10. STEAM AND POWER CONVERSION SYSTEM

10.1 Summary Description

The components of the steam and power conversion system are designed to produce electrical power utilizing the steam generated by the reactor, condense the steam into water, and return the water to the reactor as heated feedwater (FW), with a major portion of its gaseous, dissolved, and particulate impurities removed in order to satisfy the reactor water quality requirements.

The steam and power conversion system includes the turbine main steam system (TMSS), the main turbine generator, main condenser, condenser air removal system, turbine gland seal system (TGSS), turbine bypass system (TBS), condensate purification system (CPS), and the condensate and feedwater system (CFS). The heat rejected to the main condenser is removed by the circulating water system (CIRC) and discharged to the normal power heat sink.

Steam, generated in the reactor, is supplied to the high-pressure turbine and the second-stage reheater of the steam moisture separators/reheaters (MSRs). Steam leaving the high-pressure turbine passes through a combined MSR before entering the low-pressure turbines. The moisture separator drains, steam reheater drains, and the drains from the two high-pressure FW heaters are drained to the direct contact FW heater, which is combined with a FW storage tank. The reactor FW pumps take suction from the direct contact FW heater storage tank. The low-pressure FW heater drains are cascaded to the condenser.

Steam exhausted from the low-pressure turbines is condensed and deaerated in the condenser. The condensate pumps take suction from the condenser hotwell and deliver the condensate through filters and demineralizers, the gland steam condenser, the steam jet air ejector (SJAE) condenser, offgas recombiner condensers, and through the low-pressure FW heaters to the direct contact FW heater storage tank. The reactor FW pumps discharge through the high-pressure FW heaters to the reactor.

The TBS, designed for 110 percent of the rated steam flow, is provided to discharge excess steam directly to the condenser.

The protective features for the steam and power conversion system include the following:

- loss of electrical load and/or turbine trip
- main steamline overpressure protection
- turbine overspeed protection
- turbine overpressure protection
- turbine missile protection
- radioactivity protection

10.2 Turbine Generator

10.2.1 Regulatory Criteria

The staff reviewed the design of the turbine generator in accordance with the Standard Review Plan (SRP) Section 10.2. The design of the turbine generator system is acceptable if its integrated design meets the requirements in Title 10, Part 50, "Domestic Licensing of Production and Utilization Facilities" (10 CFR Part 50), of the *Code of Federal Regulations*. Specifically, the design must meet the requirements of General Design Criterion (GDC) 4, "Environmental and Dynamic Effects Design Bases," in Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, as they relate to the protection of the structures, systems, and components (SSCs) that are important to safety from the effects of turbine missiles.

GDC 4 requires that SSCs important to safety shall be appropriately protected against environmental and dynamic effects, including the effects of missiles, that may result from equipment failure. Because turbine rotors have large masses and rotate at relatively high speeds during normal reactor operation, failure of a rotor may result in the generation of high-energy missiles which may affect the proper function of safety systems. To satisfy GDC 4, turbine rotor integrity must be maintained to minimize the probability of turbine rotor failure.

10.2.2 Summary of Technical Information

10.2.2.1 Turbine Generator Design

The ESBWR DCD indicates that the turbine generator consists of a 188.5-rad/s (1800-rpm) turbine, MSRs, generator, exciter, controls, and associated subsystems. The turbine for the ESBWR standard plant consists of a double-flow, high-pressure unit, and three double-flow, low-pressure units in tandem.

The generator is a direct-driven, three-phase, 60-Hz synchronous generator with a water-cooled stator and hydrogen-cooled rotor. The turbine generator uses a digital monitoring and control system, which, in coordination with the turbine steam bypass and pressure control system (SB&PC), controls the turbine speed, load, and flow for startup and normal operations. The control system operates the turbine stop valves, control valves, and combined intermediate valves (CIVs).

The high-pressure turbine has two stages of steam extraction. The steam then passes through the low-pressure turbines, each with five extraction points for the five low-pressure stages of FW heating, and exhausts into the main condenser. Two MSRs, which are located on each side of the turbine generator centerline, perform moisture separation and reheating of the high-pressure turbine exhaust steam.

During normal operation, the main stop valves and CIVs are wide open. Operation of the turbine generator is under the control of the turbine control system (TCS). The steam bypass and pressure control (SB&PC) system controls the turbine control valves through the TCS to regulate reactor pressure. The normal function of the TCS is to generate the position signals for the four main stop valves, four main control valves, and six CIVs.

The applicant stated that the primary electrical overspeed system and the emergency overspeed trip system protect against turbine overspeed. The system provides redundancy by using three separate speed signals for the primary trip and speed control systems and three additional speed signals for the emergency trip system.

The applicant also stated that upon loss of generator load from any initial load condition, the TCS acts to prevent rotor speed from exceeding the overspeed trip and controls the speed of the turbine to run the house load. In this way, failure of any single component does not result in the rotor speed exceeding design overspeed. The component redundancies used to guard against overspeed are (1) main stop valves/control valves, (2) intermediate stop valves/intercept valves, (3) primary speed control/power-load unbalance circuits/emergency trip device solenoid valves, (4) fast-acting solenoid valves/emergency trip fluid system, and (5) speed control/primary overspeed trip/emergency overspeed trip.

10.2.2.2 Turbine Generator Arrangement

The staff reviewed the general arrangement of the turbine and associated equipment with respect to safety-related structures and systems and balance of plant. The staff reviewed DCD Section 10.2.2 to determine that the system description and piping and instrumentation diagrams show the turbine generator system. On the basis of this review, the staff concludes that the ESBWR design conforms to SRP Section 10.2.2, with respect to the general layout of the turbine, associated equipment, SSCs important to safety, and balance of plant.

10.2.2.3 Turbine Steam Admission Valves

The staff reviewed the types and location of MS stop and control valves, reheat stop and intercept valves, and associated piping arrangements. The turbine is equipped with four turbine stop valves, four turbine control valves, and six CIVs, collectively referred to as turbine steam admission valves. The turbine stop valves and turbine control valves are located upstream of the high-pressure turbine steam inlet. The CIVs are located between the moisture separators and the steam inlets to the three low-pressure turbines. The CIVs consist of an intermediate stop valve and an intercept valve in a single casing; each will have independent operating mechanisms and controls. The turbine stop valves and the intermediate stop valves are in the full-open position during normal operation. The control valves are designed to modulate with load on the turbine generator. The intercept valves modulate, as required, to control turbine speed following a load rejection. All of these valves are capable of closing in approximately 0.2 seconds.

The main stop valves and control valves provide redundancy because these valves are in series and have completely independent operating controls and operating mechanisms. Closure of either all four stop valves or all four control valves shuts off all MS flow to the high-pressure turbine. The CIVs are also in series and have completely independent operating controls and operating mechanisms. Closure of either valve or both valves in each of the six sets of CIVs shuts off all MSR outlet steam flow to the three low-pressure turbines.

On the basis of the above discussion, the staff concludes that the ESBWR design conforms to SRP Section 10.2, Criteria II.2 and II.3, with respect to the availability and adequacy of the control valves.

10.2.2.4 Turbine Generator Control and Overspeed Protection Systems

In 1991, a turbine overspeed event occurred at Salem Unit 2, which resulted in a failure of some turbine blades. The fragments of blades punctured the turbine casing and traveled some distance from the turbine. The failure of the turbine overspeed protection system caused this event. The details of the event can be found in a letter dated January 7, 1992, from Charles W. Hehl of the U.S. Nuclear Regulatory Commission (NRC) to Steven E. Miltenberger of Public Service Electric and Gas Company, Subject: NRC Region I Augmented Inspection Team Review of the November 9, 1991, Salem Unit 2 Turbine-Generator Overspeed and Fire Event.

The staff asked the applicant to describe how turbine speed is monitored such that the possibility of a turbine overspeed event is minimized. The staff also asked the applicant to identify the margin between the turbine trip setpoint speed and design overspeed to demonstrate that the turbine can be tripped either manually or automatically before it reaches the design overspeed in order to assure the integrity of turbine components. In a letter dated June 12, 2006, the applicant responded that DCD Tier 2, Section 10.2.2.4, describes the triple and redundant turbine primary electrical overspeed systems and the emergency electrical trip modules. The applicant stated that the margin of safety between the turbine overspeed primary and emergency setpoints and the "design overspeed" will be provided as part of the COL application. This was identified as part of a COL information item to be included in DCD Tier 2, Section 10.2.5.1, Revision 4, and is identified as a **Confirmatory Item**.

The staff reviewed the capability of the turbine generator control and overspeed protection systems to detect a turbine overspeed condition and to actuate appropriate system valves or other protective devices to preclude overspeed. The ESBWR design provides protection against turbine overspeed via the primary electrical overspeed system and the emergency overspeed trip system. Redundancy is built into the design by using three separate speed signals for the speed control and primary trip systems and three additional speed signals for the emergency trip system.

Each circuit monitors a separate speed signal and activates a trip logic at various speed levels. The output of these circuits is used in tripping and monitoring of the turbine, as well as speed control within the primary trip module. The turbine trip is initiated upon failure of two of the three channels. Either trip module can deenergize the electrohydraulic 2-out-of-3 emergency trip device (ETD), thereby dumping the emergency trip fluid to all steam valve actuators, resulting in a turbine trip. The ETD is configured with 2-out-of-3 trip logic, and includes three electrical trip solenoid valves, all deenergized to trip. Any two trip solenoid valves shifting to the trip position will cause the emergency trip fluid to be depressurized. The applicant stated that the ETD is testable online, such that each individual trip solenoid valve can be tested one at a time.

In RAI 10.2-18, the staff requested that the applicant describe how the ESBWR design provides a diverse overspeed protection mechanism, such as a mechanical trip device, to prevent common cause failures of the system. In its response to RAI 10.2-18, the applicant stated that a triple and redundant system replaced the mechanical trip device and that diversity is provided through the primary and emergency systems. The applicant stated that redundancy is provided by using three separate signals for the primary trip and three additional signals for the emergency trip system. The staff does not agree that such an arrangement exhibits diversity in the overspeed trip mechanism because it does not prevent common cause failures inherent only to electronic components. In RAI 10.2-18 S01, the staff asked the applicant to provide a detailed justification for deviating from the criteria specified in SRP Section 10.2, Revision 2. Specifically, the staff requested that the applicant provide the following:

(1) a complete listing of turbine missile vulnerabilities

(2) a list of potential consequences of turbine missile strikes on the SSCs identified in item 1 above

(3) a comparison of the reliability of the proposed turbine overspeed trip protection capability to the reliability that is afforded by the diverse capability that exists in operating plants

(4) a failure modes and effects analysis for the proposed turbine overspeed protection equipment

(5) a comparison of the likelihood of generating turbine missiles with the turbines to be used in the new plants, with the likelihood of turbine missile generation in current plants that have diverse turbine overspeed trip capability

The staff is currently evaluating the response to this supplemental RAI and will subsequently make its final determination on this issue. The staff has identified this as **Open Item 10.2-18**.

The staff also requested that the applicant provide the overspeed basis for system actuation as described in SRP Section 10.2, Subsection III, paragraphs 2(b), 2(c), and 2(d). In its response to RAI 10.2-18, the applicant stated that the COL applicant will provide this information. This was identified as part of a COL information item to be included in DCD Tier 2, Section 10.2.5.1, Revision 4, and is identified as a **Confirmatory Item**.

On the basis of the preceding discussion and the pending resolution of Open Item 10.2-18, the staff cannot yet conclude that the ESBWR turbine generator design conforms to Criteria II.1 and II.4 of SRP Section 10.2 with regard to turbine overspeed protection.

10.2.2.5 Inservice Inspection of Valves Essential for Turbine Overspeed Protection

The staff reviewed the ISI and operability assurance provisions for valves essential for overspeed protection. The applicant stated that an ISI program for the turbine stop and control valves and CIVs will be provided, and will include dismantling and inspecting at least one turbine stop valve, one turbine control valve, one reheat stop valve, and one reheat intercept valve in order to conduct visual and surface examinations of valve seats, disks, and stems during refueling or maintenance shutdowns, coinciding with the ISI schedule required by the American Society of Mechanical Engineers (ASME) Code, Section XI, for reactor components.

The applicant stated that if unacceptable flaws or excessive corrosion is found in a valve, all other valves of that type will be dismantled and inspected. Valve bushings will be inspected and cleaned, and bore diameters should be checked for proper clearance. The applicant stated that the program requires that MS stop valves and turbine control valves be exercised at least once within each calendar quarter by closing each valve and observing the remote valve position indicator for fully open and fully closed position status. The inspection and test intervals are based on the probability of turbine missile generation, operating experience, and inspection results, which together have demonstrated satisfactory equipment performance. Therefore, the staff finds these inspection and test intervals acceptable.

The staff asked the applicant to clarify the extent of turbine valve inspections, which require that inspection of all valves of one type will be conducted if any unusual condition is discovered. In a letter dated June 12, 2006, the applicant revised DCD Tier 2, Section 10.2.3.7, to include visual inspection of turbine valves and to include cracks as items to be inspected as part of turbine valve inspection. DCD Tier 2, Section 10.2.3.7, also specifies that if one control valve is found to have an indication, all of the four control valves will be inspected but not all of the turbine valves. The applicant stated further that valves described in DCD Tier 2, Section 10.2.3.7, will be disassembled to perform the inspections. The staff finds this issue closed because these revisions clarify the general requirements for the turbine valve inspection.

