September 7, 2010

Mr. Jerald G. Head
Senior Vice President, Regulatory Affairs
GE Hitachi Nuclear Energy
3901 Castle Hayne Road MC A-18
Wilmington, NC 28401

SUBJECT: FINAL SAFETY EVALUATION FOR LICENSING TOPICAL REPORTS NEDE-33243, REVISION 2, "ESBWR MARATHON CONTROL ROD NUCLEAR DESIGN" AND NEDE-33244P, REVISION 1, "ESBWR MARATHON CONTROL ROD MECHANICAL DESIGN REPORT"

Dear Mr. Head:

On August 24, 2005, GE Hitachi (GEH) Nuclear Energy submitted the Economic Simplified Boiling Water Reactor (ESBWR) design certification application to the staff of the U.S. Nuclear Regulatory Commission. Subsequently, in support of the design certification, GEH submitted the license topical reports (LTRs) NEDE-33243P, Revision 2, "ESBWR Marathon Control Rod Nuclear Design" and NEDE-33244P, Revision 1, "ESBWR Marathon Control Rod Mechanical Design Report." The staff has now completed its review of NEDE-33243P, Revision 2 and NEDE-33244P, Revision 1.

The staff finds NEDE-33243P, Revision 2, "ESBWR Marathon Control Rod Nuclear Design" and NEDE-33244P, Revision 1, "ESBWR Marathon Control Rod Mechanical Design Report," acceptable for referencing for the ESBWR design certification to the extent specified and under the limitations delineated in the LTRs and in the associated safety evaluation (SE). The SE, which is enclosed, defines the basis for acceptance of the LTR.

The staff requests that GEH publish the revised version of the LTRs listed above within 1 month of receipt of this letter. The accepted version of NEDE-33243P and NEDE-33244P shall incorporate this letter and the enclosed SE and add an "-A" (designated accepted) following the report identification number.

If NRC's criteria or regulations change, so that its conclusion that the LTR is acceptable is invalidated, GEH and/or the applicant referencing the LTR will be expected to revise and resubmit its respective documentation, or submit justification for continued applicability of the LTR without revision of the respective documentation.

Document transmitted herewith contains sensitive unclassified information. When separated from the enclosures, this document is "DECONTROLLED."

Pursuant to 10 CFR 2.390, we have determined that the enclosed SE contains proprietary information. We will delay placing the non-proprietary version of this document in the public document room for a period of 10 working days from the date of this letter to provide you with the opportunity to comment on the proprietary aspects only. If you believe that any additional information in Enclosure 1 is proprietary, please identify such information line by line and define the basis pursuant to the criteria of 10 CFR 2.390.

The Advisory Committee on Reactor Safeguards (ACRS) subcommittee, having reviewed the subject LTR and supporting documentation, agreed with the staff's recommendation for approval following the May 18, 2010 ACRS subcommittee meeting.

Sincerely,

/RA Frank Akstulewicz for:/

David B. Matthews, Director
Division of New Reactor Licensing
Office of New Reactors

Docket No. 52-010

Enclosure:
1. Safety Evaluation (Non-Proprietary)
2. Safety Evaluation (Proprietary)

cc: See next page (w/o enclosure)

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ADAMS ACCESSION NO. - ML101750259-Package

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DATE	06/28/10	08/12/10	09/02/10	09/07/10	07/30/10	09/07/10

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SUBJECT: FINAL SAFETY EVALUATION REPORT FOR LICENSING TOPICAL REPORTS NEDE-33243P, REVISION 2, "ESBWR MARATHON CONTROL ROD NUCLEAR DESIGN" AND NEDE-33244P, REVISION 1, "ESBWR MARATHON CONTROL ROD MECHANICAL DESIGN REPORT" DATED SEPTEMBER 7, 2010

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SAFETY EVALUATION BY THE OFFICE OF NEW REACTORS
NEDE-33244P, REVISION 1, "ESBWR MARATHON CONTROL ROD MECHANICAL DESIGN REPORT," AND NEDE-33243P, REVISION 2, "ESBWR CONTROL ROD NUCLEAR DESIGN,"
GE HITACHI NUCLEAR ENERGY, LLC

1.0 INTRODUCTION

By application dated November 15, 2007 (Reference 1), and supplemented by information in References 2, 3, and 4, GE Hitachi Nuclear Energy (GEH) requested review and approval of NEDE-33244P, Revision 1, "ESBWR Marathon Control Rod Mechanical Design Report" (Reference 5). This licensing topical report (LTR) provides mechanical analysis results for the economic simplified boiling-water reactor (ESBWR) Marathon control rod blade (CRB). This report represents a complete revision of NEDE-33244P, Revision 0 June 2006 report, and includes changes to the CRB design. Mark-ups to this topical report for inclusion in Revision 2 are also listed in Reference 1.

By application dated July 2008, GEH requested review and approval of NEDE-33243P, Revision 2, "ESBWR Control Rod Nuclear Design" (Reference 6). This LTR presents the ESBWR Marathon CRB nuclear analysis. This report represents a complete revision of the NEDE-33243P, Revision 1 June 2006, report, and includes changes to the CRB design.

