff's concerns and was acceptable. The staff also evaluated relevant portions of the LTR NEDE-33259P. In this report the effects of the self generated vortex shedding on the core components were discussed and found to be insignificant and therefore acceptable. RAI 3.9-79 is resolved.

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. The staff asked the applicant to discuss the potential effects of organized wake flows from the shroud supports shedding and impinging on downstream lower plenum components. In particular, the applicant should include an assessment of the coincidence of the frequencies of organized wakes with the natural frequencies of the lower plenum components.

There appears to be a discrepancy between GEH report, NEDE-33259P, and DCD Appendix 3L

(GEH report MFN 05-116), 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. GEH report, 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 dated November 22, 2006, 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 the LTR (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 response of the applicant is 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 is closed.

3.9.2.4.4 Conclusions

Because of the open RAIs that need resolution, the staff is unable to finalize its conclusions regarding the acceptability of the initial startup FIV testing information provided by the applicant for meeting applicable regulations.

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:

- 10 CFR Part 50 and 10 CFR 50.55a, as they relate to codes and standards

- 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 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

- 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

- Appendix B to 10 CFR Part 50, as it relates to design quality control

- Appendix A to 10 CFR Part 100, as it relates to the suitability of the plant design bases for mechanical components established in consideration of site seismic characteristics

- RG 1.92, “Combining Modal Responses and Spatial Components in Seismic Response Analysis,” Revision 2, July 2006

- ASME Code, Section III

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 GEH satisfied the requirement of SRP Section 3.9.2.5 and the relevant requirements of GDC 2, 4, 14, and 15, in particular, as well as the applicable portions of the other regulatory criteria stated in Section 3.9.2.5.1 of this SER.

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 calculational 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. The applicant has not responded to RAI 3.9-81. **RAI 3.9-81 is being tracked as an open item.**

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 the applicant has satisfactorily explained how the modeling of the RPV and internals accounts for the presence of water. Therefore, RAI 3.9-82 is 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, 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 GE 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 is 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 event SSE. 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, 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 finds the applicant's qualitative justification of the adequacy of the ESBWR RPV and internals mathematical, centerline, 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/dynamic analysis. Therefore, RAI 3.9-84 is 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 the applicant 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 no significant system structural partitioning was employed in the generation of the ESBWR mathematical, centerline, beam, concentrated mass model of the RPV and internals. Therefore, RAI 3.9-85 is 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, 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 GEH response to RAI 3.9-86, the staff finds the applicant's 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 is 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, GEH 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 GE'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.

Based on its review of the applicant's response to RAI 3.6-6, as well as the information provided in Appendices B, C, and D to ANSI/ANS 58.2, the staff finds that unresolved issues related to the applicant's response remain. Section 3.6 of the SER addresses these issues. **RAI 3.9-87 is being tracked as an open item.**

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 the applicant 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 dated November 10, 2006, 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 is 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, 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. RAI 3.9-89 is 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 barrel and CRGTs, under pipe rupture loadings.

In its response dated November 10, 2006, 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 provided a reasonable and satisfactory explanation as to how it investigated the stability of the elements in compression, such as the core barrel and CRGTs, under pipe rupture loadings. Therefore, RAI 3.9-90 is closed.

3.9.2.5.4 Conclusions

Because of the open RAIs that need resolution, the staff is unable to finalize its conclusions regarding the acceptability of the dynamic system analyses that have been 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.

3.9.2.6 Correlation of Reactor Internals Vibration Tests with the Analytical Results

3.9.2.6.1 Regulatory Criteria

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

- 10 CFR Part 50 and 10 CFR 50.55a, as they relate to codes and standards
- 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 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
- 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
- Appendix B to 10 CFR Part 50, as it relates to design quality control
- Appendix A to 10 CFR Part 100, as it relates to the suitability of the plant design bases for mechanical components established in consideration of site seismic characteristics
- RG 1.20, "Comprehensive Vibration Assessment Program for Reactor Internals During Preoperational and Initial Startup Testing"
- ASME Code, Section III

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 additional knowledge gained from previous vibration tests has been used in the generation of the dynamic models for seismic and LOCA analyses for 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 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 the knowledge gained from previous vibration tests was used 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 the applicant 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 dated November 22, 2006, 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 (Hz)/Analytical Prediction/Measured
> - HPCF Coupling and Sparger/62.1/60.0
> - In Core Monitor Guide Tube/54–70/55–64.5
> - CRD Guide Tubes and Housing/18.7–20.1/16–20
>
> 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.

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 dated November 22, 2006, 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.

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 the applicant considers to be similar to the ESBWR design for possible verification of the postulated forcing function.

In its response to RAI 3.9-93 dated November 22, 2006, 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.

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 the applicant considers to be similar to the ESBWR design for possible verification of stress levels.

In its response to RAI 3.9-94 dated November 22, 2006, 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 (Kg/mm2) Analytical Results	Maximum Stress (Kg/mm2) Startup Test Results
CRDGT/CRDH	0.28	0.28
ICMH	1.2	1.0

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 the applicant considers to be similar to the ESBWR design.

DCD Tier 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 3.9-95, 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 dated November 22, 2006, 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 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 finds 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.

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 test, their bases, and compliance with RG 1.20, Revision 2 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 the applicant 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 2, issued May 1976, which is associated with the testing program for Non-Prototype Category II reactor internals.

In its response to RAI 3.9-96 dated November 22, 2006, 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 2 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. 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 the applicant considers 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 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 2, issued May 1976, 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, as outlined in Open Items 3.9.2.3-3, 3.9.2.4-10, 3.9.2.4-11, 3.9.2.4-12, 3.9.2.4-13, and 3.9.2.4-14 and Confirmatory Item 3.9.2.4-1 listed in SER Sections 3.9.2.3 and 3.9.2.4. 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. The applicant was requested to provide above information in RAI 3.9-96 S01.

In its response GEH provided the following information:

> In Technical Report 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 of Licensing Topical Report 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 finds the applicant’s response acceptable with respect to the issues discussed above. However other concerns related to RAI 3.9-96 S01 which are contained in the LTR NEDE-33259P Rev 1 are currently being reviewed and additional RAIs formulated as necessary. **RAI 3.9-96 is being tracked as an open item.**

3.9.2.6.4 Conclusions

Because of the open RAI that needs resolution, the staff is unable to finalize its conclusions about whether the applicant has adequately described the methods to be used to correlate the results from the reactor internals vibration test with the analytical results from the dynamic analyses of the reactor internals under steady-state and operational flow transient conditions, in conformance with regulatory requirements.

3.9.3 ASME Code Class 1, 2, and 3 Components, Component Supports, and Core Support Structures

The staff’s review under SRP Section 3.9.3 concerns the structural integrity and functional capability of pressure-retaining components, their supports, and CS structures that are designed in accordance with ASME Code, Section III. The staff reviewed loading combinations and their respective stress limits, the design and installation of pressure-relief devices, and the design and structural integrity of ASME Code, Section III, Class 1, 2, and 3 components and component supports.

ASME Code, Section III, requires the preparation of a design specification for ASME Class 1, 2, and 3 components. The design specifications for ASME Code Class 1, 2, and 3 components, supports, and appurtenances are prepared under administrative procedures that meet the ASME Code rules. The specifications conform with and are certified to the requirements of the applicable subsection of ASME Code, Section III. The ASME Code also requires the preparation of design reports for Class 1, 2, and 3 components that demonstrate that the as-built components satisfy the requirements of the respective ASME design specification for each component and the applicable section of the ASME Code. The license applicant, or the applicant's authorized agent, completes these design specifications and design reports in accordance with the responsibilities outlined under ASME Code, Section III. The ASME Code design reports include the record of as-built reconciliations (for example, the evaluations of changes to piping support locations, the preoperational testing and results, and reported construction deviation resolutions) as well as the small-bore piping analysis.

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

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, "Loading Combinations, Design Transients and Stress Limits," and Table 3.9-1 discuss the design and service loading combinations specified for 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 and/or design reports 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 or 3 or QG D.

For any non-Class 1 components that are subjected to cyclic loadings of a magnitude and/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 4, Section 3.9.9-2, which requires that the COL holder shall 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, “Plant Conditions,” 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 condition(s) 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	$10^{-4} > P > 10^{-6}$

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, “Reactor Pressure Vessel Assembly,” 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, discuss 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 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 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 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 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, “Valve Operability Assurance,” the applicant discussed operability assurance of active valves, classified as ASME Code valves, including the actuator that is a part of the valve. The applicant stated that active mechanical (with or without electrical operation) equipment designed to perform a mechanical motion for its safety-related function is classified as seismic Category I. Equipment with faulted condition functional requirements includes active pumps and valves in fluid systems such as the residual heat removal (RHR) system, emergency core cooling system (ECCS), and MS systems. The applicant stated that SRVs are qualified by testing and analysis and by satisfying the stress and deformation criteria at the critical locations within the valves. The valve bodies are designed, analyzed, and tested in accordance with the ASME Code, Section III, Class 1 requirements. The valves are designed to perform their mechanical motion in conjunction with a dynamic (SSE and other RBV) load event. Major active valves are modeled mathematically in the piping system analysis. The loads, amplified accelerations, and resonance frequencies of the valves are determined from the overall piping analysis. The piping supports (e.g., snubbers, rigid restraints) are located and designed to limit amplified accelerations of and piping loads in the valves to the design limits.

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 GEH 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 upon 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, “Design and Installation of Pressure Relief Devices,” 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 SER 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 dated November 22, 2006, 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, dated December 11, 2006, 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 is 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 dated November 22, 2006, 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 is closed.

The staff reviewed the load definitions, loading combinations, and responses to the staff's RAIs. The staff finds that they are consistent with the guidance in SRP Section 3.9.3 and are therefore acceptable.

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 indicate the application of these probabilities to the plant events listed. In its response dated November 22, 2006, 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 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 staff concurs with the response to this RAI. Therefore, RAI 3.9-99 is 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 dated April 18, 2007, 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 staff finds the response to this RAI acceptable. Therefore, RAI 3.9-100 is 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 S_m. In its response dated November 22, 2006, 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 S_m, 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 concurs with the applicant's response. Therefore, RAI 3.9-101 is 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 SER 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 dated November 22, 2006, the applicant stated that the pressure boundary components and related component supports listed in DCD Tier 2, Table 3.2-1, were compared with 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 in accordance with the requirements stated in SRP Section 3.9.3 for ASME Code, Section III, Class 1, 2, and 3 components.

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 evaluation of 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, "Major Active Valves," and Section 3.9.3.5.2, "Other Active Valves."

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 dated December 15, 2006, 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. Therefore, RAI 3.9-103 is closed.

In RAI 3.9-104, the staff asked the applicant to describe Section 4.4 of the GEH Environmental Qualification Program and to indicate whether the NRC has reviewed and approved this program. In its response dated November 22, 2006, the applicant stated that this information appears in LTR NEDE-24326-1-P, "General Electric Environmental Qualification Program," Proprietary Document, January 1993, which was approved by the NRC and is referenced in Section 3.11.4 of NUREG-1503. The staff finds this response acceptable. Therefore, RAI 3.9-104 is 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 for faulted conditions. In its response dated November 22, 2006, the applicant verified that the stresses in active valve bodies conform to the requirements in SRP Section 3.10, Revision 3, issued April 1996, as identified in DCD Tier 2, Table 1.9-20. 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 is closed.

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 dated January 15, 2007, 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.

The applicant stated that all of the preceding requirements that demonstrate the functionality of active valves are documented as a part of the certified stress report for the assembly. The format of the documentation clearly shows that each consideration has been properly evaluated, and 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 dated January 15, 2007, 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 with 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. Therefore, RAI 3.9-107 is closed.

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 in accordance with the provisions stated in SRP Section 3.9.3.II.2. In its response dated November 11, 2006, 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 finds this response acceptable. Therefore, RAI 3.9-108 is 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 provide a reference to the section in DCD Tier 2 that discusses this issue. In its response dated December 15, 2006, 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 staff's RAI regarding testing requirements in the referenced TMI action item. Therefore, RAI 3.9-109 is 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 dated November 22, 2006, 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 will be in full compliance 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 is 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 3.9.3.1 of this SER. 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 applicant stated that expansion anchor bolts shall not be used for any safety-related system components. The design and installation of all anchor bolts will be performed in accordance with Appendix B to ACI 349-01, “Anchoring to Concrete,” subject to the conditions and limitations specified in RG 1.199, 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, “Piping Supports,” 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 allowables 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 in accordance with ASME Code, Section III, Subsection NF and Appendix F. The applicant stated that supports are generally designed either by load rating method in accordance with Subsection NF-3280 or by stress limits in accordance with Subsection NF-3143. The critical buckling loads for the Class 1 piping supports subjected to faulted loads are determined using the methods discussed in Appendix F to the ASME Code. To avoid buckling in the piping supports, the allowable loads are limited to two-thirds of the determined critical buckling loads. The staff finds that piping supports are designed to quality standards that meet the intent of SRP Section 3.9.3 and, therefore, are acceptable.

DCD Tier 2, Section 3.9.3.7, mentioned seismic Category II “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, in 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. Therefore, RAI 3.9-111 is closed.

DCD Tier 2, Section 3.9.3.7.1, states that the building structure component supports designed in accordance with ANSI/AISC N690, ”Nuclear Facilities-Steel Safety-Related Structures for Design, Fabrication and Erection,” or the AISC Specification for the Design, Fabrication, and Erection of Structural Steel 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.

By letter dated February 16, 2007, 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 for 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 requirement of SRP Sections 3.8.3 and 3.8.4 and is acceptable. Therefore, RAI 3.9-112 is 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, and 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, considering the types of supports, their characteristics (such as stiffness), and the components or structures to which they are attached.

In its response to RAI 3.12-37 by letter dated December 11, 2006, 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 millimeters (mm) (1/16 in.) for erection and operation loading is used for the design of piping supports, based on Welding Research Council (WRC)-353, paragraph 2.3.2. For the consideration of loads from SSE and in the cases involving springs, the deflection limit is increased to 3.2 mm (1/8 in.). By letter dated February 16, 2007, the applicant further stated that the revision of Section 3.9.3.7 (Rev. 3) clarifies the design of the pipe support structure with respect to design limits. The applicant clarified that the design/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. Where 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.II.3 and Appendix A to SRP Section 3.9.3, and 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 into the design specification. The staff concluded that the applicant's response adequately addresses the concerns identified for component support design, including service level stress limits, deflection limits, and operability consideration. Therefore, RAI 3.9-113 is closed.

The applicant stated that the friction loads caused by unrestricted motion of the piping because of 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 friction loads are not considered during seismic or dynamic loading evaluation of pipe support structures. The staff finds this to be acceptable.

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 SER provides the staff's evaluation of small-bore piping using handbook methodology.

The applicant stated that the load caused by dead weight is the operating load on spring hangers 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.

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 finds 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 they 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 their 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 synchronism of activation level or release rate will be evaluated, if deemed necessary, in the piping analysis model 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. Pending response from GEH, **RAI 3.9-114 is being tracked as an open item.**

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 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, and it 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. By letter dated February 16, 2007, 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 adequate. Therefore, RAI 3.9-115 is closed.

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. It should be noted that although classified as a standard support, snubbers require special consideration because of their unique function. In RAI 3.9-116, the staff requested that the applicant provide a detailed discussion on the specific design rules of Subsection NF that are 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.

By letter dated February 16, 2007, 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/test results, which would not typically require a separate independent verification by the COL applicant. Based on these responses, the staff considers the applicant to have adequately resolved the RAI. Therefore, RAI 3.9-116 is 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, and 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 the applicant to (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. By letter dated February 16, 2007, 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 addresse all questions in RAI 3.9-117. The staff, therefore, requested that the applicant supplement its response to the RAI on the snubber production and qualification test programs. For a more specific delineation, the staff asked the applicant to address, for mechanical and hydraulic snubbers of all makes and sizes, (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, and (8) verification that the production operability tests for the large-bore hydraulic snubbers (greater than 50 kips load rating) include (i) a full Service Level D load test to verify sufficient load capacity, (ii) testing at the full load capacity to verify proper bleed with the control valve closed, (iii) testing to verify that the control valve closes within the specified velocity range, and (iv) testing to demonstrate that breakaway and drag forces are within the acceptable design limits. Pending response from the applicant, **RAI 3.9-117 is being tracked as an open item.**

In DCD Tier 2, Section 3.9.3.7.1(3)c(ii), 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 the applicant to 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 is being tracked as an open item,** pending resolution of RAI 3.9-117.

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 addition, the staff asked the applicant to include this issue in DCD Tier 2, Section 3.9.9, as part of the COL action items.

By letter dated February 16, 2007, 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 furnish 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. The applicant also revised Section 3.9.3.7.1(3)e (Rev. 3) to state that the preservice examination plan of all snubbers covered by the plant-specific technical specifications is prepared in accordance with the requirements of the ASME Operation and Maintenance (OM) Code, Subsection ISTD. The inservice examination and testing plan of all snubbers covered by the plant-specific technical specifications are also prepared in accordance with the requirements of the ASME OM Code, Subsection ISTD. Snubber maintenance, repairs, replacements, and modifications are performed in accordance with the requirements of the ASME OM Code, Subsection ISTD. The ISI and testing plan, which shall be provided by the COL applicant referencing the ESBWR design, 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 found the applicant's responses to be acceptable. 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 is 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 the applicant to clarify that during initial system heatup and cooldown, snubber thermal movements will be verified according to an acceptable code requirement. By letter dated November 30, 2006, the applicant stated that it will revise DCD Tier 2, Section 3.9.3.7.1(3)e, to make a specific reference to 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 has revised the pertinent portion of Section 3.9.3.7.1(3)e to incorporate the changes as stated. Therefore, RAI 3.9-120 is 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. By letter dated November 30, 2006, 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 the specification for preservice examination and testing of snubbers in accordance with the ASME OM Code will be prepared 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, and it has verified that the applicant revised the DCD as required. Therefore, RAI 3.9-121 is 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 action items 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.

By letter dated November 30, 2006, 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, “Preservice and Inservice Inspection and Testing of Class 2 and 3 Components and Piping,” are in accordance with ASME Code, Section XI, and further ensure snubber operability during plant operation. The staff has verified that DCD Tier 2, Revision 3, Section 3.9.9.3, “Inservice Testing

Programs," includes the above-stated snubber IST and inspection program as a COL information item. Items (1) and (2) of RAI 3.9-122 are, 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 also for 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/or performing the required testing and ISIs of components. The staff reviewed DCD Tier 2, Revision 3, Section 3.8.3.7, and confirmed that the applicant has incorporated the above provisions as stated. Therefore, RAI 3.9-122 is 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 following eight snubber information items as required by SRP Section 3.9.3.II.3.B(3), issued March 2007, and confirm that they are included as part of COL action items in DCD Tier 2, Section 3.9.9:

(1) the general functional requirement
(2) operating environment
(3) applicable codes and standards
(4) materials of construction and standards for hydraulic fluids and lubricants
(5) environmental, structural, and performance design verification tests
(6) production unit functional verification tests
(7) packaging, shipping, handling, and storage requirements
(8) description of provisions for attachments and installation

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. By letter dated February 16, 2007, the applicant stated that in DCD Tier 2, Section 3.9.3.7.1(3), it will add 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 has reviewed DCD Tier 2, Revision 3, Section 3.9.3.7.1(3), and verified that the applicant has 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, Revision 4, Section 3.9.9, the applicant has included COL Information Item 3.9.9-4-A to commit to provide a milestone for implementation of the snubber inspection and test program, as identified in Section 3.9.3.7.1(3)e, including the 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 is closed.

In RAI 3.9-124, the staff requested that the FSAR should identify and tabulate all safety-related components that use snubbers in their support systems, consistent with the requirements of SRP Section 3.9.6.II.4.c. The tabulation should include the (1) identification of the systems and components in those systems that use snubbers, (2) the number of snubbers used in each system and on components in that system, (3) the type(s) of snubber (hydraulic or mechanical) and the corresponding supplier, (4) specification whether the snubber was constructed in accordance with ASME Code, Section III, Subsection NF, (5) statement whether the snubber is used as a shock, vibration, or dual-purpose snubber, and (6) for snubbers identified as either dual-purpose or vibration-arrestor type, an indication of whether both snubber and component were evaluated for fatigue strength, in accordance with Appendix A to SRP Section 3.9.3. DCD Tier 2, Section 3.9.9, does not currently include the above items. The staff requested that the applicant provide the rationale for excluding these items from the listing of COL action items.