In response to RAIs 10.2-20 and 10.2-22, the applicant identified that a requirement to provide details of the turbine inservice test and inspection program was provided in DCD Tier 1, Section 2.11.4 as ITAAC 4.b. In addition, the applicant included a requirement to provide a description of inservice tests, inspections, and maintenance activities for the turbine and valve assemblies that are required to support the calculated turbine missile probability, including inspection and test frequencies with technical bases, type of inspection, techniques, areas to be inspected, acceptance criteria, disposition of reportable indications, and corrective actions as part of the Turbine Missile Probability Analysis to be included in DCD Tier 2, Section 10.2.3.8, Revision 4. This was identified as part of a COL information item to be included in DCD Tier 2, Section 10.2.5.1, Revision 4, and is identified by the staff as a **Confirmatory Item**.

On the basis of the above discussion, the staff concludes that the ESBWR ISI and operability assurance program for valves essential for overspeed protection conform to SRP Section 10.2.3.5.

10.2.2.6 Turbine Missile Protection

In DCD Section 3.5.1.1.1.3, the applicant stated that the turbine generator placement and orientation of the ESBWR meet the guidelines of Regulatory Guide (RG) 1.115, "Protection Against Low-Trajectory Turbine Missiles," Revision 1, issued July 1977. RG 1.115 establishes that turbine orientation and placement, shielding, quality assurance in design and fabrication, inspection and testing programs, and overspeed protection systems are the principal means of safeguarding against turbine missiles. In SRP Section 3.5.1.3, the staff determined that plant designs that have a favorable turbine generator placement and orientation and adhere to the guidelines presented in RG 1.115 will be considered adequately protected against turbine missile hazards, and that exclusion of safety-related SSCs from low-trajectory turbine missile strike zones constitutes adequate protection against low-trajectory turbine missiles. Based on the applicant's conformance to RG 1.115, the staff finds this aspect of the design acceptable.

In NRC Information Notice 94-01, "Turbine Blade Failures Caused by Torsional Excitation from Electrical System Disturbance," dated January 7, 1994, the staff discussed turbine blade failures of low-pressure turbines which were attributed to torsional excitation of the turbine generator shaft as a result of an electrical system disturbance. The staff asked the applicant to discuss whether the turbine will be designed to preclude torsional excitation of the shaft. In response, the applicant proposed to add a new Section 10.2.3.8, Turbine Missile Probability Analysis, in DCD Tier 2, Revision 4, that includes a requirement ensure that the torsional vibration analysis is considered in the turbine design. In addition, the applicant included in DCD Tier 1, Section 2.11.4, ITAAC 5 a requirement for providing a turbine missile probability analysis. The applicant also proposed to include a COL information item in DCD Tier 2, Section 10.2.5.1, Revision 4, that requires the COL Holder to provide a Turbine Missile Probability Analysis meeting the requirements specified in proposed Section 10.2.3.8. The staff finds this acceptable for addressing torsional vibration in the turbine design and identifies this as a **Confirmatory Item**.

10.2.2.7 Conclusions

Due to the open items that remain to be resolved for this section the staff was not able to finalize its conclusions on acceptability.

10.2.3 Turbine Rotor Integrity

General Design Criterion (GDC) 4 of Appendix A to Title 10 of the *Code of Federal Regulations*, (10 CFR) requires that structures, systems and components (SSCs) important to safety shall be appropriately protected against environmental and dynamic effects, including the effects of missiles, that may result from equipment failure. Because turbine rotors have large masses and rotate at relatively high speeds during normal reactor operation, failure of a rotor may result in the generation of high-energy missiles which may affect the proper function of safety systems. To satisfy GDC 4, turbine rotor integrity must be maintained to minimize the probability of turbine rotor failure.

SRP Section 10.2.3, Revision 2, “Turbine Rotor Integrity,” provides guidance to achieve integrity of the turbine rotor. Specifically, SRP Section 10.2.3 provides criteria to ensure that the turbine rotor materials have acceptable fracture toughness and elevated temperature properties to minimize the potential for failure. In addition, these criteria will ensure that the rotor is adequately designed and will be receiving pre-service inspections and periodic inservice inspections to monitor potential degradation. The staff used the criteria in SRP Section 10.2.3 to evaluate the integrity of the turbine rotor in Section 10.2.3 of DCD Tier 2, Revision 3.

10.2.3.1 Summary of Technical Information

DCD Tier 2, Revision 3, states that turbine rotors and parts are made from vacuum melted or vacuum degassed Nickel-Chromium-Molybdenum-Vanadium (Ni-Cr-Mo-V) alloy steel to minimize flaw occurrence and provide adequate fracture toughness. Chemical elements such as sulfur and phosphorus are controlled to low levels. Fracture appearance transition temperatures (FATT) obtained from Charpy energy will be obtained based on industry standards. Nil-ductility transition temperature (NDT) obtained in accordance with industry standards may be used in lieu of FATT. The FATT and Charpy energy of the rotor material are maintained within the acceptable value.

Fracture Toughness

DCD Tier 2, Revision 3, states that suitable material toughness is obtained through the use of selected materials to produce a balance of material strength and toughness to ensure safety while simultaneously providing high reliability, availability and efficiency during operation. Stress calculations include components due to centrifugal loads, interference fit and thermal gradients where applicable. The ratio of material fracture toughness, K_{IC} (as derived from material tests on each major part or rotor), to the maximum tangential stress at speeds from normal to design speed, is at least 2 √in. Adequate material fracture toughness needed to maintain this ratio is assured by a large historical database of tests.

Turbine operating procedures are employed to preclude brittle fracture at startup by ensuring that metal temperatures are (a) adequately above the FATT, and (b) sufficient to maintain the fracture toughness to tangential stress ratio at or above 2 √vin. Sufficient warmup time will be specified in the turbine operating instruction to also ensure that toughness is adequate to prevent brittle fracture during startup.

The operating temperatures of the high-pressure rotors are below the stress rupture range. Therefore, creep-rupture is not a significant failure mechanism.

Turbine Design

The turbine assembly is designed to withstand normal conditions and anticipated transients, including those resulting in turbine trip, without loss of structural integrity. Turbine shaft bearings are designed to retain their structural integrity under normal operating loads and anticipated transients, including those leading to turbine trips. The multitude of natural critical frequencies of the turbine shaft assemblies existing between zero speed and 20 percent overspeed are controlled in the design and operation so as to cause no distress to the unit during operation. The maximum turbine rotor tangential stress resulting from centrifugal forces, interference fit, and thermal gradients does not exceed 0.75 of the yield strength of the materials at 115 percent of rated speed. Turbine components are designed for an overspeed far above the 8 percent resulting from a loss of load. The turbine rotor design facilitates inservice inspection of all high stress regions.

Pre-service Inspection (PSI)

Each finished, machined rotor is subjected to 100 percent volumetric (ultrasonic), and surface visual examinations, using established acceptance criteria. Subsurface indications will be either removed or evaluated to ensure that they do not grow to a size which would compromise the integrity of the unit during its service life. All finished machined surfaces are subjected to a magnetic particle test with no flaw indications permissible. Each fully bladed turbine rotor assembly is factory spin-tested at 20 percent overspeed which is approximately 10 above the highest antipated speed resulting from loss of load. Pre-service inspections include air leakage tests on the hydrogen cooling system, hydrogen purity tests, generator windings and motors tests, vibration tests on motors, hydrostatic tests on all coolers, and piping and valve leakage tests.

Inservice Inspection (ISI)

The inservice inspection program for the turbine assembly includes the complete inspection of all normally inaccessible parts, such as couplings, coupling bolts, turbine shafts, low-pressure turbine buckets, low-pressure and high-pressure rotors. Turbine inspections are performed in sections during the refueling outages so that a total inspection has been completed at least once within the time period recommended by the manufacturer. The turbine inspection consists of visual examination of all accessible surfaces of the rotors, visual and surface examination of all low-pressure buckets, and 100 percent visual examination of all couplings and coupling bolts.

DCD Tier 2, Revision 3, states that the inservice inspection of valves important to overspeed protection includes the following tests and inspections. (1) All main stop valves, control valves, extraction non-return valves, and Combined Intermediated Valve (CIVs) will be tested under load. (2) Main stop valves, control valves, extraction non-return valves, and CIVs will be tested by the COL licensee in accordance with the Boiling Water Reactor Owners Group (BWROG) turbine surveillance test program. (3) Tightness tests of the main stop and control valves are performed at least once per maintenance cycle by checking the coast-down characteristics of the turbine from no load with each set of four valves closed alternately. (4) All main stop valves, main control valves, and CIVs will be inspected once during the first three refueling or extended maintenance shutdowns. Subsequent inspections will be scheduled by the COL licensee, in accordance with the BWROG turbine surveillance test program. The inspections will be conducted for: wear of linkages and stem packings, erosion of valve seats and stems, deposits on stems and other valve parts, and distortions/misalignment. (5) Inspection of all valves of one type will be conducted if any unusual condition is discovered.

10.2.3.2 Staff Evaluation

10.2.3.2.1 Turbine Rotor Design

The staff used SRP Section 10.2.3 to review the turbine rotor material selection, turbine design, and inspection requirements in Section 10.2.3 of DCD Tier 2. The goal of the staff’s evaluation is to ensure that the turbine rotor integrity is maintained to minimize the probability of turbine missile generation. This evaluation also touched briefly on turbine overspeed controls and turbine valve inspections. The details of turbine overspeed control is discussed in detail in Section 10.2.2 of this safety evaluation.

The staff asked the applicant to provide additional information regarding the turbine rotor design, such as diagrams of the turbine rotor, the number of rotor stages, the bucket design, how the buckets are attached to the rotor, and rotor fabrication. In a letter dated August 2, 2007, the applicant proposed to add a new Section 10.2.3.8, Turbine Missile Probability Analysis, in DCD Tier 2, Revision 4, that includes a requirement to provide turbine rotor design details as part of this analysis. In addition, the applicant included in DCD Tier 1, Section 2.11.4, ITAAC for providing a discussion of the design and structural integrity of the turbine rotor. The applicant also proposed to include a COL information item in DCD Tier 2, Section 10.2.5.1, Revision 4, that requires the COL Holder to provide a Turbine Missile Probability Analysis meeting the requirements specified in proposed Section 10.2.3.8. The staff finds this acceptable for addressing the turbine rotor design details and identifies this as a **Confirmatory Item**.

10.2.3.3.2 Turbine Rotor Material Specifications

SRP Section 10.2.3.II.1.A recommends that sulfur and phosphorus in the turbine rotor material be controlled to low levels because high level of sulfur and phosphorus have a deleterious effect on toughness of the turbine rotor. The staff asked the applicant to provide the percentage of sulfur and phosphorus in the turbine rotor material and discuss whether their chemical contents are considered low level. In letter dated June 12, 2006, the applicant proposed a revision to DCD Section 10.2.3.1 to be consistent with SRP Section 10.2.3.II.1.A regarding sulfur and phosphorus requirement. However, the applicant does not have the information on the exact percentage of sulfur and phosphorus in the rotor material at this time because the turbine has not been purchased. Thus, the applicant proposed, in a letter dated August 2, 2007, to revise Section 10.2.5.1 of DCD Tier 2 to require turbine material property data be provided as part of the turbine missile probability analysis discussed in a proposed new Section 10.2.3.8 in Revision 4 of the DCD. In addition, the turbine rotor material property data is required by ITAAC 4.a. of DCD Tier 1, Section 2.4.11, Revision 3. The staff finds that the applicant's proposed revisions are consistent with SRP Section 10.2.3.II.1.A and, therefore, are acceptable. The staff identifies the proposed revisions to the DCD as a **Confirmatory Item**.

Section 10.2.3.1 of DCD Tier 2, Revision 1, stated that the processing of the turbine materials is controlled to maintain the FATT below -1 °C (30 °F), which is inconsistent with SRP Section 10.2.3.II.1.B. SRP Section 10.2.3.II.1.B recommends that the 50 percent FATT, as obtained from Charpy tests performed in accordance with specification ASTM A-370, be no higher than 0 °F for low-pressure turbine rotors. SRP Section 10.2.3.II.1.B recommends that in lieu of FATT, NDT obtained in accordance with ASTM E-208 may be used. The staff asked the applicant to discuss the discrepancy and identify the industry codes used to obtain the FATT and Charpy energy of the low-pressure turbine rotor. In letter dated June 12, 2006, the applicant proposed a revision to Section 10.2.3.1 of DCD Tier 2, Revision 1, to be consistent with SRP Subsection 10.2 3.II.1.B. The staff finds that the applicant's revision to Section 10.2.3.1 of DCD Tier 2, Revision 1, is consistent with SRP Section 10.2.3.II.1.B and, therefore, is acceptable.

SRP Section 10.2.3.II.1.C recommends that the Charpy V-notch energy at the minimum operating temperature of each low-pressure rotor in the tangential direction be at least 60 ft-lbs. Section 10.2.3.1 of DCD Tier 2, Revision 1, stated that the room temperature Charpy energy is above 45 ft-lbs, which is not consistent with the minimum 60 ft-lb recommended in SRP Section 10.2.3.II.1.C. In letter dated June 12, 2006, the applicant proposed a revision to Section 10.2.3.1 of DCD Tier 2, to be consistent with SRP Subsection 10.2.3.II.1.C with regard to the recommended 60 ft-lb Charpy V-notch energy. Based upon that commitment the staff found that the proposed revision to Section 10.2.3.1 of DCD Tier 2, Revision 1, is consistent with SRP Section 10.2.3.II.1.C and, therefore, is acceptable. However, following the review of changes made in Revision 3 to the DCD, the staff noted an inconsistency in DCD Tier 2, Revision 3, Section 10.2.3.1 (page 10.2-10, third paragraph). Specifically, the DCD stated that the FATT will be no higher than +30 degrees F; and that the Charpy V-notch energy at the minimum operating temperature will be at least 45 ft-lbs. The staff requested that the applicant justify these two design limits because they are not consistent with SRP Section 10.2.3. II.1. In a letter dated August 5, 2007, the applicant responded that material testing has shown that FATT increases (and Charpy V-notch energy decreases) from the outer surface to the deep-seated region of the forging as a result of variation (slowing from outside to center) in the cooling rate during the quenching process. The cooling rate variation causes the FATT (and Charpy V-notch energy) to change rapidly near the surface of the forging and then changes gradually at deeper forging locations. As a result, material acceptance requirements for FATT and Charpy V-notch greatly depend on the location in the forging where test samples are obtained.