The proposed ESBWR CRB design is evaluated to ensure (1) the integrity of the reactor coolant pressure boundary, (2) the capability to shut down the reactor and maintain it in a safe shutdown condition, and (3) the capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures as set forth in Title 10 CFR Part 100.

2.0 REGULATORY EVALUATION

Regulatory framework for the review of fuel system designs and reactivity control systems are General Design Criteria (GDC) 10, 26, 27, and 35 in Appendix A, "General Design Criteria for Nuclear Power Plants," to Reference 18. GDC 10, "Reactor Design," establishes specified acceptable fuel design limits (SAFDLs) that should not be exceeded during any condition of normal operation, including the effects of anticipated operational occurrences (AOOs). GDC 26, "Reactivity Control System Redundancy and Capability," requires two independent reactivity control systems of different design principles including control rods capable of reliably controlling reactivity changes to ensure that under conditions of normal operations, including AOOs, SAFDLs are not exceeded. GDC 27, "Combined Reactivity Control Systems Capability," and GDC 35, "Emergency Core Cooling," establish requirements for combined reactivity control system capability and emergency core cooling capability under postulated accident conditions.

Regulatory guidance for the review of fuel system design and adherence to the GDC listed above appears in NUREG-0800, Revision 3, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants" (SRP), Section 4.2, "Fuel System Design," issued March 2007 (Reference 7). In accordance with SRP Section 4.2, the objectives of fuel system safety review are to ensure the following:

- The fuel system is not damaged as a result of normal operation and AOOs.

- Fuel system damage is never so severe as to prevent control rod insertion when it is required.

- The number of fuel rod failures is not underestimated for postulated accidents.

- Coolability is always maintained.

GEH proposed a set of acceptance criteria for evaluating CRB designs in 26A6642A, Revision 5, "ESBWR Design Control Document," Tier 2, Chapter 4, "Reactor," issued May 2008 (Reference 9):

- Control rod stresses, strains, and cumulative fatigue shall be evaluated to not exceed the ultimate stress or strain limit of the material, structure, or welded connection.

- The control rod design shall be evaluated to be capable of insertion into the core during all modes of plant operation within the limits assumed in the plant analyses.

- Control rod materials shall be shown to be compatible with the reactor environment.

- Control rod reactivity worth shall be included in the plant core analyses.

3.0 TECHNICAL EVALUATION

The following summarizes the objectives of the review by the staff of the U.S. Nuclear Regulatory Commission (NRC) of NEDE-33243P, Revision 2, and NEDE-33244P, Revision 1:

- Provide assurance that the CRB design criteria are consistent with the regulatory criteria identified in SRP Section 4.2.

- Verify that the CRB design complies with the licensing acceptance criteria proposed by GEH in Reference 1, Section 4, and Reference 9, Section 4C.

- Verify that the CRB design satisfies regulatory requirements.

- Verify that the mechanical design methodology is capable of accurately or conservatively evaluating each component with respect to the applicable design criteria.
- Verify that the GEH analysis supports the mechanical lifetime reported in the LTR. If necessary, implement a surveillance program to monitor in-reactor behavior and confirm the design calculations.

- Verify that the structure of the CRB is evaluated during all normal and upset conditions and is found to be mechanically acceptable.

- Verify that the methods and models used to calculate nuclear lifetime are consistent with regulatory criteria identified in SRP Section 4.2.

The staff conducted two separate audits at the GEH offices in Wilmington, NC. Pacific Northwest National Laboratory staff assisted the agency staff in the review of the ESBWR

Marathon CRB structural evaluations and participated in the audits. A summary of the audits is given in the NRC's "Audit Report and Summary (2007 & 2008) for Global Nuclear Fuels Control Blade and Fuel Assembly Design," dated December 22, 2008 (Reference 10).

3.1 ESBWR Marathon Control Rod Mechanical Design Evaluation

This section evaluates the ESBWR Marathon CRB mechanical analysis results contained in Reference 1. GEH currently manufactures the long-life Marathon CRB for BWR/2 through BWR/6. The NRC acceptance of the Marathon CRB is documented in a letter dated July 1, 1991 (Reference 11). The design presented in Reference 1 is a Marathon CRB adapted for use in the ESBWR.

3.1.1 Design Change Description

The GEH ESBWR Marathon CRB is a derivative of the boiling-water reactor (BWR)/2–6 Marathon design approved in NEDE-31758P-A, "GE [H] Marathon Control Rod Assembly," issued October 1991 (Reference 8). The primary difference between the ESBWR Marathon and the BWR/2–6 Marathon designs is a shorter absorber section appropriate for ESBWR application. The ESBWR Marathon design uses the same square absorber tube design as the BWR/2–6 Marathon design. Compared to the original BWR/2–6 design, the ESBWR capsule of boron carbide (B_4C) has [[

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The basic design of the ESBWR Marathon CRB is the same as that of the BWR/2–6 Marathon CRB approved in the July 1, 1991 US NRC letter (Reference 11). The ESBWR Marathon CRB is an all B_4C design, with all tubes filled with either B_4C capsules or empty capsule plenums. The six design changes to the BWR/2–6 Marathon are listed below:

(1) Absorber Section Length: Absorber zone length for the ESBWR Marathon CRB assembly is shorter than in the BWR/2–6 since the active fuel height of the ESBWR design is shorter than the BWR/2–6 active fuel height. The nominal length of the BWR/2-6 Marathon CRB is [[ ]]; for the ESBWR Marathon CRB, this is reduced to [[ ]] (Table 2-1 of Reference 1).