By letter dated February 16, 2007, the applicant stated that it will revise DCD Tier 2, Section 3.9.3.7.1(3)c, to add 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 type(s), hydraulic or mechanical, and name of supplier
- constructed to ASME Code, Section III, Subsection NF, or other
- snubber used as shock, vibration, or dual purpose
- for those snubbers identified as dual-purpose or vibration-arrestor type, an indication whether both snubber and component were evaluated for fatigue strength

The staff has reviewed DCD Tier 2, Revision 3, Section 3.9.3.7.1(3), and verified that the applicant has added this information as subparagraph (iv) of DCD Tier 2, Section 3.9.3.7.1(3)c. In addition, DCD Tier 2, Revision 4, has identified COL Information Item 3.9.9-4-A to include a data table that would cover the above tabular snubber information. Therefore, RAI 3.9-124 is closed.

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 and/or anchor motions 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, dead weight, 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, dead weight, 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 three pieces of 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

By letter dated February 16, 2007, 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 has 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 reviewed DCD Tier 2, Revision 3, Section 3.9.3.7.1, including Section 3.9.3.7.1(5), and has verified that the applicant has made appropriate changes to reflect the above responses for the frame supports. Therefore, and RAI 3.9-125 is closed.

To minimize the use and application of snubbers, special engineered pipe supports may be used in some instances where either struts or frame-type supports cannot 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 has modified Section 3.9.3.7.1(6) to reflect these changes. This is acceptable to the staff.

In DCD Tier 2, Section 3.9.3.7.2, the applicant stated that the ESBWR RPV sliding supports are as 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 is acceptable to the staff.

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. This is acceptable to the staff.

In DCD Tier 2, Section 3.9.3.7.4, the applicant stated that floor-mounted major equipment, such as the PCC and 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. This is acceptable to the staff.

In DCD Tier 2, Section 3.9.3.7.5, the applicant stated that other ASME Code, Section III, component supports and their attachments are designed in accordance with ASME Code, Subsection NF, up to the interface with the building structure. The building structure component supports are designed in accordance with the AISC Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings. The loading combinations for the various operating conditions correspond to those used to design the supported components. DCD Tier 2, Section 3.9.3.1, discusses the component loading combinations, and DCD Tier 2, Section 3.9.3.5, discusses active component supports. The stress limits and the buckling stress criteria are in accordance with ASME Code, Section III, Subsection NF and Appendix F.

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.

By letter dated February 16, 2007, 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 is closed.

The staff will further review the responses to the remaining open items as identified above to determine compliance with the applicable requirements of 10 CFR 50.55a and the guidelines of SRP Section 3.9.3.

3.9.3.4 Conclusions

Based on its review of the information provided in DCD Tier 2, up to Revision 3, as well as the additional information provided by the applicant, up to May 14, 2007, the staff concludes that, because of pending resolution of the remaining open items, the staff will defer its final conclusion about the ESBWR design to meet the requirements of 10 CFR Part 50, specifically 10 CFR 50.55a and GDC 1, 2, 4, 14, and 15.

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 and 10 CFR 50.55a require that the CRD system be designed to quality standards commensurate with the importance of the safety functions to be performed.

- GDC 2 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 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 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 o f 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, “Control Rod Drive System,” 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 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 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 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.

3.9.4.3 Staff Evaluation

The staff's review under SRP Section 3.9.4 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 to the acceptance criteria in SRP Section 3.9.4.

Section 3.9.3 of this SER 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 using 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.

Sections 3.9.4 and 4.6.1 of DCD Tier 2 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, "System Quality Group Classification," 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 of 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 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.

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 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 SER 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 the additional supporting technical information provided by the applicant, and for the reasons set forth 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 in Appendix A to 10 CFR Part 50, as related to designing 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 related to designing reactor internals to withstand the effects of earthquakes without loss of capability to perform their safety functions

- GDC 4, as related 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 LOCAs

- GDC 10, “Reactor Design,” as related to designing reactor internals with appropriate margin to ensure 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 related 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 50.34, “Contents of Construction Permits and Operating License Applications; Technical Information,” as related to specifying the margin of safety associated with normal operation and anticipated operating transients

- RG 1.20, Revision 2, “Comprehensive Vibration Assessment Program for Reactor Internals During Preoperational and Initial Startup Testing,” issued May 1976

With regard to GDC 4, the design basis excludes dynamic effects associated with postulated pipe ruptures if analyses demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping.

3.9.5.2 Summary of Technical Information

ESBWR DCD Tier 2, Revision 3, Section 3.9.5, addresses the RPV internals as discussed in SRP Section 3.9.5, draft Revision 3, issued April 1996. RPV internals consist of all structures and mechanical components inside the reactor vessel. 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, postulated accidents including LOCAs, and from events and conditions outside the nuclear power unit.

3.9.5.2.1 Identification and Discussion of Structural and Functional Integrity of the Major RPV Internals, including Core Support Structures

RPV Internals. ESBWR 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 header
- sparger and piping
- in-core guide tubes 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

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 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 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 ledge in the lower region of the shroud. The top guide consists of a circular plate with square openings for fuel. Each opening provides a lateral support and guidance for four, 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 orifice 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 long cylinder, 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 cross-flow 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 expansion growth 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 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 noncondensible gases from the reactor head to the steamlines during startup and operation. The in-core guide tubes 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. A latticework of clamps, tie bars, and spacers provides lateral support and rigidity to the guide tubes.

The surveillance sample holders are welded baskets hanging from the brackets attached to the inside of the reactor vessel wall and extend to the mid-height 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.

<u>Flow Induced Vibrations:</u> Appendix 3L to DCD Tier 2 outlines a program for evaluating and ensuring the integrity of reactor internal components. This program is in progress and includes an evaluation phase, a startup test phase, and an inspection phase along the lines of RG 1.20 and is intended to show that no FIV problems exist. In the first part of the evaluation, components are identified 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. In the second part of the evaluation, finite element analyses and correlation functions based on prior data will be established to determine stress levels for those components deemed to require additional work to demonstrate their adequacy and that fatigue stress limits (68.95 MPa) are not exceeded. The analyses will include the determination of vibration frequencies and mode shapes, as necessary. GEH will present the results of these evaluations in a future report. 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, further analysis has begun on the chimney partition and the steam dryer because the chimney partition is a component that has never been subjected to preoperational or initial startup testing, as required by RG 1.20, and the steam dryer design will be patterned after the replacement steam dryer design being developed for BWR operating plants. Once the BWR operating plant program is completed, the design and evaluation of the ESBWR steam dryer will be completed.

GEH report, NEDE-33259P, " ESBWR Reactor Internals Flow Induced Vibration Program, " January 2006 further evaluates internal components, other than the chimney partition and the 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 the 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, further evaluation is not considered necessary for the remaining internal components.

3.9.5.2.2 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 ASME Code, 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, Subsection NG-3000, and must be constructed so as not to adversely affect the integrity of the CS structures (Subsection 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

The report 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 may be tested during power ascension in the ESBWR prototype. The steam dryer was chosen for testing based on recent industry experience, since steam dryers in operating BWR plants have cracked and failed 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 that their stresses are bounded by fatigue limits (68.95 MPa). Section 3.9.5.2.1 of this SER 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 GEH Report, NEDE-33259P

The stress, deformation, and fatigue limit criteria of safety-related components appear in a table, from which appropriate criteria are selected for a specific component and loading condition. GEH 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, Subsection NG-3000. 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 Subsection NG-1122). 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 SER, Appendix 3L to DCD Tier 2 and GEH report, NEDE-33259P, describe a method of 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. The criterion used in GEH report, 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. Because the ABWR and ESBWR designs are similar, GEH considers the ESBWR a Non-Prototype Category II design in accordance with RG 1.20.

3.9.5.2.5 Loading Conditions

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—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 RBV caused by suppression pool dynamics)

(2) earthquake—subjects the CS structures and reactor internals to significant forces as a result of ground motion and consequent RBVs

(3) SRV or DPV discharge—RBVs caused by suppression pool dynamics and structural feedback

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.

GEH 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). In order to determine the maximum pressure differences across the reactor internals, a two sigma statistical uncertainty study was performed to determine the upper bound pressure difference adders that are applied to the normal pressure differences.

In DCD Tier 2, Section 3.7, GEH described a dynamic analysis method used to determine the loads resulting from earthquake and other building vibrations acting on the reactor vessel internals.

<u>Flow Induced Vibrations:</u> For FIV, the normal operating pressure differential drives the coolant flow that impinges on and loads the reactor internal components in different ways. Flow velocities and vortex shedding frequencies appear in Table 3 of GE report, NEDE-33259P, for ESBWR and ABWR components deemed similar.

According to Appendix 3L to DCD Tier 2, two-phase hydraulic flow testing simulating expected reactor flow conditions has been completed 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 will be determined by performing a SMT of the ESBWR design at the GEH SMT facility. Additional elements of the load definition process are the determination of the acoustic natural frequencies and mode shapes of the reactor steam dome by acoustic finite element analysis (AFEM), and the use of a load interpolation algorithm (LIA) to extrapolate the limited measured pressures to the fine mesh of the structural FEM. GEH asserted that the BWR 3 SMT was benchmarked against plant data to confirm the capability of the GEH SMT methodology to predict the steam dryer acoustic load definition.

GEH stated that future reports will present specific loading definitions for the other internal components that have been identified for further evaluation and instrumentation during startup testing.

3.9.5.2.6 Design Bases

DCD Tier 2, Section 3.9.5.4, states that the reactor internals, including CS structures, shall 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.

GEH stated that the design loading categories for the CS structures and safety class internals stress limits are consistent with ASME Code, Subsection NG.

The stress and fatigue limits for the CS structures are in accordance with ASME Code, Subsection NG.

GEH provided the stress, deformation, and fatigue criteria for safety-related reactor internals (except CS structures) that 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 service conditions (i.e., normal, upset, emergency, and faulted).

Components inside the RPV, such as control rods, are examined to determine if adequate clearance exists during emergency and faulted conditions.

GEH 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, Subsection NG-3000, and are constructed so as not to adversely affect the integrity of the CS structures (ASME Code, Subsection NG-1122).

Flow Induced Vibrations: Appendix 3L to DCD Tier 2 states that the primary design basis is to maintain the dynamic (fatigue) stresses below the limit (68.95 MPa). As discussed in Section 3.9.5.2.1 of this SER, dynamic stress analysis using FEM will be performed for all the reactor internal components that will be instrumented during startup testing. Future reports will include these results, except the results for the chimney partition, which appear in Appendix 3L to DCD Tier 2.

GEH 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), so an equivalent static analysis was performed to show that the fatigue stress limits bounded the calculated stress.

GEH stated that the structural evaluation of the steam dryer is presented for the design certification phase.

3.9.5.2.7 Combined License Information

In DCD Tier 2, Section 3.9.9.1, GEH identified the information regarding the design of reactor vessel internals that the COL applicants will provide.

3.9.5.2.8 Basis for Considering the ESBWR as Non-Prototype Reactor Internals

Section 3.9.2.4 of this SER summarizes the basis for considering the ESBWR as non-prototype reactor internals. The applicant provided the relevant information in ESBWR DCD Tier 2, Sections 3.9.2.4 and 3.9.5; Appendix 3L to DCD Tier 2; and GEH report NEDE-33259P.

3.9.5.3 Staff Evaluation

3.9.5.3.1 Identification and Discussion of the Structural and Functional Integrity of the Major RPV Internals, Including Core Support Structures

As described in Section 3.9.5.2.1 of this SER, GEH has identified the major safety-related reactor internal structures, including CS structures, for the ESBWR. In addition, GEH has identified the non-safety-related internal structures. DCD Tier 2, Section 3.9.5, summarizes the functions of the internals. GEH has adequately discussed the physical arrangement of these components inside the vessel, which provides axial support and lateral retention to 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 thermal and other effects.

The method described in Appendix 3L to DCD Tier 2 and GEH report, NEDE-33259P, for establishing component integrity for FIV under normal operating conditions was used for about half of the internal components to show that their fatigue stresses are bounded by the limit of 68.95 MPa. 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, GEH indicated that many of the reactor internal components require additional analysis to demonstrate their design adequacy. Furthermore, FIV evaluation analyses are required for all 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 in-core monitor guide tubes and housings, the chimney partition, and the steam dryer.

In its response dated November 22, 2006, the applicant stated that it will submit additional analysis work for most of the components identified in the RAI in its revision of NEDE-33259P. This report was originally scheduled for release to the NRC in March 2007. The applicant has decided that no analyses are necessary of the CRGTs and CRD housings, and in-core monitor guide tubes and housings. The staff considers RAI 3.9-132 unresolved because the applicant has not yet submitted the additional analyses. The applicant should also explain why it would not perform any analyses of the CRGTs and CRD housings, and the in-core monitor guide tubes and housings. **RAI 3.9.-132 is being tracked as an open item.**

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 are based on ASME Code, Division 1, Subsection NG. Section 3.9.5.3.6 of this SER provides further evaluation of 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 acceptable for assessing the adequacy of the chimney assembly and steam dryer because the chimney is a new component to the ESBWR design and the steam dryer has experienced cracking and failure in operating reactors over the past few years. The staff also finds the use of a fatigue limit of 68.5 MPa acceptable because it satisfies the ASME Code requirement. However, the staff has several concerns, discussed below and identified as open items and COL action items, regarding how the applicant is attempting to satisfy these criteria.

The original submittal by GEH Letter MFN 05-116, DCD Appendix 3L, Reactor Internal Flow Induced Vibration, 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 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 data for all equipment listed in Table 3L-4 will be acquired during testing.

The applicant responded to RAI 3.9-133 in a letter dated April 2, 2007 (MFN 07-194). In this response, the applicant committed to instrumenting the prototype ESBWR steam dryer in accordance with DCD Tier 2, Section 3.9.2.4, and Section 3L.4.6 of Appendix 3L to DCD Tier 2; and the prototype ESBWR chimney partitions in accordance with Section 3L.5 of Appendix 3L to DCD Tier 2. 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 has also clarified that vibration data for all equipment listed in DCD Tier 2, Table 3L.4, will be acquired 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 applicant's response acceptable but requested that the applicant include its clarifications in a revision to the DCD. **RAI 3.9-133 S01 is being tracked as an open item.**

The applicant stated that most recent BWR steam dryer fatigue failures resulted from "strong narrow-band Pa" 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 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.

(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 by letter dated May 16, 2007 (MFN 07-268), 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. 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, GEH revised DCD Tier 2, Sections 3L.4.4 and 3L.5.4, and Tables 3L-5 and 3L-6, in Revision 3.

Since GEH 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, RAI 3.9-134(b) and RAI 3.9-134(c) are considered closed. Since the ESBWR SRV standpipe and piping layout designs are currently under evaluation as indicated in the GEH response, RAI 3.9-134(a) will remain open until the designs are completed, the resonant conditions are characterized, and the results are communicated to the staff before prestartup or startup testing. **RAI 3.9-134(a) is being tracked as an open item.**

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. The applicant responded to RAI 3.9-135 in a letter dated April 2, 2007 (MFN 07-194). The applicant referred to the following additional GEH documents that were to be submitted later:

- Reference 3L-5, “Steam Dryer—Acoustic Load Definition,” NEDC-33312P, Class III (Proprietary)

- Reference 3L-6, “Steam Dryer—Structural Evaluation,” NEDC-33313P, Class III (Proprietary)

- Reference 3L-7, “Steam Dryer—Instrumentation and Power Ascension Monitoring,” NEDC-33314P, Class III (Proprietary)

In RAI 3.9-135 S01, the staff asked the applicant to submit these documents so that its response to RAI 3.9-135 can be evaluated.

References 3L-5 and 3L-6 were submitted on November 16, 2007, and November 15, 2007, respectively. Pending review of these reports, **RAI 3.9-135 SO1 is being tracked as an open item.**

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 Pa acting on the steam dryer, and it uses an LIA to compute a fine discretization of pressure/time histories over the steam dryer surfaces based on measurements made in the GEH SMT facility. The LIA includes AFEMs as part of its load estimating process.

In RAI 3.9-136, the staff asked the applicant to provide the following:

(a) The staff asked the applicant to submit the LIA method for review (including the AFEM procedures), along with 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 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. In accordance with SRP Section 3.9.2, the staff asked the applicant to submit this benchmarking information, along with an assessment of the SMT uncertainties and bias errors. The applicant should confirm 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.

The applicant responded to RAI 3.9-136 in a letter dated April 2, 2007 (MFN 07-194). In its response, the applicant referred to a future GEH report—Reference 3L-5, “Steam Dryer—Acoustic Load Definition,” NEDC-33312P, Class III (Proprietary)—to address parts (a) and (b) of this RAI. Therefore, the staff is treating RAIs 3.9-136(a) and (b) as open items. In RAI 3.9-136 S01, the staff asked the applicant to submit this document so that its response to RAI 3.9-136 can be evaluated. The applicant submitted the subject report on November 16, 2007. Pending review of this report, **RAI 3.0-136 S01 is being tracked as an open item.**

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 provide the following:

(a) The staff asked the applicant to 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) In accordance with SRP Section 3.9.2, the staff asked the applicant to 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.

The applicant responded to RAI 3.9-137 in a letter dated April 2, 2007 (MFN 07-194). The applicant attached a copy of DCD Tier 2, Revision 3, Section 3L.4.6, that 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. Therefore, RAI 3.9-137 is closed.

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) The applicant should state how many accelerometers will be mounted to the steam dryer support ring and in what direction(s) will they be oriented.

(b) The applicant should indicate how many accelerometers will be mounted to the steam dryer skirt, and how many in circumferential positions.

(c) The applicant should 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) The applicant should state how many strain gauges will be mounted to the shroud, in what orientation(s), and in how many circumferential positions.

(e) The applicant should clarify the meaning of "steam dryer FIV instrument post" for the pressure transducer to be mounted in the vessel dome region.

The applicant responded to RAI 3.9-138 in a letter dated April 2, 2007 (MFN 07-194). In its response, the applicant addressed parts (d) and (e) of the RAI. In response to part (d), two strain gauges will be mounted on the shroud surfaces near the highest stress points associated with the lower structural modes. Displacement sensors mounted to the top guide will augment the strain gauges. In response to part (e), 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. In its response to parts (a), (b), and (c) of the RAI, the applicant refers to a GEH report—Reference 3L-7, "Steam Dryer—Instrumentation and Power Ascension Monitoring," NEDC-33314P, Class III (Proprietary)—which is not yet available for review. 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 to date is not sufficient to fully address the RAI. **RAI 3.9-138, parts (a)–(c), is being tracked as an open item.**

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) The applicant should explain the determination of those limits for each type of instrumentation, particularly for the pressure transducers.

(b) In accordance with SRP Section 3.9.2, the applicant should 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 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 conservatively low acceptance criteria for fatigue failure (10,000 psi) to ensure that the steam dryer is not experiencing high alternating stresses that might cause fatigue failures. Therefore, the staff finds these acceptance criteria for the steam dryer adequate. RAI 3.9-139(a) is closed.

In its response to RAI 3.9-139(b), the applicant stated that if the limit curves are exceeded, the load definition will be revised based on the measured loading, stress analysis will be repeated using this loading, and the revised limit curves will be established. If necessary, a detailed stress analysis of high-stress region of the dryer will be performed. If the stresses are still not acceptable, further power ascension will be delayed until the affected dryer components are modified and installed. The response to RAI 3.9-139(b) is acceptable because it ensures the dryer's structural integrity during power ascension. RAI 3.9-139 is closed.