The values for FATT and Charpy V-notch energy (0 degrees F and 60 ft-lbs., respectively) specified in SRP Section 10.2.3.II.1 are based on material acceptance data taken from specimens at the surface of a shrunk-on wheel (disc) forgings. In cases where the shrunk-on disc design is utilized, surface specimens are used because deep-seated specimens (specimens taken from near the center of the forging) cannot be obtained during acceptance testing without destroying the wheel forging. FATT test results based on surface measurements are lower (and the Charpy V-notch energy is higher) than test results based on deep-seated forging properties.

The values for FATT and Charpy V-notch energy included in the ESBWR DCD Tier 2, Revision 3, Section 10.2.3.1 pertains to integral rotor forgings. The values are based on material acceptance data obtained from specimens taken from a radial trepan (closer to the center of the forging), beyond the region where FATT changes rapidly with position. This is the location where measurements are made on every ESBWR integral rotor forging. As such, the criteria established in the ESBWR DCD for integral rotor forgings are deep-seated values for FATT and Charpy V-notch energy, as opposed to surface values. A large data set of centerline FATT values and FATT location variation is available from previous integral rotor testing. Evaluation of this data set shows that the FATT and Charpy V-notch limits set forth in the DCD accurately reflect the material capability for single piece rotor forgings, and provide suitable means to evaluate the bore FATT. Based upon the known stress-related fracture mechanics associated with integral rotors, crack propagation typically originating from the center of the forging, it is more appropriate to evaluate the material characteristics based on these deep-seated values to verify structural integrity. The fact that the bore stresses for integral rotors are lower than those of the shrunk-on wheel design provides an additional margin of safety. The staff finds the applicant’s basis acceptable and concurs with its conclusion that the specified fracture toughness criteria (FATT no higher than +30 degrees F; and Charpy V-notch of 45 ft-lb energy at the minimum operating temperature) is acceptable for a large integral turbine rotor because a large data set of centerline FATT values and FATT location variation is available from previous integral turbine rotor testing to support the applicant’s conclusions.

During its review of DCD Tier 2, Revision 3, the staff noted that Section 10.2.3.2 is not consistent with SRP Section 10.2.3.II.2 because it is not clear how fracture toughness properties of the turbine rotor are obtained. SRP Section 10.2.3.II.2 specifies four methods (a, b, c, and d) for obtaining fracture toughness properties for the turbine rotor. The staff requested that the applicant describe the method that will be used in the DCD. In a letter dated August 5, 2007, the applicant responded that each integral (single piece) rotor forging receives the following material acceptance tests: (1) tensile test, (2) room temperature Charpy V-notch test, and (3) FATT determination. These tests are conducted in the body of the rotor at a representative radial trepan. When a rotor is bored, these tests are also conducted in the center core material. Previous testing of this nature performed on integral rotors fabricated from the same material has established a database with reliable material characteristic correlations suitable for application on new, unbored rotor forgings. The fracture toughness (K_{1c}) value is determined using a value of deep-seated FATT based on the measured FATT values from trepan specimens, and a correlation factor obtained from historical integral rotor test data as described above. This is the same methodology that was utilized for analysis of the shrunk-on wheel rotors in the past. This method of verification most closely resembles method (c) in SRP Section 10.2.3 II.2, with the exception that the correlation factors used are derived from the manufacturers' test data and extensive background on integral forged rotors (in place of the Begley-Logsdon paper, which was published in 1971). The applicant indicated that test data and calculated toughness curve are to be part of the missile analysis report for the turbine that is discussed in a proposed new Section 10.2.3.8 to be included in Revision 4 of the DCD. The applicant also proposed that in Revision 4 of DCD, Section 10.2.3.2 will be revised to document and clarify rotor fracture toughness test requirements. The staff finds that the applicant's proposal to revise Section 10.2.3.2 of DCD Tier 2, Revision 4 acceptable because the fracture toughness, $K_{1c,}$ will be determined using deep-seated FATT based on the measured FATT values from trepan specimens, and correlation factor obtained from historical integral rotor test data. The staff identifies this as a **Confirmatory Item**.

Section 10.2.3.2 of DCD Tier 2, Revision 1, stated that the ratio of material fracture K_{IC}, to the maximum tangential stress at speeds from normal to 115 percent of rated speed is at least 10 $mm^{1/2}$. The staff asked the applicant to clarify whether this ratio is obtained at the minimum operating temperature as recommended in SRP Section 10.2.3.II.2. In letter dated June 12, 2006, the applicant proposed a revision to Section 10.2.3.2 of DCD Tier 2, Revision 1, to specify that the ratio is obtained at minimum operating temperature. The staff finds that the applicant's proposed revision is consistent with SRP Section 10.2.3.II.2, and, therefore, is acceptable. Staff confirmed that Revision 3 of the DCD accurately incorporated the applicant's proposed revision.

Section 10.2.3.2 of DCD Tier 2, Revision 1, stated that stress calculations include components due to centrifugal loads, interference fit, and thermal gradients where applicable. The staff asked the applicant to provide a description of the stress calculations. If unavailable, the staff requested that Section 10.2.5.1 of DCD Tier 2, Revision 1, include a commitment to provide such calculations as a COL action item. In letter dated June 12, 2006, and as updated in an August 2, 2007 letter, the applicant proposed to revise the COL information item in Section 10.2.5.1 in Revision 4 of DCD Tier 2, to require the COL Holder to provide an analysis whose requirements are specified in a new proposed Section 10.2.3.8 that includes the material property data, warm-up time, and stress calculations of turbine components when the turbine is purchased and the turbine-specific data are available. Further, in Revision 3 to the DCD, the applicant stated that in Tier 1, Section 2.11.4, an ITAAC was added to require stress analysis that includes turbine material property data, rotor and blade design (including loading combinations, assumptions and warm-up time). The staff finds the applicant's approach of requiring the turbine rotor design information and a detailed analysis be submitted as part of ITAAC to be acceptable since the analysis will require the COL Holder to utilize as-built, plant-specific turbine rotor data.

Section 10.2.3.3 of DCD Tier 2, Revision 1, stated that operating temperatures of the high-pressure rotors are below the stress rupture range; therefore, creep-rupture is not a significant failure mechanism. To verify the above statement, the staff asked the applicant to identify the normal operating temperatures and the maximum possible temperature of the high pressure rotors, and identify the temperature at the stress rupture range and discuss how this temperature was obtained. In letter dated June 12, 2006, the applicant responded that Figure 10.1-2 of DCD Tier 2, Revision 1, shows the turbine main steam temperature to be approximately 540.6 °F. Long term creep rupture begins to occur at about 800 to 900 °F in Ni-Cr-Mo-V low alloy steels and increases with increasing temperature. Therefore, stress rupture is not a plausible failure mode because the maximum turbine temperature will be about 555 °F which is significantly less than 800 °F. The staff agrees with the applicant that at maximum operating temperature of about 555 °F the turbine will not exceed the temperature at which creep-rupture occurs. Therefore, the staff concludes that creep-rupture is not a concern for the high pressure turbine rotors.

During its review of DCD Tier 2, Revision 3, Section 10.2.5.1 the staff noted that the DCD stated that the COL Holder is required to provide an evaluation of the probability of turbine missile generation using criteria in accordance with NRC requirements. As discussed in SRP Section 3.5.1.3, the probability of turbine missile generation should be completed prior to license issuance so that the staff can verify whether the probability of turbine missile generation meets the acceptance Criteria in SRP Section 3.5.1.3. The staff requested that the applicant justify the use of "the COL Holder" in lieu of "the COL Applicant" in Section 10.2.5.1. In a letter dated August 2, 2007, the applicant responded 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. It is expected that 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 discusses external turbine missile probability and requires it to be less than $1x10^{-4}$ per turbine year. Also, reference Tier 1, Table 2.11.4-1, ITAAC 5 states: "An analysis exists that documents that the probability of turbine material and overspeed related failures, resulting in external turbine missiles, is < $1x10^{-4}$ per turbine year." Based on proposed turbine rotor designs that utilize integral forgings, the probability of turbine missile generation is less than $1x10^{-5}$ for the ESBWR as stated in the 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. This probability is to be confirmed by calculation and/or analysis in the Turbine Missile Probability Analysis in accordance with ITAAC 5. In order to clarify the scope of the Turbine Missile Probability Analysis and meet the guidance of RG 1.206, the applicant proposed to add a new Section 10.2.3.8 to Chapter 10 in Revision 4 to the DCD. New Section 10.2.3.8 requires the Turbine Missile Probability Analysis to include the aspects described in COL items 10.2.5.1, 10.2.5.2, and 10.2.5.3 that appeared in Revision 2 of DCD Chapter 10. The applicant also proposed to revise COL information item 10.2.5.1 for the Turbine Missile Probability Analysis reference new Section 10.2.3.8. The NRC staff finds that the specified value of less than $1x10^{-5}$ for the ESBWR probability of turbine missile generation is acceptable because this value is lower than that required by SRP Section 3.5.1.3. The staff identifies the proposed changes to be included in DCD Revision 4 as a **Confirmatory Item**.

The preservice inspection of the turbine rotor is discussed in Section 10.2.3.5 of DCD Tier 2. The staff asked the applicant to clarify the acceptance criteria for indications as a result of rotor inspection. In letter dated June 12, 2006, the applicant responded that when a surface indication is detected on the rotor, it will be blended. If a subsurface indication is detected, it will be excavated and plug welded. The procedure for rotor surface inspection will be supplied to the owner as a turbine owners maintenance manual with receipt of the turbine. All subsurface indications are addressed prior to the rotor being accepted and shipped to the owner. In addition, Section 10.2.3.6 of DCD Tier 2 includes a discussion on requirements to perform visual inspections on all low-pressure turbine rotor, buckets and coupling bolts. During its review of Revision 3 of the DCD, the staff requested that the applicant describe the specific codes and standards to which the preservice examination (ultrasonic and surface) of the forgings will be adhered as recommended by SRP Section 10.2.3.II.3. In its response to the staffs request, the applicant stated in its letter dated August 5, 2007, that in accordance with standard industry practices, pre-service surface and visual examinations of the finish-machined rotor forgings will be conducted during the pre-service inspection phase of the turbine rotor fabrication. As a result, the applicant proposed to revise DCD Tier 2, Section 10.2.3.5, in Revision 4 to state that 100 percent ultrasonic examination and acceptance criteria that is equivalent or more restrictive than the criteria specified for Class 1 components in ASME Code, Section III and V will be performed on the turbine rotor. In addition, surface and visual examination, including any bores, keyways, or drilled holes, are subject to magnetic particle examination, and all flaw indications in keyways and drilled holes are required to be removed. Further, the turbine and turbine valve inservice test and inspection program are covered by ITAAC 4b in DCD Tier 1, Table 2.11.4-1 which requires that the program includes scope, frequency, methods, acceptance criteria, disposition of reportable indications, corrective actions and technical basis for inspection frequency. The staff finds the applicants approach acceptable and identifies the proposed revision to Section 10.2.3.5 as a **Confirmatory Item**.

Following the staff's review of changes made to Revision 3 of the DCD, the staff requested that the applicant explain why details pertaining to the turbine inservice test and inspection program were deleted from the DCD. In a letter dated August 2, 2007, the applicant responded that this information was relocated to DCD Tier 1, Section 2.11.4 as ITAAC 4b. ITAAC 4b requires that the turbine and turbine valve inservice test and inspection program includes scope, frequency, methods, acceptance criteria, disposition of reportable indications, corrective actions, and technical basis for inspection frequency. In-service test, inspection and operating procedures are to be in accordance with industry practice and meet original equipment manufacturer (OEM) requirements for turbine missile probability. The staff finds this acceptable because the ITAAC would ensure that the turbine test and inservice program will be conducted and that the turbine will meet the OEM requirements for turbine missile probability.

The staff finds that the inservice inspection of the turbine rotor as discussed in Section 10.2.3.5 of DCD Tier 2, Revision 1, is consistent with SRP Section 10.2.3. However, the staff asked the applicant to clarify visual and/or surface examination of turbine rotors, buckets, and couplings. In letter dated June 12, 2006, the applicant responded that necessary subsurface inspections and repairs will be addressed during turbine manufacturing. Surface inspections will detect possible propagation of surface indications caused by pitting, cracks, erosion, or corrosion. Buckets are not removed from the rotor when performing visual examinations of the rotor and buckets. A surface examination at the rotor/bucket interface (root) is acceptable to detect new flaws as they propagate from the outside surface toward the inside surface which can be visually detected. The subsequent inspection results of the turbine components are compared to the pre-service inspection results to determine whether new degradation has occurred. Any indications are evaluated and dispositioned as a repair or replacement, as required.

The preservice and inservice inspection procedures discussed above are the general and minimum requirements specified by the DCD. The individual turbine manufacturer will provide inspection procedures to the plant owner at the time of turbine delivery. SRP Section 10.2.3.II.5 recommends that the inservice inspection and maintenance program for the turbine assembly comply with the manufacturer's recommendations. Section 10.2.3.5 of DCD Tier 2, requires that the turbine inservice inspection be performed within the time period recommended by the turbine manufacturer. The staff finds that the turbine preservice and inservice inspection descriptions in the DCD are consistent with SRP Section 10.2.3 and, therefore, are acceptable.

