Addendum to the Safety Evaluation for NEDC-33083P-A, "Application of the TRACG Computer Code to the ECCS and Containment LOCA Analysis for the ESBWR Design"

GE Hitachi Nuclear Energy, LLC (GEH) submitted topical report NEDC-33083P, "TRACG Application for ESBWR," in November 2002, during the preapplication phase of the economic simplified boiling-water reactor (ESBWR) design certification review. The staff of the U.S. Nuclear Regulatory Commission (NRC) reviewed and accepted the GEH TRACG code for analyzing loss-of-coolant accident (LOCA) events for the ESBWR design with confirmatory items (Reference 1)[1]. In addition, from December 11 through December 15, and resuming for the period between December 19 and December 20, 2006, the NRC staff conducted an audit of the TRACG code as it is applied to ESBWR LOCA analyses to evaluate updates to the code and methodology since its original approval (Reference 2). The detailed basis for the staff's approval of TRACG is described in the Safety Evaluation Report, which is incorporated in the proprietary approved version, NEDC-33083P-A (Reference 1). Hereafter, all citations to Reference 1 apply to the staff safety evaluation, unless noted otherwise.

The staff documented "confirmatory items" during this review. The staff stated that these items "were identified as needing confirmation at the design certification stage. These items do not affect the applicability or the capability of the code, but do address the response of the plant design and adequacy of the documentation." The Summary of TRACG LOCA SER Confirmatory Items (Summary of September 9, 2005 NRC/GE Conference Call on TRACG LOCA SER Confirmatory Items) (Reference 3) identifies the confirmatory items and the planned GEH actions for each item. In Reference 4, GEH provided Design Certification information for Confirmatory Item 1 related to the Reactor Pressure Vessel (RPV) Level Response for the Long Term PCCS Period, and identified major design changes from the pre-Application review to the Design Certification Document (DCD) design. Reference 5 provides information requested by the staff in the Acceptance Review for NEDC-33083P. Reference 6 is a revised response to the Acceptance Review items which incorporates changes to the TRACG model representing the feedwater line break.

The following safety evaluation report (SER) addendum documents the staff's evaluation of these items. Each section contains the confirmatory item directly quoted from Section 4.0 of the staff SER (the approved staff safety evaluation for TRACG application for ESBWR) (Reference 1).

1 Item 1: Phenomena Identification and Ranking Table for Long-Term Core Cooling

1.1 <u>Confirmatory Item 1</u>

> *"The PIRT at the design certification stage should include the long-term cooling phase of the LOCA since the long-term cooling phase is highly design dependent. Should it be found that unreviewed phenomena occur during the long-term cooling phase, the appropriate models and correlations in the TRACG code will be revisited by the staff."*

[1] See ADAMS Accession No. ML051390265 pages 11 through 185.

1.2 Staff Evaluation of Confirmatory Item 1

In support of the design certification application, and to satisfy pre-application confirmatory items, GEH submitted details on long-term core cooling in Reference 4 and in Chapter 6, Section 6G, of the ESBWR DCD Revision 5 (Reference 34). GEH included a discussion of long-term inventory distribution for four break locations—(1) main steamline break (MSLB), (2) feedwater line break (FWLB), (3) bottom drainline break (BDLB), and (4) gravity-driven cooling system (GDCS) line break (GDLB).

The requirements for a realistic methodology in Title 10 of the *Code of Federal Regulations* (10 CFR) 50.46 are somewhat different than those for a prescriptive methodology in that more realistic models can be used and a measure of the uncertainty in the code must be determined. Various means of achieving an estimate of uncertainty are available. GEH has chosen to follow the basic Code Scaling Applicability and Uncertainty (CSAU) approach outlined in NUREG/CR-5249 (Reference 8). While the CSAU approach defines the process by which uncertainty analysis is performed, it leaves room for the applicant to determine the exact statistical methodology to be applied. In both the AOO application of TRACG and the ATWS application, GENE chose to apply a Normal Distribution One-Sided Upper Limit statistical methodology. The approach taken for application of TRACG to the ESBWR LOCA event is somewhat different.

Previous uses of the TRACG methodology have made use of Normal Distribution One-Sided Upper Tolerance Limit statistics to assess the uncertainty in the analyses. Application of the code to the ESBWR advanced passive system design relies on a very different approach to uncertainty since all calculations indicate the core remains covered and does not heat up. Uncertainty evaluation is done in this case using a much simpler [[ ]]. Staff concludes that this is acceptable since it is in accordance with the guidance given in Regulatory Guide 1.157, "Best-Estimate Calculations of ECCS Performance," May 1989 (Reference 35).

The CSAU methodology (Reference 8) states that an applicant should identify the important phenomena and rank them with respect to their effect on the safety criteria for the scenario. GEH provided a phenomena identification and ranking table (PIRT) that includes consideration of long-term core cooling for the ESBWR in Reference 4 and in Chapter 6, Section 6G, of the ESBWR DCD (Reference 7). For higher elevation breaks (i.e., MSLB and FWLB), the parameters that affect the long-term core cooling are the capacity of the GDCS pool relative to the reactor pressure vessel (RPV) volume, the heat removal capacity of the passive containment cooling system (PCCS) relative to the decay heat, and the condensation on drywell surfaces relative to the condensation in the PCCS. The phenomena that ranked high for the MSLB and FWLB are decay heat, GDCS pool volume versus elevation, and RPV volume versus elevation. GEH gave PCCS capacity a ranking of medium for these events.

For lower elevation breaks (i.e., GDLB and BDLB), the parameters that affect the long-term behavior are the capacity of the GDCS pool relative to the lower drywell volume, the pressure drop through the depressurization valves (DPVs), the heat removal capacity of the PCCS relative to decay heat, and to a smaller degree, the condensation on drywell surfaces relative to the condensation in the PCCS. The phenomena that ranked high for the BDLB and GDLB are decay heat, DPVs (break flow and pressure drop), PCCS capacity, lower drywell volume versus elevation, GDCS pool volume versus elevation, and RPV volume versus elevation.

For the higher elevation breaks, the RPV is filled to the break elevation during the re-flood phase. After the GDCS drains, the level is maintained by the PCCS drain flow which condenses the steam generated by the decay heat. These phenomena are not different from those reviewed by the staff for the short-term response and are documented in the staff SER and pre-application LTR (the approved staff safety evaluation and pre-application LTR for TRACG application) (Reference 1). The purpose of the PIRT ranking is to ensure that TRACG has the necessary models and qualification to simulate the important phenomena.

As discussed in the staff SER (Reference 1), the staff determined that TRACG04 has all of the necessary models and qualification to simulate this behavior. Therefore, the PIRT does not require revision at this time. If GEH proposes to use the rankings to select the uncertainties to be included in an uncertainty analysis in the future, a PIRT revision may be requested. The staff finds the GEH PIRT acceptable for demonstrating long-term core cooling of higher elevation LOCAs.

For the lower elevation breaks, the RPV is filled to the top of the chimney partition during the re-flood phase. After the GDCS drains, the level continues to drop to the level of the spillover holes in the drywell, and similar to the case of the higher elevation breaks, the level is maintained by the PCCS drain flow condensing the steam generated by the decay heat. These phenomena are not different from those reviewed by the staff for the short-term response and are documented in the staff SER and Pre-Application LTR (Reference 1). The size of the lower drywell becomes important during the long term.

As discussed in the staff SER (Reference 1), the staff determined that TRACG04 has all of the necessary models and qualifications to simulate this behavior; the PIRT does not require revision at this time. If GEH proposes to use the rankings to select the uncertainties to be included in an uncertainty analysis in the future, a PIRT revision may be requested. The staff finds the GEH PIRT acceptable for demonstrating long-term core cooling of lower elevation LOCAs.

Some condensation of the steam will occur in the drywell, which may affect the volume of water that will return to the vessel from the PCCS drainline. The TRACG ESBWR containment model was designed to maximize peak pressure and does not contain heat sinks, so it may not accurately calculate this condensation. Because of the large heat transfer area in the PCCS relative to that considered in the drywell, the staff concluded that the amount of condensation in the drywell should be small in comparison to the condensation in the PCCS.

In Request for Additional Information (RAI) 6.2-144 (Reference 9), the staff requested that GEH investigate the effects of assuming lower pressure in the drywell on RPV level calculations. In the RAI response the applicant provided the long-term post LOCA containment parameters which are within the design limits and therefore are acceptable to the staff. This study confirmed that this issue does not have a large impact on long-term core cooling. Based on the applicant's response, RAI 6.2-144 was resolved. Confirmatory Item 1 is closed.

2 Item 2: Break Spectrum and Core Uncovery

2.1 <u>Confirmatory Item 2</u>

"During the design certification review, the staff will verify that the TRACG application procedures conservatively calculate the collapsed water level in the chimney above the hot

channel for the three break locations, MSLB [main steamline break], BDLB [bottom drainline break] and GDLB [gravity driven cooling system line break].

"Reference [NEDC-33083P, "TRACG Application for ESBWR," November 2002], Table 2.4-2 indicates that the GDLB results in the lowest static head in the chimney of the three break locations examined, the GDCS line, the main steam line, and the bottom drain line. At the design certification stage, GENE will need to provide supporting analyses for a spectrum of break locations to demonstrate that there is no core uncovery for the possible break locations. Should core uncovery occur, review of the TRACG code will be revisited to determine the adequacy of the applicable models and correlations.

"The procedures should be applicable to both short term and long term LOCA events (i.e., up to 72 hours)."

2.2 Staff Evaluation of Confirmatory Item 2

The LOCA analysis methodology in the Pre-Application LTR (applicant's submittal contained in the approved TRACG application for ESBWR) (Reference 1) was applied to minimum water level calculations for double-ended guillotine-sized breaks in the GDCS line, a bottom drainline, and a main steamline. This confirmatory item required that GEH perform a break spectrum analysis using break sizes and locations different from those used in the applicant's submittal contained in the Pre-Application LTR (Reference 1).

2.2.1 Other Break Locations

In response to staff RAI 6.3-46, GEH provided the results of analyses of additional break locations (Reference 10). In addition to the FWLB, MSLB, GDLB, and BDLB break results presented in DCD, Tier 2, (Reference 7), GEH listed the collapsed chimney levels for double-ended guillotine breaks in the GDCS equalizing line, the DPV stub tube/isolation condenser (IC), reactor water cleanup/shutdown cooling return line, and the IC return line. DCD Tier 2 showed that the most limiting cases are GDCS injection line and ICS drainline breaks. The applicant's results do not show heatup or core uncovery for any of the analyzed LOCAs. The applicant provided the full spectrum break analyses according to the guidance in SRP 6.3 and incorporated this information in DCD Revision 4, Section 6.3, which the staff found acceptable. Based on the applicant's response, RAI 6.3-46 was resolved.