Section 3L.3 of Appendix 3L to DCD Tier 2 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 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 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) The applicant should provide the 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. The applicant should also provide the magnitude and frequency content of the associated loads. Finally, the applicant should 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) The applicant should 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) The applicant should 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) by letter dated November 22, 2006, the applicant stated that the inlet flow conditions that were used in the test appear in a table and bound the actual flow conditions. The maximum load was measured in the 1/6-scale test at 7.5 kilopascals (KPa) (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. This test setup effectively modeled this interface and simulates the pressure conditions that occur in the mixing chamber. The staff considers 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 uniformly on the plates and used the SRSS method for the sum of Pa 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 °C) and 56.6 Hz (20 °C) 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, and no damping effects were considered. The staff agrees with the applicant's conclusions.

In its response to RAI 3.9-140(c), the applicant stated that the FEM analysis modeled the 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 outmost ends of the partitions to provide rigidity. The staff considers the applicant's response to RAI 3.9-140(c) acceptable.

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 GEH Report NEDE-33259P

Because of open RAIs that need resolution in Sections 3.9.5.3.6, 3.9.2.3, 3.9.2.4, and 3.9.2.6 of this SER, the staff is unable to finalize its conclusion regarding the adequacy of RPV internal structures other than steam dryer and chimney assemblies. However, the staff recognizes that the criteria used by the applicant for assessing the adequacy of RPV internal structures other than 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.

In GEH report NEDE-33259P, the applicant described testing of the prototype ABWR plant in Japan and provided a table of selected FIV parameters measured in the ABWR and the estimates for the ESBWR. However, the applicant did not include steam dryer data in the table. To justify the applicant's classification of the ESBWR dryer as a Non-Prototype Category II (in accordance with RG 1.20), 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 Pa 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 ESBWR steam dryers.

The applicant responded to RAI 3.9-141 in a letter dated April 2, 2007 (MFN 07-194). The response to this RAI includes a revision of Section 3L.4.1 and Table 3L-1 of Appendix 3L to DCD Tier 2. The prototype for the ESBWR dryer is the replacement dryer installed in several existing BWR 3 plants. The replacement dryer is considerably stiffer and stronger than the original dryers, since it was designed to withstand abnormally high fluctuating loads caused by flow-induced resonance tones (valve "singing") in SRVs in reactor MSLs. The applicant stated that SRVs in the ESBWR have been designed so that valve singing will not occur, reducing dryer loads considerably. Table 3L-1 shows that the differences between the prototype and ESBWR dryers are minor. In addition, since the applicant has already committed to extensive testing of the first ESBWR dryer, the staff finds its answer to this RAI acceptable. Therefore, RAI 3.9-141 is closed.

In RAI 3.9-142, the staff asked the applicant to explain the fluctuating Pa 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 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 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 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 IC and GDSC systems 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 vane passing frequencies 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 steam lines of BWR plants and have caused pressure waves and vibrations that have damaged plant equipment, including steam dryers and SRVs. In supplemental 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 vane passing frequencies. 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.

The applicant responded to RAI 3.9-142 S01 in a letter dated August 7, 2007. The applicant stated that :

> 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 lowest natural frequencies of the reactor components of interest near the vessel nozzle are:
>
> | Name of Component | Lowest Natural Frequency (Hz.) |
> |---|---|
> | Standby Liquid Control Piping | [[ ]] |
> | Shroud/Chimney/Separator | [[ ]] |
>
> 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 finds this explanation acceptable. Therefore, RAI 3.9-142 S01 is 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, and 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 in a letter dated June 6, 2007 (MFN 07-308):

> 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 GE'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 is very unlikely. The existence of weld cracks in some older plants were 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 GEH reached the above conclusion. Therefore, in RAI 3.9-143 S01, the staff asked GEH to provide the following information to justify its conclusions:

(1) the maximum transversal movement of the CRD housing and the CRGT (a) during normal operation and (b) under the condition with weld failure

(2) the 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) the 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) the results of the calculations for vortex shedding frequencies of the system configuration identified in (2) above, and the resulting maximum stress in the CRD

Pending response from GEH, **RAI 3.9-143 S01 is being tracked as an open item.**

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-term 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

The applicant responded to RAI 3.9-144 in a letter dated June 11, 2007 (MFN 07-325). In its response regarding RAI 3.9-144A(a–d), the applicant stated the following:

> The steam dryer instrumentation and power ascension plan is described in Subsection 3L.4.6 of DCD, Tier 2, Appendix 3L. Details regarding the confirmation of the ESBWR steam dryer load definition and stress analysis during initial power ascension will be provided in a future reference report: General Electric Company, “Steam Dryer—Instrumentation and Power Ascension Monitoring,” NEDC-33314P, Class III (Proprietary), and NEDO-33314, Class I (Non-Proprietary). See RAI 3.9-58 Response.

Since the applicant has not yet submitted the new references NEDC-33314P and NEDO-33314, **RAI 3.9-144 A(a–d) S01 is being tracked as an open item.**

Regarding RAI 3.9-144.A(e), GEH 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, GEH indicated that instrumentation will be installed on two MSLs, and 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 GEH 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 GEH to discuss its plans to provide sufficient instrumentation and locations to demonstrate that potential adverse flow effects, such as 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. **RAI 3.9-144A(e) is being tracked as an open item.**

In its response regarding 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 is 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) is closed.

In its response to RAI 3.9-144.B(b–h) provided in MFN 07-325 dated June 11, 2007, GEH 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 current version of the Appendix 3L to DCD Tier 2 does not provide sufficient detail for the staff to prepare a safety evaluation on the ESBWR design certification regarding the consideration of potential adverse flow effects as part of the power ascension plan and startup test procedure. Therefore, in RAI 3.9-144B(b–h) S01, the staff asked GEH to revise Appendix 3L to DCD Tier 2 to include the information provided in the response to RAI 3.9-144. **RAI 3.9-144B(b–h) S01 is being tracked as an open item.**

3.9.5.3.5 Loading Conditions

The staff finds that 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 SER) are acceptable 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 SER, 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 SER, the applicant has identified loading conditions for reactor internals. GEH stated that it has 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.

The applicant responded to RAI 3.9-145 in a letter dated March 26, 2007 (MFN 07-177). In its response, the applicant stated that GEH had previously responded to a similar RAI 4.4-20 in a letter (MFN 06-498) from David H. Hinds of GEH to the NRC, dated December 7, 2006. Section 4.4 of this SER contains the staff's evaluation of the GEH 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 (kPaD) 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.

The applicant responded to RAI 3.9-146 in a letter dated April 2, 2007 (MFN 07-194). 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 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 GEH SMTs. Pending review of the report in response to RAI 3.9-136, **RAI 3.9-146 is being tracked as an open item.**

Since the natural circulation of the working fluid in the ESBWR is a new feature and only occurs when the fuel assemblies generate heat, in RAI 3.9-147, 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 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. **RAI 3.9-147 S01 is being tracked as an open item.**

3.9.5.3.6 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 SER, are, in general, acceptable because they 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 service conditions (normal, upset, emergency, and faulted).

As indicated in Section 3.9.5.2.6 of this SER, GEH 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, an equivalent static analysis was performed 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 SER, the applicant stated that the design and construction of the CS structures are in accordance with ASME Code, 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.

The applicant has not responded to RAI 3.9-148. **RAI 3.9-148 is being tracked as an open item.**

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.

The applicant responded to RAI 3.9-149 in a letter dated April 30, 2007 (MFN 07-238). 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

$(P + Q)/E \leq (0.9/SF_{min}).\varepsilon$

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.

The applicant has not responded to RAI 3.9-149 S01. **RAI 3.9-149 S01 is being tracked as an open item.**

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), in RAI 3.9-150, the staff asked the applicant 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 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. **RAI 3.9-150 S01 is being tracked as an open item.**

3.9.5.3.7 Combined License Information

Provided the applicant satisfactorily resolves the open items and COL action items identified in Sections 3.9.5 and 3.9.2.4 of this SER, 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 to the prototype.

In its response to RAI 3.9-151 dated November 22, 2006, the applicant stated the following:

> The program that GE intends to complete pertaining to FIV of reactor internal components is explained in LTR 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. GE's plan is to complete this work in 2007 prior to submittal of the first COL submittal. Regarding the steam dryer FIV program, GE 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. This is not acceptable. The DCD should include this information so that the COL applicant would be aware of it. **RAI 3.9-151(a) S01 is being tracked as an open item.**

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. **RAI 3.9-151(b) S01 is being tracked as an open item.**

3.9.5.3.8 Basis for Considering the ESBWR as Non-Prototype Reactor Internals

Section 3.9.2.4 of this SER provides the staff's evaluation of the basis for considering the ESBWR as non-prototype reactor internals, given in DCD Tier 2, Sections 3.9.2.4 and 3.9.5; GEH report, NEDE-33259P; and Appendix 3L to DCD Tier 2.

3.9.5.4 Conclusions

Because of the open items identified above, the staff is unable to finalize its conclusion regarding the acceptability of the design of reactor internals for the ESBWR to show compliance with the requirements of GDC 1, 2, 4, and 10 and 10 CFR 50.55a.

3.9.6 Functional Design, Qualification, and Inservice Testing Programs for Pumps, Valves, and Dynamic Restraints

3.9.6.1 Regulatory Criteria

In 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," the applicant described the design, qualification, and functional tests of certain major and safety-related active components and supports in the ESBWR. In DCD Tier 2, Section 3.9.6, "Inservice Testing of Pumps and Valves," the applicant discussed IST of certain safety-related pumps and valves typically designed as ASME Code, Section III, Class 1, 2, and 3. DCD Tier 2, Section 3.9.3.7, "Component Supports," specifies that ASME Code, Section III, component supports shall be designed, manufactured, installed, and tested in accordance with all applicable codes and standards. The NRC staff based its review of DCD Tier 2, Sections 3.9.3, 3.9.3.7, 3.9.6, 5.2.2, and 6.3.2, and its acceptance criteria, on meeting the relevant requirements in 10 CFR 50.55a; GDC 1, 2, 4, 14, 15, 37, 40, 43, 46, and 54 in Appendix A to 10 CFR Part 50; Appendix B to 10 CFR Part 50; 10 CFR 52.47(a)(1)(iv); and 10 CFR 52.97(b)(1).

- GDC 1 and 10 CFR 50.55a require 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.

- 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.

- 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.

- 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.

- GDC 15 requires that the 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.

- 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 leaktight 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.

- 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 leaktight 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.

- 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 leaktight 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 intended safety function.

- 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 leaktight 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.

- 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.

- Appendix B to 10 CFR Part 50 requires that applicants establish and maintain an acceptable QA program, including design, testing, and records control. Meeting the requirements of 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)(6) 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 of the ASME code described in the regulation. In 10 CFR 50.55a(b)(3), the regulations take exception to, or supplement, the ASME 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 code incorporated by reference in 10 CFR 50.55a at the time the construction permit or design certification is issued under 10 CFR Part 52, “Licenses, Certifications, and Approvals for Nuclear Power Plants.”

    – IST programs implemented during the initial 120-month interval must comply with the requirements in the latest edition and addenda of the ASME 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 ASME 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)(1)(iv) requires that applications for design certification contain proposed technical resolutions of the unresolved safety issues and medium- and high-priority generic safety issues that are identified in the version of NUREG-0933, "A Prioritization of Generic Safety Issues," current on the date 6 months before the application and that are technically relevant to the design.

- Compliance with 10 CFR 52.97(b)(1) 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.

3.9.6.2 Summary of Technical Information

DCD Section 3.9, "Mechanical Systems and Components," describes the functional design, qualification, and IST program for pumps, valves, and dynamic restraints used in the ESBWR. For example, DCD Tier 2, Section 3.9.2.2, "Seismic Qualification of Safety-Related Mechanical Equipment (Including Other RBV [Reactor Building Vibration] 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. DCD Tier 2, Section 3.9.3, discusses the structural integrity of pressure-retaining components, their supports, and CS structures that are designed in accordance with the rules of the ASME Code, Section III, and the GDC in Appendix A to 10 CFR Part 50.

DCD Tier 2, Section 3.9.3.5, specifies that safety-related valves are qualified by testing and analysis and by satisfying the stress and deformation criteria at critical locations within the valves. DCD Tier 2, Section 3.9.3.5.1, describes the qualification of specific valves including MSIVs, MS SRVs, SLC injection valves, and DPVs. The applicant discussed the qualification of other safety-related active valves that are ASME Code Class 1, 2, or 3 to perform their mechanical motion during dynamic loading conditions in DCD Tier 2, Section 3.9.3.5.2.

DCD Tier 2, Section 3.9.3.6, discusses MS SRVs, other SRV and VB valves, and DPVs.

DCD Tier 2, Section 3.9.3.7, specifies that ASME 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, specifies that supports and their attachments for essential 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 jurisdictional boundaries as defined by Subsection NF. With respect to snubbers, Section 3.9.3.7.1 states that the ISI and testing plan of all snubbers covered by the plant-specific technical specifications is prepared in accordance with the requirements of the ASME OM Code, Subsection ISTD. Section 3.9.3.7.1 also states that the details of the inservice examination and testing program, including test schedules and frequencies, are reported in the ISI and testing plan to be provided by the COL holder referencing the ESBWR design.

DCD Tier 2, Section 3.9.6, discusses the IST program for pumps and valves. The applicant indicated that the IST program typically includes safety-related pumps and valves designated as Class 1, 2, or 3. Other pumps and valves not categorized as ASME Code Class 1, 2, or 3 may be included if they are considered to be safety-related. The applicant referenced the GDC in Appendix A to 10 CFR Part 50, and 10 CFR 50.55a(f).

The applicant also indicated that it has considered additional guidance in NUREG-1482, "Guidelines for Inservice Testing at Nuclear Power Plants," and implemented this guidance as appropriate.

The applicant noted that the ESBWR uses ASME OM Code cases that refer to IST of pumps and valves and are accepted in RG 1.192, "Operation and Maintenance Code Case Acceptability, ASME OM Code," issued June 2003.

The applicant stated that DCD Section 3.9.6 outlines the IST program plan based on the requirements of the ASME OM Code, Subsections ISTB and ISTC and the mandatory Appendix I. The applicant asserted that the ESBWR design does not use pumps to mitigate the consequences of an accident or to maintain the reactor in a safe-shutdown condition. The applicant also stated that the COL holder referencing the ESBWR design will provide the details of the IST program, including test schedules and frequencies.

ESBWR DCD, Section 3.9.9, "COL Information," indicates additional information to be provided for specific aspects in Section 3.9. For example, GEH stated in Section 3.9.9.3, "Inservice Testing Programs," that the COL holder will provide a plan for the detailed pump and valve IST and inspection program. This plan will (1) include baseline preservice testing to support the periodic IST of the components required by the technical specifications, (2) provide a study to determine the optimal frequency for valve stroking during IST, and (3) address the concerns and issues identified in GL 89-10, "Safety-Related Motor-Operated Valve Testing and Surveillance," dated June 28, 1989, and specifically the method of assessment of the loads, the method of sizing the actuators, and the setting of the torque and limit switches. GEH also stated that the COL holder will provide a plan for the detailed snubber IST and inspection program in accordance with the ASME OM Code, including baseline preservice testing to support the periodic IST of all snubbers covered by the plant-specific technical specifications.

DCD Section 3.9.10 references the 2001 Edition, with 2003 addenda, of the ASME OM Code for the ESBWR design..

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 the components to function under design-basis conditions.

The development of a complete 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 establish a baseline ASME code edition and addenda to ensure that IST requirements of the baseline code can be performed without exception, and that the ESBWR systems and components provide access to permit the performance of testing pursuant to 10 CFR 50.55a(f)(3). In Section 3.9.9.3, the ESBWR DCD specifies that the "COL holder" will provide a plan for the detailed pump and valve IST and inspection program. The Commission's SRM dated September 11, 2002, for the NRC staff's Commission paper SECY-02-0067, "Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC)," dated April 15, 2002, stated that ITAAC for an operational program are unnecessary if the program and its implementation are fully described in the application and found to be acceptable by the NRC at the COL stage. The Commission also stated that the burden is on the applicant to provide the necessary and sufficient programmatic information for approval of the COL without ITAAC. In its SRM dated May 14, 2004, 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" to mean 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's effectiveness and acceptability. The statement in the ESBWR DCD that the COL holder will provide a plan for the detailed IST program is inconsistent with the Commission's direction that the COL applicant will fully describe the operational program (in this case, IST) in the application. The staff has requested additional information in RAI 3.9-198 inreference to DCD Revision 4. **This is being tracked as Open Item 3.9-198.**

The NRC staff evaluation of the functional design, qualification, and IST program for pumps, valves, and dynamic restraints as discussed in the ESBWR DCD is described below.

3.9.6.3.1 Scope

Subsection ISTA-1100 of the ASME OM Code specifies that the 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 (including long-term DHR following an accident). Section 3.9.6 of the SRP also states that the IST program may include other pumps, valves, and dynamic restraints not categorized as ASME Code Class 1, 2, or 3 if the staff considers them to be safety-related. ESBWR DCD Section 3.9.6 states that the ESBWR design does not use pumps to mitigate the consequences of an accident or to maintain the reactor in a safe-shutdown condition. Therefore, no pumps are listed in the IST program.

In RAI 3.9-152, the staff requested that the applicant identify the safety-related systems that are required to perform a specific function in shutting down a reactor to the safe-shutdown condition (during normal operation), in maintaining the safe-shutdown condition, or in mitigating the consequences of an accident (including long-term DHR following an accident). In its response, provided in MFN 06-489 (November 30, 2006), the applicant did not specify the requested systems but stated that the safety-related systems, identified in DCD Tier 2, Tables 3.6-1 and 3.6-2, needed to achieve a reactor safe-shutdown condition do not use pumps. However, Tables 3.6-1 and 3.6-2 identified only safety-related systems, components, and equipment for postulated pipe failures inside and outside containment. These tables did not show the specific safety-related systems that are used for shutting down the reactor and maintaining the reactor in a stable safe-shutdown condition. In a supplemental RAI, the staff requested that the applicant specify the safe-shutdown conditions for the ESBWR and clarify the associated safety-related systems that are used for shutting down the reactor and maintaining the reactor in a stable safe-shutdown condition. The applicant has not responded to the supplement to RAI 3.9-152.

In its response to RAI 3.9-152, provided in MFN 06-489, the applicant stated that non-safety-related systems perform postaccident long-term DHR, which is acceptable as noted in NRC staff Commission paper SECY-94-084. According to SECY-94-084, non-safety-related systems are acceptable for DHR 72 hours after the accident. Therefore, those non-safety-related pumps and valves associated with postaccident DHR are not subject to the IST requirements, because they are required 72 hours after the DBA.

DCD Table 3.9-8 specifies a refueling outage IST frequency for certain valves. The ASME OM Code allows a refueling outage test frequency if testing is not practical for plant design or if redesign of an existing system is required to perform the ASME OM Code-required quarterly test. However, quarterly testing is the base testing frequency in the ASME OM Code and the original intent of that code. According to item H of SECY-94-084, the vendors for advanced passive reactors, for which the final designs are not complete, have sufficient time to include provisions in their valve and piping system designs to allow quarterly testing at power. In RAI 3.9-159, the staff requested that the applicant justify for each valve why a new and advanced ESBWR cannot be designed and engineered to accommodate the quarterly test. In its response to RAI 3.9-159, provided in MFN 06-489, the applicant stated that, where the ASME OM Code, Subsection ISTC-3510, nominal exercise frequency of 3 months is not specific in Table 3.9-8, the referenced notes provide the basis for the alternate frequency. The bases notes are related to location or operation where valve damage could result or system shutdowns would be necessary and not to testing frequency. The applicant stated that redesign of a system solely for the purpose of increasing test frequency, even where possible, would require adding more valves and bypass loop piping. The applicant asserted that the ESBWR design complies with the ASME OM Code, Subsections ISTC-3510 and 3520. In a supplemental RAI, the staff asked the applicant to address why systems cannot be designed to allow ASME OM Code-required quarterly testing since the final design for a new reactor is not complete. The applicant has not responded to this supplement to RAI 3.9-159. **RAI 3.9-159 is being tracked as an Open Item.**

DCD Section 3.9.6 states that the COL holder referencing the ESBWR design will provide details of the IST program, including test schedules and frequencies. DCD Tier 2, Section 3.9.9.3, identified this as a COL information item. The COL holder is responsible for implementing the IST programs that comply with the requirements in the latest edition and addenda of the ASME OM Code incorporated by reference in 10 CFR 50.55a on the date 12 months before the date scheduled for initial fuel loading. The applicable ASME OM Code for the ESBWR design at this time is the 2001 edition with addenda through 2003. In addition, the COL applicant must describe or specify the system, piping and component design, and equipment qualification provisions to ensure that pumps and valves (as applicable) are designed, manufactured, tested, and installed to perform their intended safety functions for a full range of system differential pressures and flows, ambient conditions, and available voltage (as applicable) from normal operating to design-basis conditions, as well as to accommodate or enable anticipated IST required by 10 CFR 50.55a and the ASME OM Code. In addition to seismic, dynamic, and environmental qualification, pumps, valves, and dynamic restraints within the scope of the IST program must be qualified functionally to demonstrate their capability to perform their intended functions for a full range of system differential pressure and flow, flow temperature, and ambient conditions, from normal operating to design-basis conditions. The COL applicant should describe the qualification requirements and acceptance criteria for each size, type, and model of components within the IST program under required and expected operating conditions up to design-basis conditions. This issue is related to SER Open Item 3.9-198.