The staff asked the applicant to discuss how the environmental conditions, the operational parameters, design features, fabrication, material properties, and maintenance are managed and considered to mitigate potential degradation of the turbine rotor and buckets. In letter dated June 12, 2006, the applicant responded that Section 10.2.3 of DCD Tier 2, Revision 1, gives the design guidelines that will be followed during the initial turbine design, installation, pre-service inspection, inservice inspection, and testing program. These guidelines along with the recommended operational and maintenance parameters will mitigate degradation in the turbine rotor and buckets. Section 10.2.4 of DCD Tier 2, Revision 3, further describes that the turbine is designed, constructed and inspected to minimize the possibility of any major turbine component failure. The staff finds that the applicant has demonstrated that the turbine is designed and fabricated to minimize potential degradation. The associated turbine inspection program is designed to monitor the integrity of the turbine components.

The staff concludes that the rotor design and material selection in Section 10.2.3 of DCD Tier 2, Revision 3, are consistent with SRP Section 10.2.3, and therefore, are acceptable. The staff also concludes that the rotor inspection in Section 10.2.3 of DCD Tier 2, Revision 3 is consistent with SRP Section 10.2.3.

10.3 Turbine Main Steam System

10.3.1 Regulatory Criteria

The staff reviewed the design of the TMSS in accordance with Section 10.3 of the SRP, Revision 3, 1984. The design of the TMSS is acceptable if its integrated design meets the requirements of 10 CFR Part 50.

Specifically, acceptability of the TMSS design is based on meeting the following:

- GDC 2, "Design Bases for Protection against Natural Phenomena," with respect to the safety-related portions of the system being capable of withstanding the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, and floods, and the positions of the following:
  - RG 1.29, "Seismic Design Classification," Revision 4, issued March 2007, as related to the seismic design classification of system components, Positions C.1.a, C.1.e, C.1.f, C.2, and C.3

- GDC 4 with respect to the ability of portions of the system important to safety to withstand the effects of external missiles and internally generated missiles, pipe whip, and jet impingement forces associated with pipe breaks

- GDC 5, “Sharing of Structures, Systems, and Components,” with respect to the ability of the shared systems and components important to safety to perform required safety functions

The NRC staff review also considered the following guidance:

  – SECY-93-087, “Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs,” dated April 2, 1993, applicable to boiling-water reactor (BWR) plants that do not incorporate a main steam isolation valve leakage control system (MSIVLCS) and for which main steamline fission product holdup and retention are credited in the analysis of design-basis accident radiological consequences

10.3.2 Summary of Technical Information

The function of the TMSS is to transport the steam generated in the reactor to the MS turbine plant. The TMSS is bounded by, but does not include, the seismic interface restraint, turbine stop valves, and turbine bypass valves. Steam supply lines to other services, up to and including their isolation valves, are also part of the TMSS. The system is designed to deliver steam from the reactor to the turbine generator system for a range of flows and pressures varying from warmup to rated conditions. It also provides steam to the reheaters, the SJAEs, the turbine gland seal system, the offgas system, and the deaerating section of the main condenser and the TBS.

The TMSS is not required to perform or support any safety-related function. However, the supply system is designed to (1) accommodate operational stresses such as internal pressure and dynamic loads without failures, (2) provide a seismically analyzed fission product leakage path to the main condenser, (3) provide suitable accesses to permit inservice testing and inspections, and (4) close the steam auxiliary valve(s) on a main steam isolation valve (MSIV) isolation signal.

The TMSS piping consists of four lines from the seismic interface restraint to the main turbine stop valves. The four main steamlines are connected to a header upstream of the turbine stop valves to permit testing of the MSIVs during plant operation with a minimum load reduction. Section 5.4 of this report discusses in detail the portions of the MS and FW piping located upstream of the seismic restraints, including the MS isolation system.

10.3.3 Staff Evaluation

The applicant stated that the system is analyzed, fabricated, and examined to ASME Code Class 2 requirements, classified as seismic Category II, and subject to pertinent quality assurance (QA) requirements of Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants,” to 10 CFR Part 50. ISI will be performed in accordance with ASME Section XI requirements for Code Class 2 piping. In RAI 10.3-1, the staff requested the applicant to justify the discrepancy with SRP Section 10.3, Criterion III.3.b, and RG 1.29 Position C.1.e, which provide that the subject portions of the TMSS are designed to seismic Category I.

In its response to RAI 10.3-1, the applicant stated that the portion of the MS piping inside the containment, including the inboard MSIVs, containment penetrations, outboard MSIVs, and piping up to the seismic restraints, is classified as seismic Category I. The applicant also stated that the TMSS piping portion of the MS piping (i.e., downstream of the seismic restraint) is a non-safety system, located in a non-safety building designed to seismic Category II, and is analyzed to demonstrate structural integrity under safe-shutdown earthquake (SSE) loading conditions. The staff finds this acceptable.

However, the applicant also stated that the ASME authorized nuclear inspector (ANI) and ASME Code stamping is not required for these portions of the system. In its response to RAI 3.2-1, the applicant agreed to include ANI and ASME Code stamping for all ASME Class 1, 2, and 3 piping. The staff finds this acceptable. The staff requested that the applicant revise the response to RAI 10.3-1 and the DCD to acknowledge the commitment made in response to RAI 3.2-1. (Section 3.2 of this report discusses in detail the main steamline seismic design classification and adherence to RG 1.29.) This is identified as **Confirmatory Item 10.3-1**.

The applicant stated that the system design accommodates steam hammer and relief valve discharge loads. The COL applicant will develop operating and maintenance procedures that include adequate precautions to avoid steam hammer and discharge loads as described in DCD Tier 2, Section 10.3.3. The requirement to develop operating and maintenance procedures is included as a COL information item in DCD Tier 2, Section 13.5.3.

The staff reviewed the capability to detect and control system leakage and to isolate portions of the system in case of excessive leakage or component malfunction. Most of the currently licensed BWRs rely on the MSIVLCS to mitigate the radiological consequences of MSIV leakage following a design-basis loss-of-coolant-accident (LOCA) and to stay within the limits of 10 CFR Part 100, “Reactor Site Criteria,” if the MSIV leakage rate exceeds the technical specification limit. The ESBWR will not have an MSIVLCS and will rely instead on the TMSS coupled with the main condenser and the TBS to contain MSIV leakage, thus relying on plateout and holdup of fission products to limit the radiological consequences to within the 10 CFR Part 100 requirements. In response to RAI 10.3-11, the applicant stated that a procedure is needed to provide the operator actions required to ensure that the MSIV fission product leakage path is isolated from TMSS auxiliaries. The requirement to develop procedures for operation, abnormal events, and emergencies is included as a COL information item in DCD Tier 2, Section 13.5.3.

The applicant stated that a drainline is connected to the low points of each main steamline, both inside and outside the containment. Both sets of drains lead to a common header and are connected with isolation valves to allow flow to the main condenser. Section 15.4 of this report discusses the maximum allowable MSIV leakage. To take credit for the TMSS and main condenser for containment and holdup of MSIV leakage, the TMSS, the main condenser, and connections from the main steamlines to the condenser must be capable of maintaining their integrity during and following an SSE. As discussed above, the TMSS (including the drain paths) is analyzed to demonstrate structural integrity under SSE loading conditions. Section 3.2 of this report contains a detailed evaluation of the seismic analysis requirements for the TMSS and the main condenser.

In order to process the MSIV leakage, a path must be ensured either through the MS drainlines to the main condenser or through the TBS to the main condenser. Regardless of which of these two paths is chosen, reliable power sources must be available so that a control operator can establish the flow path assuming a single active failure. In RAI 10.3-10(a), the staff asked the applicant to demonstrate how the ESBWR design provides reliable methods for ensuring that flow paths can be established to process MSIV leakage through the drainlines or through the turbine bypass valves to the main condenser. In its response to RAI 10.3-10(a), the applicant stated that the drain valve(s) that are required to change position to establish the MSIV leakage path to the condenser will be equipped with reliable power sources or designed to fail to the required position on loss of power or air and will receive periodic inspection and testing to ensure continued reliability. The staff considered this response an insufficient basis for concluding that the design provisions to ensure availability of the power sources are acceptable. The staff therefore requested that the applicant provide a description similar to that provided for the ABWR, which identifies the classification of the power source (specifically, if it is a Class 1E) and configuration for all MSIV alternate leakage treatment (ALT) path valves, including the turbine bypass valves. The applicant submitted a supplemental response to clarify this issue, which the staff review found to acceptably address the concern.

In addition, in RAI 10.3-10(b), the staff requested that the applicant clarify if valves that are required to open the ALT path will be included in the COL holder’s inservice testing (IST) program. In its response to this RAI, the applicant stated that a periodic test program will verify continued reliability of the valves, but the IST program will not include the valves. The staff found this unacceptable because it is not consistent with the staff’s position given in “Safety Evaluation on GE Topical Report, NED-3185P, Revision 2, ‘BWROG Report for Increasing MSIV Leakage and Elimination of Leakage Control Systems,’” in which the staff determined that valves required to open the ALT path should be included in the plant IST program. The ALT path system is classified as ASME Class 2 and Quality Group B and therefore may be subject to the provisions of 10 CFR 50.55a, “Codes and Standards,” and hence to the requirements of the ASME Code for Operation and Maintenance of Nuclear Power Plants (O&M Code). If these valves, which are relied on to mitigate the consequences of an accident, are powered from emergency power sources, then, pursuant to 10 CFR 50.55a, they are required to be included in the IST program. The applicant submitted a supplemental response to clarify this issue, which the staff found acceptable in addressing the IST program governing the ALT path system valves.

The applicant stated that inspection and testing will be in accordance with the requirements of DCD Tier 2, Section 6.6. The main steamline will be hydrostatically tested to confirm leak tightness. The staff finds this acceptable. Section 6.7 of this report discusses in detail system pressure tests and inspections.

The requirements of GDC 2, as related to safety-related portions of the system, do not apply since there are no safety-related portions of the TMSS. However, the staff found that the

TMSS meets the requirements of GDC 2 because the system is dynamically analyzed to demonstrate structural integrity under SSE loading conditions and is subject to pertinent QA requirements of Appendix B to 10 CFR Part 50. Section 3.2 of this report contains a detailed discussion of the seismic qualification requirements.

The requirements of GDC 5 are not applicable to the ESBWR because it is designed as a single-unit facility.

The requirements of GDC 34 are not applicable to direct cycle plants (i.e., BWRs), therefore they are not applicable to the ESBWR design.

As discussed above, the TMSS includes all components and piping from the outermost containment isolation valve up to and including the turbine stop valves. The system has no safety-related portions. The system is analyzed, fabricated, and examined to ASME Code Class 2 requirements, classified as seismic Category II, and subject to pertinent QA requirements of Appendix B to 10 CFR Part 50. ISI will be performed in accordance with ASME Section XI requirements for Code Class 2 piping. The scope of the review included layout drawings, piping and instrumentation diagrams (P&IDs), and descriptive information for the system.

10.3.4 Conclusions

Based on the above discussion the staff concludes that the TMSS for the ESBWR satisfies the requirements of GDC 4 and meets the SRP Section 10.3 acceptance criteria and is, therefore, acceptable.

10.3.5 Not Used

10.3.6 Steam and Feedwater System Materials

10.3.6.1 Regulatory Criteria

The staff reviewed DCD Tier 2, Section 10.3.6, “Steam and Feedwater System Materials,” in accordance with SRP Section 10.3.6, “Steam and Feedwater System Materials.”

The materials selection, fabrication, and fracture toughness criteria of ASME Code Class 2 and 3 pressure boundary components of the steam and FW systems are acceptable if they meet the relevant requirements in 10 CFR 50.55a; GDC 1, “Quality Standards and Records,” and GDC 35, “Emergency Core Cooling,” in Appendix A to 10 CFR Part 50; and Appendix B to 10 CFR Part 50. These requirements are discussed below.

- Compliance with GDC 1 and 10 CFR 50.55a requires that SSCs be designed, fabricated, erected, constructed, tested, and inspected to quality standards commensurate with the importance of the safety function to be performed.

- Compliance with GDC 35 requires that for ferritic pressure-retaining components of a critical nature, the containment capability is assured, in part, by requiring minimum fracture toughness performance of the materials from which they are fabricated.

- Appendix B to 10 CFR Part 50 provides QA requirements for the design, construction, and operation of SSCs that are important to safety.

Descriptive information on the MS system materials, with the exception of those portions included in the reactor coolant pressure boundary (RCPB), appears in DCD Tier 2, Revision 1, Section 10.3.6.

As described below, the staff reviewed the materials aspect of the MS and FW components, as presented in the DCD, in accordance with the guidelines in SRP Section 10.3.6.

10.3.6.2 Summary of Technical Information

The steam and feedwater component materials that are within the RCPB are addressed in DCD Tier 2, Section 5.2.3 and are evaluated in Section 5.2.3 of this report. The materials specified for use in ASME Code Class 2 components meet ASME Code, Sections II and III, or RG 1.84, "Design, Fabrication, and Materials Code Case Acceptability, ASME Section III." The materials used in the ASME Code Class 2 portion of the TMSS meet the fracture toughness requirements of paragraph NC-2300 of the ASME Code. The steam and FW systems in the ESBWR design contain no ASME Code Class 3 piping.

The recommendations in RG 1.71, "Welder Qualification for Areas of Limited Accessibility," and RG 1.37, "Quality Assurance Requirements for Cleaning of Fluid Systems and Associated Components of Water-Cooled Nuclear Power Plants," apply to the ESBWR design. The ESBWR design may employ an alternative to RG 1.71, which is discussed in DCD Tier 2, Section 5.2.3.4.2. ASME Code, Section III, paragraphs NC-2550 through 2570, will be used as the acceptance criteria for nondestructive examination of tubular products.