(2) Capsule Geometry: The ESBWR Marathon CRB uses a B_4C capsule with the same cross-sectional dimensions as the Marathon-5S CRB capsule (NEDE-33284P, Revision 1, "GEH Proprietary Information Licensing Topical Report 'Marathon-5S Control Rod Assembly,'" issued November 2007 (Reference 12)). However, the ESBWR CRB design uses [[ ]].

The boron neutron absorption reaction releases helium gas, some of which is retained within the boron carbide powder matrix, causing the powder column to swell. [[

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(3) Capsule Length: The ESBWR Marathon CRB absorber section is shorter than that of the new BWR/6 Marathon control rod assembly. The nominal capsule length of the original Marathon CRB for BWR/2–6 was 11.4 inches. The absorber section design nominal lengths for the ESBWR Marathon CRB are [[ ]] and [[ ]]. These lengths are shorter than the nominal lengths of the new BWR/2–6 Marathon-5S CRB [[ ]].

Per NEDE-33244P, Rev. 1 (Reference 1), [[

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(4) Connector: The ESBWR control rod drive system uses an electrohydraulic fine motion control rod drive mechanism that provides electric-motor-driven positioning for normal insertion, and a hydraulic control unit provides rapid insertion (scram) during abnormal operating conditions. To be compatible with the fine motion control rod drive mechanism, the ESBWR Marathon CRB uses a connector as shown in Figures 2-3 and 2-4 of Reference 1, rather than the velocity limiter used in Marathon CRBs for BWR/2–6.

(5) Handle with Spacer Pads: The ESBWR Marathon CRB uses a raised spacer pad similar to that currently used for the D-lattice (BWR/2–4) Marathon CRB applications. The raised spacer pad is expected to eliminate the possibility of stress-corrosion cracking (SCC). The original Marathon CRB uses a traditional handle with rollers with wear pads that is susceptible to SCC within its handle pin-hole.

(6) Full-Length Tie Rod: The Marathon CRB uses multiple tie rod segments along the center of the cruciform shape. The Marathon-5S CRB uses a single tie rod segment along the center of the cruciform shape that runs the entire length of the assembly.

The ESBWR Marathon CRB employs a single tie rod that runs through the entire length of the assembly, similar to that in the Marathon-5S CRB.

3.1.2 Mechanical Design Evaluation

The review methodologies used in the evaluation of acceptability of the ESBWR Marathon CRB design are the following (References 1, 8, and 9):

1. Control rod stresses, strains, and cumulative fatigue shall be evaluated to not exceed the ultimate stress or strain limit of the material, structure, or welded connection.

2. The control rod design shall be evaluated to be capable of insertion into the core during all modes of plant operation within the limits assumed in the plant analyses.

3. Control rod materials shall be shown to be compatible with the reactor environment.

4. Control rod reactivity worth shall be included in the plant core analyses.

5. The ESBWR Marathon CRB surveillance program shall be shown to provide increased assurance of the CRB's ability to perform their intended functions.

This section will discuss the first three licensing criteria. Section 3.2 will address Criterion 4, and Section 3.3 will address the proposed surveillance program.

3.1.2.1 Stress, Strain, and Fatigue

GEH's proposed licensing criterion is that control rod stresses, strains, and cumulative fatigue shall be evaluated to not exceed the ultimate stress or strain limit of the material, structure, or welded connection due to normal, abnormal, and faulted loads. The integrity of the welds under these loading conditions is also part of this criterion. This criterion is consistent with the SRP Section 4.2 (Reference 7) acceptance criteria for complying with the agency's regulations.

Section 3 of Reference 5 describes the method of analysis for the structural evaluation of the ESBWR Marathon CRB under various loading conditions including the worst-case or bounding loads and limiting material properties.

Effective stresses and strains were determined using the Von Mises distortion energy theory and compared to allowable limits. Both the Von Mises and Tresca stress criteria are used to predict the conditions for yielding under both uniaxial and multiaxial stress states. The Tresca criterion measures the maximum shear stress present, and the Von Mises criterion accounts for all principal stresses in the calculation of the conditions where yielding occurs.

Each structural analysis is first evaluated to determine whether unirradiated or irradiated material properties are appropriate. The analyses are divided into two categories: (1) analysis with an applied load (i.e., scram) for which a maximum stress is calculated and compared to the limiting unirradiated stress limit, and (2) analysis with an applied displacement (i.e., seismic bending) for which a maximum strain is calculated and compared to the limiting irradiated strain.

The evaluation used the licensing criteria of Section 4 of Reference 1, which states that control rod stresses and strains and cumulative fatigue shall be evaluated to not exceed the ultimate stress or strain of the material, structure, or welded connection. The figure of merit employed by GEH for the stress-strain limit is the design ratio, which is effective stress divided by stress limit or effective strain divided by strain limit. The design ratio must be less than or equal to 1.0. The evaluation adds conservatism by limiting stresses to one-half of the ultimate tensile value (Table 3-2 of Reference 1).