3.9.6.3.2 Pumps

ESBWR DCD Section 3.9.6 and the response to RAI 3.9-153 state that the ESBWR design does not use pumps to mitigate the consequences of an accident or to maintain the reactor in a safe-shutdown condition. Based on the applicant's information, the ESBWR IST program includes no safety-related pumps.

3.9.6.3.3 Valves

NRC regulation requires 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 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.

DCD Sections 3.9.3, 3.9.6, 5.2.2, 6.3.2, and 6.3.4 address issues related to the functional design, qualification, and IST program for certain major valves including POVs, biased-open CVs, squib valves, SRVs, and other DPVs. Based on its review, the NRC staff finds that the COL applicant should fully describe its plant-specific IST program including the following aspects:

- tests performed on each component and the ASME Code requirement met by each test
- test parameter and frequency of the tests
- normal, safety, and fail-safe position on each valve
- component type for each component
- piping layout coordinates for each component.

In addition, the COL applicant should submit any requests for relief, and the NRC staff will review these requests on the basis of the applicable ASME code edition and addenda incorporated by reference in 10 CFR 50.55a(b), together with applicable limitations and modifications specified in the regulations at the time a COL might be issued, and the state-of-the-art IST methods available at the time of the COL application. This issue is related to SER Open Item 3.9-198.

The staff review of specific valves is discussed below.

3.9.6.3.3.1 Power-Operated Valves.

POVs include such valves as motor-operated valves (MOVs), air-operated valves (AOVs), 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 operational readiness to perform their safety functions. The NRC staff reviewed the information in the ESBWR DCD Tier 2 to evaluate the functional design, qualification, and IST of POVs with safety functions in the ESBWR.

In RAI 3.9-161, the 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 provided in MFN 07-058 (January 23, 2007), 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, 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, discusses the structural integrity of pressure-retaining components, their supports, and CS structures, which are designed in accordance with the rules of the ASME Code, Section III, and the applicable GDC of the NRC regulations. DCD Tier 2, Section 3.9.3.5, specifies that safety-related valves are qualified by testing and analysis and by satisfying the stress and deformation criteria within the valves. In a supplement to RAI 3.9-161, the staff asked the applicant to address the program for ensuring the functional capability of POVs. The applicant has not responded to the supplement to RAI 3.9-161. **RAI 3.9-161 is being tracked as an open item.**

In response to RAI 3.9-162, the applicant revised Section 3.9.6.1, DCD Tier 2, Revision 3 to specify that POV equipment specifications, including those for the pneumatic-operated (air or nitrogen), pneumatic-motor operated, hydraulic-operated, solenoid-operated, motor-operated, and pyrotechnic-operated valves, require the incorporation of the results of either in situ or prototype testing with full flow and pressure, or full differential pressure, to verify the proper actuator sizing and correct control settings of the valves. The DCD indicates that guidelines for prototype testing of MOVs in Supplement 1 to GL 89-10 will also be applied to prototype testing of other POVs. The DCD also specifies that the COL holder referencing the ESBWR design will perform a study to determine the optimal frequency for POV stroking during IST such that unnecessary cycling and damage to the valve does not occur as a result of the testing. The staff will base its acceptance of this position on the resolution of SER Open Item 3.9-198, which relates to the responsibilities of the COL applicant.

Section 3.9.6.1, DCD Tier 2, Revision 3 notes that the concerns and issues identified in GL 89-10 will be addressed before plant startup. The method of assessing the loads, the method of sizing the actuators, and the setting of the torque and limit switches will be specifically addressed. The guidance developed by the Joint Owners Group on AOVs will influence the methods selected for assessing loads, sizing valve actuators, and determining control settings for AOVs. This guidance will be used to address these same issues for other POVs.

GL 96-05, “Periodic Verification of Design-Basis Capability of Safety-Related Motor-Operated Valves,” dated September 18, 1996, provides guidance for establishing programs for the periodic verification of MOV design-basis capability. The Joint Owners Group on AOVs established guidelines for periodic AOV testing. DCD Section 3.9.6.1, Revision 3, indicates that the guidance in these sources should be used to develop a periodic test program for other POVs. The DCD states that the COL holder referencing the ESBWR design will address the program for periodic verification of design-basis capability for all POVs. The staff will base its acceptance of this position on the resolution of SER Open Item 3.9-198, which relates to the responsibilities of the COL applicant.

DCD Section 3.9.6.1, Revision 3, indicates that IST of POVs relies on diagnostic techniques that are consistent with the state of the art and that permit an assessment of the performance of the valve under actual loading. The DCD specifies that periodic testing in accordance with Subsection ISTC of the ASME OM Code is conducted under adequate differential pressure and flow conditions that allow a justifiable demonstration of continuing capability for design-basis conditions, including recovery from inadvertent valve positioning. The DCD states that POVs failing the acceptance criteria are declared inoperable. The DCD also states that the COL holder referencing the ESBWR design will develop a program to establish the frequency and the extent of disassembly and inspection based on suspected degradation of all safety-related POVs, including the basis for the frequency and the extent of each disassembly. The DCD indicates that the program may be revised throughout the plant life based on past disassembly experience. The staff will base its acceptance of this position on the resolution of Open Item 3.9-198, which relates to the responsibilities of the COL applicant.

DCD Section 3.9.6.1 states that leaktight integrity is verified for each valve relied on to provide a leaktight function. These valves include (1) pressure isolation valves, (2) temperature isolation valves, and (3) containment isolation valves. The DCD specifies that leakage rate testing for valves is in accordance with the ASME OM Code, Subsection ISTC-3600.

DCD Tier 2, Revision 3, Section 3.9.9.3, requires COL holders to provide a plan for the detailed pump and valve IST and inspection program. This plan will include baseline preservice testing to support the periodic IST of the components required by the technical specifications. The plan will include provisions to test the pumps, valves, and POVs in accordance with the ASME OM Code and safety-related classification as necessary, depending on test results. The plan will also provide a study to determine the optimal frequency for valve stroking during IST. The plan will address concerns and issues identified in GL 89-10, specifically, the method of assessment of the loads, the method of sizing the actuators, and the setting of the torque and limit switches. The staff will base its acceptance of this position on the resolution of Open Item 3.9-198, which relates to the responsibilities of the COL applicant.

3.9.6.3.3.2 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 for information to provide confidence that certain critical CVs will be designed, manufactured, qualified, installed, and periodically tested for the performance of their applicable safety functions.

For the ESBWR, the GDCS uses bias-open CVs, which are extremely important in passive plant designs. In RAI 3.9-155, the staff requested information for the design differential pressure (ΔP) for holding the valve in the closed position and the maximum expected ΔP across the CV during operation. In its response, provided in MFN 06-489, the applicant stated that the GDCS CV will be placed in a vertical orientation, thereby allowing the valve to remain open and provide a path for thermal expansion of water. Placing the valve in the vertical position will resolve the concern of overpressurization between the squib valve and CV and is therefore acceptable. This CV orientation also resolves RAI 3.9-156, in which the staff requested information on the design flow for lifting the GDCS CV disc and the minimum flow for holding the disc in a stable open position.

During normal reactor operations, the GDCS CV will be actuated remotely through the use of a nonintrusive magnetically coupled torque-motor. In RAI 3.9-154, the staff requested that the applicant provide the acceptance criteria and basis for the acceptance criteria to assess degradation and performance characteristics of the CV. In its response, provided in MFN 06-489, the applicant stated that the GDCS CV is capable of position indication. Preoperational testing will verify the valve position 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 holder 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 actual plant construction. In a supplemental RAI, the staff requested that the applicant specify in the ESBWR DCD the responsibility of the COL applicant to include in its IST program plan the acceptance criteria and the bases for assessing degradation and the performance characteristics of pumps, valves, and dynamic restraints in the IST program and to describe the diagnostic equipment and techniques to be used in the IST program. The applicant has not responded to the supplement to RAI 3.9-154. **RAI 3.9-154 is being tracked as an open item**.

In RAI 3.9-158, the staff requested that for all CVs, including GDCS CVs, the applicant describe how the CV test results will measure and identify the flow required to open the valve and maintain the valve disc in a stable, fully open position. If the CV testing will involve nonintrusive techniques, the staff asked the applicant to describe the techniques and acceptance criteria used to assess the degradation and the performance of the CVs. In its response to RAI 3.9-158, provided in MFN 06-489, the applicant stated that the GDCS CV will have a vertical orientation, thereby allowing the valve to remain fully open and providing a stable position where any flow will not be impeded and will be allowed to develop fully. The full-open indicated position is said to confirm this. The applicant also stated that the COL holder will implement the GDC and NUREG guidelines identified in DCD Tier 2, Section 3.9.6. In response to a supplemental RAI, the applicant stated in MFN 06-489 (S03), dated August 29, 2007, that the IST techniques in the IST program are the responsibility of the COL holder. The staff will base its acceptance of this position on the resolution of Open Item 3.9-198, which relates to the responsibilities of the COL applicant.

In its response to RAI 3.9-2, the applicant stated that hinge pin wear has been identified as a major failure mode for the GDCS bias-open CV. In RAI 3.9-157, the staff requested that the applicant discuss or describe a method of monitoring the condition of the hinge pin. In its response to RAI 3.9-157, provided in MFN 07-190 (March 28, 2007), the applicant stated that the GDCS CVs are designed such that the CV is fully open when zero differential pressure is applied across the CV. 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. The applicant did not determine that the condition of the hinge pin in the GDCS CVs needs to be monitored. In response to this RAI, the applicant updated DCD Tier 2, Revision 3, Section 6.3.2.7.2, to describe the GDCS CV. For example, DCD Tier 2, Revision 3, states that the GDCS CV is classified as QG A, Seismic Category I, and ASME Code, Section III, Class 1. As a supplement to RAI 3.9-157, the staff asked the applicant to describe the IST program activities for GDCS CVs. The applicant has not responded to the supplement to RAI 3.9-157. **RAI 3.9-157 is being tracked as an open item.**

3.9.6.3.3.3 Safety/Relief Valves, Depressurization Valves, Containment Vacuum Breakers and Vents, Safety/Relief Valves Rupture Disks, and Other Relief Devices

In addition to its requirements for pressure boundary integrity, ASME Code, Section III, also requires the RCS SRVs and DPVs, the containment VBs, the SRV discharge rupture disks, and other relief valves to be capacity certified to adequately discharge the necessary fluid flow to ensure system overpressure protection. The specific DCD sections reviewed that contain general information relating to the design of pressure-relief devices are Sections 3.9.3, 3.9.6, 5.2.2, and 6.3.2. The staff has determined that the applicant has committed to meet the requirements of ASME Code, Section III, for 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 Code, Section III, requirements, the staff also reviews other issues relating to the proper qualification and testing of relief devices, including issues based on operational experience and any specific knowledge of the valve operation or system functions. These issues include verifying that RCS and containment integrity is ensured, that piping has adequate pressure relief, that piping loads do not affect relief valve operation, and that all necessary relief devices are within the IST program.

In its response to RAI 3.9-1, provided in MFN 06-127 (June 16, 2006), the applicant reported that testing of the DPV and VB valves was conducted during development of the simplified BWR in the 1990 timeframe. The design of these valves remains the same for the ESBWR, except that the quantity of valves has increased to accommodate the larger plant size. The applicant provided several documents in support of the review of the testing of the DPV and VB valves. In MFN 06-127, the applicant indicated that it will separately provide the GEH report GEFR-00879, “Depressurization Valve Development Test Program Final Report,” issued October 1990. In a supplemental RAI, the staff asked the applicant to discuss the size of the prototypes in relation to the production valves, the replacement procedure in that the thermal aging testing is justified for 6 years, and the actions to be taken for the production valves. The applicant has not responded to the supplement to RAI 3.9-1. **RAI 3.9-1 is being tracked as an open item**.

In its response to RAI 5.2-20, provided in MFN 06-178 (June 16, 2006), the applicant stated that it has not finalized the detailed design and selection of the ESBWR SRVs. It will consider lessons learned from valves installed in current operating BWRs during the selection phase for the ESBWR SRVs. GEH will evaluate potential valve suppliers during the selection phase with an emphasis on optimum performance in the areas of setpoint drift, actuator reliability, and seat leakage. In its response to RAI 5.2-22, also provided in MFN 06-178, the applicant stated that it will prepare for the SRVs a purchase specification, which uses the GEH environmental qualification experience base. This specification is intended to define the design and qualification requirements for the SRVs. The SRV will be subjected to environmental and dynamic qualification as identified in the purchase specification, which will define the environmental conditions, such as radiation, temperature, pressure, and humidity, and the seismic and dynamic conditions, including the RRS. The purchase specification will also define the requirements for the environmental and dynamic qualification program, such as radiation aging, thermal aging, mechanical aging, and vibration testing. In response to supplemental RAIs, the applicant provided additional information in MFN 06-178, S01 (dated May 3, 2007) regarding the design and selection of the ESBWR SRVs. In particular, the applicant stated that the ESBWR design will use ASME Code, Section III, Subsection NB-7540, “Safety Valves and Pilot Operated Pressure Relief Valves with Auxiliary Actuating Devices,” as a reference. The applicant also referred to ASME Code, Section III, Subsection NB-7510, “Safety, Safety Relief and Relief Valves,” and Subsection NB-7520, “Pilot Operated Pressure Relief Valves,” for applicable rules for overpressure protection system valves. As noted by the applicant, DCD Tier 1, Table 2.1.2-2, item 1, contains an ITAAC to confirm the basis configuration for the nuclear boiler system that includes programmatic reviews of SRV design and environmental qualifications.

In its response to RAI 5.2-25, provided in MFN 06-178, the applicant reported that the SRVs are mounted on flanges and can be removed for maintenance or bench testing during normal plant shutdown. Section 3.9.6 and Table 3.9-8 in DCD Tier 2 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. When any valve is removed for maintenance or bench testing, 100 percent of the external and flange seating surfaces of the SRVs are inspected. 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 provides 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 staff's maintenance procedures, which ensure that the design life will not be exceeded for any SRV component.

In its response to RAI 3.9-164, provided in MFN 06-519 (December 15, 2006), 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. Therefore, they are designed and qualified to meet ASME Code, Section III, requirements for Class 1 components. The IST program includes these relief valves, which DCD Table 3.9-8 identifies as B21 NBS valves F006 and F003.

In its response to RAI 3.9-164, provided in MFN 06-519, 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 VB valve (F002) are classified as Safety Class 2 and are designed and qualified to meet ASME Code, Section III, requirements for Class 2 components. The IST program includes these valves, as identified in DCD Table 3.9-8.

In its response to RAI 3.9-165, provided in MFN 06-452 (November 14, 2006), the applicant stated that DCD Tier 2, Table 3.9-8, lists VB F002 and VB 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 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 design (including capacity) certification and procurement will be performed for ASME Code Class 2 components.

DCD Section 5.2.2 discusses the design of SRV rupture disks. In its response to RAI 3.9-173, provided in MFN 06-519, the applicant confirmed that these rupture disks meet the ASME Code, Section III, requirements and will be included in the IST program. In response to the RAI, the applicant updated Table 3.9-8 in DCD Tier 2, Revision 3, to include the SRV rupture disks with their ASME Code class and category, valve function, and test parameters and frequencies.

In RAI 3.9-166, the NRC staff requested that the applicant provide information with respect to thermally induced pressurization of containment isolation penetrations. In particular, the staff asked the applicant to (1) verify that all sections of containment penetration piping that may be isolated with trapped liquid are protected from thermally induced pressurization by a pressure-relief device, (2) verify that the IST program includes these devices, (3) identify those sections of isolated piping that are protected from excessive pressurization by other methods and describe the methods, and (4) verify that the resulting thermally induced pressurization and resulting differential pressure on isolation valves do not exceed those for which the valves are qualified.

In its response to RAI 3.9-166, provided in MFN 07-303 (May 30, 2007), the applicant stated that the current level of detail for the design of piping and piping penetrations for primary containment does not permit the requested verifications. The applicant stated that the IST program is a COL holder responsibility and includes the relief valves within the scope of the IST program boundary. The staff will base its acceptance of this position on the resolution of SER Open Item 3.9-198, which relates to the responsibilities of the COL applicant. The applicant stated that it will revise DCD Tier 2, Section 6.2.4, to specify that penetration piping is evaluated for entrapped liquid subject to thermally induced pressurization following isolation. The DCD will indicate 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 will also indicate that use of a separate relief valve is permissible on a case-by-case basis. The staff will confirm this in a later revision of the DCD.

The staff provided a supplement to RAI 3.9-166, which asked GEH to discuss the basis for assigning the responsibility for pressure-relief devices to the COL holder rather than to the COL applicant. The applicant has not responded to this supplement. The staff will base its acceptance of the applicant’s position on the resolution of SER Open Item 3.9-198, which relates to the responsibilities of the COL applicant. **RAI 3.9-166 is being tracked as an open item.**

In RAI 3.9-167, the NRC staff requested that the applicant provide information with respect to thermally induced pressurization of piping and valves. In particular, the staff asked the applicant to (1) describe any noncontainment isolation configurations where thermally induced pressurization may be possible, (2) describe how excessive pressurization is prevented and how isolation valves remain operable, as necessary, and (3) verify that the IST program includes any pressure-relief devices. In its response to RAI 3.9-167, provided in MFN 07-303, the applicant stated that the development of individual system piping design is not yet sufficient to address those piping systems, or portions of systems, that might be susceptible to thermally induced pressurization. The applicant reported that overpressure protection is a design responsibility under the piping design codes, including ASME Code, Section III, and ASME/ANSI B31.1 (the power piping code). The applicant stated that the ASME Code defines owner responsibilities for review and acceptance, and the COL holder must perform these responsibilities. The applicant indicated in DCD Tier 2 that the IST program is a COL holder responsibility. The applicant also stated that the responsibilities assigned to the COL holder in the DCD ensure that records for the as-built plant design will be available to confirm the adequacy of overpressure protection and the inclusion of the necessary relief valves in the IST program. The staff provided a supplement to RAI 3.9-167, which is the same as the supplement to RAI 3.9-166. The applicant has not responded to the supplement to RAI 3.9-167. The staff will base its acceptance of the applicant’s position on the resolution of Open Item 3.9-198, which relates to the responsibilities of the COL applicant. **RAI 3.9-167 is being tracked as an open item**.

In RAI 3.9-168, the NRC staff requested that the applicant provide information with respect to the scope of valves that meet the requirements of ASME Code, Section III. In particular, the staff asked the applicant to verify that the IST program includes all relief devices that perform a function of providing pressure relief to ensure the integrity of safety-related SSCs and that are designed, qualified, and capacity certified to meet all applicable requirements of ASME Code, Section III. In addition to any other systems that provide a safety-related function, the staff requested that the applicant provide this information for the RCS, the MS system, the facility and auxiliary pool cooling system, the SDC/SLC system, the CRD system, the plan PSWS, and the RB component cooling water system.