10.3.6.3 Staff Evaluation

The staff reviewed and evaluated the information in DCD Tier 2, Section 10.3.6, to ensure that the materials and fabrication of ASME Code Class 2 components meet the requirements detailed in SRP Section 10.3.6. The steam and FW systems in the ESBWR design have no ASME Code Class 3 piping.

10.3.6.3.1 Material Selection and Fabrication of Class 2 Components

To meet the requirements of GDC 1 and 10 CFR 50.55a, the materials used in the ASME Code Class 2 portion of the MS and FW systems must meet the requirements of Sections II and III of the ASME Code or the recommendations of RG 1.84 and follow the recommendations in RG 1.50, "Control of Preheat Temperature for Welding of Low-Alloy Steel," issued May 1973, RG 1.71, and ASME Code, Section III, Article D-1000.

DCD Tier 2, Section 10.3.6, does not identify material specifications for MS or FW piping. However, it references MS and FW components that are covered as part of the RCPB in Chapter 5. In RAI 10.3-4, the staff asked the applicant to provide a complete list of all material specifications and grades that are used in the MS and FW systems by component types, including weld filler metal, and to specify the ASME Code Class. By letter dated May 18, 2007, the applicant indicated that ASME Code Class 2 piping material used in MS and FW systems is the same as the material identified for use in the RCPB, as specified in DCD Tier 2,

Table 5.2-4. The staff has reviewed the MS and FW system materials listed in Table 5.2-4 and finds them acceptable because they meet the requirements of Sections II and III of the ASME Code for use in Class 2 systems. The applicant indicated that it would revise DCD Tier 2, Section 10.3.6, to list MS and FW piping material specifications and grades used in Class 2 MS and FW systems. The applicant also stated that the ESBWR steam, FW, and condensate system piping has no ASME Code, Section III, Class 3/Quality Group C piping. The applicant did not provide weld filler material specifications and grades for use in ASME Code Class 2 MS and FW systems. In supplemental RAI 10.3-4(a) S02, the staff requested that the applicant provide the staff with a list of the weld filler material specifications and classifications used in Class 2 MS and FW systems. The staff has identified this issue as part of **Open Item 10.3-4**.

In DCD Tier 2, Section 10.3.1.1, the applicant states that the MS system is analyzed, fabricated, and examined to meet ASME Code Class 2 requirements, classified as nonseismic, and subject to pertinent QA requirements of Appendix B to 10 CFR Part 50. ISI will be performed in accordance with ASME Code, Section XI, requirements for Code Class 2 piping. ASME authorized nuclear inspector (ANI) and ASME Code stamping is not required.

In RAI 10.3-7, the staff asked the applicant to provide a basis for the exclusion of ASME ANI and ASME Code stamping requirements for ASME Class 2 piping and components. In a letter dated July 19, 2006, the applicant stated that the N11 TMSS piping is analyzed, fabricated, and examined to ASME Code Class 2 requirements, classified as non-safety, seismic Category II, and subject to the pertinent QA requirements of Appendix B to 10 CFR Part 50. ISI will be performed in accordance with ASME Code, Section XI, requirements for Code Class 2 piping. ASME ANI and ASME Code stamping is not required. In supplemental RAI 3.2-1 S04, the staff requested additional information regarding the applicant’s intended exclusion of ASME Code stamping and ASME ANI. The staff’s evaluation of the applicant’s aforementioned position is pending upon the completion of the staff’s safety evaluation of DCD Tier 2, Section 3.2.1 “Seismic Classification,” and Section 3.2.2 “System Quality Group Classification.” The staff has identified this issue as **Open Item 10.3-7**, and it will be resolved as part of **Open Item 3.2-1**.

The guidelines listed in RG 1.71 assure the integrity of welds in locations of restricted direct physical and visual accessibility. RG 1.50 provides staff-approved methods to control preheat temperatures before postweld heat treatment when welding low-alloy steel. ASME Code, Section III, Article D-1000, provides recommended minimum preheat temperatures used to weld carbon steel and low-alloy steel components that are acceptable to the staff. RG 1.37 provides acceptable procedures for cleaning and handling Class 2 components of the steam and FW systems.

ASME Code Class 2 components are acceptable if welds located in areas of restricted direct and visual accessibility are welded by personnel qualified according to the guidance of RG 1.71. This guide describes methods acceptable to the staff for providing better control of welder techniques in production welding. DCD Tier 2, Section 10.3.6.2, indicates that an alternative to RG 1.71 may be used as shown in DCD Tier 2, Section 5.2.3.4.2. The staff reviewed the applicant’s alternative to RG 1.71 as stated in DCD Tier 2, Section 5.2.3.4.2. The staff has determined that the applicant’s alternative is consistent with the intent of RG 1.71. The applicant’s alternative will provide reasonable assurance that welders working in restricted access positions will be appropriately qualified.

The ESBWR design complies with RG 1.37 except as noted in DCD Tier 2, Table 1.9-21B. The alternative that the applicant may use is documented in Table 2-1 of "GE Nuclear Energy Quality Assurance Program Description," NEDO-11209-04a, Class I (nonproprietary), Revision 8, March 31, 1989, which was approved by the NRC on March 31,1989, and is therefore acceptable. Section 4.5.1.2.5 of this safety evaluation report further discusses the applicant's level of compliance with RG 1.37. The acceptance criteria for nondestructive examination of tubular products will meet the requirements of ASME Code, Section III, paragraphs NC-2550 through NC-2570, which are consistent with the acceptance criteria in SRP Section 10.3.6.

RG 1.50 requires that all low-alloy steel welds be maintained at the minimum preheat temperature until the performance of postweld heat treatment. In response to RAIs 5.2-44 and 6.1-4, the applicant discussed its alternative to the guidance provided in RG 1.50 for welding components such as the reactor pressure vessel (RPV) and the standby liquid cooling accumulator tank, to ensure that delayed cracking of the weld metal or weld heat affected zone will not occur. The applicant's alternative entails the use of postweld baking with times and temperatures based on the welding process used and prior qualification testing.

The staff considers the applicant's proposal to perform postweld baking to be an acceptable alternative to the guidance in RG 1.50, which requires the maintenance of preheat until postweld heat treatment is performed. The staff notes that this method has been successfully used in several other applications, such as fossil fuel electric generation facilities and petrochemical facilities, with materials that are much more sensitive to hydrogen cracking than those materials used in ASME Code Class 1 and 2 systems in the ESBWR design. Postweld baking is an effective measure to prevent delayed hydrogen cracking in welds that do not go directly from preheat temperature to postweld heat treatment. The staff therefore considers the applicant's alternative to RG 1.50 acceptable, given that it provides reasonable assurance that delayed hydrogen cracking will not occur in the time that a weld is completed through completion of postweld heat treatment.

Although the staff considers the applicant's alternative to RG 1.50 acceptable, the staff requested in supplemental RAI 10.3-4 S02 that the applicant modify the DCD to include its alternative to RG 1.50 as it applies to all ASME Code Class 1, 2, and 3 piping and components. In addition, the staff asked that the applicant modify the DCD to include its response to RAI 6.1-4, in which it states that ASME Code, Section III, Appendix D, Article D-1000, minimum preheat recommendations will be applied to all Class 1, 2, and 3 carbon steel and low-alloy steel piping and components in the ESBWR design. The staff requested that the applicant make these modifications to DCD Sections 5.2.3, 6.1.1, and 10.3.6. The staff has identified these issues as part of **Open Item 10.3-4**.

10.3.6.3.2 Fracture Toughness of Class 2 Components

DCD Tier 2, Section 10.3.6.1, states that the ASME Code, Section III, Class 2, portion of the TMSS meets the fracture toughness requirements of NC-2300. Although this is acceptable to the staff, the applicant did not indicate the fracture toughness requirements for the Class 2 FW system. In supplemental RAI 10.3-4 S02(b), the staff requested that the applicant modify DCD Tier 2, Section 10.3.6, to include the fracture toughness requirements for Class 2 FW components. The staff has identified this issue as part of **Open Item 10.3-4**.

10.3.6.3.3 Flow-Accelerated Corrosion

ASME Code, Section III, paragraph NC-3121, requires that material subject to thinning by corrosion, erosion, mechanical abrasion, or other environmental effects shall have provision made for these effects during the design or specified life of the component by a suitable increase in or addition to the thickness of the base metal over that determined by the design formulas. The staff evaluated information supplied by the applicant in the DCD regarding material selection and design of ASME Code Class 2 MS and FW systems and non-ASME Code, Section III, FW and condensate systems to mitigate the effects of erosion/corrosion. The staff notes that historically, documents such as Generic Letter (GL) 89-08, "Erosion/Corrosion-Induced Pipe Wall Thinning," have referred to flow-accelerated corrosion (FAC) as erosion/corrosion. Therefore, FAC and erosion/corrosion are used interchangeably throughout Section 10.4.3.3 of this safety evaluation report.

The applicant indicated that ASME Code Class 2 MS piping will be constructed of SA-335, Grade 6, and FW piping will be constructed of SA-335, Grade P22. In RAI 10.3-6, the staff requested that the applicant describe the mitigation steps taken in the ESBWR design related to (1) utilization of materials resistant to erosion/corrosion, (2) specification of an adequate corrosion allowance, and (3) consideration of minimizing the effects of erosion/corrosion in the design of all ESBWR FW, steam, and condensate system piping from effects such as fluid velocity, bend locations, and flashpoints. The applicant responded by letter dated July 19, 2006, and stated the following:

> The TMSS piping is designed to consider the effects of erosion/corrosion for a 60 year life expectancy. Piping containing dry, single phase steam is constructed of carbon steel. Piping exposed to wet, two-phase steam is constructed of erosion/corrosion resistant low alloy steel. Velocities in the TMSS piping to the high pressure turbine are limited to reduce the potential for pipe erosion. Low point drains are provided for collecting and draining moisture and to help reduce the potential for water carryover to the high and low pressure turbines. In addition to material selection, pipe size and layout may also be used to minimize the potential for erosion/corrosion in systems containing water or two-phase flow.

The applicant's response to RAI 10.3-6 referenced only the TMSS and did not address MS, FW, and condensate piping, as requested in the RAI. In supplemental RAI 10.3-6 S01, the staff asked that the applicant provide a response that addresses RAI 10.3-6 for all MS, FW, and condensate system piping (ASME Code Class and non-Code piping) in the ESBWR design. By letter dated May 18, 2007, the applicant stated the following:

> The ESBWR standard plant has a 60-year design life. As part of the design of the condensate, feedwater and main steam piping, an erosion-corrosion evaluation is performed. The evaluation is used to determine the expected erosion-corrosion rate, i.e., yearly reduction in wall thickness, based on the system geometry, system configuration, and chemical properties of the process fluid and piping. With the erosion rate known, the results are compared against the 60-year design life. Areas that do not meet the design life are addressed by

> piping configuration changes, material substitutions, or a combination of both…. The remainder of the non-ASME Code Class 1, 2, or 3 Condensate and Feedwater System piping is designed and fabricated with consideration given to the deleterious effects of erosion.

For the TMSS, the selected materials, coupled with the applicant's evaluation to determine the expected erosion/corrosion rate based on the system geometry, system configuration, and chemical properties of the process fluid and piping, are acceptable to the staff and fulfill the design requirements of ASME Code, Section III, paragraph NC-3121. For the ASME Code Class 2 FW systems, which would tend to be more susceptible to FAC than the TMSS, the staff notes that the applicant has selected SA-335, Grade P22 (2.25 percent chromium, 1 percent molybdenum) which provides an increased level of protection against erosion/corrosion. The selection of P22, coupled with the applicant's evaluation to determine the expected erosion/corrosion rate, is acceptable to the staff and fulfills the design requirements of ASME Code, Section III, paragraph NC-3121.

During a teleconference between the NRC staff and the applicant on June 7, 2007, the applicant indicated that the design of non-ASME Code, Section III, systems is not yet complete. In supplemental RAI 10.3-6 S02, the staff asked that the applicant modify the DCD to include a COL applicant action item to include materials specifications and grades for non-ASME Code, Section III, MS, FW, and condensate piping and components that could potentially be susceptible to erosion/corrosion and discuss a basis for the selection of these materials. The staff has identified this issue as **Open Item 10.3-6**.

In addition to design considerations to minimize erosion/corrosion, as described in GL 89-08, an appropriate long-term monitoring program must be implemented to detect the potential wall-thinning of high-energy piping, ASME Code, Section III, Code Class 1, 2, 3, and non-safety-related piping, caused by erosion/corrosion. The applicant's description of the required augmented inspection program to monitor erosion/corrosion is acceptable to the staff and is located in Section 6.6.3.8 of this safety evaluation report.

10.3.7 Conclusions

Due to the open items that remain to be resolved for this section the staff was not able to finalize its conclusions on acceptability.

10.4 <u>Other Features of Steam and Power Conversion System</u>

10.4.1 Main Condenser

10.4.1.1 <u>Regulatory Criteria</u>

The staff reviewed the design of the main condenser in accordance with SRP Section 10.4.1, Revision 2, 1981. The design of the main condenser is acceptable if its integrated design meets the requirements of GDC 60, "Control of Releases of Radioactive Materials to the

Environment," in Appendix A to 10 CFR Part 50, as they relate to the design of the system to ensure that failures do not result in excessive releases of radioactivity to the environment, do not cause unacceptable condensate quality, and do not flood areas housing safety-related equipment.

The guidance in SECY-93-087 is applicable for new BWR plants that do not incorporate an MSIVLCS and for which main condenser holdup and plateout of fission products are credited in the analysis of design-basis accident radiological consequences. The applicable guidance from SECY-93-087 states that a seismic analysis should be performed to ensure that the condenser anchorages and the piping inlet nozzle to the condenser are capable of maintaining their structural integrity during and after an SSE.