The irradiation-resistant special melt austenitic stainless steel type 304 (304S) used for CRB absorber tubes is manufactured using standard industrial processes and solution annealing. Results from GEH's irradiated tensile tests demonstrated the strength and ductility of the material in the radial direction. As part of an audit (Reference 10), the staff investigated the ductility limit of 304S at end-of-life (EOL) properties and the accuracy of the stress-strain curves used to model the post yield behavior at beginning-of-life (BOL) and EOL. In Request for

Additional Information (RAI) 4.2-32, the staff requested experimental data to validate GEH finite-element analysis (FEA) modeling assumptions. Comparison of the as-modeled stress-strain curves to actual test data showed different behavior past the material yield point. This was not critical for irradiated cases because none of the irradiated analyses had loads beyond the yield point; however, the unirradiated cases were of concern. To address these concerns, GEH demonstrated that the as-modeled stress-strain curves were greatly conservative compared to actual 304S test data as documented in the response to RAI 4.2-32. Based on the applicant's response, RAI 4.2-32 was resolved.

During the review of the FEA modeling approach, the staff also noted that the worst-case geometry was not being modeled.

In RAI 4.2-31 (Reference 2), the staff asked GEH to demonstrate that adequate design margin still existed by using the as-modeled geometry to perform a worst-case geometry check. The worst-case geometry evaluation showed that substantial design margin still remained. Based on the applicant's response, RAI 4.2-31 was resolved.

Since the ESBWR Marathon CRB uses the same square absorber tube as the BWR/2–6 Marathon CRB, welding processes are the same. Welding processes for CRBs are developed and qualified against a set of acceptance standards, which includes meeting minimum penetration standards, smooth blends between blended numbers, and no cracks, holes, or porosity.

In NEDE-33244 (Reference 1), GEH commits to performing weekly metallographic evaluations on sample laser welds to confirm that the results of the welding process remain acceptable. Figure 3-16 of Reference 1 shows photomicrographs of a typical laser weld. Comparison of the grain structure at the edge of the weld to an area away from the weld shows that there is no effective heat-affected zone (HAZ) for a laser weld. This combined lack of HAZ, Ta stabilization, and low carbon chemistry accounts for the good carbide test results.

The combination of low heat input welding, Ta stabilization, and restrictive carbon limits provides an effective barrier to intergranular SCC.

The CRB absorber tubes and capsules must provide positioning and containment of the neutron absorber material throughout its nuclear and mechanical life and prevent migration of the absorber material out of the capsules during normal, abnormal, emergency, and faulted conditions. The ESBWR Marathon CRB contains capsules with B_4C powder contained within absorber tubes. Helium gas produced from the boron-10 (B-10) (n, α) reaction causes the B_4C powder to swell, which causes the capsule to expand. A fraction of the helium escapes from the capsule and fills the absorber tube gap. In the BWR/2–6 Marathon capsule design, the expansion of the capsule causes a strain in the absorber tube near the end of nuclear life. Per NEDE-33244 (Reference 1) and RAI 4.2-27 response (Reference 4), the ESBWR capsule is designed such that its expansion allows for clearance between the capsule and the absorber tube, even at 100-percent local B_4C depletion at all locations along the length of the tube.

Test capsules of B_4C were irradiated in a reactor for a period of 10 years, and their dimensions were measured before and after irradiation in a hot cell. Diametral swelling results based on a conservative [[

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A thermal FEA of the absorber tube was performed to determine the peak B_4C temperature using worst-case dimensions, maximum EOL crud buildup, combined with maximum BOL heat generation. The pressure in the absorber tube results from the helium release that increases with temperature. For the thermal FEA analysis, corrosion was modeled as the buildup of an insulating layer of crud, the thickness of which was twice that assumed for the BWR/2–6 Marathon design. Data from the analysis (Table 3-10 of Reference 1) shows significant dependence of helium release fraction on the irradiation temperature.

To assess the limiting mechanical lifetime for the ESBWR Marathon CRB, the staff performed confirmatory FEAs to determine the pressurization capability of the absorber tube due to helium gas production.

The burst pressure is defined as the internal pressure at which any point in the tube reaches stress intensity equal to the true ultimate strength of the material. The burst pressure capability of the tube is calculated using square absorber tube nominal dimensions. The applicant reduced the burst pressure by half to add a safety factor of 2 to the peak operating pressure. The resulting peak operating pressure is further reduced (scaled down) by [[ ]], based on experimental observations compared against FEA results of a previous absorber tube design. Table 3-20 of NEDE-33244 (Reference 1) indicates that although the burst pressure is less than the nominal single tube value, it is bounded by the scaled burst pressure. Therefore, the staff concludes that the design-basis absorber tube allowable pressure is conservative.

Analysis of stress components performed by GEH at the point of maximum stress intensity for the absorber tube, with maximum allowable internal pressure, found the point of maximum stress intensity on the inside of the absorber tube. The principal stress components as listed in Table 3-18 of NEDE-33244 (Reference 1) are within the allowable stress value for 304S tubing.