In RAI 6.3-65 S01 (Reference 11), the staff also requested that GEH analyze a break in the standby liquid control system (SLCS) line and demonstrate that it is not the limiting break. The evaluation of RAI 6.3-65 S01 shows that an SLCS line break is not limiting. Based on the applicant's response, RAI 6.3-65 S01 was resolved.

2.2.2 Break Spectrum

In the SER for ESBWR, Chapter 6, Section 6.3.2.3.5, the staff evaluated the break spectrum. The staff concluded that GEH analyzed all vessel penetration break locations and break sizes, which resulted in analysis of the most limiting break. No new phenomena were introduced compared to the LOCA analysis listed in Licensing Topical Report (LTR) 33083-P-A.

2.2.3 Long-Term Core Cooling

The long-term core cooling PIRT evaluation, discussed in Confirmatory Item 1, is acceptable for the reasons noted above. On August 24, 2007, the staff received the response to RAI 6.3-79 (Reference 32), regarding the long-term core cooling analysis. GEH's response stated that for the ESBWR design, conformance to the requirement of adequate long-term cooling is assured and demonstrated for any LOCA where the water level can be restored and maintained at a level above the top of the reactor core. The response discussed TRACG calculation results for a short term (0 to 2,000 seconds) and a long term (0 to 72 hours). These calculations used assumptions with possible emergency core cooling system (ECCS) component single failures. (The FSER for Chapter 6, Section 6.3 provides a more detailed evaluation of RAI 6.3-79.)

The staff finds that this analysis demonstrates that the design provides for adequate long-term cooling. Based on the applicant's response, RAI 6.3-79 was resolved. The response to RAI 6.3-79 also closed one item included in RAI 21.6-98, which requests that GEH submit the long-term core cooling analysis.

In RAI 21.6-96 S01, the staff asked GEH to justify the TRACG model treatment of noncondensable (NC) gases, which effectively forces all of the air and noncondensable gases out of the drywell during a LOCA. The staff was concerned that this approach may not be conservative for long-term core cooling calculations, where the presence of non-condensibles in the PCCS would degrade the capability of the PCCS to condense steam and return inventory back to the vessel. The GEH response dated August 26, 2008 includes a discussion and a reference to RAI 21.6-69 S01 for the MSLB case as an example. GEH described that most of the NC gases in the drywell annulus are purged into the wetwell, and in the example case, the NC gas mass fraction entering into the PCCS is very low after a few hours. A comparison to the decay heat shows that the PCCS is over capacity in a few hours. During this over-capacity condition, the PCCS regulates the heat removal rate to match decay heat by accumulating NC gases in the lower part of the PCCS tube. A small increase in NC gas accumulation reduces the PCCS condensation capacity and will cause an increase in the drywell pressure. This drywell pressure increase will cause some NC gases in the lower part of the PCCS tube to be pushed through the PCCS vent into the wetwell. This increases the PCCS heat condensation capability, and equilibrium is reestablished with the drywell conditions.

The staff found the above GEH description of the phenomena reasonable. Acknowledging that the minimum RPV water level is reached in the earlier phase of a LOCA and that an adequate water inventory in the RPV is presented after GDCS injection, the staff agrees that the accuracy of NC gas modeling in the PCCS has little impact on the core cooling. The TRACG model ensures that most of the NC gases are purged into the wetwell, which is a conservative approach for peak containment pressure modeling. The staff considers the modeling of the NC gases to be acceptable in the long-term LOCA analysis. Based on the applicant's response, RAI 21.6-96 S01 Part A was resolved.

2.2.4 Conclusion

For all of the additional break locations and sizes that GEH simulates using TRACG for the LOCA analysis, including long-term core cooling, the ESBWR shows no heatup. Therefore, the staff does not need to revisit its review of the TRACG code to reexamine its application to core heatup in the ESBWR. Confirmatory Item 2 is therefore closed.

3 Item 3: Missing Definitions in TRACG Equations

3.1 <u>Confirmatory Item 3</u>

"GENE has committed to incorporate the missing definition for Ef, and new equations for the transition criterion between churned turbulent and annular flow, including the drift velocity term in updated code model description documentation."

3.2 <u>Staff Evaluation of Confirmatory Item 3</u>

The constitutive correlations for interfacial shear and heat transfer in TRACG are dependent on the flow regime in each hydraulic cell. Therefore, the flow regime for each cell must be identified before the flow equations are solved for that cell. Transition between annular flow and dispersed droplet flow is given by the onset of entrainment. For low vapor flow, annular flow will exist, and as the vapor flux is increased, more and more entrainment will occur, causing a gradual transition to droplet flow.

When reviewing the pre-application LTR (Reference 1), the staff based its evaluation of the TRACG interfacial shear model on NEDE-32176P, Revision 2, "TRACG Model Description" (Reference 12). The staff requested additional information on the models describing the GEH calculation for transition to annular flow and the entrainment fraction. GEH had modified this model in TRACG04, and therefore, the description of the models in NEDE-32176P" (Reference 12) was not applicable to the version of TRACG being used to perform design calculations of the ESBWR. GEH submitted the updated models in NEDE-32176P, "TRACG Model Description", Revision 3 (Reference 13), in April 2006.

The models for flow regime transitions in TRACG02 had been qualified only at high pressure in NEDE-32177P, Revision 2, "TRACG Qualification" (Reference 16). GEH qualified TRACG against low-pressure data to extend the applicability of TRACG to LOCA applications. In TRACG04, GEH made changes to the model for transition from churned turbulent to annular flow to better match these data. The GEH criterion for transition to annular flow is when the liquid film can be lifted by the vapor flow relative to the liquid in the churn turbulent regime. This is satisfied at the void fraction where the same velocity is predicted for churn turbulent flow as it is for annular flow. GEH set the vapor velocity in the churn regime equal to that in the annular regime and solved for the transition void fraction. GEH modified the distribution parameter used to calculate the vapor velocity in the churn turbulent regime.

As described in Section 5.1.2 of NEDE-32176 (Reference 13), GEH also modified the entrainment model to better match the low-pressure data. An entrainment correlation developed by Mishima and Ishii is used in TRACG. GEH modified the model for entrainment in the case where only a fraction of the wall surface has gone into film boiling. GEH assumes that the liquid will flow only on the fraction of the wall that has not experienced boiling transition and can be wetted. The TRACG02 model uses a linear model that directly modifies the entrainment fraction in terms of the fraction of rod groups in boiling transition (Ef). The model in TRACG04 incorporates the wetted perimeter in the calculation of the hydraulic diameter in the entrainment correlation such that the entrainment fraction has a nonlinear relationship with the wetted perimeter. Both the TRACG02 and TRACG04 models have the correct limits in that, if there are no rod groups in boiling transition, there is no modification to the entrainment fraction.

If all rods are in boiling transition, in TRACG02, Ef goes to 1, which forces the entrainment fraction to be equal to 1; in TRACG04, as the wetted perimeter gets smaller, the hydraulic diameter goes to infinity, causing the entrainment fraction to be 1 since entrainment is calculated using a hyperbolic tangent (tgh(η)) dependency of the hydraulic diameter.

GEH further modified the Mishima and Ishii correlation based on the TRACG assessment against void fraction data. GEH found that the void fraction was overpredicted for conditions where there is a large entrainment fraction. GEH found that, since the entrainment was based on the hyperbolic tangent function (tgh(η)), it approached 1.0 too fast, causing the overprediction of the void fraction. GEH modified the tgh(η) functional dependence and kept the dimensionless property groups intact.

Figure 5-3 in Reference 13 shows the TRACG04 entrainment correlation compared to data. The correlation predicts well, with an average error in the entrainment fraction of +0.0008 and a standard deviation of 0.056.

The drift velocity used to calculate interfacial shear in the dispersed annular flow regime is based on the entrainment fraction. In RAI 21.6-75 (Reference 14), the staff requested that GEH submit the updated qualification report. In response, GEH submitted Revision 3 of the TRACG qualification report (Reference 15) in August 2007.

The staff reviewed the GEH qualification of its void fraction data provided in this report to ensure that the modifications to the entrainment fraction and its subsequent use in the interfacial shear model compare well with the data. The void fraction assessment results from NEDE-32177P, Revision 3, "TRACG Qualification, August 2007" (Reference 15) are very close to the results from NEDE-32177P, Revision 2, (Reference 16) which was assessed as satisfactory during the ESBWR preapplication phase of the design certification review. This ensures that the conclusion from the preapplication TRACG review is still valid. In addition, NEDE-32177P, Revision 3, increases the assessment cases to include Toshiba Low-Pressure Void Fraction Tests, Ontario Hydro Void Fraction Tests, and Centro Informzioni Studi Esperienze (CISE) Density Measurement Tests. The Toshiba tests were added to extend the qualification basis to lower pressures at 0.5 and 1.00 megapascal (MPa). The Ontario Hydro Void Fraction test results provide void fraction data for a large-scale pumped flow facility. The CISE Density Measurement test results provide data for void and quality relationships. The TRACG assessment showed good agreement with the data from those tests. The assessment from NEDE-32177P, Revision 3, reinforced the conclusion from the approved GEH LTR NEDC-33083P-A that the interfacial shear model is acceptable. For these reasons, the staff concluded that the applicant's response was adequate, and RAI 21.6-75 was resolved. Confirmatory Item 3 is closed.

4 Item 4: Update TRACG Model Description

4.1 <u>Confirmatory Item 4</u>

"The description of the TRACG model, Reference [NEDE-32176P, Rev. 2, "TRACG Model Description", December 1999], will be updated to reflect all current models and correlations, thereby providing a level of detail consistent with a stand-alone document."

4.2 Staff Evaluation of Confirmatory Item 4

In Revision 2 of NEDE-32176P, GEH removed the containment-related sections for the various models and correlations that had been included in Revision 1. GEH has returned this information to Revision 3 of NEDE-32176P. NEDE-32176P, Revision 4, “TRACG Model Description,” issued January 2008 (Reference 19), supersedes NEDE-32176P, Revisions 2 and 3. (References 13 and 18).

GEH had also removed Section 7.11 (“Containment Components”) from the “Component Model” section of NEDE-32176P in Revision 2. As a result, the information on drywell, wetwell air space, suppression pool, and main vents, such as that included in Table 6.5-3 in Revision 1, was not in Revision 2. GEH has returned Section 7.11 to Revision 3 of NEDE-32176P. However, the Revision 1 subsection “Model Assessment” was significantly shortened when it became Section 7.11.7.7, “Model Applicability,” in Revision 3, by the removal of three figures (Figure 7.11-5, “Pressure Suppression Test Facility”; Figure 7.11-6, “Drywell Pressure Response”; and Figure 7.11-7, “Vent Flow Transient”), and the related details.