10.4.1.2 Summary of Technical Information

The main condenser is designed to function as the steam cycle heat sink. During normal operation, it receives, condenses, deaerates, and holds up for N-16 decay the main turbine exhaust steam and turbine bypass steam whenever the TBS is operated. The main condenser is also a collection point for other steam cycle miscellaneous drains and vents. The main condenser is utilized as a heat sink in the initial phase of reactor cooldown during a normal plant shutdown. The main condenser does not perform, support, or ensure any safety-related function and thus has no safety design basis. The applicant stated that it is designed with the necessary shielding and controlled access to protect plant personnel from radiation. Sections 11.1 and 11.3 of this report describe the anticipated inventory of radioactive contaminants during operation and shutdown.

DCD Tier 2, Section 10.4.1 describes the main condenser system of the ESBWR design. DCD Tier 2, Table 10.4.1-1, "Main Condenser Data," lists the design parameters of the condenser (such as heat transfer capability, surface area, design operating pressure, shell-side pressure, circulating water flow, and tube-side temperature rise). Section 10.4.1 of DCD Tier 2 references this table.

The applicant stated that, during anticipated operational occurrence conditions, the condenser is designed to receive turbine bypass steam and high-level dump from the FW heaters and MSR drain tanks. The condenser is also designed to receive relief valve discharges and any necessary venting from MSR vessels, FW heater shells, the gland seal steam header, steam seal regulator, and various other steam supply lines. The condenser will be designed with spray pipes and inlet baffles to preclude component or tube failures. Turbine low-pressure diaphragms are also installed in the condenser to protect the condenser and turbine from overpressure damage. During startup, steam is admitted to the condenser shell to assist in condensate deaeration.

10.4.1.3 Staff Evaluation

The staff reviewed whether the system description delineates the main condenser system capabilities including the minimum system heat transfer and system flow requirements for normal plant and turbine bypass operation. The staff also reviewed measures provided to prevent loss of vacuum, corrosion, and/or erosion of main condenser tubes and components and hydrogen buildup in the main condenser.

The staff concluded that the ESBWR design is consistent with the guidance of SECY-93-087 because the condenser supports and anchors are designed to maintain condenser integrity following an SSE. Section 3.2 of this report discusses the seismic design qualification and analysis.

In RAI 10.4-2, the staff asked the applicant to provide a detailed description of design measures to prevent the loss of the condenser. In its response, the applicant stated that design measures to prevent loss of condenser include treatment of circulating water to prevent algae or other growth from fouling the condenser tubes. The tube metal selected will be stainless steel or titanium, both of which are resistant to erosion, corrosion, and galvanic action. The tubesheet will be selected to complement the tube material and resist corrosion and galvanic action. Coating of the water box material will protect the circulating water system from corrosion and galvanic action resulting from the dissimilarity of the metal of the tubes and tubesheet to the water box plate material. The staff finds this acceptable.

Leakage will be into the condenser since it will normally be operated at a vacuum. The online instrumentation and process sampling system described in DCD Tier 2, Section 9.3.2, monitor leakage of circulating water into the condenser shell. Conductivity and sodium are continuously monitored at the discharge of the condensate pumps. High condensate conductivity and sodium content, which indicate a condenser tube leak, are individually alarmed in the main control room. The condenser air removal system, discussed in detail in Section 10.5.2 of this report, monitors radioactive leakage into and out of the main condenser.

The staff reviewed whether the failure of the main condenser system could cause unacceptable condensate quality or flooding of areas housing safety-related components. In DCD Tier 2, Section 3.4.1.4.3, the applicant stated that no components in the turbine building can affect the safe shutdown of the reactor. (Section 3.4.1 of this report discusses protection from flooding for safety-related equipment.) The staff finds this acceptable.

The staff requested that the applicant provide a detailed description of controlling and correcting methods including alarm setpoints, operator intervention, and plant response as described in SRP Section 10.4.1. In its response, the applicant committed to revise the DCD to include threshold values and recommended operator actions for chemistry excursions in the condensate system. In DCD Tier 2, Revision 2, the applicant identified this as COL Action Item 10.4.10.5. In Revision 3, the applicant removed the action item. The staff asked the applicant to provide a justification for its decision, since the COL applicant must provide this information. In its response, the applicant stated that it would restore this COL Action item in DCD Tier 2, Revision 4. The staff finds this acceptable and identifies it as **Confirmatory Item 10.4-14**.

10.4.1.4 Conclusions

As discussed above, the staff reviewed the design of the main condenser in accordance with SRP Section 10.4.1. On the basis of this review the staff concludes that the main condenser system is acceptable and meets the requirements of GDC 60 with respect to controlling excessive releases of radioactivity to the environment that result from failures in the system design. The applicant has met this requirement by providing suitable radioactivity monitoring, as described in DCD Tier 2, Section 3.1.6.1, and measures to prevent loss of condenser vacuum.

10.4.2 Condenser Air Removal System

10.4.2.1 Regulatory Criteria

The staff reviewed the main condenser air removal system in accordance with the acceptance criteria in SRP Section 10.4.2, Revision 2, 1981. The design of the condenser air removal system is acceptable if its integrated design meets the requirements of GDC 60 in Appendix A to 10 CFR Part 50, as it relates to the condenser air removal system design for the control of releases of radioactive materials to the environment. The design must also meet the requirements of GDC 64, “Monitoring Radioactivity Releases,” as it relates to monitoring releases of radioactive materials to the environment.

The SRP includes RG 1.33, “Quality Assurance Program Requirements (Operation),” in the acceptance criteria. RG 1.123, “Quality Assurance Requirements for Control of Procurement of Items and Services for Nuclear Power Plants,” has been withdrawn and is therefore no longer applicable. The applicant may meet the requirements of GDC 60 and 64 by using the guidance contained in the following RGs and industrial standard:

- RG 1.26, “Quality Group Classifications and Standards for Water-, Steam-, and Radioactive-Waste-Containing Components of Nuclear Power Plants,” as it relates to the condenser air removal system quality group classification that may contain radioactive materials but is not part of the RCPB and is not important to safety

- RG 1.33, as it relates to the QA programs for the condenser air removal system components that may contain radioactive materials

- The Heat Exchanger Institute’s “Standards for Steam Surface Condensers,” 6th Edition, as it relates to the condenser air removal system components that may contain radioactive materials

10.4.2.2 Summary of Technical Information

The condenser air removal system is designed to remove noncondensable gases from the power cycle. The condenser air removal system removes the hydrogen and oxygen produced by radiolysis of water in the reactor and other power cycle noncondensable gases and exhausts them to the offgas system during plant power operation and to the turbine building compartment exhaust (TBCE) system during plant startup, cooldown, and power operation. Condenser vacuum is established and maintained during power operation by either of the two 100-percent capacity, double-stage SJAEs, or by two 50-percent capacity mechanical vacuum pumps during early startup. One SJAE unit is normally in operation and the other is on standby.

The SJAEs are placed in service to remove the gases from the main condenser after vacuum is established in the main condenser by the mechanical vacuum pumps and when sufficient nuclear steam pressure is available. During normal power operations, the SJAEs are normally driven by cross-around steam, with the MS supply on automatic standby. The MS supply, however, is normally used during startup and low-load operation, and auxiliary steam is available for normal use of the SJAEs during early startup, as an alternative to the MS or if the mechanical vacuum pumps are unavailable. Section 9.4 of this report discusses the auxiliary steam system in detail.

10.4.2.3 Staff Evaluation

The staff reviewed the condenser air removal system to determine the flow paths of gases through the system, including all bypasses, and the points of release of gaseous wastes to the environment or other systems.

In RAI 10.4-10, the staff asked the applicant to revise DCD Tier 2, Revision 2, Figure 10.4-3, to include the location of the cross-around and MS supply connections, which the figure does not show. In its response to RAI 10.4-10, GEH committed to revise the drawing to delete the specific reference to the auxiliary steam system because the SJAEs can be supplied from several steam sources. In DCD Tier 2, Revision 3, the applicant revised the drawing to reflect this commitment. The staff finds this acceptable.

RGs 1.33 and 1.26 are applied as they relate to the QA programs for the condenser air removal system components that may contain radioactive materials. The applicant stated that the applicability of RG 1.33 will be addressed by the quality assurance program during construction and operation, which is identified in DCD Tier 2, Revision 3, as **COL Action Item 17.2.1**. The staff finds this acceptable.

The components of the condenser air removal system are designed to Quality Group D as defined in RG 1.26 and are not designed to SSE seismic standards. The applicant stated that the quality standards meet the requirements of 10 CFR 50.55a for water- and steam-containing components that may contain radioactive materials but are not part of the RCPB. Section 3.2 of this report discusses the seismic and quality group classification of components in detail. The staff finds this acceptable.

The staff reviewed whether the condenser air removal system design meets the intent of GDC 64 as it relates to the design for monitoring of releases of radioactive materials to the environment. The offgas from the main condenser is one source of radioactive gas in the station. The applicant stated that the discharge of the vacuum pump is routed to the TBCE system because at that point there is very low effluent radioactivity present. Section 11.4 of this report discusses an inventory of radioactive contaminants in the effluent from the SJAEs. Radiation detectors in the TBCE system and plant vent stack will alarm in the main control room if they detect abnormal radioactivity in the steam being supplied to the condenser. The staff finds this acceptable.

In the DCD Section 10.4.2.3 states that steam supply to the second-stage ejector is maintained at a minimum specified flow to ensure adequate dilution of hydrogen and prevent the offgas from reaching the flammability limit of hydrogen. In addition, maximum power limits are placed on operation of the mechanical vacuum pumps to ensure that the flammability limit of hydrogen is not reached. In RAI 10.4-5, the staff asked the applicant to provide minimum steam flow, maximum power limit on the operation of the vacuum pump, and design steam content volume percentage, in accordance with SRP Section 10.4.2, to ensure that hydrogen flammability levels are not reached. In its response to RAI 10.4-5, the applicant stated that the staff concerns are applicable only if the ESBWR design includes a hydrogen water chemistry (HWC) system. The applicant stated that the HWC system is an option that the owner may choose as a later plant modification and is not offered in the ESBWR standard plant design. The staff finds this acceptable.

10.4.2.4 Conclusions

On the basis of the above discussion, the staff concludes that the condenser air removal system design meets the requirements of GDC 60 and 64 with respect to the control and monitoring of radioactive materials to the environment and is, therefore, acceptable.

10.4.3 Turbine Gland Seal System

10.4.3.1 Regulatory Criteria

The staff reviewed the design of the TGSS in accordance with SRP Section 10.4.3, Revision 2, 1981. The design of the TGSS is acceptable if it meets the requirements of GDC 60, as it relates to the control of releases of radioactive materials to the environment. It must also meet GDC 64, as it relates to monitoring releases of radioactive materials to the environment. The applicant may meet the requirements of GDC 60 and 64 by using the guidance in the following RGs:

- RG 1.26, as it relates to the TGSS quality group classification that may contain radioactive materials but is not part of the RCPB and is not important to safety

- RG 1.33, as it relates to the QA programs for the TGSS components that may contain radioactive materials

10.4.3.2 Summary of Technical Information

The TGSS prevents the escape of radioactive steam from the turbine shaft/casing penetrations and valve stems and prevents air in-leakage through subatmospheric turbine glands. The TGSS does not perform, ensure, or support any safety-related function and thus has no safety design basis. The high-pressure turbine shaft seals must accommodate a range of turbine shell pressures from full vacuum to approximately 30 kPaG (4.35 psig). The low-pressure turbine shaft seals operate against a vacuum at all times. The gland seal outer portion steam/air mixture is exhausted to the gland steam condenser via the seal vent annulus, which is maintained at a slight vacuum. In addition, the auxiliary steam system is designed to provide a 100-percent backup to the normal gland seal process steam supply. Section 9.4 of this report discusses the auxiliary steam system.

The annular space through which the turbine shaft penetrates the casing is sealed by steam supplied to the shaft seals. Where the gland seals operate against positive pressure, the sealing steam flows either inwards for collection at an intermediate leak-off point or outwards and into the vent annulus. Where the gland seals operate against vacuum, the sealing steam either is drawn into the casing or leaks outward to a vent annulus. At all gland seals, the vent annulus is maintained at a slight vacuum and receives air in-leakage from the outside. From each vent annulus, the air-steam mixture is drawn to the gland steam condenser.

A pressure controller automatically regulates the seal steam header pressure. During startup and low-load operation, the auxiliary boiler supplies the seal steam. Above a certain plant load, seal steam is evaporated by the gland steam evaporator. The source of steam for the evaporator is plant heat cycle (i.e., MSRs). The applicant stated that by employing the evaporator, the plant power operation can be maintained without appreciable radioactivity releases even if highly abnormal levels of radioactive contaminants are present in the process steam. At all loads, gland sealing can be achieved using clean steam directly from the auxiliary boiler or the evaporator. In low-load and normal operation, MS is a backup supply to the seal steam. The outer portion of all glands of the turbine and MS valves is connected to the gland steam condenser, which is maintained at a slight vacuum by the exhauster blower. During plant operation, the gland steam condenser and one of the two installed 100-percent capacity motor-driven blowers are in operation. The exhauster blower to the TBCE system effluent stream is continuously monitored before being discharged. The gland steam condenser is cooled by main condensate flow. The TGSS returns the condensed steam to the condenser and exhausts the noncondensable gases, via the TBCE system, to the plant vent.

The applicant stated that the TGSS has enough capacity to handle steam and airflows resulting from twice the normal packing clearances. The TGSS provides for the collection and condensation of sealing steam and the venting and treatment of noncondensable gases. The applicant stated that components are designed to Quality Group D standards, as defined in RG 1.26, and, consistent with the RG, they are not designed to SSE seismic standards.