Welding of the absorber section of the CRB generates two potential issues: sensitization and residual stress. The low-heat-input laser welding process does not result in sensitized material. The integrity of the absorber tube welds is confirmed by the weekly metallographic evaluations performed by GEH as specified in NEDE-33244 (Reference 1).

One major effect of the welding process is that it will introduce tensile residual stress in the narrow weld/HAZ region. Residual stresses are not a significant concern for two reasons: (1) the field cracking has not been associated with the weld HAZ and (2) the irradiation experienced by the CRB over the initial time of operation can significantly reduce these stresses by 60 percent or more through the radiation creep process. At the level of reduced stress, there is little concern for any effect on SCC initiation.

Pressurization of the absorber tube causes axial expansion of the tubes as the internal pressure pushes against the end plugs that seal the ends of the absorber tubes. Table 3-19 of Reference 1 lists the maximum elongation and other parameters used in the calculation. The maximum elongation is found to be relatively small and will not affect the fit, form, or function of the CRB.

The finite-element model for pressurization calculations uses unirradiated material properties. To confirm that usage of unirradiated material properties is conservative, GEH performed two test cases using irradiated material properties and calculated peak stress and strain intensities and compared them to material allowable ultimate stress and strain in Table 3-21 of Reference 1. This comparison confirmed that the unirradiated material analysis for absorber

tube pressurization is generally conservative. The staff reviewed the material property comparisons, and agrees that the use of unirradiated material properties is more conservative for use as input to this finite-element model.

The original Marathon CRB (described in Reference 8) possessed a tendency for irradiation-assisted stress-corrosion cracking (IASCC) in the handle near the roller pin. To eliminate the possibility of IASCC initiating within the handle pin-hole, the ESBWR Marathon CRB employs a raised spacer pad, shown in Figure 2-4 of Reference 1. Also, the Marathon absorber tube is manufactured from GEH proprietary stainless steel, Rad Resist 304S, which is optimized to be resistant to IASCC.

The ESBWR Marathon CRB, in addition to using IASCC-resistant 304S, is designed such that the swelling of the B_4C capsule does not exert a mechanically imposed stress or strain on the absorber tube, thereby reducing the likelihood of SCC.

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The applicant performed an absorber tube mechanical limit calculation as a function of average percent depletion of B-10 based on peak heat generation, temperatures, and helium release fractions. Table 3-23 of NEDE-33244 (Reference 1) lists the CRB mechanical lifetime, in terms of four-segment average B-10 depletion. The four-segment mechanical lifetime limit is [[ ]]. The staff concurs with this mechanical lifetime limit based on the use of approved methods and conservative assumptions. The nuclear depletion limit is calculated to be [[ ]] in NEDE-33243 (Reference 6). Therefore, the nuclear lifetime of the ESBWR Marathon CRB is limiting, in the sense that the mechanical lifetime exceeds the nuclear lifetime.

Section 3.8 of Reference 1 details the load combinations, including AOOs and fatigue loads associated with those combinations. Loads experienced by the CRB during scram and safe-shutdown earthquake (SSE) were evaluated. The combined loads were evaluated for the cumulative effect of maximum cyclic loadings, based on reactor cycles. The fatigue usage was evaluated against a limit of 1.0. Tables 3-12 through 3-14 of Reference 1 show that the low number of cycles represents only a small amount of cumulative damage, well below the design limit. This conclusion is based on the ASME Code Section III fatigue design for unirradiated austenitic material.

Fatigue evaluation for any flow-induced vibration for the CRB was performed in terms of loads induced by transverse loading. It was determined that the load considered was so small that it would not lead to any risk of fatigue.

Based on the use of conservative material properties, conservative design approach, review of GEH calculations, and staff confirmatory analyses, the staff finds the ESBWR Marathon CRB mechanical design analyses acceptable.

3.1.2.2 Control Rod Insertion

SRP Section 4.2 acceptance criteria stipulate that the control rod reactivity and insertability must be maintained. The GEH proposed licensing criterion stating that the CRB design shall be evaluated to be capable of insertion into the core during all modes of plant operation within the limits assumed in the plant analyses is consistent with SRP Section 4.2 and therefore acceptable.

Conservative structural analyses of the CRB were performed assuming 100-percent failed control rod drive buffer. Structural stresses were determined from scram loads, using weld quality factors and worst-case geometry (Figure 3-1 and Table 3-4 of Reference 1). Table 3-5 of Reference 1 indicates that sufficient margin exists against failure for all cross-sections and welds.

Section 3.4 of Reference 1 addresses CRB insertion with respect to seismic conditions and fuel channel bow-induced bending. The SSE analysis for the ESBWR Marathon CRB was performed by evaluating the strain in the CRB absorber section with maximum SSE deflection. Table 3-6 of Reference 1 shows that under combined worst-case conditions, the maximum strain is well below the limiting maximum allowable strain at irradiated conditions.

FEA evaluating the combined effect of CRB bending due to SSE and channel bulge and bow deflection at the full-length tie rod to absorber tube weld showed that the resulting stresses are acceptable against design criteria (Figure 3-2 and Table 3-7 of Reference 1).