In its response to RAI 3.9-168, provided in MFN 07-021 (March 27, 2007), 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 ASME Code, Section III. The relief devices that provide a pressure-relief function to ensure safety-related SSCs include nuclear boiler system SRVs (F006 and F003), the SLC system accumulator tank relief valve (F030A/B), and the containment drywell wetwell VB valve (F002), which are included in the IST program. In a supplement to RAI 3.9-168, 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, Revision 3, and their bases. The applicant has not responded to the supplement to RAI 3.9-168. **RAI 3.9-168 is being tracked as an open item.**

In RAI 3.9-169, the NRC staff requested that the applicant provide information with respect to piping and valve load interaction. In particular, the staff asked the applicant to verify that, for all relief devices that perform a function of providing pressure relief to ensure the integrity of safety-related SSCs, the analysis of the upstream and downstream piping includes all the valve discharge fluid dynamic loads. In addition, the staff asked the applicant to verify that the fluid dynamic loads imposed by the piping on 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, provided in MFN 07-303, the applicant stated that, at this time, the development of individual system piping design is insufficient to address which piping systems or portions of systems include relief valves for overpressure protection. The applicant noted that the COL holder is assigned owner responsibilities for review and acceptance, data collection and recording, and records for the as-built plant design. The staff issued a supplement to RAI 3.9-169, which is the same as the supplement to RAI 3.9-166. The applicant has not responded to the supplement to RAI 3.9-169. The staff will base its acceptance of the applicant's position on the resolution of Open Item 3.9-198, which relates to the responsibilities of the COL applicant. **RAI 3.9-169 is being tracked as an open item**.

In RAI 3.9-170, the NRC staff requested that the applicant provide valve-specific information needed by the staff to complete its review. In particular, the staff asked the applicant to provide (1) a list of all safety-related relief devices credited with providing pressure relief in the plant safety analysis and (2) their associated system design pressures, the device design set pressures and tolerances, and the certified relief capacities. In its response to RAI 3.9-170, provided in MFN 07-303, the applicant stated that the development of individual system piping design and equipment procurement is presently insufficient to address the piping systems or portions of systems that include relief valves for overpressure protection. The applicant noted that the COL holder is assigned the owner responsibilities for review and acceptance, data collection and recording, and records for the as-built plant design. 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 staff provided a supplement to RAI 3.9-170, which is the same as the supplement to RAI 3.9-166. The applicant has not responded to the supplement to RAI 3.9-170. The staff will base its acceptance of the applicant’s position on the resolution of Open Item 3.9-198, which relates to the responsibilities of the COL applicant. **RAI 3.9-170 is being tracked as an open item.**

3.9.6.3.3.4 Squib Valves.

DCD Section 6.3.2.7.2 describes the design, function, and actuation of a typical squib valve that satisfies the GDCS requirements. However, the DCD does not describe and establish the qualification provisions and acceptance criteria for demonstrating that the valve will perform its function for a range of system pressure, pressure differential, temperature, and ambient conditions from normal operating up to design-basis conditions. Therefore, the staff requested this information in RAI 3.9-160. In its response, provided in MFN 06-489, the applicant stated that, before delivery to a site, the manufacturer will conduct mechanical testing of GDCS squib valves. The testing will include a full range of pressures and temperatures from ambient conditions to design-basis conditions. In a supplemental RAI, the staff requested that the applicant specify the acceptance criteria for the design and qualification of the GDCS squib valves. The applicant has not responded to the supplement to RAI 3.9-160.

In RAI 3.9-171, the NRC staff requested that the applicant provide information regarding how the squib explosives are qualified to ensure proper 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 regarding the sample IST of the squib explosives which demonstrates that the rates and total amounts of energy release are acceptable. In its response to RAI 3.9-171, provided in MFN 07-208 (April 16, 2007), the applicant described the qualification process for pyrotechnic-actuated valves used in the ESBWR. In its RAI response, the applicant also indicated that IST is 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. The staff considers the applicant’s response to be acceptable. In a supplemental RAI, the staff asked the applicant to provide for information regarding GEFR-00879, referenced in the DCD and the RAI response. The staff also asked the applicant to incorporate its response to this RAI in the DCD. The applicant has not responded to the supplement to RAI 3.9-171. **RAI 3.9-171 is being tracked as an open item**.

In RAI 3.9-172, the staff asked the applicant to provide information regarding how the space below the piston is prevented from being pressure locked with liquid, either by leakage or diffusion. In its response to RAI 3.9-172, provided in MFN 07-021, the applicant indicated that Figure 6.3-2 is only a concept of how to build the GDCS squib valve and does not show the specific details of the valve design. The applicant indicated that the detailed design will include flowpaths to prevent a hydraulic locked condition. The staff will review this feature as part of the evaluation of a COL application for the ESBWR.

3.9.6.3.4 Dynamic Restraints

Subsection ISTA-1000 of the ASME OM Code specifies that the general preservice and IST requirements be applied to dynamic restraints (snubbers) 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 (including long-term RHR following an accident). Subsection ISTD of the ASME OM Code specifies the preservice and inservice examination of the snubbers. SRP Section 3.9.6 also states that the IST program may include other snubbers not categorized as ASME Code Class 1, 2, or 3, if the staff considers them to be safety-related.

DCD Tier 2, Section 3.9.3, presents the technical information supporting the design basis for the dynamic restraints. These act to restrain piping against response to the dynamic excitation and the associated differential movement of the piping system support anchor points. DCD Tier 2, Section 3.9.3, discusses the criteria for locating dynamic restraints and ensuring adequate load capacity, their structural and mechanical performance parameters, and their installation and inspection considerations.

In response to an RAI, the applicant revised Section 3.9.3.7.1(3)e of DCD Tier 2 in Revision 3 to specifically refer to the ASME OM Code for both preservice testing and IST of dynamic restraints. The ASME OM Code, in Subsections ISTD-4000 and ISTD-5000, provides the requirements for the preservice examination and testing. DCD Tier 2, Revision 3, states in Section 3.9.3.7.1(3)e that snubber maintenance, repairs, replacements, and modifications are performed in accordance with the requirements of the ASME OM Code, Subsection ISTD. The applicant stated that the specification for preservice and inservice examination and testing of dynamic restraints in accordance with the ASME OM Code is prepared after the detailed design, including piping system stress analysis, is complete so that the number and type of dynamic restraints to be tested are known. DCD Tier 2, Revision 3, Section 3.9.9.3, states that the COL holder will provide a plan for the detailed snubber IST and inspection program in accordance with the ASME OM Code. The plan will include baseline preservice testing to support the periodic IST of all snubbers covered by the plant-specific technical specifications. The staff will base its acceptance of this position on the resolution of SER Open Item 3.9-198, which relates to the responsibilities of the COL applicant.

In RAI 3.9-175, the NRC staff requested that the applicant describe the method for functional design and qualification for dynamic restraints. In its response in MFN 07-086 (February 16, 2007), the applicant stated that DCD Tier 2, Section 3.9.3.7.1(3)c, and ASME Code, Section III, Subsection NF, cover the functional design and qualification of snubbers. In a supplemental RAI, the staff is requesting that the applicant specify this cross-reference in Section 3.9.6 of the DCD. The applicant has not responded to this supplement to RAI 3.9-175. **RAI 3.9-175 is being tracked as an open item.**

3.9.6.4 Conclusions

On the basis of its review of DCD Tier 2 and NRC policies and practices, the NRC staff concludes that, because of the pending resolution of the open items identified in this safety evaluation, the staff is unable to finalize its conclusion about the program proposed by the applicant for the functional design, qualification, and IST program for pumps, valves, and dynamic restraints in the ESBWR as part of the design certification application.

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 staff of the NRC:

- GDC 1 and GDC 30, "Quality of Reactor Coolant Pressure Boundary," of Appendix A of 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 of 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 jet impingement forces
- GDC 14 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 1987
- RG 1.122, "Requirements for Required Response Spectra (RRS) Peak Broadening of +/-15 Percent," issued 1978
- RG 1.61, "Requirements for Damping Values for Seismic Design of Nuclear Power Plants," 1973
- RG 1.92, "Combining Modal Responses and Spatial Components in Seismic Response Analysis," Revision 2, July 2006
- RG 1.29, "Seismic Design Classification," Revision 3, September 1976
- RG 1.100, 'Seismic Qualifications of Electrical Equipment for Nuclear Power Plants," 1988
- 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 addresses methods of test and analysis employed to ensure the operability of mechanical and electrical equipment (including instrumentation and controls (I&Cs)) under the full range of normal and accident loadings (including seismic and RBV). Mechanical and electrical equipment are 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 include equipment associated with systems that are essential to shut down the reactor, containment isolation, reactor core cooling, and containment and reactor heat removal, or otherwise are 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 their 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 the GEH, LTR 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 Section 3.10, Draft Revision 3, issued April 1996, of NUREG-0800.

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 continues 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, dated August 1, 2006, the staff asked the applicant to explain the absence of compliance to meet the requirements of Appendix S to 10 CFR Part 50 in ESBWR DCD Tier 2, Section 3.10.

By letter MFN-06-307, dated September 1, 2006, in 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 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. The RRS are generated from the building dynamic analysis, as described in DCD Tier 2, Section 3.7. 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 SER 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 the functions essential for reactor shutdown, containment isolation, reactor core cooling, reactor protection, containment and reactor heat removal, and emergency power supply, or that otherwise are 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 GEH 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, 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, as modified and endorsed by RG 1.100.

For seismic and dynamic qualification of mechanical and electric equipment in the ESBWR, DCD Tier 2 listed three versions of IEEE-344 as the guidelines to be followed—(1) IEEE-344-2004, (2) RG 1.100, Revision 2, issued 1988, which endorses IEEE-344-1987 with some conditions, and (3) Section 4.4 of NEDE-24326-1-P, issued January 1983, regarding the GEH Environmental Qualification Program, which used IEEE-344-1975 as its guidelines. In RAI 3.10-2, dated August 1, 2006, 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 (pending completion of Revision 3) 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, dated September 1, 2006 (MFN-06-307), the applicant stated that the ESBWR will meet IEEE-344-1987, and 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 GEH 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, dated March 26, 2007 (MFN-06-307, S01), the applicant stated that "(R1993)" means that the IEEE-344 Committee reaffirmed the 1993 edition without any changes that year. GEH further stated that IEEE-344-1987(R1993) meets the conditions in RG 1.100, Revision 2, issued June 1988.

However, the GEH 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 GEH responses to RAIs 3.10-3 and 3.10-4, GEH 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 GEH 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 GEH to confirm in the DCD that Section 9 of IEEE-344-1987 is not applicable to ESBWR.

In ESBWR DCD Tier 2, Revision 4, GEH 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 meet the requirements of IEEE-344. In RAI 3.10-3, dated August 1, 2006, 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/review.

In its response to RAI 3.10-3, dated September 1, 2006 (MFN-06-307), the applicant stated that GEH 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 GEH 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 GEH to clarify in the DCD the use of qualification by experience. In its response to RAI 3.10-3 S01, dated March 26, 2007 (MFN-06-307, S01), the applicant stated that GEH does not use operating experience as a basis for equipment qualification. Instead, GEH will use testing, analysis, or a combination of the two, as explained in its response to RAI 3.11-1 (MFN-07-174). 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 applicant’s approach to seismic and dynamic qualification of mechanical and electrical equipment is, in general, appropriate. However, 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 Reactor Building Vibration Induced Loads)

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., HCU). 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 SER 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 staff evaluation 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), GEH 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 taken into consideration. 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 would perform its safety-related function through 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 effects of the malfunction are determined and documented in the final test report. The applicant indicated that the final test report contains a summary of test/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 large number of 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), GEH 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, in order 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.

- 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 GEH response to RAI 3.10-3 in Section 3.10.3.1 of this SER, the staff had concerns with the GEH approach for the qualification of equipment by experience. As described above, GEH indicated that it would follow the methods outlined in IEEE-344. In RAI 3.10-4, dated August 1, 2006, the staff asked GEH to clarify which version of IEEE-344 it commits to follow. As indicated in RAI 3.10-2 and discussed in Section 3.10.3.1 of this SER, the NRC staff does not accept some aspects of the criteria provided in Section 10 of IEEE-344-2004. For example, the staff does not agree with (1) the use of median-centered spectra to define the RRS for candidate equipment, (2) inadequate provisions for meeting the OBE requirements, (3) the use of the mean of the test response spectra (TRS) to define test experience spectra (TES), (4) inadequate provisions for meeting OBE TES requirements, and (5) inadequate provisions for demonstrating operability during and after the SSE loads and Service Level D RBV dynamic loads. In RAI 3.10-4, dated August 1, 2006, the staff noted some unacceptable criteria provided in IEEE-344-2004 as described above and asked GEH 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/review.

In its response to RAI 3.10-4, dated September 1, 2006 (MFN-06-307), GEH stated that it does not use operating experience for equipment qualification and that it does not maintain any database for operating experience. GEH further stated that it would not make any DCD changes in response to this RAI. The staff finds the GEH response unacceptable because, if GEH 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 GEH to address a question similar to that described in RAI 3.10-3 S01, but from the standpoint of IEEE-344-1987. In its response to RAI 3.10-4 S01, dated March 26, 2007 (MFN-06-307, S01), GEH provided the same response as for 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 shall 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, dated August 1, 2006, the staff asked GEH to clarify (1) the applicability of the above methods with respect to the ESBWR and 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, dated September 1, 2006, GEH 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, GE did not respond to question (2) above. Therefore, **RAI 3.10-6 is being tracked as an open item.**

3.10.3.4 High-Frequency Seismic Excitations

Recent ground motion studies for some hard rock sites indicated 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 TRS may have shown the 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. In order 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 have to be demonstrated. The frequency content of the Fourier transform of the test waveform or the frequency content of the power PSD 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 asked GEH 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 is being tracked as an open item.**

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 of the AISC Specification for the Design, Fabrication and Erection of Structural Steel for Buildings. 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 determined to 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 (NSSS) equipment supports as described above, the staff finds the applicant’s approach acceptable.

3.10.3.5.2 Non-Nuclear 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:

- 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

- 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 FRS 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 FRS are combined by an upper bound envelope.

Based on the review of the limited information provided 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. However, DCD Tier 2, Section 3.10.3.2, did not present specific criteria. The staff requested additional information and evaluates the applicant's response to the requested information in Section 3.9.2 of this SER.

Local Instrument Supports

The applicant stated that, for field-mounted seismic Category I instruments supports, the following bases are applicable:

- The mounting structures for the instruments have a fundamental frequency above the excitation frequency of the RRS.
- 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.
- 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 non-NSSS 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 shall 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/audit. In RAI 3.10-5, dated August 1, 2006, the staff asked GEH 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/audit.

In its response to RAI 3.10-5, dated September 1, 2006 (MFN-06-307), GEH stated that it will revise DCD Tier 2, Sections 3.10.2.3 and 3.10.2.4, to include qualification documentation and 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 the qualification documentation required in the report if qualification 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. However, the applicant has not implemented these resolutions in DCD Tier 2, Revision 2, Sections 3.10.2.3 and 3.10.4.

In RAIs 3.10-5 S01 and 3.10-5 S02, the staff asked GEH to clarify the operating experience in DCD Tier 2, Section 3.10.2.4, and the qualification records maintenance requirement in Section 3.10.4. Furthermore, the staff also asked when the DQRs will be made available for staff review/audit.

In its resolution of RAIs 3.10-3 and 3.10-4, the GEH response to RAI 3.10-5 S01 (MFN-06-307, S01, dated March 26, 2007), and the GEH response to RAI 3.10-5 S02 (MFN-06-307, S03, dated August 28, 2007), in DCD Tier 2, Revisions 3 and 4, GEH 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 provide a milestone for completing the DQR in accordance with Section 3.10.1.4. The staff considers this response to be partially acceptable. The NRC asks GEH to revise the COL information for DQR in DCD Tier 2, Revision 4, to 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.
RAI 3.10-5 S02 is being tracked as an open item.

3.10.4 Conclusion

Because of the open RAIs that need resolution, the staff is unable to finalize its conclusions regarding the acceptability of the design.

3.11 Environmental Qualification of Mechanical and Electrical Equipment

3.11.1 Regulatory Criteria

The applicant addressed the environmental qualification (E
Q) of mechanical, electrical, and I&C equipment for the ESBWR in DCD Tier 2, Section 3.2, “Classification of Structures, Systems, and Components”; Section 3.11, “Environmental Qualification of Mechanical and Electrical Equipment”; and Appendix 3H, “Equipment Qualification Design Environmental Conditions.” The staff of the NRC based its review of the EQ of mechanical, electrical, and I&C equipment on meeting the relevant requirements set forth in (10 CFR) and the applicable Commission policy directives as described below:

- The regulation at 10 CFR 50.49, “Environmental Qualification of Electrical Equipment Important to Safety for Nuclear Power Plants,” 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, 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, anticipated operational occurrences, 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 loss of coolant accidents. 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, anticipated operational occurrences, and accident and postaccident environmental conditions.

- GDC 23, ”Protection System Failure Modes,” 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, “Design Control,” of Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants,” 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, anticipated operational occurrences, and accident and postaccident environmental conditions.

- Criterion XI, “Test Control,” of Appendix B to 10 CFR Part 50 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, anticipated operational occurrences, and accident and postaccident environmental conditions.

- Criterion XVII, “Quality Assurance Records,” of Appendix B to 10 CFR Part 50 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, anticipated operational occurrences, and accident and postaccident environmental conditions.

- In the SRM 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.

3.11.2 Summary of Technical Information

In ESBWR DCD Tier 2, Section 3.2, the applicant stated that ESBWR SSCs are categorized as safety-related (as defined in 10 CFR 50.2, “Definitions”) 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 RCPB, (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) or 10 CFR 100.11, “Determination of Exclusion Area, Low Population Zone, and Population Center Distance.” Safety-related SSCs are said to conform to the QA requirements of Appendix B to 10 CFR Part 50. Non-safety-related SSCs have QA provisions applied commensurate with the importance of the function of the SSC.

In ESBWR DCD Tier 2, Section 3.11, the applicant described the EQ of mechanical and electrical equipment. The EQ of safety-related equipment is said to be based on limiting design conditions (including normal operating conditions, abnormal operating conditions, test conditions, accident conditions, and postaccident conditions). DCD Tier 2, Section 3.11, specifies that the equipment qualification document (EQD) must describe the methods and procedures used to demonstrate the capability of equipment to perform its required safety-related functions when exposed to the environmental conditions in its respective locations.

The applicant stated that electrical equipment within the scope of this section includes all three categories of 10 CFR 50.49(b). The applicant stated that DCD Tier 2, Section 3.2, defines and identifies safety-related mechanical equipment (e.g., pumps, MOVs, SRV, and check valves). Mechanical and electrical equipment is intended to have a design life of 60 years.

The applicant identified 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 have the capability to perform its design safety functions under all anticipated operational occurrences 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.

Appendix 3H to DCD Tier 2 documents the environmental conditions for the zones where safety-related equipment is located. The environmental parameters include thermodynamic parameters (temperature, pressure, and relative humidity), radiation parameters (dose rates and integrated doses of neutron, gamma, and beta exposure), and chemical spray parameters (chemical composition and the resulting pH).

For mechanical and electrical equipment required to perform an intended function between the occurrence of the event but less than 10 hours into the event, DCD Section 3.11.2 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 of more than 10 hours, the equipment is to be demonstrated to remain functional under accident conditions for a period of time at least 10 percent longer than the required operation time.

Safety-related mechanical and electrical equipment located in harsh environments is said to perform its proper safety functions in environments during normal, abnormal, test, DBA, and postaccident conditions, as applicable. DCD Section 3.11.1 specifies that the EQD must include a list of safety-related mechanical and electrical equipment located in a harsh environment area. Safety-related electrical equipment that is located in a harsh environment will be qualified by test or other methods as described in IEEE-323-2003 “Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations” and permitted by 10 CFR 50.49(f). Equipment-type test is the preferred method of qualification. Safety-related mechanical equipment that is located in a harsh environment will be qualified by analysis of materials data, which are said to be generally based on test and operating experience. ESBWR DCD Tier 2 references the qualification program and methodology described in GEH, LTR NEDE-24326-1-P, “General Electric Environmental Qualification Program,” issued January 1983.