10.4.3.3 Staff Evaluation

The staff reviewed the TGSS to determine the source of sealing steam and the disposition of steam and noncondensables vented from the gland seal to determine if the design meets GDC 60. The TGSS includes the equipment and instruments to provide a source of sealing steam to the annulus space where the turbine and large steam valve shafts penetrate their casings. The scope of the review included the source of sealing steam and the provisions incorporated to monitor and control releases of radioactive material in effluents.

RGs 1.33 and 1.26 are applicable as they relate to the QA programs for the turbine gland sealing systems that may contain radioactive materials. The applicant stated that the applicability of RG 1.33 will be addressed by the QA program during construction and operation, which is identified in DCD Tier 2, Revision 3, as COL Action Item 17.2.1. The staff finds this acceptable.

The staff reviewed the TGSS with respect to monitoring releases of radioactive materials to the environment. The applicant stated that the TGSS effluents are first monitored by a system-dedicated, continuous, radiation monitor installed on the gland steam condenser exhauster blower discharge. High monitor readings are alarmed in the main control room. The system effluents are then discharged to the TBCE system and the plant vent stack, where further effluent radiation monitoring occurs. The applicant stated that a radiological analysis of the TGSS effluents based on conservative site-specific parameters will be performed at the COL phase. From this analysis, the COL applicant will determine the various actions to be taken if and when the TGSS effluent radiation monitor detects preset levels of effluent contaminations, including the level at which the MS is not used to supply seal steam to the TGSS. This is identified in DCD Tier 2, Revision 3, Section 12.2, as COL Action Item 12.2.4.2. The staff finds this acceptable.

In RAI 10.4-6, the staff asked the applicant to provide inspection, test, analysis, and acceptance criteria (ITAAC) in DCD Tier 1 for the TGSS. In its response to RAI 10.4-6, the applicant stated that the TGSS does not perform or support safety-related functions nor does it qualify as important to safety because its failure would not result in an accident. The staff did not agree with this position and held subsequent discussions with the applicant. Although the TGSS is not safety related or important to safety, it does a have a role in controlling and monitoring releases of radioactive materials to the environment, as required by GDC 60 and GDC 64. Subsequently, in DCD Tier 1, Revision 3, GEH included an ITAAC table for the TGSS that will verify the as-built system and main control room alarm operability. The staff finds this acceptable.

10.4.3.4 Conclusions

Based on the preceding discussion, the staff concludes that the TGSS is acceptable because it meets the requirements of GDC 60 and 64 for controlling and monitoring releases of radioactive material to the environment. The system also meets the acceptance criteria of SRP Section 10.4.3.

10.4.4 Turbine Bypass System

10.4.4.1 Regulatory Criteria

The staff reviewed the design of the TBS in accordance with SRP Section 10.4.4, Revision 2, 1981. The acceptability of the system design is based on meeting the following GDC as described in the SRP:

- GDC 4, as it relates to the system’s being designed in such a way that a failure of the system (because of a pipe break or system malfunction) does not adversely affect safety-related systems or components

- GDC 34, “Residual Heat Removal,” as it relates to the ability to use the TBS to shut down the plant during normal operations by removing residual heat without using the turbine generator

10.4.4.2 Summary of Technical Information

The TBS provides the capability to discharge MS from the reactor directly to the condenser to minimize step load reduction transient effects on the nuclear boiler system. The TBS is also used to discharge MS during reactor hot standby and cooldown operations. Operation of the TBS eliminates the need to rely solely on safety-related systems for shutting down the plant during normal operations.

The TBS, in combination with the reactor systems, provides the capability to accept a full load rejection without reactor trip and without the operation of safety relief valves. The turbine bypass valves are opened by redundant signals received from the SB&PC whenever the actual steam pressure exceeds the preset steam pressure by a small margin. This occurs when the turbine cannot use the entire amount of steam generated by the reactor. This bypass demand signal causes fluid pressure to be applied to the operating cylinder, which opens the first of the individual valves. As the bypass demand increases, additional bypass valves are opened, dumping the steam to the condenser. The bypass valves are equipped with fast-acting solenoid valves to allow rapid opening of bypass valves upon turbine trip or generator load rejection.

10.4.4.3 Staff Evaluation

The TBS will not perform or support any safety-related function. There is no safety-related equipment in the vicinity of the TBS, except four position sensors at each bypass valve that provide valve status to the reactor protection system (RPS) logic. In its response to RAI 10.4-11, the applicant stated that these sensors are not relied on to shut down the reactor and mitigate the consequences of a postulated piping failure outside containment, and thus are not considered essential components. In addition, the four position sensors, which are mounted on each turbine valve, are fail safe, such that if the bypass valve fails to open or the switch fails to change state during the approximately 200 ms after the detection of a fast turbine control valve closure or turbine stop valve closure, the RPS scram is not bypassed, and thus the position sensors cannot prevent actuation of the reactor protection function. The staff finds this acceptable. Section 7.2 of this report discusses RPS operational bypasses. Sections 15.2 and 15.3, respectively, of this report discuss failures of the TBS during anticipated operational occurrences and during infrequent events.

Although the TBS will not be required to serve or support any reactor safety function, it will have a post-LOCA function for the ESBWR. In the absence of an MSIVLCS, the main steam lines and condenser will be used to collect MSIV leakage following a LOCA. Therefore, the TBS must be capable of maintaining its integrity following an SSE. The turbine bypass line from the bypass valve to the condenser will be seismically analyzed to demonstrate that it is capable of sustaining the SSE loading conditions without failure. (Section 3.2 of this safety evaluation report contains additional discussion and evaluation of the capability of the turbine bypass piping to meet this requirement.)

The TBS includes all components and piping from the branch connection at the MS system to the main condensers. The scope of review of the TBS for the ESBWR design included layout drawings, P&IDs, and descriptive information for the TBS and the auxiliary supporting systems that are essential to its operation.

The applicant stated that all turbine bypass valves will be tested for operability. The steamlines will be hydrostatically tested to confirm leak-tightness. Pipe weld joints will be inspected by radiography per ASME III, Class 2, requirements upstream of the bypass valves and in accordance with ASME B31.1 downstream. The bypass valves will be tested while the unit is in operation. Periodic inspections will be performed on a rotating basis within a preventive maintenance program in accordance with the manufacturer's recommendations. The staff finds this acceptable.

10.4.4.4 Conclusions

The basis for accepting the design, design criteria, and design bases of the TBS is their conformance to GDC 4 and 34 of Appendix A to 10 CFR Part 50, as explained below:

- The ESBWR TBS design meets the requirements of GDC 4 such that its failure will not prevent the plant's safe shutdown.

- The ESBWR design meets the requirements of GDC 34 with respect to the ability to use the TBS to shut down the plant during normal operations. The TBS is designed such that sufficient steam can be bypassed to the main condenser so that the plant can be shut down during normal operations without using the turbine generator.

Based on the preceding, the staff concludes that the design of the TBS conforms to SRP Section 10.4.4, meets the requirements of GDC 4 and 34 and is, therefore, acceptable.

10.4.5 Circulating Water System

10.4.5.1 Regulatory Criteria

The staff reviewed the CIRC in accordance with SRP Section 10.4.5, Revision 2, 1981. Acceptability of the system is based on meeting the requirements of GDC 4, as they relate to provisions in the ESBWR design to accommodate the effects of discharging water that may result from a failure of a component or piping in the CIRC. Compliance with GDC 4 is based on meeting the relevant acceptance criteria specified in the SRP, such as the following:

- means to prevent, detect, and control flooding of safety-related areas resulting from leakage from the CIRC

- means to prevent adverse effects of malfunction or failure of CIRC piping on functional capabilities of the safety-related systems or components

- control of water chemistry, corrosion, and organic fouling in the CIRC

10.4.5.2 Summary of Technical Information

The CIRC consists of (1) condenser water boxes and piping and valves, (2) condenser tube cleaning equipment, and (3) a water box drain subsystem. The cooling water is circulated by fixed-speed motor-driven pumps. The pumps are arranged in parallel, and discharge lines combine into two parallel circulating water supply lines to the main condenser. Each circulating water supply line connects to a low-pressure condenser shell inlet water box. An interconnecting line fitted with a butterfly valve is provided to connect both circulating water supply lines. The discharge of each pump is fitted with a remotely operated valve. This arrangement permits isolation and maintenance of any one pump while the others remain in operation and minimizes the backward flow through a tripped pump.

The CIRC and condenser are designed to permit isolation of each set of the three series connected tube bundles to permit repair of leaks and cleaning of water boxes while operating at reduced power. The CIRC includes water box vents to help fill the condenser water boxes during startup and removes accumulated air and other gases from the water boxes during normal operation.

A chemical additive subsystem is also provided to prevent the accumulation of biological growth and chemical deposits within the wetted surfaces of the system.

10.4.5.3 Staff Evaluation

The staff reviewed whether the system meets GDC 4, as it relates to accommodating the effects of discharging water that may result from a failure of a component or piping in the CIRC by providing a means to prevent or detect and control flooding of safety-related areas. The applicant stated that the CIRC and related facilities are designed such that the selected combination of plant physical arrangement and system protective features ensures that all credible potential circulating water spills inside the turbine building remain confined inside the turbine building condenser area. Level switches in the turbine building trip the pumps and close the valves of the CIRC in case of a system component failure. The flooding signal initiates from the detection of a high-high water level.

The staff reviewed the system to verify that a malfunction or failure of a component or piping will not have unacceptable adverse effects on the functional performance capabilities of safety-related systems or components. The CIRC provides cooling water for removal of the power cycle waste heat from the main condensers and transfers this heat to the normal power heat sink. The applicant stated that CIRC does not interface with any safety-related SSC, and a CIRC failure could not adversely affect any safety-related SSC.

The applicant performed a flooding analysis of the turbine building, postulating a complete rupture of a single expansion joint. If a circulating water system pipe, water box, or expansion joint failure is not detected and isolated, the water discharged would cause internal turbine building flooding up to slightly above grade level, with excess water potentially spilling over on site. If a failure occurred within the condensate system (condenser shell side), the resulting flood level would be below grade level because of the relatively small hotwell inventory compared to the turbine building capacity. The staff finds this acceptable. Section 3.4 of this report contains a detailed description of general flooding provisions.

The applicant stated that certain portions of the system are outside the scope of the ESBWR standard plant. These include the (1) screen house and intake screens, (2) pumps and pump discharge valves, and (3) related support facilities such as the makeup water system, water treatment, inventory blowdown, and general maintenance. In addition, the DCD states that some site-dependent system design features and additional information are also outside the scope of the ESBWR design certification. These include the (1) compatible design as described in DCD Section 10.4.5.2, (2) evaluation per DCD Section 10.4.5.3, (3) tests and inspections per DCD Section 10.4.5.4, (4) instrument applications per DCD Section 10.4.5.5, and (5) flood protection per DCD Section 10.4.5.6. Before Revision 3, the applicant had identified this information in the DCD as COL Action Item 10.4.10.4. However, in Revision 3, the applicant removed this action item; the staff finds this to be acceptable.

10.4.5.4 Conclusions

On the basis of its review the staff concludes that the design of the CIRC meets the requirements of GDC 4, with respect to the effects of discharging water that may result from a failure of a component or piping in the CIRC. Acceptance is based on the following design provisions:

- The CIRC is designed to prevent flooding of safety-related areas so that leakage from the CIRC will not preclude the intended safety function of a system or component.

- The CIRC is designed to detect and control flooding of safety-related areas so that leakage from the CIRC will not preclude the intended safety function of a system or component.

- Malfunction of a component or piping of the CIRC, including an expansion joint, will not have unacceptable adverse effects on the functional performance capabilities of safety-related systems or components.

The staff concludes that the design of the CIRC meets the acceptance criteria of SRP Section 10.4.5 and; thereby, the requirements of GDC 4. The staff, therefore, finds the design acceptable.

10.4.6 Condensate Purification System

10.4.6.1 Regulatory Criteria

The staff reviewed the CPS description in accordance with SRP Section 10.4.6, “Condensate Cleanup System.” Staff acceptance of the design is based on compliance with the requirements of GDC 14, “Instrumentation and Control,” as it relates to the water chemistry control being capable of preventing adverse chemistry conditions that could degrade the primary coolant boundary integrity.

RG 1.56, “Maintenance of Water Purity in Boiling Water Reactors,” Revision 1, July 1978, describes a method acceptable to the NRC staff for implementing the criteria with regard to minimizing the probability of corrosion-induced failure of the RCPB in BWRs by maintaining acceptable purity levels in the reactor coolant. It further describes instrumentation acceptable to the NRC staff for determining the condition of the reactor coolant and coolant purification system.

10.4.6.2 Summary of Technical Information

The CPS purifies and treats the condensate to maintain reactor FW purity. The CPS uses filtration to remove suspended solids, including corrosion products, and demineralizers to remove dissolved solids from condenser leakage and other impurities.

The CPS consists of the following major components:

- filters
- demineralizers
- resin storage tank
- resin receiver tank
- filter backwash tank

The CPS does not perform any safety-related functions.

10.4.6.3 Staff Evaluation

The staff reviewed the CPS description in accordance with SRP Section 10.4.6, "Condensate Cleanup System." Staff acceptance of the design is based on compliance with the requirements of GDC 14 as related to assuring the integrity of the RCPB.

The CPS removes dissolved and suspended solids from the condensate in addition to some radioactive material, activated corrosion products, and fission products that are carried over from the reactor, to maintain a high quality of FW to the reactor under all normal plant operating conditions. The CPS will also remove corrosion products from the condensate to limit any accumulation of corrosion products in the cycle.