FEA to determine the effect of lateral load imposed on CRB absorber due to an excessively bowed channel indicated that the maximum stress intensity is less than the absorber tube allowable load (Table 3-12 of Reference 1). This lateral load model was also evaluated using EOL irradiated material properties; the evaluation determined that both maximum stress intensity and maximum strain intensity were less than corresponding ultimate stress and strain, respectively.

Based on the staff's review of the underlying engineering calculations and results presented in Reference 1, the staff finds that the ESBWR Marathon CRB design satisfies the control rod insertion licensing criterion.

3.1.2.3 Control Rod Material

GEH's proposed licensing criterion is that the material of the CRB shall be shown to be compatible with the reactor environment for the life of the CRB. The CRB design shall consider the effects of crudding, crevices, stress corrosion, and irradiation on the material. This criterion is consistent with SRP Section 4.2 and therefore acceptable.

The ESBWR Marathon CRB uses the same materials as the current Marathon design. No new material has been introduced. The square absorber tubes are made of the same high-purity stabilized type 304S. Table 1 of Reference 1 lists limiting unirradiated material strengths of the CRB components. GEH requires that the mechanical properties of all materials used in the fabrication of CRBs meet material specification limits.

Based on the information submitted, the staff finds that the ESBWR Marathon CRB design has satisfied the licensing criterion.

3.2 ESBWR Marathon Control Rod Nuclear Design Evaluation

3.2.1 Design Specifications

Section 1 of GEH letter MFN 08-562, dated July 3, 2008 (Reference 6), describes the ESBWR Marathon CRB nuclear design specifications. The ESBWR Marathon CRB is designed such that its initial cold worth matches the Duralife CRB initial cold worth. The CRB EOL is specified

as the percent B-10 depletion resulting in a 10-percent cold worth reduction in any quarter segment of the blade. This EOL specification is consistent with previous CRB designs. GEH Letter MFN 09-343, dated June 11, 2009 (Reference 13) gives the historical basis for the nuclear lifetime criterion.

3.2.2 Nuclear Design Evaluation

3.2.2.1 Depletion Methodology

The nuclear lifetime for a particular CRB is calculated by the use of a two-dimensional Monte Carlo analysis applied in a stepwise fashion to account for B-10 depletion over time. For each time step, the poison reaction rates are assumed to be constant, and the poison inventories are calculated in each discrete area of the blade. The poison number densities are then updated by averaging on a cell-by-cell basis, and the process is repeated until the reduction in cold worth reaches the end-of-nuclear-life criterion.

This process was used and approved previously for both the Marathon and Marathon-5S CRB designs (References 8 and 12, respectively). For the ESBWR nuclear design evaluations, GEH has replaced the Monte Carlo code used in Reference 8 (MERIT) with a GEH-controlled version of MCNP4A. MCNP4A is an industry standard code developed by Los Alamos National Laboratory (LANL) for Monte Carlo analysis of neutron transport. It has been approved by the staff for use for many different uses for many years. The staff therefore approves this change in methodology.

As previously noted in Reference 4, the NRC staff is concerned about system geometry definitions for the poison region when a MCNP-based approach is used to calculate B-10 depletion. To preclude the appearance of B-10 drifting during the averaging of number densities in each region for each time step, the region thicknesses should be on the order of one neutron mean free path. Reference 6 accounts for B-10 drift by dividing the B_4C column into four rings of equal area, resulting in ring thicknesses that are approximately one neutron mean free path or less. The staff finds that by dividing the B_4C column in this fashion, the averaging of the poison number densities over the cell at each time step is a reasonable approximation of how the B-10 poison would be burned out over time and is therefore acceptable.

3.2.2.2 Nuclear Lifetime and Initial Control Rod Worth

The NRC staff reviewed the ESBWR CRB nuclear lifetime results for the lattice provided in the MCNP4A input deck (GEH Letter MFN 08-464, dated May 27, 2008 (Reference 14)), as calculated by the methodology described in Section 3.2.2.1 of this safety evaluation. Based on the findings in Section 3 of Reference 6, the EOL fluence is [[ ]] (corresponding to [[ ]] maximum quarter segment B-10 depletion). Using Reference 14, the NRC staff was able to verify that this EOL fluence is appropriate through confirmatory analyses involving conservative assumptions. Table 2.1 of Reference 6 provides the nominal and limiting axial burnup profiles used to determine the blade EOL. Furthermore, Section 5 of Reference 6 describes how the axial depletion profile is used in conjunction with the radial depletion profile to determine the average depletion fraction in the limiting rod. This is important for determining if the depletion is within the limit of the mechanical design depletion limit. Since results show that the depletion in the limiting tube is greater than the mechanical limit, a plenum region at the bottom is introduced at the bottom of the tube for pressure relief from the helium release.

During audits conducted at GEH's Wilmington, NC, site, the NRC staff reviewed sample MCNP decks used in calculating the CRB reactivity worth (Reference 10). The staff determined that the methodology described in Section 3.2.2.1 of this safety evaluation was correctly implemented. Specifically, the staff inspected the MCNP input decks to ensure that (1) the B_4C regions were modeled to handle "B-10 drift", (2) material densities were correctly calculated, (3) the overall geometry matched that presented in Reference 6, and (4) temperature-dependent neutron cross-section libraries were used appropriately and concurrently with material temperature specification; this includes S(α,β) cross-section libraries.