The staff considers these figures to be important, as they show the facility schematics and dimensions and compare the TRACG predictions with the measured drywell pressure and vent flow rate data. In RAI 21.6-107, the staff asked GEH to either justify the removal of these figures or include the figures as updated for the latest design. In the response to RAI 21.6-107, GEH stated that the removal of the figures is justified because they are related to TRACG assessment and not to TRACG model description. The staff disagreed with this response and requested in RAI 21.6-107 S01 that GEH replace the figures. In its response to RAI 21.6-107 S01, GEH committed to including the figures in a future submittal and did include Figures 7.11-6 and 7.11-7 in NEDE-33440P, Revision 1, “ESBWR Safety Analyses—Additional Information,” issued June 2009 (Reference 17). The TRACG comparisons with experimental data previously reported in Figures 7.11-6 and 7.11-7 have been redone using more recent TRACG04 calculations. Figure 7.11-5 is available as Figure 5.5-1 in Reference 18. Based on the applicant’s response, RAI 21.6-107 S01 was resolved.

When reviewing the pre-application LTR (Reference 1), the staff based its evaluation of the TRACG models and correlations on Revision 2 of the TRACG model description (Reference 12). This document is the basis for TRACG02. Since GEH uses TRACG04 for ESBWR licensing calculations, the staff requested that GEH submit an updated model description that reflects the models and correlations in TRACG04. GEH submitted Revision 3 to the TRACG model description in April 2006 (Reference 13) and submitted Revision 4 (Reference 19) in January 2008.

GEH submitted a list of the changes from TRACG02 to TRACG04 with its application to migrate the approved methodology for boiling-water reactor (BWR)/2–6 anticipated operational occurrence (AOO) and anticipated transient without scram (ATWS) overpressure analyses from TRACG02 to TRACG04 (Reference 19). A description of the differences between the versions and the staff’s evaluation as applied to ESBWR LOCA analyses follows.

4.2.1 PANAC10 to PANAC11

TRACG02 is based on PANAC10 physics methods, whereas TRACG04 is based on those of PANAC11. Since ESBWR LOCA analyses do not use three-dimensional neutron kinetics, this change does not affect the staff’s acceptance of TRACG for performance of ESBWR LOCA analyses as documented in the staff SER (Reference 1). However, Section 4.3 of the staff's SER on ESBWR design certification discusses the staff's review of PANAC11 applicability to ESBWR steady-state nuclear design. In addition, the safety evaluation (Reference 20) for NEDE-33083P, Supplement 3, "Application of the TRACG Computer Code to the Transient Analysis for the ESBWR Design," discusses a review of TRACG04 three-dimensional kinetics as applied to ESBWR transients.

4.2.2 Decay Heat Model

The American Nuclear Society decay heat model is implemented in TRACG04 as an optional model in addition to the existing May-Witt model. Since ESBWR LOCA analyses do not use the decay heat model in TRACG, this change does not affect the staff's acceptance of TRACG to perform ESBWR LOCA analyses as documented in the staff SER (Reference 1).

For ESBWR LOCA analyses, GEH takes decay heat values from a power table that is input into TRACG. The staff's review of the decay heat model as applied to ESBWR AOO analyses appears in Reference 20.

4.2.3 Quench Front Model

As part of TRACG04, GEH enhanced and activated the quench front model within the TRACG04 code. This model is used during the initialization of the re-flood phase of a LOCA. The staff has not reviewed this model; however, since the ESBWR does not experience heatup during a LOCA, the quench front model is not used. Therefore, this change does not affect the staff's acceptance of TRACG to perform ESBWR LOCA analyses as documented in the staff SER (Reference 1).

4.2.4 Hot Rod Model

GEH implemented a hot rod model in the TRACG one-dimensional thermal-hydraulic model of the channel component. This is to account for the thermal-hydraulic cross-sectional variations that lead to reduced heat transfer and higher fuel temperatures in certain rods. This model is used where peak cladding temperatures (PCTs) are calculated, such as during a LOCA. The staff did not review the hot rod model for LOCA application since the ESBWR does not experience heatup during a LOCA event. Therefore, this change does not affect the staff's acceptance of TRACG to perform ESBWR LOCA analyses as documented in the staff SER (Reference 1).

4.2.5 Minimum Film Boiling Temperature

The boundary between the transition boiling regime and the film boiling regime is defined by the minimum stable film boiling temperature. In addition to the Iloeje correlation and the homogeneous nucleation correlation, GEH implemented an additional option for calculating the minimum stable film boiling temperature, the Shumway correlation. The TRACG input decks used for the LOCA analyses use the Iloeje correlation. The staff has not reviewed the Shumway correlation and finds the use of the Iloeje correlation acceptable for ESBWR applications for LOCA, AOO, and ATWS. For LOCA and AOO events, the core does not enter film boiling, and therefore this correlation is not used. For ATWS events where the core does go into film boiling, the minimum stable film boiling temperature is used only to determine when the core will quench and has no effect on the value of the maximum PCT.

4.2.6 Entrainment Model

GEH modified the entrainment model in TRACG to better match low-pressure void fraction data for LOCA applications, as described in Section 3 of this report.

4.2.7 Flow Regime Map

GEH modified the transition from churn turbulent to annular flow models in TRACG to better match low-pressure void fraction data for LOCA applications, as discussed in Section 3 of this report.

4.2.8 Fuel Rod Thermal Conductivity

The default fuel thermal conductivity modeling in TRACG04 is based on the PRIME03 code, which the NRC has not reviewed and approved for ESBWR. RAI 6.3-54 requested that GEH justify use of the PRIME03-based thermal conductivity model in TRACG04, since PRIME03 has not been reviewed and approved by the NRC for ESBWR. RAI 6.3-55 requested that GEH justify the use of gap conductance and fuel thermal conductivity from different models (GSTRM and PRIME03-based TRACG04, respectively).

The GEH response to RAI 6.3-55 includes a description of the TRACG04 calculations, as discussed in the following paragraphs for RAI 6.3-54. The response to RAI 6.3-55 does not provide sufficient justification for combining models. However, the response to RAI 6.3-54 S01 addresses the impact of using gap conductance and fuel thermal conductivity from different models (GSTRM and PRIME03-based TRACG04, respectively) on TRACG04 calculations. Since this issue is being addressed in the supplements to RAI 6.3-54, the staff concludes that RAI 6.3-55 is closed.

The GEH response to RAI 6.3-54 states that the fuel files generated using the GSTRM code are being used as input to TRACG04 and that the TRACG04 thermal conductivity model is used. The TRACG04 thermal conductivity model is based on the thermal conductivity model in the PRIME03 code, and accounts for [[ ]]. Since the TRACG04 thermal conductivity model has not been approved in previous versions of TRACG and since the thermal conductivity model has not been approved as part of a PRIME03 review for ESBWR, the NRC staff requested that GEH provide experimental data and benchmarks as well as TRACG02 (GSTRM) versus TRACG04 (PRIME03-based) thermal conductivity sensitivity study results in RAI 6.3-54 S01. In response to RAI 6.3-54 S01 (MFN 08-713), GEH provided the results from sensitivity studies comparing representative AOO, ATWS, and Stability cases analyzed with the GSTRM model and the TRACG04 (PRIME03-based) model to the base cases using GSTRM gap conductance and TRACG04 (PRIME03-based) thermal conductivity. GEH did not submit experimental data and benchmarks to support use of the PRIME03 code or the TRACG04 thermal conductivity model for ESBWR.

GEH did not include LOCA sensitivity studies in response to RAI 6.3-54 S01 because the water level remains above the top of active fuel in ESBWR LOCA analyses. Consequently, there is no fuel heat up. Therefore, the impact of fuel thermal conductivity and gap conductance is much less significant than in cases where fuel heat-up is calculated. In addition, dynamic gap conductance is not used in LOCA analysis because the PIRT parameters related to gap conductance were not determined to be of high importance to ESBWR LOCA analysis (NEDC-33083P).

NRC staff performed ESBWR LOCA fuel conductivity sensitivity confirmatory calculations using the TRACE model. The results showed that the minimum water level in the limiting LOCA is not sensitive to the 30-percent fuel thermal conductivity reduction. (The 30-percent fuel thermal conductivity impact was a bounding reduction used by the staff in its confirmatory calculations to verify the GEH calculation results showing that AOO and IE results are not sensitive to the PRIME and GESTR fuel thermal conductivity model differences.)

Therefore, the staff has reasonable assurance that the LOCA acceptance criteria are not exceeded in the LOCA analyses in the ESBWR DCD and in the TRACG for ESBWR LOCA analysis topical report. However, the fact remains that the PRIME03 code as well as the TRACG04 (PRIME03-based) thermal conductivity model have not been submitted for ESBWR application with the appropriate supporting empirical data. Therefore, future ESBWR TRACG LOCA analyses must be performed using the GSTRM model for both gap conductance and thermal conductivity, and the conclusions and limitations (including [[ ]] penalty) drawn by the NRC staff evaluation of GEH's Part 21 report (Appendix F to the SE for NEDC-33173P) (Ref. 33) are applicable to this SE. Should the NRC subsequently approve PRIME03 or another methodology for thermal conductivity and gap conductance for use with TRACG04 for ESBWR LOCA analyses, the fuel conductivity and gap conductance models must be consistent.

4.2.9 Cladding Perforation Models

GEH implemented models for the uncertainty in fuel rod internal pressure, the cladding yield stress, and the cladding rupture stress. GEH implemented these models for use in statistical analyses of a LOCA. The staff did not review these models since the ESBWR does not experience heatup during a LOCA and therefore does not invoke these models. In addition, GEH does not currently perform a statistical uncertainty analysis of ESBWR LOCA events. The staff finds that this change does not affect the staff's acceptance of TRACG to perform ESBWR LOCA analyses as documented in the staff SER (Reference 1).

4.2.10 Cladding Oxidation Model

GEH modified the cladding oxidation model to be consistent with the Cathcart and Pawel correlation. The staff did not review this model since cladding oxidation occurs at high temperatures. TRACG is not calculating heatup in any of the ESBWR LOCA events; therefore, this change does not affect the staff's acceptance of TRACG to perform ESBWR LOCA analyses as documented in the staff SER (Reference 1).

4.2.11 Enhanced Default Pump Homologous Curves

TRACG uses homologous curves to describe the pump head and torque response as a function of fluid volumetric flow rate and pump speed. GEH has supplemented the default pump homologous curves in TRACG04 with curves representative for large pumps. The ESBWR design does not credit pumps in performing LOCA analyses. However, GEH modeled PCCS vent fans in TRACG using a pump homologous head versus flow curve and provided points on this curve in ESBWR DCD Tier 2 Section 6.2. The pump homologous head versus flow curve provides minimum requirement for performance of PCCS vent fans. The staff used this curve as input in its confirmatory MELCOR containment LOCA analyses. Based on its review and confirmatory analysis, the staff determined that TRACG modeling of PCCS vent fans using a pump homologous head versus flow curve acceptable.