The CPS consists of six back-washable filters and eight mixed-bed demineralizers arranged in parallel. One demineralizer is normally on standby. Demineralizers are equipped with a resin trap downstream of each vessel to prevent resin from entering the effluent and to catch resin fine leakage as much as possible. Demineralizers have a bypass valve which can be controlled manually or automatically from the main control room. The CPS operates continuously to maintain FW purity levels at all times. Waste generated in the CPS is sent to the radwaste system for treatment and/or disposal.

The CPS contains instrumentation that monitors different parameters throughout the system. The parameters monitored in the CPS are conductivity, differential pressure, and flow. Conductivity of the condensate flow is measured just before entrance to the system and at the outlet flow of the demineralizers. Measuring conductivity just before entrance to the system helps detect condenser leakage, whereas conductivity measured at the outlet flow of the demineralizers provides indication of resin exhaustion. Differential pressure is measured across each filter vessel, demineralizer vessel, and across each vessel discharge resin strainer to help detect flow blockage. Condensate flow is measured through each demineralizer and used as input to ensure that the flow is distributed evenly through all operating demineralizing vessels.

All of these parameters are recorded at the CPS local control panel. Any parameter that is not within its required value will be alarmed in the control panel, which is connected to the main control room where all these alarms are directed.

The applicant stated that the CPS complies with RG 1.56, Revision 1. However, the application was unclear as to whether the CPS complies with EPRI Report NP-4947-SR, "BWR Hydrogen Water Chemistry Guidelines," 1987 Revision. Therefore, by letter dated February 1, 2006, the staff asked the applicant to clarify whether the CPS complies with the "BWR Hydrogen Water

Chemistry Guidelines." In its response dated February 28, 2006, the applicant stated that the HWC system is not offered in the ESBWR standard plant design, although provisions have been made to install the system as a COL applicant option. The applicant stated that if the COL applicant considers the option to include the HWC system, the CPS will be modified, as required, to comply with the subject EPRI chemistry guidelines. The staff finds the applicant's response acceptable.

The CPS components and related support facilities are located in the turbine building and other non-safety-related buildings. Any component failure of the CPS will not compromise any safety-related system or component nor will it preclude the ability to achieve and maintain a safe shutdown.

10.4.6.4 <u>Conclusions</u>

The CPS includes all components and equipment necessary for the removal of dissolved and suspended impurities that may be present in the condensate.

Based on its review of the applicant's proposed design criteria and design bases for the CPS and the requirements for operation of the system, the staff concludes that the design of the CPS and supporting systems is acceptable and meets the primary boundary integrity requirements of GDC 14. The staff reached this conclusion because the applicant's design meets the requirements of GDC 14 as it relates to maintaining acceptable chemistry control for reactor coolant during normal operation and anticipated operational occurrences by reducing corrosion of reactor system components. The design of the CPS meets the regulatory positions of RG 1.56, Revision 1.

Based on this information, the staff concludes that the CPS design for the ESBWR is acceptable.

10.4.7 Condensate and Feedwater System

10.4.7.1 <u>Regulatory Criteria</u>

The staff reviewed the CFS in accordance with SRP Section 10.4.7, "Condensate and Feedwater System," Revision 3, 1984. Conformance with the acceptance criteria of the SRP forms the basis for concluding that the CFS satisfies the following criteria:

- GDC 2, with respect to withstanding the effects of natural phenomena (such as earthquakes, tornadoes, and floods)
- GDC 4, with respect to withstanding the effects of possible fluid flow instabilities (such as water hammers)
- GDC 5, "Sharing of Structures, Systems, and Components," with respect to the ability of the shared systems and components important to safety to perform required safety functions

- GDC 44, “Cooling Water,” with respect to the capability to transfer heat loads from the reactor system to a heat sink under both normal operating and accident conditions

- GDC 45, “Inspection of Cooling Water System,” with respect to permitting periodic ISI of systems, components, and equipment

- GDC 46, “Testing of Cooling Water System,” with respect to design provisions to permit functional testing of the system and components for structural integrity and leak-tightness

10.4.7.2 Summary of Technical Information

The CFS consists of the piping, valves, pumps, heat exchangers, controls, and instrumentation and the associated equipment and subsystems that supply the reactor with heated FW in a closed steam cycle utilizing regenerative FW heating. The system is divided into two subsystems: (1) piping and components extending from the RPV inside the containment, to the seismic interface restraint located upstream of the outermost FW isolation valve, outside of the containment, and (2) piping, pumps, valves, heat exchangers, controls, and instrumentation extending from the main condenser outlet to, but not including, the seismic interface restraint. DCD Tier 2, Revision 3, Section 5.4.9, describes subsystem (1), as discussed above.

The FW lines are routed from the turbine building to the MS and FW pipe tunnel, through containment penetrations, at which point they branch into six lines that connect to the RPV in the upper drywell. There is a connection at each of the two lines for detection and monitoring of differential pressure between the two FW lines. The six branch lines inside containment provide FW flow distribution to the RPV. The control rod drive system injection line connects to the reactor water cleanup/shutdown cooling (RWC/SDC) system loop “A” return line, which is connected to a thermal sleeve in the “B” FW line in the tunnel. The fuel and auxiliary pool cooling system low-pressure coolant injection line connects to the RWC/SDC system loop “B” return line, which connects to the “A” FW line in the tunnel.

The CFS consists of four 33–37 percent capacity condensate pumps (three normally operating and one on automatic standby,) four 33–45 percent capacity reactor FW pumps (three normally in operation and one on automatic standby), four stages of low-pressure closed FW heaters, a direct contact FW heater (FW tank), and two stages of high-pressure FW heaters, piping, valves, and instrumentation. The condensate pumps take suction from the condenser hotwell and discharge the deaerated condensate into one common header, which feeds the CPS. Downstream of the CPS, the condensate is taken by a single header, through the auxiliary condenser/coolers, one gland steam exhauster condenser, and two sets of SJAE condensers and offgas recombiner condensers (coolers). The condensate then branches into three parallel strings of low-pressure FW heaters. Each string contains four stages of low-pressure FW heaters. The strings join together at a common header, which is routed to the FW tank, which supplies heated FW to the suction of the reactor FW pumps.

The reactor FW pumps discharge into two parallel high-pressure FW heater strings, each with two stages of high-pressure FW heaters. Downstream of the high-pressure FW heaters, the two strings are then joined into a common header, which divides into two FW lines that connect to the reactor. A bypass is provided around the FW tank and reactor FW pumps to permit the supply of FW to the reactor during early startup without operating the FW pumps, using only the condensate pumps.

One more bypass, equipped with a flow control valve, is provided around the high-pressure heaters to provide a flow path around a single string for heater maintenance/failure or for reducing final FW temperature to extend the end of the fuel cycle. During power operation, the condensate is deaerated in the condenser, and continuous oxygen injection is used to maintain the level of oxygen content in the final FW. To minimize corrosion product input to the reactor during startup, recirculation lines to the condenser are provided from the high-pressure FW heater outlet header.

The DCD states that before plant startup, FW cleanup is accomplished by allowing the system to recirculate through the condensate polishers for treatment before feeding any water to the reactor during startup. Section 10.5.6 of this report discusses the condensate cleanup system.

During operation, radioactive steam and condensate are present in the FW heating portion of the system, which includes the extraction steam piping, FW heater shells, heater drain piping, and heater vent piping. Chapter 12 of this report discusses shielding and access control provisions.

10.4.7.3 Staff Evaluation

The staff reviewed the system to determine that it meets GDC 2 as it relates to the ability to withstand the effects of earthquakes. The FW lines are designed as Quality Group A and ASME Section III, Class 1, from the RPV through the outboard isolation check valves, and Quality Group B and ASME Section III, Class 2, through the isolation shutoff valves to the seismic interface restraint. The FW lines are seismic Category I from the RPV to the seismic interface restraint upstream of the isolation shutoff valve, seismic Category II to the last FW heater, and nonseismic thereafter. (Section 3.2 of this safety evaluation report discusses the details of seismic classification.) The staff finds this acceptable.

The staff reviewed the system to determine that it meets GDC 4 with regard to protection against the effects of high-energy pipe ruptures and with respect to withstanding the effects of possible fluid flow instabilities (such as water hammers). The piping design pressure and temperature of the Class 1 portions are, respectively, 8.62 MPa gauge (1250 psig) and 302 °C (576 °F).

The applicant stated that the FW control system is designed to ensure that there could not be large sudden changes in FW flow that could induce water hammer. During normal operations FW flow is varied as needed by using the adjustable speed of the motor-driven speed pumps, which eliminates the need for flow control valves and thus minimizes the likelihood of a water hammer event. During low-flow conditions (less than 25 percent of rated reactor power), the FW control system uses single-element control based on vessel water level.

Single-element control reduces the likelihood of water hammer events by minimizing valve cycling at low loads when compared to three-element controllers. In this mode, the conditioned level error from the master level controller is used to determine the demand to either the low-flow control valve or to an individual feed pump adjustable speed drive. Section 7.7 of this report provides a detailed discussion of the FW control system.

The staff finds that the FW control system includes adequate design considerations to avoid water hammer events and is consistent with the guidelines of NUREG-0927, "Evaluation of Water Hammer Occurrences in Nuclear Power Plants." DCD Tier 2, Section 10.3.7, states that the operating and maintenance procedures include adequate precautions to avoid steam hammer. Section 3.4.1 of this safety evaluation report discusses protection of safety-related equipment from flooding. Based on the preceding discussion, the staff finds that the ESBWR FW system includes adequate considerations to avoid and withstand the effects of high-energy pipe ruptures and of fluid flow instabilities, as required by GDC 4.

The requirements of a GDC 5 are not applicable to the ESBWR design because it is designed as a single unit.

The staff concludes that the system meets GDC 44 as it relates to the capability to transfer heat loads from the reactor system to a heat sink under both normal operations and accident conditions and provisions for redundancy and isolation of components, subsystems, or piping. The staff concludes that failure of the CFS will not compromise any safety-related system or function or prevent safe shutdown as demonstrated by the results of the CFS component failure analysis provided in DCD Tier 2, Table 10.4-6. The CFS trip logic and control schemes respectively use coincident logic and redundant controllers and input signals to assure that plant availability goals are achieved and spurious trips are avoided. This specifically includes all FW heater level controllers, all CFS flow and minimum flow controllers, pump suction pressure trips, FW heater string isolation/high-level trips, and CFS bypass system(s) operation.

The staff concludes that the system meets GDC 45, as related to permitting periodic ISI of system components and equipment, and GDC 46, as related to design provisions to permit appropriate functional testing of the system and components to assure structural integrity and leak-tightness, operability and performance of active components, and capability of the integrated system to function as intended during normal, shutdown, and accident conditions. The performance status, leak-tightness, and structural leak-tight integrity of all system components are demonstrated by continuous operation. The applicant stated that each FW heater and condensate pump receives a shop hydrostatic test, which is performed in accordance with applicable codes. All tube joints of FW heaters are shop leak tested. Before initial operation, the complete CFS will receive a field hydrostatic and performance test and inspection. Periodic tests and inspections of the system are performed in conjunction with scheduled maintenance outages. The Class 1 portions of the system are inspected and tested in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, as discussed in Section 5.2.4 of this report.

Section 10.4.3 of this safety evaluation report discusses considerations for piping systems, including material standards and inspection programs, to avoid erosion and corrosion effects and compliance with GL 89-08 and the guidelines in EPRI NP-3944, "Erosion/Corrosion in Nuclear Plant Steam Piping: Causes and Inspection Guidelines." Section 6.7 of this report discusses PSI and ISI provisions. The staff finds this acceptable.

DCD Revision 3, Section 3.9.3.2, states that the FW nozzle design incorporates the requirements in NUREG-0619, “BWR Feedwater Nozzle and Control Rod Derive Return Line Nozzle Cracking: Resolution of Generic Technical Activity A-10,” Revision 1, issued November 1980, and GL 80-95, “Generic Activity A-10,” dated November 13, 1980, and GL81-11 “BWR Feedwater Nozzle and Control Rod Drive Return Line Nozzle Cracking.” However, in addition to the design considerations, the staff requested the applicant to confirm that the ESBWR complies with all NUREG-0619 provisions, including an FW nozzle PSI and ISI program. Specifically, the staff requested GEH to confirm that the ESBWR FW nozzles are designed to provide access for the examinations described in NUREG-0619, in accordance with ASME Section XI requirements. The staff also asked the applicant to include a COL action item to ensure that the COL applicant will include the provisions of NUREG-0619 in its PSI and ISI inspection programs. The applicant provided a supplemental response to clarify this issue which the staff found acceptable. The applicant has included a COL action item in DCD Tier 2, Section 5.2.6 to address development of the PSI and ISI programs by the COL applicant.

10.4.7.4 Conclusions

On the basis of its review the staff concludes that the design of the CFS meets the NRC regulations in GDC 2, 4, 44, 45, and 46 and is, therefore, acceptable. The following provides the basis for this conclusion:

- The ESBWR meets the requirements of GDC 2 with respect to the system’s ability to withstand the effects of earthquakes by conforming with RG 1.29.
- The ESBWR meets the requirements of GDC 4 with respect to the dynamic effects associated with high-energy piping failures and possible fluid flow instabilities.
- The ESBWR meets the requirements of GDC 44 because the applicant demonstrated that failure of this system cannot compromise any safety-related system or function, or prevent safe shutdown.
- The ESBWR meets the requirements of GDC 45 and GDC 46 because the system will be tested and inspected in accordance with the applicable codes and regulatory requirements. Periodic tests and inspections of the system are performed in conjunction with scheduled maintenance outages.

10.4.8 Steam Generator Blowdown System (PWR)

Not applicable to the ESBWR design.

10.4.9 Auxiliary Feedwater System (PWR)

Not applicable to the ESBWR design.