Per NEDO-33244 P-A, "Licensing Topical Report, ESBWR Marathon Control Rod Mechanical Design Report," GEH has committed to bounding the effects of the reduction in control blade worth by imposing a 1% shut down margin design criteria which is nearly 3 times greater than the tech spec limit in the analyses. In addition, the startup physics testing confirms the blade worths. Based on the additional margin used in the analyses and the physical testing performed on a cycle by cycle basis, the staff concludes that there is reasonable assurance that all safety limits related to the nuclear lifetime and shut down margin will be met.

3.2.2.3 Heat Generation Rates

One major concern in calculating the CRB mechanical lifetime is the calculation of the internal pressure resulting from the release of helium generated after a B-10 atom captures a neutron. Helium release is directly affected by temperature, and therefore the heating rate is critical when calculating mechanical lifetime.

GEH calculates the heat generated by the neutron-CRB interaction as solely an (n,α) interaction resulting in 2.79 megaelectronvolts (MeV) of energy deposition for each interaction between a neutron and a B-10 atom. The NRC staff was concerned about a possible undercounting of the energy deposition because the carbon-neutron scattering and gamma contributions were not being considered. In RAI 4.2-30 (Reference 15), the staff requested additional information regarding GEH's handling of energy deposition within the MCNP models.

GEH explained (Reference 15) that by calculating the μ value (ratio of average absorptions in the control poison to the total fissions in the adjacent bundles) and multiplying by the 2.79-MeV energy deposition, the calculational method used in Reference 6 is bounding. On average, 2.79 MeV is deposited locally in the B_4C absorber region only 6 percent of the time, while 94 percent of the time, interactions between a neutron and B-10 produce lithium-7 (Li-7) in an excited state, which then produces a 0.48-MeV (17 percent of the total 2.79 MeV) gamma ray through decay. The NRC staff performed a confirmatory calculation to determine the mean free path of a 0.48-MeV photon traveling through compacted B_4C powder (70 percent theoretical density). Using a mass attenuation coefficient of 9.55×10^{-2} square centimeters per gram (cm^2/g) (based on carbon, which is more limiting than boron) and a density of 1.76 grams per cubic centimeter (g/cm^3), the linear attenuation coefficient is 0.168 cm^{-1}, resulting in a mean free path of approximately 6 cm. This shows that the probability of interaction of the decay gamma in the B_4C absorber region is negligible, which implies that on average, approximately 2.34 MeV is deposited in the B_4C region per B-10 neutron absorption. By assuming that the entire 2.79 MeV remains in the absorber region, the GEH calculation is considered bounding. GEH calculations show this in a confirmatory analysis (GEH Letter MFN 08-840, dated October 31, 2008 (Reference 15)), which takes a more realistic approach by including all reaction types in the B_4C absorber region (including elastic scattering with carbon atoms and all photon interactions). The assumption in Reference 6 of 2.79 MeV per absorption results in a heating rate that is approximately [[ ]] higher than GEH's realistic confirmatory case. The staff agrees that

GEH's assumptions in its simplified heating rate calculations, as described in Reference 6, are conservative and appropriate.

3.3 ESBWR Marathon Surveillance Program

During staff audits at GEH-Wilmington (described in References 10 and 16), the NRC staff informed GEH that a rigorous surveillance program should be described for ESBWR Marathon CRBs consistent with the approved surveillance program for Marathon-5S. The staff discussed this concern in RAI 4.2-26 S01. In response, GEH proposed a revision to section 5.0 of LTR NEDE-33244P to specify surveillance requirements for ESBWR Marathon CRBs. The staff determined that the surveillance requirements, as followed, would detect any unusual degradation before a safety significant issue could develop and therefore finds the proposed requirements to be acceptable for inclusion in the approved version of the LTR. Based on the applicant's response, RAI 4.2-26 was resolved.

4.0 CONCLUSION

Based on its review of NEDE-33243P, Revision 2, NEDE-33244P, Revision 1, and the conclusion that the CRB design meets the criteria described in Section 2 of this report, the staff finds the ESBWR Marathon CRB design acceptable for licensing applications in ESBWR power plants. Licensees referencing this LTR will need to comply with the conditions listed in Section 5.0.

5.0 CONDITIONS AND LIMITATIONS

Applicants referencing NEDE-33243P, Revision 2, and NEDE-33244P, Revision 1, must ensure compliance with the following conditions and limitations:

(1) The ESBWR Marathon CRB design is restricted to the design specifications provided in Sections 2 and 3 of References 1 and 6. Changes in component design, materials, or processing specifications may alter the in-reactor behavior of this design and the basis of the staff's approval.

(2) The ESBWR Marathon CRB design is restricted to the use of B_4C absorber material. The introduction of alternative absorber materials (e.g., hafnium) requires NRC review and approval. Further, the staff's review did not consider enriched B_4C powder (i.e., powder with an artificially increased B-10 isotopic concentration); therefore, this safety evaluation does not approve the use of enriched powder.

(3) The inspection and reporting requirements in the ESBWR Marathon Surveillance Program, detailed in the response to RAI 4.2-26 S01 (Reference 2), must be fulfilled.