4.2.12 Improved Free Convection Heat Transfer

GEH implemented the McAdams correlation for free convection heat transfer used in drywell calculations. Section 15.2 of this report addresses the staff's evaluation of GEH's implementation of this correlation.

4.2.13 Optional Six-Cell Jet Pump

TRACG02 currently uses a five-cell jet pump model. TRACG04 has an option to subdivide the straight section between the suction inlet and the diffuser into two cells for a six-cell jet pump model. The ESBWR does not have jet pumps. Therefore, this change does not affect the staff's acceptance of TRACG to perform ESBWR LOCA analyses as documented in the staff SER (Reference 1).

4.2.14 Improved Boron Model

Boron is not modeled in ESBWR LOCA analyses; therefore, this change does not affect the staff's acceptance of TRACG to perform ESBWR LOCA analyses as documented in the staff SER (Reference 1). The safety evaluation of NEDE-33083P, Supplement 2, "Application of the TRACG Computer Code to Anticipated Transients Without Scram for the ESBWR Design" (Reference 27) discusses the application of the TRACG04 boron model to ESBWR ATWS analyses.

4.2.15 Revision 4 Evaluation

The changes made in Revision 4 of LTR NEDE-32176P (Reference 19) can be categorized into three types. The first type involves editorial changes, which have no impact on the code and its application. The second type includes changes to the model, and the third includes the changes related to the ESBWR modeling. This section presents evaluations of the second and third types of changes.

<u>Model Changes</u>

In Revision 4, GEH made the following changes to the model:

- change in the mass flux at which the Biasi correlation is used from 300 kilograms/square meter second (kg/(m^2s)) to 200 kg/(m^2s) (Section 6.6.6)

- change in values of constants xa and xb [[
  ]] (Section 9.5.1)

The staff discussed the two model changes with GEH. GEH stated that these changes are only documentary correction and do not involve any actual code changes. The staff verified the TRACG source code during an onsite review and found that the codes use the correct values.

The staff did not find any new changes to the source codes. Therefore, the staff does not consider these to be changes that affect the code performance and concludes that the documentary corrections are acceptable.

Modeling Change

In Revision 4, GEH made the following change in modeling:

- addition of a paragraph to discuss test data from PANDA pertaining to the wetwell gas space (Section 7.11.2)

GEH discussed how the test data from the PANDA facility show that the top of the wetwell gas space, which receives leakage flow from the drywell through the vacuum breakers, is at a higher temperature than the lower part of the gas space because of thermal stratification. [[

]] an irreversible frictional loss. The staff concurs that this approach produces conservatively high local gas space temperatures in the vicinity of the leakage and therefore is acceptable.

4.2.16 Conclusions

The staff has evaluated the changes in TRACG from TRACG02 and TRACG04. Many of the changes have no impact on the ESBWR LOCA calculations. For those changes that do affect the ESBWR LOCA calculations, the staff finds that the impacts are minor and acceptable.

5 Items 5 and 6: Isolation Condenser Testing

5.1 Confirmatory Items 5 and 6

> *"Further investigations are needed to conclusively determine the sound in the PANTHERS-IC testing that may have been due to water hammer, and to confirm its prevention in the ESBWR (e.g., by changing the hardware design of the IC [isolation condenser] inlet line or the startup procedure).*
>
> *"The PANTHERS-IC testing was terminated when leakages were detected in the IC upper header. As a result, the leakage issue was never resolved, and is an IC structural integrity issue that needs to be resolved for the ESBWR design certification."*

5.2 Staff Evaluation of Confirmatory Items 5 and 6

To prevent water hammer, GEH will control the slope of the condensate return line to avoid trapping of steam in the drain piping. In addition, GEH will control the rate of opening of the condensate return valves. The design of the isolation condenser system (ICS) is presented in DCD, Tier 2, Section 5.4.6 and was reviewed as part of the design certification review.

In Section 21.5.3 of the SER for the ESBWR design certification, the staff discussed its evaluation of the testing of the ICS at PANTHERS. GEH has agreed to perform power ascension tests to confirm the structural integrity of the ICS. GEH will also be able to confirm the possibility of water hammer during this testing. The staff therefore finds that successful completion of the IC startup testing, as described in Chapter 14 of the DCD (Reference 7), will adequately address Confirmatory Items 5 and 6.

6 Item 7: Scram Delay Time

6.1 <u>Confirmatory Item 7</u>

> *"During the design certification review stage, the ECCS baseline model should include the scram delay time and the 2 percent power measurement uncertainty."*

6.2 <u>Staff Evaluation of Confirmatory Item 7</u>

In the Summary of TRACG LOCA SER Confirmatory Items (Reference 3), GEH stated that it has included the scram delay and 2-percent power uncertainty in the DCD, Chapter 6 analyses. However, the time at which the scram occurs is different from that discussed in the pre-application LTR (Reference 1) in response to pre-application RAI-324. For the analyses presented in the ESBWR DCD (Reference 7), GEH assumed a scram upon initiation of the break. The scram occurs with the loss of power assumption coincident with the break. GEH incorporated 2 seconds of delay time because of the signal delay. GEH accounted for the travel time in the rods in the decay heat curve. GEH submitted these details in response to RAI 6.3-52 (Reference 21). The staff received the RAI response on December 21, 2007. GEH noted that the scram time delay used in the TRACG input decks for the LOCA events described in DCD, Tier 2, Chapter 6, is 2.25 seconds. This delay time was incorporated into the DCD, Tier 2, Chapter 6, LOCA TRACG input decks through a TRIP card. This total time delay of 2.25 seconds is based on and justified by the following partial time delays:

- 2.00 seconds for sensor delay
- 0.05 seconds for sensor trip scram solenoid to deenergize (reactor protection system logic)
- 0.20 seconds for scram solenoid deenergized rods to start to move (scram valve open)

Based on the applicant's response, RAI 6.3-52 was resolved.

DCD, Tier 2, Table 6.3-11, "Plant Variables with Nominal and Bounding Calculation Values" documents the 2 percent reactor power uncertainty which is included in the DCD TRACG calculations. Since this uncertainty has been included in the calculations, the staff considers Confirmatory Item 7 to be closed.

7 Item 8: Additional Detail in TRACG Modeling

7.1 <u>Confirmatory Item 8</u>

> *"During the design certification stage, separate modeling of the vessel shield, the reflective thermal insulation layer, and the air gap from the lumped heat structure will be necessary."*

7.2 Staff Evaluation of Confirmatory Item 8

In response to this confirmatory item, GEH stated that separate modeling of the vessel shield, the reflective thermal insulation layer, and the air gap from the lumped heat structure was added to the TRACG model (Reference 3). The staff evaluated the modeling documents at the GEH site during an onsite review trip and confirmed that the TRACG model includes the required input. Confirmatory Item 8 is satisfied.

8 Item 9: Chimney Nodalization Studies

8.1 Confirmatory Item 9

> *"Nodalization studies will be necessary at design certification to calculate the minimum water level in the chimney partition."*

8.2 Staff Evaluation of Confirmatory Item 9

During the preapplication phase of the TRACG for ESBWR LOCA review, GEH and the NRC staff investigated the effect of nodalization and bundle power distributions on the calculated minimum water level in the chimney during a LOCA in the ESBWR. The core and chimney region are represented by three concentric rings in the TRACG input deck. GEH performed studies varying the radial peaking factors in the bundles feeding the three rings in the core. GEH found that, when all of the bundles in Ring 1 (the innermost ring in the TRACG input deck) are set to the highest radial peaking factor (with the two outer rings reduced accordingly), the difference in minimum level calculated by the three separate rings could vary by about [[ ]]. GEH stated that, because of the "drafting" effect (i.e., enhanced two-phase flow and heat transfer in the hot ring because of additional two-phase driving head in the chimney), this modeling strategy would be nonconservative (see RAI-329 and RAI-406 in pre-application LTR (Reference 1).

The staff agreed with GEH that the drafting effect would make this modeling strategy nonconservative. The staff performed independent calculations in an attempt to reduce the drafting effect by creating a smaller chimney partition above a smaller number of hotter bundles in Ring 1. The staff found that this modeling strategy reduced the minimum static head in the chimney. The staff concluded that the nodalization presented in Figure 2.7-1 in pre-application LTR (Reference 1) is adequate for calculating the core-average minimum chimney water level during an ESBWR LOCA.

GEH submitted in a letter the Summary of TRACG LOCA SER Confirmatory Items (Reference 3) to address the staff's confirmatory items related to the SER on TRACG as applied to an ESBWR LOCA. In this letter, GEH stated that it had addressed this item and that the nodalization includes individual chimney partitions. In addition, the staff requested in RAI 21.6-98 that GEH provide all TRACG nodalization changes and that the five chimneys used to calculate minimum water level be identified. In the response to RAI 21.6-98 (Reference 25), GEH explained that two individual chimneys are added to the three super chimneys that represent each of the three rings. The staff reviewed the TRACG input decks submitted by GEH and determined that GEH had added two individual chimney partitions to the ESBWR vessel. These are represented by [[ ]] components, with one located above each of the two hot channels. GEH uses these components to calculate the collapsed liquid level in the

ESBWR chimney. The staff found that the revised nodaliztion described in the applicant's response to RAI 21.6-98 adequately represents the ESBWR reactor vessel. Subsequent DCD TRACG analyses have been based on this refined vessel model, so the staff considers RAI 21.6-98 resolved. This closes Confirmatory Item 9.

9 Item 10: Treatment of Loss of Feedwater

9.1 <u>Confirmatory Item 10</u>

> *"The assumption of the loss of feedwater flow used by GENE is not conservative. Therefore, the existing GENE MSLB model and the current analysis approach underestimate the maximum containment pressure and temperature. At the design certification phase, this should be resolved."*

9.2 <u>Staff Evaluation of Confirmatory Item 10</u>

In RAI 21.6-103, the staff requested that GEH address this confirmatory item. GEH responded to RAI 21.6-103 in a letter dated April 24, 2009 (Reference 26). In this response, GEH added a feature to isolate ESBWR feedwater following a LOCA on high-high drywell pressure.

Other features available to isolate feedwater following a LOCA include (1) high feedwater differential pressure coincident with high drywell pressure, (2) high drywell pressure coincident with lower drywell high water level, (3) reactor low-low water level with a 1-hour time delay, and (4) reactor high water level (ESBWR DCD, Tier 2, Section 5.4.5.3.3). GEH also added features to mitigate the effect of another outside water source that automatically initiates in LOCA events, high-pressure injection mode of the control rod drive system (HP CRD): (1) HP CRD makeup isolation signal on two out of three GDCS pool low level and (2) HP CRD makeup isolation signal on drywell water level high coincident with drywell pressure high. In addition, GEH made design changes to increase the containment margin for LOCA events: (1) raising the drywell to suppression chamber spillover hole 0.5 meters (m), which reduces the amount of high-temperature inventory added to the suppression pool during breaks below reactor normal water level and (2) changing technical specification maximum allowable operating drywell pressure to 15.5 pounds per square inch absolute (psia), which reduces the mass of NC gas in the containment. GEH performed containment pressurization analysis after making the above changes.

DCD, Tier 2, Chapter 6, (Reference 7) documents the bounding MSLB cases with loss of feedwater (LOFW) and without LOFW. The LOFW case is illustrated in Reference 24, Table 6.2-7g and Figures 6.2-14f and 6.2-14g. Reference 24, Table 6.2-7h and Figures 6.2-14j and 6.2-14k illustrate the no-LOFW case. A comparison of the figures shows almost identical containment temperature and pressure results for the two runs. In both cases, containment pressure following a LOCA would stay below the containment design value for 72 hours.

By making the above changes, GEH addressed the staff's concern about the assumption of the LOFW flow during containment analysis, since the results with or without feedwater available are shown to be almost identical and the containment design pressure is not exceeded in either case. Based on the applicant's response, RAI 21.6-103 was resolved. This closes Confirmatory Item 10.

10 Item 11: Feedwater Heater Modeling

10.1 Confirmatory Item 11

"Without detailed feedwater heater system design information, both the staff and GENE had to make assumptions about the mass and energy discharge from the feedwater heater system. The staff believes that the bounding containment peak pressure and temperature need to be evaluated during the design certification stage after the feedwater heater system design is finalized. If the evaluation indicates that the code application range is exceeded or a new scenario, such as wetwell flooding, has not been examined during the pre-application stage, the staff may choose to review the TRACG code for such new use."

10.2 Staff Evaluation of Confirmatory Item 11

As stated in the ESBWR preapplication SER "TRACG Application for ESBWR," the staff was concerned about an assumption that the feedwater pump is tripped and the feedwater flow is lost after an MSLB accident (see staff SER (Reference 1)). Although this led to a conservative PCT evaluation as it reduces the available coolant inventory, the assumption is nonconservative for containment analysis. The feedwater carrying the feedwater heater train stored energy increases the mass and energy discharge through the break into the containment leading to higher containment pressures and temperatures.

GEH included modeling of the feedwater line system in the TRACG analysis. ESBWR DCD, Tier 2, Figure 6.2-8b, shows the TRACG nodalization of the ESBWR feedwater line system. In addition, as discussed in Section 9 of this report, GEH added features to isolate feedwater after a LOCA. For the containment analysis, GEH assumed a continued flow of feedwater into the containment until its isolation. This addresses the staff's concern because feedwater is isolated following an MSLB accident. This closes Confirmatory Item 11.

11 Item 12: Address Power Transient Resulting from Main Steam Isolation Valve Closure

11.1 Confirmatory Item 12

> *"The quick closure of the MSIVs while control rods are being inserted may increase the total core power due to void collapse. At the design certification stage, GENE should evaluate the effects of void collapse for the GDCS and BDLB LOCA cases."*

11.2 Staff Evaluation of Confirmatory Item 12

GEH stated that there is no significant power transient because of void collapse from the main steam isolation valve (MSIV) closure effect since the control rods are always inserted before the MSIVs close for all of the breaks. The staff was able to confirm this upon review of the ESBWR LOCA analyses. The staff agrees with the GEH assessment and concurs that this is not an issue for the ESBWR LOCA event. This closes Confirmatory Item 12.

12 Item 13: Assess TRACG against Some Standard Containment Problems

12.1 <u>Confirmatory Item 13</u>

> *"During the staff's earlier review of the SBWR [simplified boiling-water reactor], work that GENE relies on for the ESBWR, the staff noted that GENE had not evaluated more traditional integral containment tests such as the Marviken tests, the Carolinas Virginia Tube Reactor test 3 without sprays, and the Battelle-Frankfurt Model Containment tests C-13 and C-15, for MSLBs. In response to staff RAI 317.1, GENE agreed to perform assessments of TRACG to model containment performance against integral test data that is publicly available for International Standard Problems where the test facilities and tests are well defined. The tests to be analyzed will be specified later, and the analysis will be completed during the design certification review.*

"The staff also requested that GENE provide a plan and schedule to assess the ability of TRACG to model containment performance against additional separate effects tests. Separate effects tests that should be considered include the Wisconsin Flat Plate condensation tests, (References … [I.K. Huhtiniemi and M.L. Corradini, "Condensation in the Presence of Noncondensible Gases", Nuclear Engineering Design, 141, pp. 429-446, 1993; M. Siddique, "The Effects of Noncondensible Gasses on Steam Condensation Under Forced Convection Conditions," MIT, January 1992; and K. Lian, "Experimental and Analytical Study of Direct Contact Condensation of Steam and Water", MIT, May 1991]).

In response to staff RAI 317.2, GENE agreed to perform assessments of TRACG to model containment performance against separate effects test data that is publicly available for International Standard Problems where the test facilities and tests are well defined. The tests to be analyzed will be specified later, and the analysis will be completed during the design certification review."

12.2 <u>Staff Evaluation of Confirmatory Item 13</u>

In RAIs 21.6-98 and 21.6-103, the staff requested that GEH address this confirmatory item. The response to RAI 21.6-103 (Reference 26) states that the response to RAI 21.6-98 addresses Confirmatory Item 13. The response to RAI 21.6-98 dated August 29, 2008 (Reference 25) includes two standard problems. Attachments A and B of the response include TRACG simulation results for the integral Marviken blowdown test 18 and the Wisconsin Flat Plate separate effect condensation tests. The staff's review of Reference 25 finds the TRACG simulation results to be acceptable because of the good agreement with the test results. This information is also included in LTR NEDE-33440P, Revision 1 (Reference 17), as referenced in the ESBWR DCD, Tier 2, Revision 6, Reference 6.2-11.

GEH performed a comparison of the TRACG simulation results with the Marviken test data for the short term (0 to 4.4 seconds) and the long term (0 to 220 seconds). The purpose was to assess TRACG's capability to predict a vent clearing transient (short term), steam/air transport through the vent system (long term), and containment pressure and temperature responses (short and long term). The staff reviewed this comparison and concluded that considering the measurement uncertainties, TRACG calculations agree well with the Marviken test data. General trends were predicted successfully.

GEH also evaluated the TRACG capability to predict the Wisconsin Flat Plate steam condensation data obtained in the vertical position of the test section in the presence of NC gases. Measured average condensation heat transfer coefficients were not sensitive to the plate inclination angle. Two different condensation correlations were assessed in a one-dimensional TRACG nodalization model of the vertical pipe simulating a PCCS section. Even though both correlations overpredicted the test data by a widely varying degree, the ESBWR post-LOCA peak drywell pressure is not sensitive to the choice of correlation. This is because, during a LOCA in the ESBWR, most of the NC gas is displaced to the wetwell gas space, and the NC gas mass fraction near the drywell wall is very small. The staff agrees with the GEH assessment, since it is consistent with observations from past tests, and therefore, Confirmatory Item 13 is considered closed.

13 Item 14: Gravity-Driven Cooling System Gas Space and Wetwell Vent Modeling

13.1 Confirmatory Item 14

"GDCS gas space and the wetwell vent should be modeled correctly during the design certification stage."

13.2 Staff Evaluation of Confirmatory Item 14

In DCD, Tier 2, Revision 5, GEH changed the ESBWR design so that the GDCS gas space is now connected to the drywell. GEH stated in Reference 3 that it would submit all TRACG nodalization changes related to NRC SER confirmatory Items.

In addition, the response to RAI 21.6-98 notes that the changes to TRACG nodalization are discussed in Sections 6A and 6B of the ESBWR DCD (Reference 24). The staff reviewed the detailed comparison provided in DCD Table 6A-1 between the original TRACG model described in the approved version of NEDC-33083P-A (Reference 1) and the revised TRACG model, which reflects the changes in design. DCD, Tier 2, Appendix 6B provides a description of the GEH evaluation of the differences in the LOCA results using the revised TRACG model and the original design results. The staff determined that all significant model parameters were addressed, and that the design changes were appropriately modeled. The detailed TRACG containment and RPV nodalization diagrams provided in DCD Figures 6A-1 and 6A-2, respectively, were also evaluated by the staff and determined to be sufficiently refined to represent the ESBWR design. This closes Confirmatory Item 14.

14 Item 15: Add Detail to the Containment Portion of the Emergency Core Cooling System Evaluation Model

14.1 Confirmatory Item 15

"During the design certification review, if the ECCS evaluation model is used beyond 2000 seconds, additional VESSEL levels need to be added on top of the existing [[ ]], and the pool needs to be modeled in the same fashion as is done for containment/LOCA modeling."

14.2 Staff Evaluation of Confirmatory Item 15

GEH combined the containment and ECCS evaluation (RPV level) model into one model for the design certification, and therefore, the additional levels have been added to the containment for the ECCS evaluation (RPV-level calculations). Although GEH has combined the two input decks, they are slightly different, as certain assumptions are needed to make each analysis conservative. GEH submitted the differences between the two input decks in response to RAI 6.3-45 (Reference 27). For the bounding calculations, GEH maintained the conservative assumptions that the staff previously reviewed in Section 2.7.2.1 for vessel water level and Table 3.7-1 of for peak pressure in the pre-application LTR (Reference 1). Because of design changes and error corrections, GEH has implemented nodalization changes, which were evaluated by the staff during an audit of TRACG as applied to an ESBWR LOCA. In RAI 21.6-98, the staff requested that GEH formally submit these changes to the staff. In the response to RAI 21.6-98 (Reference 25), GEH noted that Sections 6A and 6B of the ESBWR DCD (Reference 24) discuss the changes to TRACG nodalization.

Some nodalization changes made to the TRACG model for calculating peak containment pressure were not implemented for the TRACG model that calculates long-term core cooling. The changes implemented in the TRACG model for calculating peak pressure are spillover holes, higher intake elevation for the GDCS drainpipes, two vent paths between the GDCS air space and the drywell versus one vent path, and a fine nodalization of the PCCS vent line. GEH stated, and the staff agrees, that the effect of these items occurs at a later stage of the transient, and therefore, these changes will have no impact on minimum water level for the LOCA. However, the staff issued a supplement to RAI 6.3-45 requesting that GEH justify its contention that, even though the input deck for calculating minimum water level lacks the modifications applied to the containment input deck, it still provides accurate or conservative results for the long-term core cooling analysis.

The staff received the response to RAI 6.3-45 on June 20, 2007, and the response to RAI 6.3-45 S01 on March 25, 2008. GEH responded that the model differences described in the response to RAI 6.3-45 have been reconciled in the analyses of DCD, Tier 2, Revision 4. A consistent set of assumptions, the same TRACG model, and a consistent input deck have been used to calculate minimum water levels and perform containment peak pressure of nominal cases. However, different assumptions were made for the bounding cases between containment analysis and RPV water-level analysis. GEH updated the table in the response to RAI 6.3-45 and identified the differences for the bounding cases. These differences include normal water level in the downcomer and suppression pool.

Because of the conservative minimum initial water level, the staff agrees with GEH that using the lower water level is bounding for the LOCA analysis minimum water-level calculation and using the higher water level in the suppression pool (SP) is bounding for the peak containment pressure calculation. GEH clarified the difference between the minimum water level calculation and the peak containment pressure analyses. Based on the applicant’s response, RAI 6.3-45 was resolved.

GEH combines the TRACG model for the containment peak pressure evaluation with that of the RPV minimum water level calculation. This is inconsistent with the approved methodology in the pre-application LTR (Reference 1), which states that “the drywell model [is] set to minimize containment pressurization rate.” In RAI 6.2-144, the staff asked GEH to justify the use of the containment model in calculating minimum water level. In response, GEH evaluated the impact of containment back pressure on the ECCS performance and presented this evaluation in DCD, Tier 2, Revision 4, Appendix 6C (Reference 28). The staff reviewed GEH's evaluation and determined that the minimum chimney collapsed level is not sensitive to the changes in the containment back pressure expected for the ESBWR design under LOCA conditions. Based on the applicant's response, RAI 6.2-144 was resolved. Confirmatory Item 15 is closed.

15 Item 16: [[ ]] Factors

15.1 <u>Confirmatory Item 16</u>

"Prior to submission of the final design analyses in support of design certification, GENE should perform a review of the appropriateness of the [[ ]] factors and the liquid/vapor interface heat transfer used in the containment modeling."

15.2 <u>Staff Evaluation of Confirmatory Item 16</u>

[[ ]] factors are used to account for the way in which the presence of NC gases reduces the interfacial heat transfer.

In NEDE-32176P, Revision 3, GEH made the following modifications to address this item:

- GEH previously used the Holman correlation (Equation 6.5-28) to model the interfacial heat transfer at the suppression pool free surface. A sensitivity study by GEH found that the TRACG model results were not very sensitive to the Holman correlation. However, the staff was concerned that the conclusion was not valid for all possible situations. GEH explored more correlations and found the McAdams correlation to be more general. NEDE-32176P, Revision 3, Section 6.5.8, includes a detailed description of the McAdams, Grashof, and Prandtl numbers-based free-convection correlation for flat plates (Equation 6.5-51). The McAdams correlation is the default model for the interfacial heat transfer at a free surface, though Holman's simplistic expression can still be selected via the user input.

- GEH has also included additional details in Section 6.5.8 of NEDE-32176P, Revision 3, to describe the Sparrow-Uchida degradation factor that accounts for the reduction of the interfacial heat transfer due to the presence of the NC gases. GEH has replaced Figure 6.5-1 from NEDE-32176P, Revision 1, with Figure 6-13 in Revision 3.

  The new figure not only shows the composite Sparrow-Uchida curve shown on Figure 6.5-1 (Revision 1) that TRACG uses, but also the individual Uchida and Sparrow curves that were independently developed for the high and low NC gases-to-steam ratios, respectively. In Section 6.5.8.2, GEH has added a description of how the composite Uchida-Sparrow data are implemented within the TRACG code.

- GEH has expanded Section 6.5.8.3 in NEDE-32176P, Revision 3, to explain the applicability of the McAdams and Holman correlations for a variety of conditions. While the Holman correlation is applicable to turbulent flow ($GrPr > 10^9$) (Gr and Pr are Grashof and Prandtl numbers) only, the McAdams correlation is applicable to a much wider range ($10^5 < GrPr < 3x10^{10}$). The discussion also addresses the effect of heat transfer enhancement due to interfacial ripples and the uncertainties in the Sparrow-

Uchida degradation factor and the Kuhn-Schrock-Peterson (K-S-P) correlation and their interrelation.

The staff reviewed the applicability of the [[ ]] correlation to the ESBWR interfacial heat transfer at the pool interface. The staff acknowledges that interfacial heat transfer, in general, is a complex phenomenon and the available physical models are subject to substantial uncertainties. Since the sensitivity study described in NEDE-32176P, Revision 3 indicates that this phenomenon (i.e., degradation of heat transfer at the pool surface due to noncondensable gases) has a relatively small effect on the peak containment pressure the staff finds the TRACG interfacial heat transfer at the pool interface to be acceptable for ESBWR design certification analyses.

The staff concludes that GEH has provided sufficient explanation of the range of the applicability of the correlations and hence, Confirmatory Item 16 is closed.

16 Item 17: GEH Assurance that TRACG Models and Correlations Are Consistent with the Final ESBWR Design

16.1 <u>Confirmatory Item 17</u>

"Prior to performing the final design analyses at the design certification stage, GENE should perform a thorough evaluation of the ESBWR design records and TRACG ESBWR model development records to substantiate that the TRACG models and correlations are consistent with the final design requirements and intended application."

16.2 <u>Staff Evaluation of Confirmatory Item 17</u>

GEH stated in Reference 3 that the design records for ESBWR and TRACG model development are consistent with the GEH quality assurance (QA) system and that the application range of the correlations in the final design is within the reviewed application range. The NRC staff performed an audit of TRACG as applied to ESBWR LOCA analyses and was able to evaluate the GEH QA processes and their application to TRACG development and use for ESBWR design certification. The staff confirmed that GEH has rigorous QA processes for TRACG04A and that TRACG04A is being applied within its application range for ESBWR LOCA applications. The staff found that TRACG04P is being used for some licensing calculations. The staff issued RAI 21.6-95 and RAI 21.6-96 to address the open items associated with the audit of TRACG04P.

The staff received the response to RAI 21.6-95 from GEH on November 19, 2007. RAI 21.6-95 requested that GEH address the changes to TRACG04 from Versions 42 to 45. In GEH's response, it summarized the changes in TRACG04 from Versions 42 to 45. GEH claimed that these changes have been demonstrated to have no or minimal impact on the calculated ESBWR and operating BWR results. The staff confirmed this statement by review of the GEH calculations during the QA audit (Reference 36). The staff therefore considers RAI 21.6-95 to be closed.

The staff received the response to RAI 21.6-96 on June 21, 2007, and the response to RAI 21.6-96 S01 on August 26, 2008. RAI 21.6-96 requested that GEH clarify the TRACG code version used in DCD Chapters 4, 6, and 15 and compare the results from TRACG04A (ALPHA VMS version) to the results from TRACG04P (PC version). GEH provided the versions used in

DCD Chapters 4, 6, 15 and the comparisons of the key parameters between TRACG04A and TRACG04P. In its response to RAI 21.6-96, GEH stated that the differences between TRACG04 ALPHA and PC were caused partly by the inability of TRACG to accurately predict NC gas distributions in general. GEH used a conservative approach to minimize the long-term containment pressure sensitivity to NC gas concentrations. This conservative approach entailed modification of the input nodalization to force all NC gases out of the drywell. Using this approach, GEH was able to reduce the predicted long-term containment pressure differences between ALPHA and PC to < 1.0 percent.

After reviewing the response to RAI 21.6-96, the staff requested more information in RAI 21.6-96 S01, which has two parts. Part 1 requested that GEH address the conservatism in the NC gas assumption on the long-term core cooling water level in the RPV. The second part requested qualification of the code version used for the LOCA analysis.

GEH provided the qualification for TRACG04P in the responses to RAIs 21.6-96 S01 and 21.6-96 S02 to address the second part of this supplemental RAI.

GEH acknowledged that TRACG cannot accurately predict NC gas distributions in general and that a conservative approach was used, which minimizes the long-term pressure response sensitivity to NC gas concentrations by modifying the input model nodalization to force all the air out of the drywell. The staff remained concerned that this approach may not be conservative for long-term core cooling, since the presence of NC gases in the PCCS would degrade the capability of the PCCS to condense steam and return inventory to the vessel. GEH states that the PCCS is over capacity at about 3 hours. Under this condition, the PCCS regulates the heat removal rate to match the decay heat through the feedback between heat removal, condenser pressure, and NC gas holdup in the condenser. If additional heat removal is needed to condense the steam generated by decay heat, the pressure in the condenser would be high, which would increase the flow of NC gases out of the condenser to the vent. The decreased amount of NC gases in the condenser tubes would result in an increase in heat removal. The staff agrees that the NC gases assumption used does not result in nonconservative PCCS modeling for long-term core cooling because under this condition, the PCCS heat removal rate always matches the decay heat rate through one of the two operating modes. If the steam condensation is established, the PCCS heat exchangers can remove more steam than that generated by the actual level of decay heat. If, due to the NC gas collection, the PCCS condensation rate decreases, the DW pressure increases to the point when drywell to wetwell pressure difference (delta-P) exceeds the submergence of the PCCS vent pipe (without clearing the main horizontal vents), establishing the flow to the suppression pool and removing the NC gas to the wetwell gas space. This “delta-P” mode of operation re-establishes steam flow from the DW and its condensation in the PCCS. These two operating modes, i.e., condensing and delta-P, are the essential design features of the PCCS self-regulating operation. The staff determined that the TRACG04P (PC version) is capable of analyzing both PCCS modes of operation and therefore is acceptable for calculating the long-term containment pressure. Based on the applicant’s response, RAI 21.6-96 S02 was closed.

Therefore, Confirmatory Item 17 is closed.

17 Item 18: Uncertainty Analysis

17.1 <u>Confirmatory Item 18</u>

"At the design certification stage, GENE should examine further whether or not an uncertainty analysis can be performed on the combined reactor coolant system/containment system calculation rather than treating the containment aspect of the ECCS LOCA calculation in a bounding way. The uncertainty analysis methodology should be applicable to both short term and long term LOCA events (i.e., up to 72 hours)."

17.2 <u>Staff Evaluation of Confirmatory Item 18</u>

In the Summary of TRACG LOCA SER Confirmatory Items (Reference 3), GEH states that since there is no core heatup, an uncertainty analysis of PCT would not provide useful results. GEH states that a bounding evaluation for the minimum water level in the chimney during a LOCA event would demonstrate that there is margin to core uncovery and heatup.

10 CFR 50.46(a)(1)(i)) (Reference 29) states, in part, that "comparisons to applicable experimental data must be made and uncertainties in the analysis method and inputs must be identified and assessed so that the uncertainty in the calculated results can be estimated. This uncertainty must be accounted for…." The regulation in 10 CFR 50.46(a)(1)(ii) states, "Alternately, an ECCS evaluation model may be developed in conformance with the required and acceptable features of Appendix K ECCS Evaluation Models." GEH has not selected either of these options. The staff issued RAI 6.3-81 requesting that GEH demonstrate how the LOCA analyses comply with this requirement.

The staff received the RAI response on January 25, 2008. GEH responded that because there is no core uncovery and no core heatup for the ESBWR LOCAs, a statistical analysis of the PCT serves no useful purpose. The best estimate PCT and the 95/95 PCT would both be close to the saturation temperature corresponding to the peak steam dome pressure reached in the accidents. For the case of ESBWR LOCAs, there is a margin of over 889 degrees Celsius (C) (1,600 degrees Fahrenheit (F)) to the limit of 1204 degrees C (2,200 degrees F) (acceptance criteria set forth in paragraph (b) of 10 CFR 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors"). GEH further noted that the static head inside the chimney (in meters of water) is selected as the figure of merit for comparison and for use in evaluating the impact of uncertainties in model parameters and plant parameters. This collapsed level is defined as the equivalent height of water corresponding to the static head of the two-phase mixture above the top of the core. The TRACG model parameter uncertainties and plant parameter uncertainties have been identified (GEH LTR NEDC-33083P-A, Sections 2.4 and 2.5.3). Sensitivity studies were performed by varying each of these parameters from the lower bound to the upper bound value. The impact on the chimney static head is between -0.3 m to +0.2 m (GEH LTR NEDC-33083P-A, Section 2.4.4.2), which is less than the minimum static head in the chimney from the parametric studies. Therefore, GEH proposed that a simple calculation be made setting the most significant parameters at the 2 sigma values to obtain a bounding estimate of the minimum level.

The staff concurs that the ESBWR LOCA results demonstrate that there is a high level of probability that there is no core uncovery or heatup and that the PCT would be close to the saturation temperature corresponding to the peak steam dome pressure reached in the accidents. The staff concludes that GEH's LOCA results comply with the requirement of 10 CFR 50.46. Therefore, based on the applicant's response, RAI 6.3-81 was closed.

18 Item 19: Passive Containment Cooling System Vent System

18.1 Confirmatory Item 19

"The actual design configuration of the PCCS vent system, especially the vent submergence, may influence the amount of steam condensed in the SP. Therefore, during the design certification review, the staff will confirm that steam entering the SP through the PCCS vent, as designed, will perform as expected to condense steam entering the SP."

18.2 Staff Evaluation of Confirmatory Item 19

The preapplication SER "TRACG Application for ESBWR" (NEDC-33083P) reports the following under PIRT item WW3, on page 39: "Based on available test data, GENE concluded that any steam entering the SP through the PCCS vent, based on the design presented for this review, will be condensed within the SP during the blowdown period of the accident."

The staff's acceptance of the above statement during the preapplication phase was based on its review of the supplemental information provided by GEH in its response to preapplication RAI 314.1 (Reference 30) regarding the PCCS performance during the blowdown. However, the staff was aware that even though the plant design has changed since the preapplication (e.g., change in power level from 4,000 megawatts (MW) to 4,500 MW, possible use of spargers), the same 0.9-m PCCS vent submergence depth as specified in NEDE-32176P, Revision 1, also appears in Revision 3.

In RAI 21.6-106, the staff asked GEH to confirm that the 0.9-m submergence depth is still valid and that the final PCCS vent design would adequately condense steam and lead to saturated steam, and not superheated steam, above the suppression pool. In response to RAI 21.6-106 and Supplements 1 through 3, GEH noted that the power increase from 4,000 MW to 4,500 MW is a 12.5-percent increase in power, which leads to a corresponding increase in PCCS vent steam mass flow rate. The number of PCCS vents was increased from four to six, resulting in an increase in vent area of 50 percent. Therefore, these changes result in a decrease of steam mass flow rate through each PCCS vent by 25 percent, which is conservative. The addition of spargers would enhance steam condensation. Therefore, the same submergence length of 0.9 m stated in NEDE-32176P, Revision 1, continues to be bounding, and the PCCS vent system would adequately condense steam and would lead to saturated steam and not superheated steam above the suppression pool. GEH's validation of the vent line design performance during the blowdown is based on experimental data. GEH performed a dimensional analysis of the condensation data for steam discharged through the PCCS vent in the LINX test facility (Reference 18). The test data showed that the steam was fully condensed in all tests that include a range of steam flow rates. Therefore, the staff determined that steam entering the SP through the PCCS vent, as designed, will perform as expected to condense steam entering the SP. GEH has documented these design changes in Chapter 6 of the ESBWR DCD, Tier 2, Revision 6. In addition, Table 6B-2 in the ESBWR DCD, Tier 2, Revision 6, contains a comparison of the design modeled in the ESBWR DCD analyses and in the original model development LTR, NEDE-32176P, which was not updated to reflect all the modeling design changes.

The staff finds the GEH justification and documentation to be sufficient. Therefore, based on the applicant's response, RAI 21.6-106 S03 was closed. Confirmatory Item 19 is closed.

19 Item 20: ESBWR Design Changes

19.1 <u>Confirmatory Item 20</u>

> *"This safety evaluation is based on the 4000 MWth ESBWR reference design as described in Reference … [NEDC-33084P, Revision 1, "ESBWR Design Description," August 2003]. At the design certification stage, GENE should demonstrate that the reference design as described in Reference … [NEDC-33084P, Revision 1] has not been altered in such a way as to affect the staff's conclusions of this report. Significant changes in the design that challenge the conclusions of this report will result in the staff reevaluating the applicability of the TRACG code."*

19.2 <u>Staff Evaluation of Confirmatory Item 20</u>

In ESBWR DCD, Tier 2, Revision 6, Chapter 6, Table 6G-2, and the response to RAI 21.6-98, GEH listed the changes to the ESBWR design between the design referenced during the preapplication review and the design submitted in the design certification application. The following subsections describe and evaluate the applicability of the staff SER and pre-application LTR (Reference 1) to each of the major changes.

19.2.1 Core Power

The preapplication power level was 4,000 megawatts thermal (MWt). The ESBWR, as described in Revision 3 of the DCD (Reference 24), has a core power level of 4,500 MWt. The higher power level will result in higher core exit and chimney void fractions. In RAI 21.6-75 (Reference 14), the staff requested that GEH submit the updated qualification report. In response, GEH submitted Revision 3 of the TRACG qualification report (Reference 15) in August 2007. The staff reviewed the GEH qualification of its void fraction data provided in this report to ensure that the modifications to the entrainment fraction and its subsequent use in the interfacial shear model compare well with data. The qualification of void fraction prediction is evaluated in Confirmatory Item 3 and is judged to be satisfactory. Based on the applicant's response, RAI 21.6-75 is closed.

19.2.2 Number of Bundles

The number of bundles was increased from 1,020 to 1,132 to accommodate the power uprate described in Section 19.2.1 of this report. The flexible input of TRACG allows GEH to change the number of bundles. This change does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.3 Change in Core Shroud Size

The size of the core shroud was increased to include the bundles added (see Section 19.2.2 of this report). This causes the downcomer volume to decrease and therefore provides less inventory during the blowdown phase of the LOCA. GEH included additional ECCS sources to provide more inventory. Although this change affects the results of the analysis, it does not affect the ability of TRACG to simulate the analysis, since the TRACG input is flexible enough that GEH can change the size of the shroud within the TRACG input deck. This change does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.4 Core Lattice

GEH changed the ESBWR control blade lattice from an F-lattice with wide blades to an N-lattice with standard blades. The purpose of this change was to simplify the design, as the N-lattice is similar to the current BWR/2–6. The TRACG LOCA model in the Pre-Application LTR (Reference 1) does not model three-dimensional kinetics and therefore does not consider the geometry of the control blades. GEH uses a decay heat table upon reactor scram.

During an audit from December 11 through December 15, 2006 and resuming for the period between December 19 and December 20, 2006, the staff reviewed the decay heat curve used in current ESBWR LOCA analyses in detail and confirmed that this change does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.5 Number of Control Rod Drives

GEH increased the number of control rod drives from 121 to 269 to accommodate the N-lattice (see Section 19.2.4 above). Control rod drives are not modeled in TRACG ESBWR LOCA analyses; therefore, this change does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.6 Gravity-Driven Cooling System Pool and Airspace Location

To simplify the ESBWR design, GEH changed the location of the GDCS pool airspace from the wetwell to the drywell. This is the same configuration as in the simplified boiling-water reactor (SBWR) and the M-series PANDA tests (Reference 31). The staff reviewed the PANDA M-series tests during its evaluation of the Pre-Application LTR Reference 1. This change does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.7 Passive Containment Cooling System

GEH increased the number of PCCS units from four to six, reduced the heat removal capability (from 13.5 MW to 11 MW) of each PCCS unit, and credited PCCS vent fans to force the flow of steam through the PCCS after 72 hours following a LOCA. GEH performed full-scale tests of the PCCS, and the staff finds these tests applicable to the ESBWR design since the condenser tube diameter, length, and pitch are the same as those tested. The only difference is in the number of tubes. Section 21.5.3 of the SER for the ESBWR design certification discusses the staff's evaluation of the PCCS testing program. The staff included the PCCS vent fans in its confirmatory MELCOR analysis.

19.2.8 Isolation Condenser System

GEH increased the power level of each IC from 30 to 33.75 MWt. The staff did not evaluate the ability of TRACG to model the ICS during its evaluation of the pre-application (Reference 1); therefore, changes to the design do not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1). The staff reviewed the GEH testing of the ICS, which is discussed in Section 21.5.3 of the SER for the ESBWR design certification. The SER for NEDE-33083P, Supplement 3, Revision 1 (Reference 20) discusses modeling of the ICS for transient analysis.

During the preapplication review of the 4,000-MWt design, the staff did not evaluate the capability of TRACG to model the ICS because the system was not part of the ECCS at that time, and the GEH analyses took no credit for ICS operation during a LOCA. The ICS has been added to the ECCS for the updated 4,500-MWt ESBWR design by providing additional liquid inventory upon opening of the condensate return valves to initiate the system.

In DCD Chapter 6, Table 6A1, GEH stated that the initial water inventory in the ICs is modeled in the analysis, and no credit is assumed for the heat transfer in the ICs. TRACG is able to model additional IC inventory, and therefore, TRACG is adequate to model ICS in the LOCA analysis.

19.2.9 Pressure Relief System

GEH changed 12 automatic depressurization system (ADS) valves to 10 ADS valves and 8 safety/relief valves (SRVs) in the latest design. The TRACG critical flow model is independent of the number of valves. Therefore, this change does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.10 Containment Vents

The suppression pool (wetwell) is connected to the drywell by a vent system. The number of vents was increased from 10 to 12. During the first part of a LOCA caused by a break in the drywell, a differential pressure is created from the drywell to the wetwell, and much of the gas and steam will be transferred to the wetwell through the vent system. The staff based its acceptance of the TRACG model of the containment vents in the staff SER (Reference 1) on comparisons of TRACG to the pressure suppression test facility (PSTF) facility for the 5703 series tests. These tests were performed for full-scale vents. TRACG was able to model the vent flow rates and time of vent clearing adequately. The change in number of vents reduced the mass flow rate in the vents, which is still within TRACG application range, and is acceptable.

19.2.11 Feedwater System

GEH changed the control logic on the feedwater system. The feedwater system is isolated during a feedwater line break due to high drywell pressure. The LOCA analyses for containment in the ESBWR DCD (Reference 24) assume alternating current (AC) power is available and the feedwater system is running. If the feedwater line break is assumed, more mass and energy is released to the containment. It is conservative to assume the availability of AC power. The staff evaluated this change in logic and determined that it is conservative, and thus this change is acceptable.

19.2.12 Turbine Bypass Capacity

GEH increased the turbine bypass capacity from 33 percent to 110 percent. This change is not modeled in TRACG ESBWR LOCA analyses and thus does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER Reference 1.

19.2.13 Passive Containment Cooling Drain Tanks

GEH removed the passive containment cooling (PCC) drain tanks that were once located in the drywell. Instead, the PCCS drains directly to the GDCS. This change simplifies the ESBWR design and represents the same configuration as in the SBWR and the M-series PANDA tests (Reference 31). The staff reviewed the PANDA M-series tests during its evaluation of the pre-application LTR (Reference 1). This change does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.14 Suppression Pool Volume

GEH changed the suppression pool (SP) volume from 3,610 m^3 to 4,424 m^3. The larger suppression pool reduces the temperature increase in the pool. The TRACG input is flexible and capable of changing this design parameter. This change does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.15 Drywell/Wetwell Volume Ratio

The drywell to wetwell volume ratio increased from 1.31 to 1.33. The TRACG geometry input is flexible and capable of changing this design parameter. This change does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.16 Lower Drywell Free Volume to Top of Active Fuel Elevation

GEH reduced the volume of the lower drywell to the top of the active fuel elevation. This improves the performance for lower elevation breaks, such as the BDLB. For the long-term cooling performance for the lower elevation breaks, GEH relies on the drywell filling to an elevation above the top of active fuel so that the PCCS has to supply only enough water to compensate for the inventory losses in the core that result from steaming from decay heat. The TRACG geometry input is flexible and capable of changing this design parameter. This change does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.17 Standby Liquid Control System Activated on Automatic Depressurization System

GEH added the SLCS to the ECCS to provide additional inventory during a LOCA. The SLCS is modeled as a [[ ]] table. The SLCS injection velocity was calculated for ESBWR ATWS (high-pressure) conditions and therefore will be bounding for use in ESBWR LOCA analyses. In letter MFN 07-312, dated June 2007 (Reference 27) GEH discusses the adequacy of using the SLCS FILL table for ATWS events. This change does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.18 Isolation Condenser System Inline Vessel

GEH added one 9-m^3 vessel in each ICS train to improve the RPV water level in the LOCA. Since no new phenomena were introduced, this change does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.19 Safety/Relief Valve Capacity

GEH increased SRV capacity by about 11 percent. Since no new phenomena were introduced, this change does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.20 Feedwater Isolation Valve Configuration

GEH changed five valves per line to four process-operated valves per line. Since no new phenomena were introduced, this change does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.21 Main Steamline Changes

GEH increased the main steamline diameter from 700 millimeters (mm) to 750 mm upstream of MSIV and pipelines of DPVs on ICs. This change does not introduce new phenomena and does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.22 Turbine Main Steam Piping Diameter

GEH changed the turbine main steam piping diameter from 800 mm to 750 mm. This change does not introduce new phenomena and does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.23 Main Steam Isolation Valve Size

GEH changed the MSIV size from 771 mm to 762 mm. This change does not introduce new phenomena and does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.24 Passive Containment Cooling System Vent Fan

GEH added one PCCS ventilation fan to each PCCS vent line, which ends submerged in the GDCS pool. This change enhances the PCCS condensation, but it does not introduce new phenomena. This change does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.25 Drywell Spray Flow

GEH changed the spray flow rate from 3785 liters per minute (1,000 gallons per minute (gpm)) to 2120 liters per minute (560 gpm). The change introduces no new phenomena and does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.26 Cross-Tie between FAPCS and RWCU

GEH added a cross-tie from the fuel and auxiliary pool cooling system (FAPCS) suction line to reactor water clean up (RWCU) train A, upstream of the nonregenerative heat exchangers. This change does not affect the staff's evaluation of TRACG as applied to an ESBWR LOCA in the staff SER (Reference 1).

19.2.27 Conclusions for Confirmatory Item 20

GEH provided all of the design changes that impact the LOCA analysis since the approval of TRACG for the ESBWR LOCA analysis (NEDO-33083-A) in the ESBWR DCD, Tier 2, Revision 5. The impacts of these changes on the LOCA analyses have been reanalyzed and documented in Sections 6.2 and 6.3 in the ESBWR DCD, Revision 6. As evaluated in Sections 19.2.1 through 19.2.28 of this report, the justifications for the TRACG model updates provided by GEH are acceptable. Therefore, Confirmatory Item 20 is closed.

20 Conclusions

The staff reviewed the additional data provided by the applicant in final approved LTR (Reference 1) to address the remaining open items. The staff finds that the open items have been adequately addressed, and they are now closed.

The staff concludes that the TRACG code and methodology described in the Pre-Application LTR (Reference 1) and associated RAI responses are applicable to the calculation of an ESBWR LOCA as described in Sections 6.2 and 6.3 of the ESBWR DCD.

21 References

1. NEDC-33083P-A, "TRACG Application for ESBWR," March 2005 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML051390265))[2]; Non-Proprietary version: NEDO-33083-A, "TRACG Application for ESBWR," October 2005, Accession No. ML053320203); Original submittal: NEDC-33083P, "TRACG Application for ESBWR," November 2002 (ADAMS Accession No. ML023260440).

2. "Summary of Exit Meeting Held on December 15, 2006, to Discuss Staff's Audit of TRACG Loss-of-Coolant Accident Analyses," January 4, 2007 (ADAMS Accession No. ML0635403880).

3. Letter from D. H. Hinds (GEH) to NRC, MFN 05-096, "Summary of September 9, 2005 NRC/GE Conference Call on TRACG LOCA SER Confirmatory Items," September 20, 2005 (ADAMS Accession No. ML052910378).

4. Letter from D. H. Hinds (GEH) to NRC, MFN 05-105, "TRACG LOCA SER Confirmatory Items (TAC # MC868), Enclosure 2, Reactor Pressure Vessel (RPV) Level Response for the Long Term PCCS Period, Phenomena Identification and Ranking Table, and Major Design Changes from Pre-Application Review Design to DCD Design," October 6, 2005 (ADAMS Accession No. ML053140223).

5. Letter from D. H. Hinds (GEH) to NRC, MFN 05-109, "GE[H] Responds to Results of NRC Acceptance Review for ESBWR Design Certification Application—Item 2 (TAC No. MC8168)," October 20, 2005 (ADAMS Accession No. ML053000054).

6. Letter from D. H. Hinds (GEH) to NRC, MFN 06-094, "Revised Response—GE[H] Response to Results of NRC Acceptance Review for ESBWR Design Certification Application—Item 2," March 28, 2006 (ADAMS Accession No. ML060900097).

[2] The Proprietary Staff Safety Evaluation Report is contained in this document on pages 11 through 185. The Non-proprietary version of the Staff Safety Evaluation is contained in NEDO-33083-A (ML053320203) on pages 6 through 178. The original proprietary submittal of the topical report is NEDC-33083P (ML023260440).

7. Letter from D. H. Hinds (GEH) to NRC, “General Electric Company—ESBWR Standard Plant Design Revision 7 to Design Control Document Tier 2,” March 29, 2010 (ADAMS Accession No. ML101340143).

8. NUREG/CR-5249, “Quantifying Reactor Safety Margins: Application of Code Scaling Applicability, and Uncertainty Evaluation Methodology to a Large-Break, Loss-of-Coolant Accident,” December 1989 (ADAMS Accession No. ML070310119).

9. Letter from J. C. Kinsey (GEH) to NRC, MFN 07-310, “Response to Portion of NRC Request for Additional Information Letter No. 85—Containment Systems and Emergency Core Cooling Systems—RAI Numbers 6.2-144, 6.2-145, 6.2-146, 6.2-147, and 6.3-66,” June 7, 2007 (ADAMS Accession No. ML071770542).

10. Letter from J. C. Kinsey (GEH) to NRC, MFN 07-049, “Response to Portion of NRC Request for Additional Information Letter No. 68—Emergency Core Cooling Systems—RAI Numbers 6.3-46 through 6.3-49,” March 20, 2007 (ADAMS Accession No. ML070860262).

11. Letter from J. C. Kinsey (GEH) to NRC, “Response to Portion of NRC Request for Additional Information Letter No. 85 Related to ESBWR Design Certification Application—Emergency Core Cooling Systems—RAI Number 6.3-65 S01,” March 25, 2008 (ADAMS Accession No. ML080870229).

12. NEDE-32176P, Rev. 2, “TRACG Model Description,” December 1999 (ADAMS Accession No. ML993630283).

13. NEDE-32176P, Revision 3, “TRACG Model Description,” April 2006 (ADAMS Accession No. ML061160238). NEDO-32176, Revision 4, January 2008 (ADAMS Accession No. ML080370271).

14. Letter from M. C. Barillas (NRC) to D.H. Hinds (GEH), “Request for Additional Information Letter No. 66 Related to ESBWR Design Certification Application,” October 10, 2006 (ADAMS Accession No. ML062790238).

15. NEDE-32177P, Rev. 3, MFN 07-452, “Transmittal of GEH Topical Report, NEDE-32177P, Revision 3, *TRACG Qualification,* August 2007,” August 29, 2007 (ADAMS Accession No. ML072480007).

16. NEDE-32177P, Revision 2, “TRACG Qualification,” January 31, 2000 (ADAMS Accession No. ML003683162)

17. NEDE-33440P, Revision 1, “ESBWR Safety Analyses—Additional Information,” June 2009 (ADAMS Accession No. ML091830295).

18. NEDC-32725P, Revision 1, “TRACG Qualification for SBWR – Document Transmittal for Pre-Application Review of ESBWR,” MFN 02-053, August 30, 2002 (ADAMS Accession No. ML022560081)

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