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.

Mechanical and electrical equipment located in a mild environment where the postulated event does not cause any significant change in the environment of the particular location is subject to its specified loads. DCD Section 3.11.2 specifies that the vendors of mechanical and electrical equipment located in a mild environment must provide a certificate of compliance certifying that the equipment has been qualified to ensure the performance of its required safety-related functions in the applicable environment. The DCD also states that a surveillance and maintenance program must be developed to ensure equipment operability during the design life.

DCD Section 3.11.2 states that the vendor must specify the qualified life, shelf life, and activities of maintenance surveillance, periodic testing, and any parts replacement required to maintain qualification of the equipment. The DCD also specifies that the procedures and results of qualification by tests, analyses, or other methods for the safety-related equipment must be documented, maintained, and reported as mentioned in DCD Tier 2, Section 3.11.5.

Section 3.11.5 specifies that COL holders prepare the EQD summarizing the qualification results for all equipment. The EQD will include (1) the test environmental parameters and the methodology used to qualify the equipment located in harsh environments and (2) a summary of environmental conditions and qualified conditions for the equipment located in a harsh environment zone in system component evaluation worksheets. The DCD also indicates that COL holders will record and maintain the results of the qualification test in an auditable file in accordance with the requirements of 10 CFR 50.49(j).

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 anticipated operational occurrences 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.

- Equipment qualification 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 for the ESBWR design 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 staff's evaluation appears in SRP

Section 3.11 of NUREG-0800; NUREG-0588, Rev. 1, “Interim Staff Position on Environmental Qualification of Safety-Related Electrical Equipment” issued July 1981 for Category I; RG 1.89, Rev. 1; and 10 CFR 50.49. For COL applicants referencing the ESBWR certified design, the staff will review specific details of the EQ programs for their plants using the evaluation bases mentioned above.

3.11.3.1 Completeness of Qualification of Electrical Equipment Important to safety

The following three categories of electrical (electrical, 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 (Category 1 and 2 postaccident monitoring equipment as specified in RG 1.97, Revision 2, ”Instrumentation for Light-Water-Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident,” issued December 1980)

In DCD 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. On September 12, 2007, the applicant stated that it will 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 finds the applicant’s response acceptable. **RAI 3.11-7 is being tracked as a confirmatory item.**

In DCD Tier 2, Section 3.11, the applicant stated that EQ shall be based on limiting design conditions for electrical equipment (including I&C components) and safety-related mechanical equipment. In RAI 3.11-8, the staff asked the applicant to confirm that digital I&C components are included. In its September 7, 2007, response, the applicant stated that the scope of EQ includes the safety-related digital I&C components. This resolved the staff’s concern.

In DCD 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 September 7, 2007, response, the applicant stated that the ESBWR design will incorporate the new guidance of RG 1.209, “Guidelines for Environmental Qualification of Safety-Related Computer-Based Instrumentation and Control Systems in Nuclear Power Plants,” issued March 2007. Additionally, the applicant provided examples of qualification methods for equipment in a mild environment, including specification and certification to temperature extremes, electromagnetic interference, radiofrequency interference, 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 electromagnetic interference, radiofrequency interference, and voltage surges; and seismically tested. A surveillance/maintenance program will be based on the vendor's recommendations, which may be supplemented with operating experience and typically includes inspections, adjustments, modifications, and calibration. The staff finds the proposed marked-up revision to the DCD acceptable. **RAI 3.11-9 is being tracked as a confirmatory item.**

The environmental parameters listed in Appendix 3H to DCD Tier 2 include thermodynamic, radiation, and chemical spray parameters. 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). In RAI 3.11-10, the staff asked the applicant to discuss these items in the equipment qualification program. In its September 7, 2007, response, the applicant stated that the equipment qualification program includes submergence (if subject to submergence), aging for safety-related equipment in harsh environments, and synergic effects for safety-related equipment in harsh environments. This information resolved the staff's concern adequately.

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 a review of the radiation and shielding of ESBWR postaccident operations has been made, and 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 the equipment required to be environmentally qualified from the radiation environment.

The NRC staff reviewed Revision 3 to Appendix 3H to DCD Tier 2 and found it to be complete. However, the staff has not completed its review of all the parameters in detail.

The radiation qualification for individual safety-related components should be developed on the basis of the following two conditions:

(1) the radiation environment expected at the component location from equipment installation to the end of qualified life, including the time the equipment is required to remain functional after the accident

(2) the limiting DBA for which the component provides a safety function

Chapter 15 of this report discusses DBA conditions.

For the local source term, the ESBWR design adopted the accident source term presented in NUREG-1465, "Accident Source Terms for Light-Water Nuclear Power Plants—Final Report," issued February 1995. The staff finds this acceptable.

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 dated September 4, 2007, the applicant stated that the EQ program will meet the guidance of RG 1.97, and it will add a reference to RG 1.97 to DCD Section 3.11. **RAI 3.11-13 is being tracked as a confirmatory item.**

In RAI 3.11-14, the staff asked the applicant whether the EQ program will meet the guidance of NUREG-0588. In its response dated September 4, 2007, 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 Category I guidance may be used if RG 1.89 does not provide relevant guidance. For example, NUREG-0588 provides detailed guidance for areas such as establishing the temperature and pressure conditions inside containment for LOCA/MSLB conditions, environmental conditions for outside containment, selection of qualification methods, qualification by test, test sequence, margin, and aging. As such, the staff recommended that GEH add NUREG-0588 to the list of references applicable to its EQ program. In its November 21, 2007, letter, the applicant stated that it will add NUREG-0588 as a reference to DCD Tier 2, Revision 5, Section 3.11.6. The staff determined that the marked-up version of DCD was acceptable. **RAI 3.11-14 is being tracked as a confirmatory item.**

3.11.3.2 Qualification Methods

3.11.3.2.1 Electrical Equipment in a Harsh Environment

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 reviewing the DCD, the staff determined that the methodology used by the applicant for the ESBWR relied primarily on IEEE-323-2003. 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, 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. However, the NRC staff has not endorsed IEEE-323-2003. In RAI 3.11-11, the staff asked the applicant to provide appropriate justification for deviations from IEEE-323-1974 consistent with current regulatory practice. In its September 7, 2007, response, the applicant stated that the NRC recently endorsed IEEE-323-2003 in RG 1.209. Additionally, IEEE-323-2003 has effectively the same requirements for harsh environment qualification as IEEE-323-1974. The applicant identified the significant changes in IEEE-323-2003. The NRC believes that the endorsement 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 is being tracked as an open item.**

In addition, for current-generation operating reactors, the staff's definition of a mild radiation environment for electronic components, such as semiconductors, or any electronic component containing organic materials differs from the definition of a mild radiation environment for other equipment. The staff defines a mild radiation environment for such electronic equipment as a total integrated dose of less than 10 gray (Gy) ($1x10^3$ rad). For other equipment, it is less than 100 Gy ($1x10^4$ rad). With the expected significant increase in the quantity and variety of electronic components in newer generation plants, the staff has increasing concern about the ability of these components to be environmentally qualified.

In Table 3H-6 of Appendix 3H to DCD Tier 2, the applicant stated that electronic equipment is qualified for gamma dose of less than $1x10^4$ 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 less than $1x10^3$ rad. In RAI 3.11-12, the staff asked the applicant to provide details regarding methods to qualify electronic equipment for gamma dose of less than $1x10^4$ rad. In response to this concern, in its September 10, 2007, letter, the applicant stated that GEH will define a mild radiation environment for electronic equipment as a total integrated dose 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). 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 finds that the applicant resolved the staff's concern satisfactorily. **RAI 3.11-12 is being tracked as a confirmatory item.**

3.11.3.2.2 Safety-Related Mechanical Equipment in a Harsh Environment

For the EQ of mechanical equipment, the NRC 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:

- Identify safety-related mechanical equipment located in harsh environment areas, including required operating time.
- Identify nonmetallic subcomponents of such equipment.
- Identify the environmental conditions for which the equipment must be qualified.
- Identify nonmetallic material capabilities.
- Evaluate environmental effects.

Mechanical equipment will experience the same environmental conditions as those defined in 10 CFR 50.49 for electrical equipment, and the staff used such conditions in reviewing the EQ of mechanical equipment.

The NRC staff reviewed Sections 3.2 and 3.11, and Appendix 3H, of ESBWR DCD Tier 2 for the EQ of safety-related mechanical equipment used in the ESBWR.

ESBWR DCD Tier 2, Section 3.11.2.2, states that safety-related mechanical equipment located in harsh environments is qualified by analyses of materials data, which are generally based on test and operating experience. In response to RAI 3.11-1 dated March 28, 2007, the applicant stated that the selection of specific equipment for the ESBWR is currently not finalized. However, the applicant indicated that pumps will be excluded since the system employs a passive design. The applicant stated that the GEH EQ program is based on the methodology and guidelines in NEDE-24326-1-P (Class III), which is a LTR based on interpretation of the NUREG-0588, Category I, provisions. In a supplemental RAI, the NRC staff requested the

applicant to indicate the acceptance of this topical report and plans to revise the DCD to indicate that the COL applicant needs to fully describe the EQ program in its application.
As a COL information item, the staff proposed in its RAI that as part of its description of an EQ program, the COL applicant should (1) provide examples of the EQ methods and standards applied to mechanical equipment located in harsh environments, (2) identify the nonmetallic subcomponents, applicable environmental conditions, required operating life, capabilities of the nonmetallic subcomponents, and basis for the EQ of mechanical equipment located in a harsh environment, and (3) discuss the surveillance and maintenance program to be developed for mechanical equipment located in a harsh environment to ensure functionality during the design life. The applicant has not responded to this supplemental RAI. **RAI 3.11-1 is being tracked as an open Item.**

ESBWR DCD Tier 2, Section 3.11.2.2, states 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 the required safety-related function in the 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 response to RAI 3.11-2 provided in its March 28, 2007, letter, 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. The applicant also stated that it cannot furnish specific examples of EQ for the ESBWR, including hardware-specific surveillance and maintenance programs, since equipment will not be procured until after the COL is issued. In a supplement to RAI 3.11-2, the NRC staff requested the COL applicant to provide this same information as discussed in the supplement to RAI 3.11-1. This issue is related to Open Item 3.11-1.

ESBWR DCD Tier 2, Section 3.11.5, states that the COL holders shall prepare the EQD summarizing the qualification results for all equipment identified in DCD Section 3.11.1. In RAI 3.11-3, the NRC staff requested that the applicant provide the basis for the EQ of safety-related mechanical equipment being addressed by the COL holder. In its response to RAI 3.11-3 provided in its March 28, 2007, letter, 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. The applicant also stated that the COL holder is responsible for maintaining the equipment qualification records summarized in the EQD. In a supplement to RAI 3.11-3, the NRC staff requested the same information as in the supplement to RAI 3.11-1. This issue is related to Open Item 3.11-1.

ESBWR DCD Tier 2, Section 3.11.5, states that the COL holders shall record and maintain the results of the qualification tests in an auditable file in accordance with the requirements of 10 CFR 50.49(j). In that 10 CFR 50.49(j) applies to electrical equipment, the NRC 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 provided in its March 28, 2007, letter, 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-323. The applicant stated that COL holders will have complete and auditable records available that describe the EQ method used for mechanical and electrical equipment in sufficient detail to document the degree of compliance with the SRP. Thereafter, such records will be updated and maintained current as equipment is replaced, tested, or qualified. In a supplement to RAI 3.11-4, the NRC staff requested that the applicant revise the DCD to specify that mechanical equipment qualification will follow 10 CFR 50.49(j), RG 1.89, and IEEE-323. The staff also requested that GEH specify that the COL applicant will need to fully describe the equipment qualification program in accordance with Commission guidance and RG 1.206. **The**

applicant has not responded to this request related to a COL information item in the supplement to RAI 3.11-4.

ESBWR DCD Tier 2, Section 3.11, discusses the EQ of safety-related mechanical equipment. In RAI 3.11-5, the NRC 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 provided in its March 28, 2007, letter, the applicant stated that equipment performance degradation from environmental aging conditions for EQ consideration follows the GEH EQ program guidelines addressed in NEDE-24326-1-P. In a supplement to RAI 3.11-5, the staff asked the applicant to address potential performance degradation of mechanical equipment under environmental conditions (such as electric motor output). In its response to the supplement to RAI 3.11-5 provided in its August 9, 2007, letter, the applicant stated that expected extremes in power supply voltage, range, and frequency as defined in the product performance specification are applied under NEDE-24326-1-P along with testing. The staff finds that the GEH response provides an adequate methodology for addressing potential EQ degradation of mechanical equipment under adverse environments. The functional qualification section of Section 3.9.6 of this SER addresses the potential output degradation of MOVs.

3.11.4 Conclusions

On the basis of its review of DCD Tier 2 and NRC policies and practices, the NRC staff concludes that because of open items that require resolution, the staff is unable to finalize its conclusion regarding the acceptability of the program proposed by the applicant for the EQ of safety-related equipment in the ESBWR.

3.12 Piping Design

This section provides the NRC staff's safety evaluation of DAC for the ESBWR piping system design documented in DCD Tier 2, Revision 3, submitted GEH. The evaluation includes those portions of DCD Section 3.7.3, "Seismic Subsystem Analysis," and Section 3.9, "Mechanical Systems and Components," that are applicable to piping systems. The staff used the NRC acceptance criteria and guidelines documented in the GDC, Sections 3.7.3 and 3.9 of NUREG-0800, RGs, and other NRC regulatory guidance documents (e.g., NUREG reports, NRC BLs) 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 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 NS 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 Title 10, Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants," of the *Code of Federal Regulations* (10 CFR Part 52) (and as stated in DCD Tier 1, Section 3.1), using the design methods and acceptance criteria discussed herein, 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 reviewed DCD Tier 2, Revision 3, Sections 3.7.3 and 3.9 in accordance with SRP Section 3.7.3, "Seismic Subsystem Analysis," Revision 2; Section 3.9.1, "Special Topics for Mechanical Components," Revision 2; Section 3.9.2, "Dynamic Testing and Analysis of Systems, Components, and Equipment," Revision 2; and Section 3.9.3, "ASME Code Class 1, 2, and 3 Components, Component Supports, and Core Support Structures," Revision 1. The basis of this review primarily includes 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 approved 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, "Codes and Standards," and the following GDC found in Appendix A of 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 10 CFR Part 50, Appendix S, with regard to design transients and resulting load combinations for piping and pipe supports to withstand the effects of earthquakes combined with the effects of normal or accident conditions

- GDC 4, with regard to piping systems and pipe supports important to safety being designed to accommodate the effects of, and to be compatible with, the environmental conditions of normal as well as postulated events, such as 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 be constructed and 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, testing, and inservice surveillance of piping and pipe supports using the following industry codes and standards, RGs, and staff technical reports:

- ASME Code, Section III, “Rules for Construction of Nuclear Power Plant Components,” which contains the material specifications, design criteria, fabrication and construction requirements, construction testing and examination techniques, and SIT of the piping and pipe supports

- ASME Code, Section XI, “Rules for Inservice Inspection of Nuclear Power Plant Components,” which contains ISI and testing requirements and repair and replacement criteria for piping and pipe supports

- RG 1.29, “Seismic Design Classification,” Revision 3, September 1976

- 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 Concrere,” November 2003

- RG 1.147, “Inservice Inspection Code Case Acceptability, Section IX, Division 1,” Revision 14, August 2005

- 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 Nuclear Regulatory Commission Piping Review Commettee—Evaluation of Other Loads and Load Combinations," Volume 4, 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 assure 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, are provided in 10 CFR 50.55a. RGs 1.84 and 1.147 list ASME Code cases that the NRC staff finds acceptable.

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, "Reactor Coolant System and Connected Systems," 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 QG D piping and its supports, DCD Tier 2, Table 3.2-3, indicates that the ASME/ANSI Standard B31.1, "Power Piping," (hereafter referred to as B31.1 piping) will be used for 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 nature associated with the design and construction practices (including inspection and examination techniques) of the ASME Code. Fixing 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 to reach 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 for 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 may be 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, such considerations, if necessary, are reflected in the various sections of this safety evaluation.

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 GEH identify the ASME Code edition and applicable addenda for the design of the ESBWR piping systems at this design certification stage. In a letter to the NRC (MFN 06-119), GEH 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, GEH 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, GEH 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 assurance that the COL applicant will satisfy all limitations and modifications specified in 10 CFR 50.55a(b)(1). Therefore, the staff finds that the revision to DCD Tier 2, Table 1.9-22, provides an acceptable resolution of RAI 3.12-1.

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. However, the COL applicant should also ensure that the design is consistent with the construction practices (including inspection and examination methods) of the ASME Code edition and addenda, as endorsed in 10 CFR 50.55a, in effect at the time of the COL application. The COL application must identify to the NRC staff for review and approval the portions of the later ASME Code editions and addenda.

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 RGs 1.84 and 1.147. The staff review is based on Revision 33 of RG 1.84, issued August 2005, and Revision 14 of RG 1.147, issued August 2005. These RGs include ASME Code cases listed up to S06 (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 RGs 1.84 and 1.147 at the time of the COL application, provided they do not alter the staff’s safety findings on the ESBWR certified design.

ASME Code cases initially listed in Table 5.2-1 of the DCD applicable to the RCS pressure boundary piping and pipe support design are listed below. The staff identified a number of 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[1], "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 (MFN 06-199, S01), GEH 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, California, on January 9–12, 2007, about the need to reference this ASME Code case, GEH indicated that it would delete this ASME Code case from the DCD. DCD Tier 2, Revision 3, 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 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 (MFN 06-119, S01), GEH revised DCD Tier 2, Revision 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 (MFN 06-119), GEH deleted the ASME Code case in DCD Tier 2, Revision 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 GEH provides the design report summary in accordance with ASME Code, Section NCA-3551.1, 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, GEH 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 (MFN 06-119, S01), GEH revised DCD Tier 2, Revision 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.

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[1] ASME Code Case N-71-17 is identified as the 17th revision of the ASME Code Case N-71.

- 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-416-2, “Alternative Pressure Test Requirement for Welded Repairs or Installation of Replacement Items by Welding, Class 1, 2, and 3, Section XI, Division 1.” In DCD Tier 2, Revision 1, Table 5.2-1, GEH stated that Revision 2 of this ASME Code case was conditionally accepted. However, the staff has unconditionally accepted the current Revision 3 of this ASME Code case (N-416-3) in RG 1.147. In response to RAI 3.12-2 (MFN 06-119, S01), GEH indicated that DCD Tier 2, Revision 2, Table 5.2-1, was revised to show that Revision 3 of the ASME Code case (N-416-3) is used unconditionally in the ESBWR piping design, consistent with the guidance in RG 1.147. In RG 1.84, the staff accepts the unconditional use of Revision 3 of ASME Code Case N-416.

- ASME Code Case N-460, “Alternative Examination Coverage for Class 1 and Class 2 Welds, Section XI, Division 1.” The staff accepts the use of this ASME Code case in RG 1.147.

- ASME Code Case N-463-1, “Evaluation Procedures and Acceptance Criteria for Flaws in Class 1 Ferritic Piping That Exceed the Acceptance Standards of IWB-3514.2, Section XI, Division 1.” ASME has annulled this unconditionally approved Code case as noted in RG 1.147. In response to RAI 3.12-2 (MFN 06-119, S01), GEH deleted this ASME Code case from DCD Tier 2, Revision 2, Table 5.2-1, and stated that the flaw evaluation is calculated in accordance with ASME Code, Section XI, requirements for the ESBWR piping design. Since GEH uses the ASME Code requirements for flaw evaluation of piping and pipe supports in the ESBWR standard plant, the staff finds this acceptable.

- ASME Code Case N-479-1, “Boiling Water Reactor (BWR) Main Steam Hydrostatic Test, Boiling Water Reactor (BWR) Main Steam Hydrostatic Test, Section XI, Division 1.” ASME has annulled this unconditionally approved Code case as noted in RG 1.147. In response to RAI 3.12-2 (MFN 06-119, S01), GEH deleted this ASME Code case from DCD Tier 2, Revision 2, Table 5.2-1, and stated that the hydrostatic pressure test is performed in accordance with the requirements of ASME Code, Sections NB-6221 and NC-6221, for the piping systems. Since GEH uses the ASME Code requirements for hydrostatic pressure testing of piping systems in the ESBWR standard plant, the staff finds this acceptable.

- ASME Code Case N-491-2, “Alternative Rules for Examination of Class 1, 2, 3 and MC Component Supports of Light Water Cooled Power Plants, Section XI, Division 1.” In DCD Tier 2, Revision 1, Table 5.2-1, GEH stated that this ASME Code case was not listed in RG 1.147. However, this ASME Code case is accepted by the staff in RG 1.147. GEH deleted this ASME Code case from Revision 2 of DCD Tier 2, Table 5.2-1. Therefore, GEH will use the rules in Section XI of the ASME Code for the examination of pipe supports, which the staff finds acceptable.

- 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, S01), GEH deleted this ASME Code case from DCD Tier 2, Revision 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 GEH 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.” This ASME Code case was conditionally accepted by the staff in the past (subject to certain limitations), but it was subsequently annulled by ASME as noted in RG 1.84. In response to RAI 3.12-2 (MFN 06-119, S01), GEH deleted this ASME Code case from DCD Tier 2, Revision 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, GEH included a sixth condition extending the use of the damping values beyond 33 hertz (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 it is now annulled by ASME. 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 GEH 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 (MFN 06-119, S01), GEH deleted this ASME Code case from DCD Tier 2, Revision 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). GEH 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 (MFN 06-119, S01), GEH deleted the footnotes in DCD Tier 2, Revision 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, California, on January 9–12, 2007, GEH stated that the ESBWR design of pipe supports uses the single angle criteria given in 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 finds that GEH has provided acceptable resolution to the concerns raised in RAI 3.12-2. The staff concludes that the ASME Code cases referenced in DCD Tier 2, as discussed above, either meet the guidelines of RGs 1.84 or 1.147, or have been reviewed and endorsed by the staff, and are acceptable for use in the ESBWR design.

3.12.3.3 Design Specifications

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

During the site audit at the GEH offices in Wilmington, North Carolina, on May 22–26, 2006, GEH provided the Nuclear Boiler Design Specification B21-4010 (26A6600, Revision 0, dated July 27, 2005) and the MS Piping System Design Specification B21-4020 (26A6910, Revision 0, dated May 17, 2006) for staff review. The staff's review of the first document (B21-4010) found no specific problems. However, when the staff reviewed the second document (B21-4020) and the sample piping analysis performed by GEH on one of the two MS piping problems, the staff found some missing and inconsistent information in the design specification related to the parameters used in the MS piping analysis. For example, the definition of the normal operating temperature of the SRV discharge piping from the MS lines to the suppression pool was missing. GEH used 57.2 °C (135 °F) in the piping analysis, although the design specification defined no such condition. The staff identified to GEH all of the items that needed correction in a future revision of the design specification.

During a followup site audit at the GEH offices in San Jose, California, on January 9–12, 2007, GEH provided Revision 1 of the MS Piping System Design Specification B21-4020 for staff review. Based on this review, the staff found that the missing information identified in the previous audit was appropriately incorporated. However, the staff found that the subject design specification still did not reflect all of the changes made to DCD Tier 2, Revision 2, with regard to the editions or versions of the codes and standards, ASME Code cases, and NRC RGs. When it reviewed another design specification entitled, "Composite Design Specification—Industry Codes and Standards" (26A6007AC, Revision 1, dated November 29, 2006), the staff found that this design specification contained the correct versions of all codes and standards and related guidelines consistent with the recent revision to the DCD Tier 2, Revision 2. With regard to Design Specification B21-4020, the staff also found that there were still some missing design parameters, including the incorrect design temperature for the SRV discharge lines under the normal plant operating condition. GEH agreed to revise Design Specification B21-4020 to include all staff-identified items before receiving its design certification.

DCD Tier 2, Revision 2, Section 3.9.9.4, indicates that COL holders referencing the ESBWR design will make available to the staff for audit purposes design specifications and design reports required by the ASME Code for vessels, pumps, valves, and piping systems.

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:

- GEH 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.
- GEH identified ASME Codes and Code cases that may be applied to ASME Code Class 1, 2, and 3 piping and pipe supports and which are acceptable to the staff.

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, transients, 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. GEH 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, GEH added Tables 3.9-10 through 3.9-12 which provide the load combinations and acceptance criteria for snubber, strut, and anchor/guide types of pipe supports. In DCD Tier 2, Section 3.7.3, GEH stated that the guidelines given in (nonmandatory) Appendix N 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 to ASME Code, Section III, in its entirety, the staff requested, in RAI 3.12-10, that GEH provide the technical justification for any criterion in Appendix N that differs from the guidance provided in the current standard review plans and RGs. In response to RAI 3.12-10, GEH withdrew the use of this appendix for the ESBWR piping design and is relying instead on the criteria given in the NRC standard review plans and RGs. The staff finds this acceptable. Section 3.12.4.11 of this SER 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 the SER discusses the staff's evaluation of the application of snubbers in the design of piping. Section 3.6.2 of the SER 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 made 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. As an alternative, DCD Tier 2, Section 3.7.2.6, allows the use of the 100-40-40 method of combination as described in ASCE Standard 4-98. The use of the SRSS method for combining the responses resulting from each of the three directions is consistent with RG 1.92, Revisions 1 and 2, and, therefore, is acceptable. The use of the 100-40-40 method that is currently accepted in RG 1.92, Revision 2, must follow the specific guidance given in the guide and not ASCE Standard 4-98. The staff is addressing this issue under RAI 3.7-41, which is evaluated in Section 3.7.2.3.6 of the SER.

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 the SER discusses this further.

The staff reviewed the DCD description of the response spectrum method with USM and found that the response spectrum method with USM is consistent with the applicable guidelines in SRP Section 3.9.2 or RG 1.92, Revision 2. Therefore, the staff finds this acceptable.

3.12.4.3 Response Spectrum Method with Independent Support Motion

ISM 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, “Multiple-Supported Equipment and Components with Distinct Inputs,” 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 which have the same time-history input. This usually means all supports located on the same floor, or portions of a floor, of a structure. Second, the responses from 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 ABS 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 ABS, 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 ABS method discussed in NUREG-1061 for combining group responses for a given direction differ). In RAI 3.12-3, the staff requested that GEH either follow the recommendations contained 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 GEH during the site audit at the GEH offices in San Jose, California, 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. GEH committed to provide 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 is being tracked as an open item,** pending staff review of the GEH study.

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.

GEH indicated that, in accordance with industry practice and as described in Section 3.2.2.1(c) of ASCE Standard 4-98, an acceptable approach for selecting the time step (Δt) is that the Δt used shall be small enough such that the use of one-half of Δt does not change the response by more than 10 percent. In RAI 3.12-4, the staff requested that GEH either clarify whether this is part of the piping analysis requirements or provide a technical justification for not considering this criteria along with the other criterion described above for seismic and hydrodynamic loading analyses. GEH responded (MFN 06-119) by stating 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 DCD, Revision 2, and found this technically acceptable, however, GEH stated that the approach is an alternate approach rather than part of the requirement in the time-history method of analysis as discussed in its letter (MFN 06-119, S01). 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 it is an industry practice typically used in the time-history analysis, the staff finds the revision of DCD Tier 2, Revision 3, acceptable. Therefore, RAI 3.12-4 is 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 as to why this approach is sufficiently accurate to capture the piping system response. GEH stated (MFN 06-119) 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 finds this acceptable; therefore, RAI 3.12-5 is 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 FRS for use as input to a response spectrum analysis for piping and equipment analysis, the peaks of the FRS, 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. GEH stated (MFN 06-119) 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 $1/(1 \pm 0.15)$ 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 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 finds this acceptable; therefore, RAI 3.12-6 is 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 be in compliance 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. GEH stated (MFN 06-119) that the use of the static coefficient method satisfies the requirements of SRP Sections 3.7.2 and 3.9.2 and committed to update 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 a 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 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, North Carolina, 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, Revision 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 finds this acceptable; therefore, RAI 3.12-7 is 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 the SER. GEH did not provide any details about 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 a letter dated May 3, 2006 (MFN 06-119), GEH stated that the ESBWR piping design and analysis do not use inelastic analysis methods. The staff reviewed DCD Tier 2, Revision 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 and analysis, except for pipe whip restraints. Section 3.6.2 of the SER provides the staff evaluation of pipe whip restraints. The staff finds the applicant's discussion of inelastic analysis methods acceptable; therefore, RAI 3.12-8 is 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 millimeters (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 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 CUFs, 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, Revision 2, Section 3.7.3.16, which indicates that the static and dynamic analysis methods defined in Section 3.7.3 of DCD Tier 2, Revision 2, 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, North Carolina, 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, Revision 2, Section 3.7.3.16, for the piping handbook are acceptable. Section 3.12.5.4 of this SER further discusses this issue as part of the decoupling criteria.

3.12.4.8 Nonseismic/Seismic Interaction (II/I)

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

For NS 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 NS Category I system. In addition, the NS 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, Revision 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 the SER 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:
    - 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
- 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. GEH stated (MFN 06-119) 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, North Carolina, on May 22–26, 2006, GEH also confirmed that no Category I buried piping is located within buried tunnels between the NI and other surrounding structures in the ESBWR design. GEH revised DCD Tier 2, Revision 2, Section 3.7.3.13, to indicate that the ESBWR design does not include buried seismic Category I piping. The staff finds this clarification acceptable; therefore, RAI 3.12-9 is 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 herein 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 GEH to identify which specific guidelines are applicable to the ESBWR piping design. GEH responded (MFN 06-119) that the NRC guidance documents (SRP and RGs) will be used in lieu of Appendix N. GEH deleted all references to Appendix N to ASME Code, Section III, from DCD Tier 2, Sections 3.7.3 and 3.7.2.9, in its Revision 2 of the DCD. The staff finds this clarification acceptable; therefore, RAI 3.2-10 is resolved.

3.12.4.12 Conclusions

On the basis of the evaluations in Section 3.12.4, the staff determined that, because open RAI 3.12-3 is not yet resolved, the staff was unable to finalize its conclusion about the analysis methods to be used for all seismic Category I piping systems, as well as NS Category I piping systems that are important to safety.

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, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants,” 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, “Piping Benchmark Problems for the General Electric Advanced Boiling Water Reactor,” 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 fine motion CRD, pumps and motors, and heat exchangers. Section 3.10 of the SER discusses the staff evaluation of equipment-qualification-related programs. 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, FEMs 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. It is through these joints that 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 response spectrum analysis 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 CUFs for Class 1, 2, and 3 piping components in accordance with Subsections NB, NC and ND-3650 of ASME Code, Section III. ANSI7 is also used to combine loads and calculate combined service levels A, B, C, and D 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/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.

GEH identified (MFN 06-119) 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, North Carolina, 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 manuals for PISYS and ANSI7 and the code validation documents for all four computer codes audited were incomplete. (Note: The user manuals for RVFOR and TSFOR are part of the code validation documents because they both are smaller computer codes in comparison to PISYS and ANSI7). During the site audit at the GEH offices in San Jose, California, on January 9–12, 2007, the staff reviewed the completed user 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 manuals for PISYS07 (NEDE-32352, 1998) and ANSI713D (NEDE-23518, Revision 1, 2000) describe the program functions. GEH did not update the programs to the current requirements given in the ASME Code and regulatory guidance documents that are described in Revision 2 of the 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 will compare the design criteria used in the two computer codes with the design criteria presented in DCD Tier 2, Revision 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). If any differences are identified, then the computer codes will be updated. The applicant will submit the results of this effort to the staff in a supplement to its response to RAI 3.12-11.

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, North Carolina, 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 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, California, 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, California, 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 demonstrated 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 ABS method for closely spaced modes. GEH indicated that it will provide some technical justification to confirm the reasons for the differences noted as part of the supplement to the RAI 3.12-11 response. This information will (1) verify that the modal combination method and the high frequency effect (missing mass) agree with RG 1.92, Revision 2, which is the current position in DCD Tier 2, Revision 2, and (2) will identify the order of the combination methods used for grouping, modal combination, and directional combination in the PISYS code.

GEH also provided the validation document for the ANSI computer code entitled, “A Piping System Analysis Program for Workstation Application—ANSI713D User’s Manual,” NEDE-23518, Revision 1, Class 2, issued October 2000. The document evaluates stresses and CUFs for Class 1 piping components in accordance with ASME Code requirements. The staff reviewed this validation document and found that it meets the guidance in SRP Section 3.9.1. GEH (as discussed earlier) needs to confirm compliance of the computer code with the specific requirements in the ASME Code, 10 CFR 50.55a(b)(1), and other commitments in DCD Tier 2, Revision 2.

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, North Carolina. Section 3.12.8 of the SER discusses the findings of the confirmatory analysis effort.

Based on the GEH response to RAI 3.12-11, the site audit review findings, and the independent confirmatory analyses discussed above, issues concerning this RAI are considered unresolved. **RAI 3.12-11 is being tracked as an open item.**

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 FEMs 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 center line. Furthermore, all pipe guides and snubbers are modeled using representative stiffness values. 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. The stiffness of the supporting structures is included in the analysis, unless the supporting structure can be shown to be rigid.

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 to, and building steel/structures supporting the pipe supports. DCD Tier 2, Section 3.7.3.3.2, provides criteria to model 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, California, 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. GEH agreed to delete this sentence from the DCD. Since DCD Tier 2, Section 3.7.3.3.1, provides acceptable criteria for the modeling of lumped masses, the reference to DCD Tier 2, Section 3.7.3.3.2, is not necessary as additional criteria and may mislead the analyst. DCD Tier 2, Revision 3, contains the revision to Section 3.7.3.3.1 which deletes the inappropriate reference to Section 3.7.3.3.2. Therefore, the staff finds the proposed resolution to RAI 3.12-12 acceptable.

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 requested 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. The GEH response (MFN 06-119) did not address the question adequately. Subsequently, DCD Tier 2, Revision 3, 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 for ESBWR design. Since special engineered supports (e.g., energy absorbers and limit stops) are not used in the ESBWR piping design, the staff finds the resolution to RAI 3.12-13 acceptable.

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. The staff requested that GEH address the following items regarding computer code benchmark procedures in RAI 3.12-14:

(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.

GEH stated (MFN 06-119) 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 site audit at the GEH offices in San Jose, California, on January 9–12, 2007, the staff indicated that the use of the piping computer codes specified in the DCD cannot be modified without staff review (i.e., they are Tier 2* criteria). DCD Tier 2, Section 3D.4.1, Revision 3, deleted the last sentence of the last paragraph regarding benchmarking by COL applicants against NUREG/CR-6049 and the computer code NOZAR for area reinforcement which will not be used for ESBWR design. Therefore, the staff finds that Revision 3 of DCD Tier 2 resolves RAI 3.12-14.

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 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 provide the analysis method of a decoupled small-bore piping from a large piping system. GEH stated (MFN 06-119) that the non-safety-related piping and components whose structural failure caused by a SSE could hinder the operation of the safety-related piping components shall be designed to withstand the SSE without loss of piping integrity. The load combination and acceptance criteria are consistent with the Class 2 piping design requirements. For dynamic and SAM analyses, GEH identified that (1) the decouple criteria is 25 to 1 in the ratio of “moment of inertia” of run pipe to branch pipe, (2) the linear spectrum with accelerations from the seismic and dynamic analyses used in the large-bore piping analysis (run pipe) are applied to this interface point for the small branch piping design, as well as the seismic and dynamic displacements at the connection point, and (3) formal analysis methods and procedures similar to the main pipe should be used, although a more conservative handbook analysis may also be used. During the audit at the GEH offices in Wilmington, North Carolina, on May 22–26, 2006, the staff asked GEH to clarify the term “linear spectrum” and to explain how the amplification of the run pipe is factored into the input spectra and SAM displacement input at the small branch line attachment to the run pipe. In addition, the staff asked GEH to provide the design criteria for decoupling and analyses of a seismic Category I branch piping as well. GEH has not yet provided the criteria for analyzing Class 1, 2, or 3 branch lines from a large-bore piping system for seismic and other dynamic loads; thus, this RAI is unresolved. **RAI 3.12-15 is being tracked as an open item.**

3.12.5.5 Conclusions

On the basis of the discussions in the above sections and evaluation of DCD Tier 2, Sections 3.7.3.3 and 3.9, the staff will, pending resolution of the open RAIs 3.12-11 and 3.12-15, defer its final conclusions regarding design control measures to ensure the quality of computer programs and design methods.

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 vs. 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 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 ESP 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 the SER 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 the SER.

3.12.6.2 Design Transients

DCD Tier 2, Table 3.9-1, lists the design transients and the number of either plant operating events or cycles for each of the design transients that will be used in the design and fatigue analyses of the ASME Code Class 1 piping systems. DCD Tier 2, Section 3.9.1.1, describes the plant events affecting the mechanical systems, components, and equipment in two groups — (1) plant operating events during which thermal-hydraulic transients occur, and (2) dynamic loading events caused by accidents, earthquakes, and certain operating conditions.

The following are plant operating conditions:

- 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

The design specification and/or stress report associated with particular equipment document the design and analysis of safety-related piping and equipment using specific applicable thermal-hydraulic transients, which are derived from the system behavior during the events listed in DCD Tier 2, Table 3.9-1. DCD Tier 2, Table 3.9-2, shows the load combinations and the standard acceptance criteria.

DCD Tier 2, Section 3.9.3.1.1, lists the probability of an event associated with the plant conditions occurring in a reactor year. The correlation identifies the relevant plant conditions and assigns the appropriate ASME Code, Section III, service levels for any hypothesized event or sequence of events.

The COL applicant will document the number of events or cycles resulting from each of the listed design transients that are applicable to other ASME Code Class piping systems in the design specification and/or stress report for each component.

3.12.6.3 Loadings and Load Combinations

GEH provided the design criteria for ASME Code Class 1, 2, and 3 piping and piping supports, using the load combinations, design transients, and stress limits in DCD Tier 2, Section 3.9.3.1. The staff reviewed the methodology used for load combinations and the selected values of allowable stress limits. As a result, the staff found several issues pertaining to this section and asked GEH to clarify them in four separate RAIs (RAIs 3.12-16, 3.12-17, 3.12-18, and 3.12-38).

DCD Tier 2, Sections 3.9.3.3 and 3.9.3.4, initially listed Equation 12 of ASME Code, Subsection NB-3600, allowable stress limit of 2.4 S_y (instead of 2.4 S_m). In RAI 3.12-16, the staff asked GEH to clarify how 2.4 S_y satisfies Equation 12 of ASME Code, Subsection NB-3600. GEH agreed (MFN 06-119) to revise these sections to 2.4 S_m in Revision 2 of the DCD. GEH also stated that the purpose of specifying 2.4 S_m, instead of 3.0 S_m, in accordance with the ASME Code-defined value for Equation 12, is to satisfy the pipe break criteria of NRC BTP MEB 3-1 in SRP Section 3.6.2. In addition, during the audit at the GEH offices in Wilmington, North Carolina, on May 22–26, 2006, GEH stated that DCD Tier 2, Table 3.9-9, notes that the cumulative usage factor (U) in the acceptance criteria for Service Levels A and B is less than 1.0 ($U<1.0$) instead of less than 0.1 ($U<0.1$). Revision 3 to DCD Tier 2, Sections 3.9.3.3 and 3.9.3.4 and Table 3.9-9, provide the corrected allowable limits. The criteria in Table 3.9-9 are then consistent with the GEH design criteria of 0.8 x 3.0 S_m allowable for Equations 12 and 13 and a usage factor less than 0.1, which is consistent with BTP MEB 3-1 as provided in SRP Section 3.6.2. The staff finds the resolution to RAI 3.12-16 acceptable.

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, Revision 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, the 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 criteria are satisfied. GEH has not responded to RAI 3.12-17, which requested a description of how the NUREG-0484 criteria were satisfied for the Service Levels C and D load combinations given in DCD Tier 2, Table 3.9-9 (and Tables 3.9-10, 3.9-11, and 3.9-12). This issue is considered unresolved. **RAI 3.12-17 is being tracked as an open item.**

Since 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 this, and Section 3.12.6.5 of this report discusses such modifications. However, in note 12 to DCD Tier 2, Table 3.9-2, GEH did not include any additions/changes to the Class 1 piping requirements in ASME Code, Section III, Subsection NB-3600, for Equations 10 and 11 (similar to the additions/changes made for Class 2 and 3 piping).

GEH revised note 12 to DCD Tier 2, Revision 3, 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 10b are additional requirements consistent with the ABWR (note 7 to DCD Tier 2, Table 3.9-2) or the AP600[2] design certification acceptance criteria. The staff finds the resolution to RAI 3.12-18 acceptable.

During the site audit at the GEH offices in Wilmington, North Carolina, 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, Revision 3, 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 finds the resolution to RAI 3.12-38 acceptable.

On the basis of its review, the staff concludes that appropriate combinations of normal, operating transients, and accident loadings are specified to provide a conservative design envelope for the design of piping systems. The load combinations, pending satisfactory resolution of the RAIs, are consistent with the guidelines provided in SRP Section 3.9.3 and the staff position on single-earthquake design, and are, therefore, acceptable.

3.12.6.4 Damping Values

In DCD Tier 2, Section 3.7.1.2, GEH initially identified RG 1.61, Revision 0, for recommended values of damping to be used in the seismic analysis of SSCs. In addition, for piping components, GEH indicated that the damping values of ASME Code Case N-411-1 may be used, as permitted by RG 1.84, in place of the RG 1.61 damping values. However, ASME annulled the conditionally accepted Code case, as noted in Revision 33 of RG 1.84. The RG lists five specific limitations regarding the use of ASME Code Case N-411-1. The DCD also indicates that ASME Code Case N-411-1 damping cannot be used for analyzing linear energy-absorbing supports designed in accordance with ASME Code Case N-420. However, ASME also annulled Code Case N-420, as noted in RG 1.84. Section 3.12.3.2 of the SER discusses the staff evaluation of these ASME Code cases.

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 the damping values of ASME Code Case N-411-1 may be used, as permitted by RG 1.84, for ASME 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.

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[2] See staff position on the use of a single-earthquake design for SSC in the AP600 standard plant, (Enclosure to RAI 210.58).

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, Revision 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, as discussed in Section 3.12.3.2 of the SER, GEH has also deleted the references to ASME Code Case N-420 from the DCD since the ESBWR piping design will not use any linear energy-absorbing supports. The staff finds this acceptable; therefore, RAI 3.12-19 is resolved.

3.12.6.5 Combination of Modal Responses

DCD Tier 2, Section 3.7.2.7, indicates that for the response spectrum method of analysis the modal responses are normally combined 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 is applicable for the combination of modal responses. Section 3.7.2.3.7 of the SER 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 approximately returns 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. GEH stated (MFN 06-119) 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, California, on January 9–12, 2007, the staff requested that GEH provide further clarification regarding the definition of f_2. DCD Tier 2, Revision 3, 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 only requires 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 degree of freedom (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., retain 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 the SER 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 as follows:

- GEH should 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 (MFN 06-119), GEH 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, RG 1.92, Revision 2, states that the criteria presented in Appendix A to SRP Section 3.7.2 would 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 the RG 1.92, Revision 2, piping design criteria for missing mass contribution in DCD Tier 2, Revision 2. Section 3.7.2.7 needs to be revised to be consistent with the staff position in RG 1.92, Revision 2. Therefore, the staff considers this issue to be unresolved.

- GEH should address nonlinear analyses used to account for gaps between the pipe and its supports when subjected to vibratory loads with significant high frequency. The description of and justification for such analyses must be submitted to the staff for review and approval before use. During the site audit at the GEH offices in San Jose, California, on January 9–12, 2007, in a proposed response to RAI 3.12-21, 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 also provided a revised copy of its first response to this part of the RAI which eliminates the potential use of nonlinear analyses, thus preventing the issue from becoming a COL action item. This approach is acceptable to the staff.

Based on the above evaluation, the staff finds RAI 3.12-21(a) unresolved. **RAI 3.12-21(a) is being tracked as an open item.** The staff finds the proposed revision to RAI 3.12-21(b) acceptable, pending GEH revision of its response to the RAI (MFN 06-119).

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 their components, the fatigue analysis must include environmental effects, and the ASME Code Class 1 piping fatigue requirements must be met.

ASME Code, Section III, requires an evaluation of all ASME Code Class 1 piping for cumulative damage from fatigue. The CUF should consider all cyclic effects caused by the plant operating transients for a 60-year design life. However, recent test data indicate that the effects of the reactor environment could reduce the fatigue resistance of certain materials. A comparison of the test data with the ASME Code requirements suggests that the margins in the ASME Code fatigue design curves might be less than originally intended. 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. The staff provided draft guidance for evaluating the environmental effect on the fatigue analysis of components in 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," issued July 2006 (subsequently published as RG 1.207 in March 2007). During the site audit at the GEH offices in San Jose, California, on January 9–12, 2007, GEH indicated that it will revise the response to this RAI to explain that the fatigue calculations will consider environmental effects to be consistent with the staff position on environmental fatigue. GEH will also request a commensurate relaxation of the pipe break criteria based on a CUF less than 0.1, as stated in SRP Section 3.6.2. This issue is considered unresolved. **RAI 3.12-22 is being tracked as an open item.**

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 QG 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 assured by 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 mixing of hot and cold fluids occur.

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 thermal transients, the effects of these transients must be included in the design.

In RAI 3.12-23, the staff requested more detailed information on the fatigue evaluation of ASME Code Class 2 and 3 and QG D piping systems that are subject to cyclic loadings. GEH stated (MFN 06-119, S01) 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 (Rev. 2) stating that, in the event that 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 performed. The staff finds this acceptable; therefore, RAI 3.12-23 is resolved.

3.12.6.9 Thermal Oscillations in Piping Connected to the Reactor Coolant System

NRC BL 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 subjected 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 discussed in NRC BL 88-08. GEH identified (MFN 06-119) several piping systems that may be vulnerable to such thermal oscillations. During the site audit at the GEH offices in Wilmington, North Carolina, on May 22–26, 2006, the staff discussed with GEH each of these systems, along with their P&IDs. GEH provided (MFN 06-119, S01) a revised response discussing the potential for systems that may subject to thermal oscillations as discussed in NRC BL 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 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 GDCS (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, California, on January 9–12, 2007, the staff discussed these systems further with GEH. Based on this discussion, GEH indicated that, to satisfy NRC BL 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 SLCS (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, its approach to satisfying the issues discussed in NRC BL 88-08 is acceptable. In its revised response, GEH also stated that, if concerns remain when routing the nuclear boiler system, thermocouples will be added to the line to monitor piping temperatures. Later, GEH withdrew this statement and committed to rerouting the head vent piping to prevent any leaks from occurring. The staff finds the proposed resolution to RAI 3.12-24 acceptable, pending GEH revision of its response (MFN 06-119, 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. GEH identified (MFN 06-119) several piping systems that are vulnerable to thermal stratification. During the site audit at the GEH offices in Wilmington, North Carolina, on May 22–26, 2006, the staff discussed each of these systems, along with their P&IDs, with GEH. The applicant provided a revised response (MFN 06-119, S01) discussing the potential for systems that may 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 (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 MOVs. 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.

The PISYS computer program calculates piping forces and moments resulting from stratification. The solution has been benchmarked with ANSYS computer program results and exact solution by hand calculation for simple cases. The results of the stratification are included in the thermal cases. For ABWR feedwater piping analyses, 46 thermal cases are calculated. Therefore, Equations 10 through 14 of ASME Code, Section III, Subsection NB-3650, incorporate the thermal stratification effects.

To confirm the conservatism of the thermal stratification inputs to the piping analysis, GEH suggested that the initial ESBWR plant will be required to perform thermal stratification testing on the feedwater system piping. DCD Tier 2, Revision 2, Section 3.9.2.1.2, includes additional stratification testing.

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 heat up, hot standby, post-scram, isolation condenser 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 above discussion, the staff concludes that GEH has taken steps in its design to minimize 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 phenomenon. The staff finds this acceptable; therefore, RAI 3.12-25 is 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, “Clarification of TMI Action Plan Requirements,” issued November 1980, 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 SER 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.

GEH stated (MFN 06-119) that SRV tests were performed at Wyle in Huntsville, Alabama, in August 1981. The forces resulting from SRV discharge were measured. The tests confirmed that a 20-millisecond (msec) opening time should be used. The test results were presented in 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.

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 only addressed the rise time parameter. GEH provided a revised response (MFN 06-119, S01) indicating that Sections 5.2 and 15.2 of DCD Tier 2, Revision 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, Revision 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 finds this acceptable; therefore, RAI 3.12-26 is 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 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 EPRI, 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 inertia and relative displacement effects should be combined by the ABS 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 ABS 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 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. GEH stated (MFN 06-119) 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 high seismic activity site.

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 SRSS combination of the inertial and SAM responses for the USM method of analysis. This combination method may not affect the piping design since inertial and SAM loads are evaluated separately in the ASME Code load combination equations. However, this will affect the pipe support design when the loads inertia and SAM loads are combined in the evaluation. This issue is considered unresolved. **RAI 3.12-27 is being tracked as an open item.**

3.12.6.14 Cutoff Frequency for Hydrodynamic Loadings

DCD Tier 2, Revision 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 is applicable to both seismic and 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 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, “Determination of Number of Earthquake Cycles,” 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 found this commitment consistent with the NRC guidance document previously discussed and the Commission-approved staff recommendations on the issue of OBE elimination.

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 the SER 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. GEH responded (MFN 06-119, S01) 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 °C (70 °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 system operating temperature of 65 °C (150 °F) or less. This temperature corresponds to typical industry practice and is considered reasonable and acceptable by the staff. GEH revised DCD Tier 2, Section 3.9.3.1, to include these criteria. Therefore, RAI 3.12-28 is 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 ALWR 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. Also, in DCD Tier 2, Appendix 3K, Section 3K.2, GEH acknowledged that the staff will require periodic surveillance and LRT of the pressure isolation valves, via technical specifications, as part of the ISI program. In RAI 3.12-29, the staff requested GEH to indicate where the DCD includes the requirement that the COL applicant must perform this periodic surveillance and LRT.

GEH responded (MFN 06-119, S01) that DCD Tier 2, Appendix 3K, Section 3K.2, describes NRC positions related to the design of a low-pressure piping system that interfaces with the RCPB. The development of the ESBWR design considered these positions, which were developed during the NRC's review of the ABWR.

GEH also stated that the question relates to an NRC requirement on surveillance and LRT of the pressure isolation valve between the RCPB and a low-pressure system. Because the ESBWR does not include pressure isolation valves of this type, this NRC requirement is not applied in the ESBWR design. In every case, where closed valves that provide a transition from high to low pressure exist in a system, there are upstream (high-pressure-side) isolation valves that are available to isolate a leak or failure in the closed pressure transition valve. Additionally, relief valves on the low-pressure side of the piping provide pressure relief in the event of leakage or failure. Appendix 3K to DCD Tier 2 includes the evaluation of individual systems.

For clarification, GEH indicated that it added the following statement to Section 3K.2 of DCD Tier-2, Revision 2, "The periodic surveillance and leak rate testing requirements for high-pressure to low-pressure isolation valves are not applicable to the ESBWR, because, as shown in this appendix, the ESBWR design does not contain a pressure isolation valve between the RCPB and a low pressure piping system." The staff finds this acceptable; therefore, RAI 3.12-29 is resolved.

3.12.6.20 Conclusions

Pending resolution of RAIs 3.12-17, 3.12-21, 3.12-22 and 3.12-27 and the satisfactory implementation of the resolution of RAI 3.12-24, the staff is unable to finalize its conclusion regarding compliance with the requirements of GDC 1, 2, 4, 14, and 15.

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 to10 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, 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 that "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 response (MFN 06-119, S01), GEH deleted all references to ASME Code Case N-476, USS Steel Manual Publication T114-2/83, and ANSI/AISC N690 from DCD Tier 2, Revision 2. 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/guides) in the ESBWR piping system.

During the site audit at the GEH offices in San Jose, California, on January 9–12, 2007, the staff reviewed the proposed load combinations detailed in DCD Tables 3.9-10 for snubbers, 3.9-11 for struts, and 3.9-12 for anchors and guides. The staff identified several items 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 SER, 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 support 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 earlier in Section 3.12.7.1 of this SER, the staff requested GEH, in RAI 3.12-30, to 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 Tables 3.9-10 for snubbers, 3.9-11 for struts, and 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.

3.12.7.4 Pipe Support Baseplate 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 BL 79-02, "Pipe Support Base Plate Designs Using Concrete Expansion Anchor Bolts," Revision 1, dated June 21, 1979. 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 BL 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 BL 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, "Anchoring to Concrete," 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 (MFN 06-119, S01) as follows:

(1) Concrete expansion anchor bolts, with regard to safety factor and anchor plate flexibility, will follow all aspects IE BL 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 BL 79-02, Revision 2, dated November 8, 1979.

(3) Seismic Category IIA does not exist.

GEH included these changes in DCD Tier 2, Revision 3, Section 3.9.3.7. The staff finds the resolution to RAI 3.12-31 acceptable.

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, Revision 3, to state that special engineered pipe supports will not be used for 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, RBV caused by a LOCA, SRV and depressurization valve 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 in which dynamic support is required because 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, repair, and/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 ASME Code, Section III, Subsection NF, standards.

The staff finds that construction of snubbers to the ASME Code, Section III, Subsection NF, standards 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.

GEH responded (MFN 06-119, S01) 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, Revision 2, Section 3.7.3.3.1, includes these criteria. The staff finds the modeling criteria to be consistent with industry practice and are, therefore, acceptable. Thus, RAI 3.12-32 is 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 type 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 inertia effects resulting from the support mass.

In a letter dated December 11, 2006 (MFN 06-119), 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, Revision 2, Section 3.7.3.3.1, and confirmed that GEH included the criteria as stated above. The staff finds that the criteria are consistent with standard industry practice and, therefore, are acceptable. Thus, RAI 3.12-33 is 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 (MFN 06-119, S01) that the friction loads caused by 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 SS, 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, Revision 2, Section 3.9.3.7.1. The staff finds this acceptable; therefore, RAI 3.12-34 is 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, describes 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, S01) that current industry practice is to limit the total gap to 1/8 of an inch 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, California, 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, Revision 3, 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 staff finds the 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, S01) 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, Revision 2, Section 3.7.3.16, details the support design and criteria for instrumentation lines 50 mm and less. 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 a standard industry practice and is 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, Revision 2, Section 3.9.3.7.1, includes a discussion of the above criteria. The staff finds this acceptable; therefore, RAI 3.12-36 is 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 specified 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 what the suspension design specification is and how the deflection limits are developed. GEH responded (MFN 06-119, S01) that the ESBWR design of piping supports considers a deflection limit of 1.6 mm for erection and operation loadings, based on WRC BL 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 "Suspension Design Specification" will be changed to "Piping Design Specification."

GEH revised Section 3.9.3.7.1 of DCD Tier 2, Revision 2, to include the criteria. The staff found 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, Revision 3, 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.

3.12.8 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— 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 close to one another. The next series of analyses were performed for dynamic loads using response spectrum analysis. For the seismic and SRV loading cases, the ISM response spectrum analysis method was utilized 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 the 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. GHE assumed 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/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 ABS group combination and SRSS modal combination without the closely spaced modal effect, consistent with the current staff positions. The group combination procedure probably accounts for most of the differences in the ISM analyses. GEH's criteria for ISM is addressed in the open item associated with RAI 3.12-3. 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 the 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. Due to limitations in its PSAFE2 program, BNL was not able to verify the PISYS implementation fo 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 anlaysis. GEH's implementation of RG 1.92 is addressed in the open item associated with RAI 3.12-11.

On the basis of this independent confirmatory analysis, pending resolution of RAIs 3.12-3 and 3.12-11, the staff is unable to finalize its conclusions the piping analysis methods described in the DCD for the ESBWR standard plant were properly implemented in the GE PISYS analyses of the MS and SRV discharge lines.

3.12.9 Conclusions

Because there are open items that need resolution, the staff is unable to finalize its conclusions that piping systems important to safety are designed to quality standards commensurate with their importance to safety.

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:

- The regulations in 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. Components important to safety must be able to perform their intended design safety functions under all anticipated conditions, including normal, anticipated operational, and postaccident conditions. In addition, 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 (hereafter 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. Components important to safety must be able to perform their intended safety functions under all anticipated operating conditions, which include normal environmental conditions, anticipated operational occurrences, and accident and postaccident conditions.

- GDC 14 and GDC 30, "Quality of Reactor Coolant Pressure Boundary," require that components which are part of the RCPB be designed, fabricated, erected, and tested to the highest standards practical to ensure an extremely low probability of abnormal leakage, rapidly propagating failure, and gross rupture.

- 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.

- 10 CFR Part 50, Appendix G, specifies fracture toughness requirements for ferritic materials of pressure-retaining components of the reactor pressure boundary of light water nuclear power reactor to provide adequate margins of safety during any conditions 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 4, Section 3.9.3.9, “Threaded Fasteners - ASME Code Class 1, 2 and 3 Components,” provides information that is needed for the staff to perform its review using the guidance provided in SRP Section 3.13, “Threaded Fasteners.” Specifically, the DCD describes the use of threaded fasteners (e.g., threaded bolts, studs, etc.) 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, “Threaded Fasteners - ASME Code Class 1, 2 and 3 Components,” Revision 4, in accordance with the guidance provided in SRP Section 3.13, issued March 2007. The review was performed in order to determine the adequacy of threaded fasteners (e.g., threaded bolts, studs, etc.) 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 provides a summary of the differences between the DCD application and the Chapter 3 SRP, did not include reference to SRP Section 3.13 since the application was submitted prior to this new SRP section.

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. The DCD, Tier 2, Section 3.9.3.9 also states that 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, shall 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 provided as 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 are 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 is in accordance with the 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 is in accordance with the 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 on 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 inches in diameter and B-G-2 for bolting with diameters 2 inches and less. The Class 1 pressure retaining bolting sample is limited to the bolting on the heat exchangers, piping, pumps, and valve that are selected for examination in the ISI program. 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 provided as 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 are required to 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 the ASME Code, Section III and Section XI requirements discussed above, the reactor vessel closure studs also comply with the supplementary requirements in RG 1.65 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 the NRC 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 inservice inspection of threaded fasteners during the operational phase of the nuclear power plant. These Code Cases, Code Case N-307-2 and Code Case N-457, are included in the DCD, Tier 2, Table 5.2-1 as alternatives to the requirements of ASME Code, Section XI. The results of that review are documented in Section 5.2.1.2.3 of the staff’s SER for Chapter 5.

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 to be used for any safety-related application. For ferritic steel threaded fasteners, conversion coatings, such as the Parkerizing process, is suitable and may be used. If fasteners are plated, low melting point materials, such as zinc, tin, cadmium, etc., 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” indicated that the ESBWR will comply with the recommendations of the NRC 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 its RG 1.37 for use in nuclear power plant components. Based upon compliance of the aforementioned ANSI standard and regulatory guide, the staff finds that controls imposed on threaded fasteners satisfy the requirements of 10 CFR Part 50, Appendix B, Criterion XIII with respect to controls for cleaning of materials and components. Additionally, the lubricants and sealants are compatible with the threaded fastener materials.

Consideration for material degradation in service is required by ASME Code, Section III paragraphs NB-2160, NC-2160, and ND-2160 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, the DCD Tier 2, Section 3.9.3.9 needs 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 is being tracked as Open Item 3.0-1 S02.**

3.13.4 Conclusions

Because of the open item that needs resolution, the staff is unable to finalize its conclusions regarding the acceptability of the threaded fasteners for ESBWR.