6.0 REFERENCES

1. GE Hitachi Nuclear Energy, Letter MFN 07-612, "Submittal of Licensing Topical Report NEDE-33244P, Revision 1, 'ESBWR Marathon Control Rod Mechanical Design Report,'" November 15, 2007 (Agencywide Documents Access and Management System (ADAMS) Accession Nos. ML073240196, ML073240227, ML073240220); Revision 2 Mark-ups, January 28, 2010 (ADAMS Accession No. ML100320352).

2. GE Hitachi Nuclear Energy, Letter MFN 08-757, "Response to Portion of NRC Request for Additional Information Letter No. 243—Related to ESBWR Design Certification Application—RAI Numbers 4.2-24 Supplement 1, 4.2-26 Supplement 1, 4.2-31 and 4.2-32," October 8, 2008 (ADAMS Accession Nos. ML082880089, ML082880090).

3. GE Hitachi Nuclear Energy, Letter MFN 08-527, "Response to Portion of NRC Request for Additional Information Letter No. 204—Related to NEDE-33244P, Revision 1, 'ESBWR Control Rod Mechanical Design Report, RAI Number 4.2-20,'" June 27, 2008 (ADAMS Accession Nos. ML081830148, ML081830149).

4. GE Hitachi Nuclear Energy, Letter MFN 08-474, "Response to Portion of NRC Request for Additional Information Letter No. 167—Related to NEDE-33244P, Revision 1 'ESBWR Control Rod Mechanical Design Report, RAI Number 4.2-21 through 4.2-27,'" June 13, 2008 (ADAMS Accession Nos. ML081690506, ML081690507).

5. GE Hitachi Nuclear Energy, NEDE-33244P, Revision 1, "Licensing Topical Report, ESBWR Marathon Control Rod Mechanical Design Report" November 2007 (ADAMS Accession Nos. ML073240220, ML073240196, ML073240227).

6. GE Hitachi Nuclear Energy, "Licensing Topical Report ESBWR Control Rod Nuclear Design," NEDE-33243P, Revision 2, July 2008 (ADAMS Accession Nos. ML081980190, ML081980189, ML081980192).

7. U.S. Nuclear Regulatory Commission, NUREG-0800, "U.S. NRC Standard Review Plan," Section 4.2, "Fuel System Design," Revision 3, March 2007 (ADAMS Accession Nos. ML070740002).

8. GE Hitachi Nuclear Energy, "GE[H] Marathon Control Rod Assembly," NEDE-31758P-A, GEH Proprietary, October 1991 (ADAMS Accession No. 9106280113).

9. GE Hitachi Nuclear Energy, 26A6642A, Revision 5, "ESBWR Design Control Document," Tier 2, Chapter 4, "Reactor," May 2008 (ADAMS Accession No. ML081820527).

10. U.S. Nuclear Regulatory Commission, Memorandum, "Audit Report and Summary (2007 & 2008) for Global Nuclear Fuels Control Blade and Fuel Assembly Design," December 22, 2008 (ADAMS Accession No. ML083230072).

11. U.S. Nuclear Regulatory Commission, Letter, "Acceptance for Referencing of Topical Report NEDE-31758P, 'GE[H] Marathon Control Rod Assembly,'" July 1, 1991 (ADAMS Accession No. 9107090009).

12. GE Hitachi Nuclear Energy, NEDE-33284P, Revision 1, Class III DRF-0000-0036-8667, "GEH Proprietary Information Licensing Topical Report 'Marathon-5S Control Rod Assembly,'" November 2007 (ADAMS Accession Nos. ML073320285, ML073320294, ML073320297).

13. GE Hitachi Nuclear Energy, Letter to NRC, MFN 09-343, "Draft Safety Evaluation by the Office of Nuclear Reactor Regulation Licensing Topical Report (LTR) NEDE-33284,

Revision 1, 'Marathon-5S Control Rod Assembly,'" June 11, 2009 (ADAMS Accession No. ML091630582).

14. GE Hitachi Nuclear Energy, Letter MFN 08-464, "Response to Portion of NRC Request for Additional Information Letter No. 162 Related to NEDE-33243P, Revision 1 'ESBWR Control Rod Nuclear Design' RAI Numbers 4.2-16, 4.2-17, 4.2-18, 4.2-19. ESBWR Lattice 1803 M5 Blade Calculation," May 27, 2008 (ADAMS Accession Nos. ML0817101628, ML081710127, ML081710128, ML081930949).

15. GE Hitachi Nuclear Energy, Letter MFN 08-840, "Response to Portion of NRC Request for Additional Information Letter No. 243—Related to Design Control Document Revision 5—RAI Number 4.2-30," October 31, 2008 (ADAMS Accession Nos. ML083090098, ML083090099).

16. U.S. Nuclear Regulatory Commission, Memorandum, "Audit Report for ESBWR GE14E Fuel Assembly Design, ESBWR Marathon Control Blade Design, and Marathon-5S Control Blade Design," September 11, 2007 (ADAMS Accession No. ML072550006).

17. *Code of Federal Regulations* (10 CFR) Part 100, "Reactor Site Criteria."

18. *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities."