SAFETY EVALUATION FOR THE TRACG APPLICATION

FOR ESBWR TRANSIENT ANALYSIS

NEDE-33083P, SUPPLEMENT 3, REVISION 1

1 INTRODUCTION

NEDC-33083P-A, "TRACG Application for ESBWR" (Reference 1), was reviewed by the staff of the U.S. Nuclear Regulatory Commission (NRC) as part of the preapplication review activities for the economic simplified boiling-water reactor (ESBWR) advanced passive design. The staff reviewed and approved NEDC-33083P-A as applied to the loss-of-coolant accident (LOCA) for the 4,000-megawatt thermal (MWt) ESBWR design. The transient analyses in Section 4.7, "Demonstration Calculations for ESBWR AOOs," of NEDC-33083P (Reference 2) were updated to coincide with the 4,500-MWt ESBWR design described in the ESBWR design control document (DCD), Revision 0.[1]

In Request for Additional Information (RAI) 21.6-63, Supplement 1, and RAI 21.6-65, Supplement 2, the staff requested that GEH submit a topical report or a supplement to NEDC-33083P-A to incorporate the information provided in References 1 and 2 related to TRACG transient analysis and the associated RAI responses. In response (as documented in Reference 3), GEH submitted NEDE-33083P, Supplement 3, Revision 1, "TRACG Application for ESBWR Transient Analysis," (Reference 4). The staff based its review of the application of the TRACG code for ESBWR transient analyses on the GEH submittal (Reference 4), which includes the information submitted in References 1 and 11, as well as the associated RAI responses. Based on the applicant's responses, RAIs 21.6-63 and 21.6-65 are resolved.

This safety evaluation report (SER) describes the staff's review and approval of NEDE-33083P, Supplement 3, as it relates to the ESBWR transient analysis. NEDE-32176P, Revision 3, "TRACG Model Description," issued April 2006 (Reference 5), describes the models contained in the code. The staff has also reviewed and approved TRACG for application to anticipated operational occurrences (AOOs) in boiling-water reactor (BWR)/2-6 (References 6 and 7), for prediction of the initial pressure peak in anticipated transients without scram (ATWSs) in BWR/2-6 (Reference 8), and for application to calculating stability margins (References 9 and 33) and LOCA analyses in the ESBWR (References 1 and 10).

2 REGULATORY BASIS

To establish a licensing basis, applications must analyze transients in accordance with the requirements of General Design Criterion (GDC) 10, "Reactor Design," in Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10 of the Code of Federal Regulations, Part 50, "Domestic Licensing of Production and Utilization Facilities," and 10 CFR 50.34, "Contents of Applications; Technical Information," and, where applicable, should address NUREG-0737, "Clarification of TMI Action Plan Requirements," issued November 1980 (Reference 11). The staff reviews the evaluation model to ensure that it is adequate to simulate

[1] Revision 0 was the initial submittal. When new information was introduced the specific DCD revision is identified in the text. When the DCD revision number is not specified the staff utilized the latest revision.

the transient or accident under consideration. This includes a review of methods to estimate the uncertainty in the calculation.

The staff provided guidance for applicants to meet the general requirements of a thermal hydraulic analysis computer code in Regulatory Guide 1.203, "Transient and Accident Analysis Methods" (Reference 12) and NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition" (hereafter referred to as the SRP), Section 15.0.2, "Review of Analytical Computer Codes," issued January 2006 (Reference 13). References 12 and 13 describe acceptable approaches by which the calculated uncertainty in the analysis methodology can be addressed. They express a preference for the code scaling, applicability, and uncertainty (CSAU) methodology described in NUREG/CR-5249, ""Quantifying Reactor Safety Margins: Application of Code Scaling, Applicability, and Uncertainty Evaluation Methodology to a Large-Break, Loss-of-Coolant Accident," issued December 1989 (Reference 14) as the means for applicants to determine the uncertainty in a code calculation. Specific regulatory criteria for AOO analyses are described below.

GDC 10 requires the following:

> The reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences.

GEH uses the TRACG code to ensure that safety limits, such as minimum critical power ratio (MCPR), peak reactor vessel pressure, and downcomer water level, are met during AOOs.

3 TECHNICAL EVALUATION

In the following subsections, the staff addresses the scope of the review, the CSAU-based technical evaluation, and the confirmatory calculations performed in support of this review.

3.1 Scope of Review

The staff performed an extensive review of the TRACG code for application to the LOCA event in the ESBWR (References 1 and 10) and for the application to AOO (References 6 and 7) and ATWS overpressure events in BWR/2-6 (Reference 8). For the review of the application of TRACG to the transient events, AOOs, and infrequent events (IEs) in the ESBWR, the staff has built on these previous reviews. The staff focused on differences between approved models and the current version of TRACG04 as described in Reference 5. The most significant differences are in the kinetics model. The staff focused on phenomena that are unique to the ESBWR design. In addition, the staff reviewed items and modeling that were not evaluated in past TRACG reviews.

The scope of this SER is limited to the capability of the TRACG code to perform AOO/IE analyses for the ESBWR. The SER on ESBWR design certification will address the acceptability of the ESBWR design.

3.2 Technical Evaluation Based on Code Scaling, Applicability, and Uncertainty

The requirements of a realistic methodology are somewhat different from those of 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 estimating uncertainty are available in the realm of statistical analysis. GEH has chosen to follow the basic CSAU approach outlined in NUREG/CR-5249 (Reference 14). While the CSAU approach defines the process by which uncertainty analysis is performed, it allows GEH to determine the exact statistical methodology to be applied. In the application of TRACG for AOO and ATWS for BWR/2-6, and the application of TRACG to the ESBWR stability analysis, GEH chose to apply a normal distribution one-sided upper limit statistical methodology. The staff discussed this approach in References 9, 6, and 8. GEH has again taken this approach for the TRACG application for AOOs in the ESBWR.

The CSAU methodology consists of 14 steps contained within three elements. The first element includes Steps 1 through 6 and determines the requirements and code capabilities. The scenario modeling requirements are identified and compared against code capabilities to determine the applicability of the code to specific plant and accident scenarios. Code limitations appear in Element 1.

The second element in the methodology includes Steps 7 through 10 and assesses the capabilities of the code by comparison of calculations against experimental data to determine code accuracy, scaleup capability, and appropriate ranges over which parameter variations must be considered in sensitivity studies.

The third element in the methodology consists of Steps 11 through 14, in which individual contributors to uncertainty, such as plant input parameters, state, and sensitivities, are calculated, collected, and combined with biases and uncertainties into a total uncertainty.

3.2.1 Element 1—Requirements and Code Capability

3.2.1.1 Step 1—Scenario Selection

The processes and phenomena that can occur during an accident or transient vary considerably, depending on the specific event being analyzed. GEH has identified the AOO scenarios (incidents of moderate frequency) applicable to the ESBWR that can be analyzed using TRACG and the associated methodology.

Table 1 arranges these scenarios with the corresponding section of the SRP.

Table 1 Event Categories and SRP Sections for Application of the ESBWR TRACG AOO Methodology	
Event Category	SRP Section
Pressurization Events	15.1.1–15.1.4 15.2.1–15.2.5 15.2.6
Depressurization Events	15.1.1–15.1.4 15.6.1
Cold Water Injection Events	15.1.1–15.1.4 15.5.1–15.5.2
Level Transient	15.2.7

Section 2.0 of the contractor technical evaluation report (TER) "Technical Evaluation Review of TRACG Applications to ESBWR AOOs," issued January 2007 (Reference 15), provides more detail on the specific events for which this methodology applies. This SER does not consider application of the methodology to transients and accidents not included in Table 1.

GEH is consistent with this step in the CSAU approach.

3.2.1.2 Step 2—Nuclear Power Plant Selection

The dominant phenomena and timing of an event can vary significantly from one nuclear power plant design to another. GEH has specified that the methodology is applicable to the ESBWR natural circulation, passive design. The staff evaluated the methodology as it applies to the 4,500-MWt ESBWR design as described in the ESBWR DCD (Reference 16).

GEH is consistent with this step in the CSAU approach.

3.2.1.3 Step 3—Phenomena Identification and Ranking

Not all phenomena that occur during an accident or transient have an equal influence on the behavior of a nuclear power plant undergoing the event. Those phenomena that are important for each event and various phases within an event must be determined. The phenomena are compared to the modeling capability of the code to assess whether the code has the necessary models to simulate the phenomena. Most important, the range of the identified phenomena covered in experiments or test data is compared to the corresponding range of the intended application to ensure that the code has been qualified for the highly ranked phenomena over the appropriate range. Development of a phenomena identification and ranking table (PIRT) establishes those phases and phenomena that are significant to the progress of the event being evaluated.

GEH identified important phenomena for AOOs in the ESBWR in a PIRT. Tables 4.1-3a and b in NEDC-33079P, Revision 1, "ESBWR Test and Analysis Program Description," issued March 2005 (Reference 17) contain the PIRT for the ESBWR AOO analysis. NEDC-33079P, Revision 1, Supplement 1, "ESBWR Test and Analysis Program Description, Discussion of PIRT Parameters," issued March 2005 (Reference 18), discusses the parameters. The transient events have been categorized into three groups: (1) pressurization events,

(2) depressurization events, and (3) cold water insertion events. For each event type, the phenomena are listed and ranked for each major component in the reactor system.

In RAI 21.6-60, the staff questioned the GEH ranking of the Doppler coefficient as “medium” for ESBWR AOOs and IEs. In a January 2007 letter to the NRC (Reference 19), GEH provided the results of sensitivity studies that were performed by perturbing the Doppler uncertainty by +1□ and -1□ and showed that there was little sensitivity to change in critical power ratio (ΔCPR/ICPR) for the loss of feedwater heating and the generator load rejection with a single failure in the turbine bypass system. GEH showed that there was little sensitivity to the peak pressure to the main steam isolation valve closure event. In addition, although GEH ranked this parameter as having “medium” importance, it still included the uncertainty in the uncertainty analysis. Section 3.2.1.6.2 of this report discusses the staff’s evaluation of the uncertainty value. Based on the applicant’s response, RAI 21.6-60 is resolved.

In addition, in RAI 21.6-61, the staff questioned why mixing in the lower plenum for cold water injection events was not ranked as “high.” The staff’s concern was that as cold water enters the core, it might not mix well in the lower plenum and areas of concentrated cold water could occur and cause a pronounced effect on ΔCPR for bundles in this location. The staff was concerned that the impact on ΔCPR would be greater than that calculated by TRACG because of the coarse noding of the lower plenum in the ESBWR TRACG model at the time that the RAI was transmitted. A PIRT ranking of “high” would ensure that the uncertainties associated with lower plenum mixing are included in the calculation of ΔCPR.

The GEH response to RAI 21.6-61 included a nodalization study of the Feedwater Controller Failure (FWCF) event. The study increased and decreased the rate of transfer between the radial rings in the lower plenum by artificially creating resistance between these cells. GEH showed that the ultimate change in ΔCPR, given the different resistances in the lower plenum, did not have a substantial effect on ΔCPR for Ring 1 (the central most) and Ring 2 (next to the central most). GEH did not display the results of the ΔCPR changes for Ring 3, which is the outermost ring and the one of most concern. However, a computational fluid dynamics study performed by the staff for the inadvertent isolation condenser initiation (IICI) cold water transient shows that the thermal mixing at the side entry orifices (which is representative of the mixing that occurs in the downcomer and lower plenum) is consistent with the results from the TRACG model. In addition, the ESBWR DCD, as well as Reference 4 (transmitted subsequent to the GEH response to RAI 21.6-61), shows that the PIRT ranking for lower plenum mixing is “high,” and the corresponding uncertainty is accounted for in the TRACG AOO methodology for the ESBWR. Therefore, based on the applicant’s response, RAI 21.6-61 is resolved.

Section 3.0 of the Technical Evaluation Report (TER) “Technical Evaluation Review of TRACG Applications to ESBWR AOOs,” (Reference 15) includes more discussion of the staff’s evaluation of the GEH AOO PIRT.

In the original documentation (Reference 1), GEH chose not to include medium-ranked phenomena in its uncertainty analysis. Other previously approved TRACG methodologies (References 20 and 6) have treated medium- and high-ranked phenomena essentially the same. In RAI 21.6-64, the staff questioned this departure from previously approved TRACG methodologies.

In RAI 21.6-64, the NRC staff requested that GEH provide the following information:

A) Provide justification for the exclusion of some medium ranked PIRT parameters in the ESBWR AOO uncertainty analysis.

B) Explain the method for selecting the medium ranked PIRT parameters that were included in the ESBWR AOO uncertainty analysis.

C) Provide a discussion of how medium ranked PIRT parameters are treated in terms of model uncertainty and bias. Specifically, are nominal values used for medium ranked PIRT parameters? If so, justify why bounding values are not used.

GEH responded to RAI 21.6-64 with the following information corresponding to the list of questions above:

A) The bases for selecting and ranking the medium and high PIRT are discussed in Section 5.0 of NEDE-33083 Supplement 3. All of the medium and high ranked PIRT listed in Table 5-1 are included in the OLMCPR statistical uncertainty analyses for selected AOO, IE, and SE transients.

B) Section 7.0 of NEDE-33083 Supplement 3

C) Section 5.0 of NEDE-33083 Supplement 3

GEH's response detailed the ways in which all of the high and medium PIRT parameters are either bounded, or biases and uncertainties are accounted for, as discussed in Section 5 of Reference 46. The high and medium PIRT parameters that are not bounded are evaluated in the statistical analysis (Section 8.4 of Reference 4). The staff finds this approach to be acceptable, since all of the significant PIRT parameters are addressed in Revision 1 of NEDE-33083P Supplement 3. Therefore, based on the applicant's response, RAI 21.6-64 is resolved.

The staff concludes that GEH is consistent with this step in the CSAU approach.

3.2.1.4 Step 4—Frozen Code Version Selection

The version of a code, or codes, reviewed for acceptance must be "frozen" to ensure that changes to the code do not impact the conclusions after an evaluation has been completed and that changes occur in an auditable and traceable manner. GEH has specified that the TRACG04 code be used for the ESBWR AOO applications. TRACG04 contains PANAC11 three-dimensional neutronic methods. PANAC11 and TGBLA06 are also used to generate the cross-section data that are input into TRACG04.

The staff reviewed the most current versions of PANAC11 and TGBLA06 codes for their applicability to the ESBWR. The staff performed an audit of these codes at the GEH office on October 16 through October 19, 2006, and resumed the audit between October 30 and November 3, 2006. GEH makes error-correction versions of its code on a regular basis. The staff considers these codes frozen, along with future revisions to the codes, as long as changes to the codes are within appropriate limitations and conditions. These conditions and limitations are specified in the staff's safety evaluation for NEDC-33239P (Reference 21).

Changes to TRACG04 are restricted by the methodology (Reference 1). The models in Reference 12 may not be changed without NRC review and approval. Changes in numerical methods to improve code convergence, or code enhancements, or error corrections must be tested and auditable records kept in accordance with Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants,” to 10 CFR Part 50. If the calculated TRACG results of the qualification tests in NEDE-32177P, Revision 2, “TRACG Qualification,” issued January 2000 (Reference 22) used to test the code change by more than the uncertainty in that assessment, the staff requires GEH to submit the changes for review. New models or features, other than input enhancements that do not affect calculated results, may not be implemented without prior NRC review and approval.

In RAI 21.6-92, the staff asked GEH to provide the exact version and revision number for all analyses performed in the ESBWR DCD (References 23 and 24). In addition, GEH has two versions of the TRACG04 code—TRACG04A runs on an Alpha VMS platform, and TRACG04P runs on a PC platform. The staff asked GEH to state which of these two codes is used to perform the analyses for which this methodology will be applied. In its response, GEH provided a list of the code versions used for each calculation in the DCD, which the staff finds sufficient. Based on the applicant’s response, RAI 21.6-92 is resolved.

3.2.1.5 Step 5—Provision of Complete Code Documentation

This step requires the applicant to provide documentation on the frozen code version such that the code’s applicability to postulated transient or accident scenarios for a specific plant design can be evaluated through a traceable record. GEH provided the documentation in its submittal of ESBWR AOO-specific information in References 1, 2, 17, 18, and 4 and code documentation in References 5 and 22.

The staff has requested that GEH update its documentation to reflect the current status of the code and current ESBWR plant design applicability. Reference 1, which presents the application methodology, is based on the preapplication (4,000-MWt) design and TRACG nodalization. Reference 2 provides demonstration calculations for the ESBWR design as described in Revision 0 of the DCD. RAI 21.6-63 requests that GEH identify the differences between the methodology described in References 1 and 2 and the current application methodology used in the ESBWR DCD. Reference 4 includes this information. Based on the applicant’s response, RAI 21.6-63 and the corresponding supplemental RAIs are resolved. In RAI 21.6-75, the staff requested that GEH submit the updated qualification report that is consistent with the current version of TRACG used in ESBWR licensing analyses (TRACG04). In response, GEH submitted Revision 3 of the TRACG qualification report in August 2007 (Reference 25). Based on the applicant’s response, RAI 21.6-75 is resolved. Detailed discussion is included in the SER for LTR NEDC-33083P, “Application of the TRACG Computer Code to the ECCS and Containment LOCA Analysis for the ESBWR Design,” Sections 3.2 and 19.2.1 (Reference 10).

GEH described the nodalization used in the ESBWR AOO/IE analysis in Reference 26 and in accordance with a staff request in RAI 21.6-97, submitted UM-0136, Revision 0, “TRACG04A, P User’s Manual,” issued December 2005 (Reference 27). Although GEH provided the appropriate updates to the documentation, in RAI 21.6-63, Supplement 1, and RAI 21.6-65, Supplement 2, the staff requested these updates as a topical report or supplement to NEDE-33083P. GEH submitted NEDE-33083P, Supplement 3, Revision 1 (Reference 4), which contains the requested information. Based on the applicant’s responses, RAIs 21.6-63, RAI 21.6-65, and RAI 21.6-97 are resolved.

3.2.1.6 Step 6—Determination of Code Applicability

As described in Section 3.6 of the staff safety evaluation for NEDC-33083P-A (which has been incorporated into Reference 1), TRACG is a two-fluid code capable of one-dimensional and three-dimensional thermal-hydraulic representation along with three-dimensional neutronic representation. The code is designed to perform realistically with conservatism added, where appropriate, via the input specifications. An analysis code used to calculate a scenario in a nuclear power plant should use many models to represent the thermal-hydraulics and components. Those models should include the following four elements:

(1) Field equations provide code capability to address global processes.

(2) Closure equations provide code capability to model and scale particular processes.

(3) Numerics provide code capability to perform efficient and reliable calculations.

(4) Structure and nodalization address code capability to model plant geometry and perform efficient and accurate plant calculations.

The staff performed an extensive review of the thermal-hydraulics models and their applicability to the ESBWR for LOCA events and containment analysis in Reference 1. During the review of TRACG for application to AOO events for the ESBWR, the staff focused on models that were not previously reviewed or that have been updated since previous reviews. The TRACG neutron kinetics models have been updated since the review of TRACG for AOOs in the BWR/2–6, and the models are now based on PANAC11 methods. In addition, the staff focused on the review of cross-section generation using TGBLA06 and isolation condenser (IC) modeling.

3.2.1.6.1 Thermal-Hydraulic Modeling

Section 4.0 of the TER (Reference 15) discusses the thermal-hydraulic modeling in TRACG and its applicability to ESBWR AOOs. This review identified the issues summarized below.

The NRC based many of the conclusions reached in this review on NEDE-32177P, Revision 2 (Reference 22), which is based on TRACG02 calculations as compared to data. Since GEH is using TRACG04 for ESBWR design certification calculations, the staff requested in RAI 21.6-75 that GEH submit an updated qualification report comparing TRACG04 to data. In response, GEH submitted Revision 3 of the TRACG qualification report in August 2007. Sections 3.2 and 19.2.1 of Reference 10 discuss RAI 21.6-75. Based on the applicant’s response, RAI 21.6-75 is resolved.

The database used to determine the uncertainty of the void fraction modeling does not appear to include fuel assemblies representative of what will be used in the ESBWR (10x10 fuel with partial length rods). Section 4.4 of the ESBWR DCD Rev 6 (Reference 28) addresses this item. As a result of RAI 4.4-2, a penalty (a thermal margin adder of 0.01) is applied to the calculated OLMCPR to account for void fraction uncertainty. This penalty is detailed in Section 5.3 of Reference 29 and should be applied for the use of TRACG for ESBWR AOOs until GEH acquires additional high void data, determines the Findlay-Dix correlation uncertainty, and obtains NRC approval. This is a condition of the staff review of TRACG for ESBWR AOOs, as detailed in item 9 of Section 4 herein.

The database for the General Electric Critical Quality Boiling Length (GEXL) correlation, which is used to calculate CPR in AOO analyses, was originally based on GE14 fuel test data. However, the applicability of the GEXL correlation to the 10-foot GE14E fuel has been verified based on GE14E critical power and pressure drop test data. The SER for Section 4.4 of the ESBWR DCD includes a detailed discussion.

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 Supplement 1 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 the degradation of thermal conductivity due to the presence of gadolinium and for the degradation of thermal conductivity as exposure increases. 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 Supplement 1 (Reference 30). In response to RAI 6.3-54 Supplement 1, 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.

For AOOs, the generator load rejection with total bypass failure (LRNBP) from ESBWR DCD Section 15.3.5 was selected as the Transient Event (AOO/IE) for the sensitivity study. This transient event is expected to be most impacted by the fuel thermal conductivity and gap conductance because it is a fast event with the most severe flux peak. The LRNBP sensitivity study results have shown in the response to RAI 6.3-54, Supplement 1 (Table 6.3-54-1) the negligible differences (< 1% ΔP and < 0.005 ΔCPR/ICPR) in Maximum Dome Pressure, Maximum Vessel Bottom Pressure, and ΔCPR/ICPR.

In addition, RAI 6.3-54 Supplement 2 (Reference 30) requested that the fuel centerline temperatures and melting temperatures for the LRNBP cases be provided. The results transmitted in the response to RAI 6.3-54 Supplement 2 (MFN 08-713 Supplement 1) show that the base LRNBP case (GSTRM gap conductance and PRIME03-based thermal conductivity) yields the most conservative maximum fuel centerline temperature. The response to RAI 6.3-54 Supplement 2, (MFN 08-713 Supplement 1) also shows that the UO_2 melting temperatures for all three cases are identical, since melting temperature is a function of exposure, and all of the cases assume the same exposure.

The Main Steam Isolation Valve Closure (MSIVC) from ESBWR DCD Section 15.5.2 was selected as the ATWS event analyzed in the sensitivity study. This ATWS event is expected to be most affected by the fuel thermal conductivity and gap conductance. The MSIVC sensitivity study results shown in the response to RAI 6.3-54 Supplement 1 (Table 6.3-54-2) show negligible differences in Associated Containment Pressure (~ 1% ΔP), Maximum Bulk Suppression Pool Temperature (< 2 ^{o}F), and Peak Cladding Temperature (< 10 ^{o}F).

The results of the sensitivity studies and relatively insignificant differences with the GSTRM/PRIME analyses provided in the response to RAI 6.3-54, give the staff reasonable assurance that the use of GSTRM model for both gap conductance and thermal conductivity in the ESBWR design certification is acceptable. The conclusions and limitations for ESBWR TRACG AOO analyses (including the 350 psi critical pressure penalty) contained in the NRC staff evaluation of GEH's Part 21 report (Appendix F to the SE for NEDC-33173P, "Applicability of GE Methods to Expanded Operating Domains") (Reference 31) are applicable to this SE. Use of other methods or analysis strategies for ESBWR must be approved by the NRC. This is a condition of the staff review of TRACG for ESBWR AOOs, as detailed in item 10 of Section 4 herein. Based on the applicant's response, RAI 6.3-54 and corresponding supplements were resolved.

3.2.1.6.1.1 Minimum Stable Film Boiling Temperature

For the minimum stable film boiling temperature, GEH specifies the Iloeje correlation for ESBWR TRACG applications. The TRACG code also includes the option of using the Shumway correlation, which, according to GEH, better captures the flow and pressure dependence. For ESBWR AOO events, the core does not enter film boiling, and therefore, neither correlation is used. The staff therefore concludes that the applicant's selection of the correlation option has no impact on the results.

In RAI 21.6-79, Supplement 1, the staff requested that GEH justify why this parameter was ranked "high" for the TRACG application for BWR/2–6 AOOs (Reference 6). The GEH response to RAI 21.6-79, Supplement 1, explains that PIRT C13 pertains to both dryout and re-wet/boiling transition. C13 is ranked as a "high" PIRT parameter for both ESBWR and BWR/2–6 AOO events because of the importance of calculating margin to dryout. However, no ESBWR or BWR/2–6 AOO events exceed the MCPR where minimum stable film boiling temperature may be encountered. Therefore, the re-wet portion of C13 is not of high importance. Based on the applicant's response, RAI 21.6-79 is resolved.

3.2.1.6.2 Three-Dimensional Neutron Kinetics Modeling

TRACG has the capability of performing three-dimensional neutron kinetics calculations. To perform these calculations, TRACG uses the PANAC11 and TGBLA06 codes. This section of the SER briefly discusses the TRACG-specific models and the interface between TRACG and PANAC11/TGBLA06. The staff's evaluation of NEDC-33239P (Reference 21) addresses the staff's detailed review of the PANAC11 and TGBLA06 methods.

TRACG04 has a one-group, coarse-mesh, nodal diffusion model with six delayed neutron precursor groups. The nodal flux calculation is the same as that performed in the PANAC11 BWR core simulator. The transient flux solution is obtained by integrating the differential neutron precursor and flux equations over space and time and solving the equations by employing a discontinuous flux and continuous current approximation.

TRACG also uses cross-sections generated by PANAC11/TGBLA06 as input via a PANAC11 "wrapup" file. The information transmitted to TRACG via this wrapup file includes the diffusion coefficient, absorption cross-section, slowing-down cross-section, fission cross-section, nu-fission cross-section, and flux discontinuity factors for the fast, epi-thermal, and thermal energy groups and the delayed neutron fraction. GEH submitted the contents of the wrapup file in its June 21, 2007, letter to the NRC (Reference 26). The staff reviewed this submittal and determined that the information transmitted to TRACG will produce adequate representation of the nuclear cross-sections.

A TRACG calculation with three-dimensional kinetics begins by initializing the steady state to a converged PANAC11 case. This is done by initializing the TRACG steady-state power distribution to that from PANAC11 and varying thermal-hydraulic conditions. Since the TRACG code and the PANAC11 code have different thermal-hydraulic models, the thermal-hydraulic solution obtained by TRACG will differ from that in PANAC11. TRACG will calculate the offset of these values so that when the TRACG thermal-hydraulic conditions are used to obtain cross-section data from the wrapup file during transient calculations, the offset will be taken into account such that these values correspond to the equivalent thermal-hydraulic conditions in PANAC11.

The staff concluded that sufficiently detailed nuclear information is conveyed from the PANAC11 results to TRACG to both initialize the model and provide for acceptable kinetic feedback modeling, and therefore found this initialization acceptable for use in ESBWR AOO/IEs. The staff's evaluation of NEDC-33239P (Reference 21) presents additional details about this process.

The PANAC11 void fraction model is based on the Findlay-Dix correlation. The staff had questions regarding the applicability of this correlation to the ESBWR. The staff requested additional information in RAI 4.4-2 on the uncertainty and applicability associated with the correlation and how it is incorporated into the ΔCPR calculation performed using TRACG and ultimately the operating limit minimum critical power ratio (OLMCPR) limit. This item is addressed in Section 4.4 of the ESBWR DCD SER (Reference 28). As a result of RAI 4.4-2, a penalty of 0.01 is added to the OLMCPR to account for the void fraction uncertainty. An additional 0.01 will be added to the limiting OLMCPR, until such time that GEH expands the experimental database supporting the Findlay-Dix void-quality correlation to demonstrate the accuracy and performance of the void-quality correlation based on experimental data representative of the ESBWR fuel design and operating conditions during steady-state, transient, and accident conditions. Detailed staff evaluation is discussed in the staff safety evaluation report for NEDC-33237P and NEDC-33413P (Reference 29).

TRACG accounts for negative reactivity from xenon by adjusting the thermal removal cross-section at each node. The PANAC11 wrapup file includes the xenon number density and the microscopic absorption cross-section. In a letter to the NRC dated June 8, 2007 (Reference 32), GEH stated that the xenon concentrations are held constant throughout the transient. Since the timeframe of concern for an AOO is on the order of seconds or minutes, and xenon concentrations change over the course of hours, the staff finds that the constant xenon assumption is reasonable. In an October 2009 letter (Reference 33), the staff discussed its evaluation of the xenon assumptions in TRACG used to simulate startup of the ESBWR.

Section 5.0 of the TER (Reference 15) provides an evaluation of the void reactivity, Doppler reactivity, and scram reactivity, including an overall discussion of the qualification of the three-dimensional kinetics model in TRACG. In RAI 21.6-108, the NRC staff requested that GEH demonstrate that PIRT items C1BX and C1CX (uncertainty in the Doppler coefficient and in scram reactivity, respectively) in Table 4.4-1 of Topical Report NEDC-33083P-A (Reference 1) are still applicable or bounding when the PANAC11 physics methods are applied. These uncertainties were established using the PANAC10 model and are also being used for the TRACG04/PANAC11 application for ESBWR AOOs and IEs.

GEH's response to RAI 21.6-108 stated that it had previously addressed this issue in its response dated June 30, 2008 (Reference 34) to RAI 21[2] concerning NEDE-32906P, Supplement 3, "Migration to TRACG04/PANAC11 from TRACG02/PANAC10 for TRACG AOO and ATWS Overpressure Transients," issued May 2006 (Reference 35).

The information in GEH's response to RAI 21 included the following:

- The uncertainty in determining the scram speed dominates the scram reactivity uncertainty (C1CX). The scram speed uncertainty is determined based on plant data obtained from scram speed tests at BWR plants and does not depend on the lattice or core physics methods.

- The Doppler coefficient uncertainty (C1BX) is conservatively determined based on calculated responses for the SPERT [Special Power Excursion Reactor Test] tests. The Doppler coefficient uncertainty (C1BX) was not directly established from lattice physics calculations. Therefore, this parameter does not directly depend on the lattice physics methods. The response from GEH contains analysis results that show the continued applicability of the Doppler coefficient uncertainty to the TRACG04 AOO calculations.

Staff found the response to RAI 21 acceptable since it was conservatively determined based on test and analysis results that show the continued applicability of the Doppler coefficient uncertainty to the TRACG04 AOO calculations. Based on the applicant's responses in MFN 08-598 (Reference 36) and MFN 08-547 (Reference 34), RAI 21.6-108 is resolved.

In RAI 21.6-84, the NRC staff requested that GEH provide the documentation of the evaluation of the TGBLA06 lattice calculations relative to Monte Carlo N-Particle (MCNP) in order to reestablish the void coefficient correction model as applied to TRACG.

The GEH response to RAI 21.6-84 notes that the void coefficient reassessment was completed for TRACG04 in topical report NEDE-32906P, Supplement 3. This reassessment for TGBLA06 against MCNP results occurred, and the void coefficient correlation model to be applied for TRACG04 was updated, before the performance of the TRACG04 qualification cases that required the use of the three-dimensional neutron kinetics model. Section 3.20.2 of the staff SER for NEDE-32906P, Supplement 3 (Reference 37), contains a detailed discussion of this item. Based on the applicant's response, RAI 21.6-84 is resolved.

3.2.1.6.2.1 Decay Heat Modeling

The decay heat model calculates the delayed component of the volumetric heat generation rate in the fuel. PANACEA calculates the steady-state nodal power distribution. The initial nodal

[2] Office of Nuclear Reactor Regulation RAI numbering sequence

decay heat is assumed to be proportional to the fission density in each node. In the transient analysis, TRACG calculates the total nodal power according to the transient flux solution for the fraction of the power produced from fission, and this contribution is combined with the decay power as predicted using the American Nuclear Society (ANS) standard. The total is the transient nodal power. Section 9.3.1 of Reference 12 describes this process. The values for the decay heat fractions and the time constants used to calculate the decay heat component are determined from the default May-Witt decay power curves, the 1979 or 1994 ANS standard decay heat models. The user may also specify decay heat group constants through input.

The May-Witt decay heat model that was approved in conjunction with TRACG02 is a five decay heat group model, which is compared to the American National Standards Institute (ANSI)/ANS-5.1-1994 (Reference 38) standard for a typical BWR EOC core. GEH compared this five decay heat group model to the best estimate calculation of fission product and actinide decay heat using the ANSI/ANS-5.1 standard. The two models are in agreement. In TRACG04, GEH implemented the ANSI/ANS-5.1-1979 and ANSI/ANS-5.1-1994 decay heat models as optional models in addition to the existing May-Witt model. The ANS model improves the simulation of the effect of exposure on the decay heat.

The ANS standards model the total decay heat as the sum of the contributions from fission products, major actinides, miscellaneous actinides, structural activation products, and fission power. The decay heat model does not explicitly account for stored energy since TRACG accounts for this using heat structures.

GEH calculated the fission fractions as a function of exposure based on fits determined from representative values for BWR fuel in NEDO-23729, "Nuclear Basics for ECCS (Appendix K) Calculations," issued November 1977 (Reference 39). GEH assumed that the fission fraction from plutonium (Pu)-241 is zero. This is a reasonable assumption for exposures below about 45 gigawatt days per metric ton (GWd/MT). NEDE-32176P, Revision 3 (Reference 5), indicates that the TRACG applications of interest occur below about 30 GWd/MT.

The fission product decay heat from the ANS standard is used to initialize the calculation described in Section 9.3.1 of Reference 5. The major difference between the 1979 and the 1994 ANS standards is that the 1994 standard includes decay heat groups to simulate decay heat from fissions for uranium (U)-235, U-239, Pu-239, and Pu-241, while the 1979 standard includes decay heat groups to simulate decay heat from fissions for U-235, U-238, and Pu-239. The 1979 standard does not include decay heat groups to simulate decay heat from fissions for Pu-241; therefore, that standard includes fissions in Pu-241 with U-235. This is conservative in the implementation by GEH because it assumes that the fission fraction from Pu-241 is zero. For each fissionable isotope included in these two standards, 23 decay heat groups are used to simulate the decay heat associated with fission for that isotope.

The functional fits described in Section 9.3.3.3 of Reference 5 include the contribution from major actinide decay (U-239 and neptunium (Np)-239); these are the same as used in the LOCA analysis. The decay heat from the neutron capture effect is accounted for by a "G-factor," described in Section 9.3.3.4 of Reference 5. The TRACG model includes other miscellaneous actinides that are not included in the ANS standard. The TRACG model also includes decay heat contribution from structural activation products produced by neutron capture in fuel structural materials. This category includes activation of gadolinium. Sections 9.3.3.5 and 9.3.3.7 of Reference 5 give the details of GEH implementation of these contributors. GEH interpolates for low-, medium-, and high-enriched fuel based on figures in these sections that represent the relative decay from miscellaneous actinide decay heat and activation products versus irradiation time.

According to GEH, the TRACG model conservatively assumes that the relative power fraction from major actinides, miscellaneous actinides, and activation products is constant throughout the TRACG transient. The staff agrees because assuming these contributions remain constant maximizes the calculated decay heat during the above mentioned transient.

The staff finds that GEH has adequately accounted for all major contributors to the decay heat model. However, GEH uses [[

]]. The staff did not review the process for generating these values and functional fits or their adequacy for ESBWR fuel. In addition, the staff did not review Reference 34 for calculating fission fractions and million electron volts per fission nor Figures 9-5 and 9-6 in Reference 5 for applicability to ESBWR fuel.

The staff finds that the decay heat model is adequate for simulation of AOO events for the following reasons. All transients that are to be analyzed with the application methodology in Section 4 of Reference 5 experience the limiting conditions before the scram such that the decay heat curve is not as important. The addition of power because of decaying isotopes during normal operations is typically on the order of 5-6 percent, and an uncertainty in this small contribution provides little or no effect on the overall transient response. The staff's acceptance of this model for simulating ESBWR AOOs does not constitute acceptance of this model for LOCA applications.

In general, the ANS standards are considered to be best estimates, and they include methods for estimating the uncertainty. Reference 5 indicates that the five decay heat group model is conservative (by 6-12 percent) when compared to the experimental data mean plus 2□ uncertainty for the shutdown times from 0 to 1,000 seconds. Therefore, using the ANS standard model with plus 2□ uncertainty included will tend to result in decay heat values less than those of the model with five decay heat groups.

In LTR NEDE-33083P Supplement 3, (Reference 4) the uncertainty calculation for the decay heat follows the ANS standards and includes uncertainty in the estimation of the energy released per fission and the uncertainty in the fission product decay heat groups. The ANS standards do not include any recommendations for uncertainty in actinide decay heat or activation of structural materials or neutron capture effect, and TRACG04 does not include these contributions to uncertainty in the decay heat estimate.

GEH ranked this parameter high in BWR/2–6 analyses (Reference 6) because of the longer time scales of loss of feedwater heating events, and it applied an additional 5 percent uncertainty in the methodology application. This parameter is not ranked high in the methodology as applied to ESBWR transients. In RAI 21.6-64, the staff questioned the ranking of the phenomena identified by GEH. The staff requested that GEH submit a topical report or a supplement to NEDE-33083P to incorporate the information provided in the responses to RAIs 21.6-63 and 21.6-65. Based on the applicant's responses, RAIs 21.6-63, 21.6-64, and 21.6-65 are resolved. Sections 3.2.1.5, 3.2.1.3, and 3.2.2.2 of this report present additional discussion of these RAIs, respectively.

3.2.1.6.3 Isolation Condenser Modeling

The isolation condenser system (ICS) provides additional liquid inventory upon opening of the condensate return valves to initiate the system. The ICS also provides the reactor with a method for depressurizing the reactor in the case of pressurization events such as a main steam isolation valve closure.

The IC testing was performed at the PANTHERS IC test facility. Section 4.2 of NEDC-32725P, Revision 1, "TRACG Qualification for SBWR," issued August 2002 (Reference 40), describes the test and the TRACG comparisons. Section 3.2 of Reference 41 provides the updated comparisons with TRACG04. The staff reviewed this information along with the additional information GEH provided in its response (Reference 42) to staff RAI 21.6-55.

GEH performed a series of steady-state and transient tests and compared these data using TRACG simulations. The steady-state tests were performed to test the intended operation of the IC, such as condensing steam during a reactor isolation event. The transient tests simulated abnormal IC operations, including noncondensable gas buildup and the pool water level transient.

3.2.1.6.3.1 Steady-State Tests

The steady-state tests were used to test the operation of the IC for pure steam condensation. The staff reviewed the conditions of the steady-state tests that TRACG was used to simulate. Since the IC is a natural circulation unit, the independent variable used is the IC inlet pressure. The simulations performed by GEH range from [[ ]]. The safety-relief valve setpoint of [[ ]] is found in Table 5.2-2, of the ESBWR DCD, Revision 3 (Reference 16). As a supplement to RAI 21.6-55, the staff requested that GEH verify the capability of TRACG to model the IC at these higher pressures. In response, GEH provided a comparison of the IC heat transfer rate as a function of pressure between the PANTHERS test data and the TRACG results, which shows excellent agreement.

The staff does not anticipate that any new phenomena would occur between [[ ]] that would change this comparison. Therefore, based on the applicant's response, RAI 21.6-55 is resolved.

GEH set the temperature and the steam flow rate equal to that of the test, and TRACG calculated the inlet pressure based on the value required to condense all of the steam. Table 4.2-8 of Reference 40 gives the comparison of the TRACG-calculated inlet pressure and heat transfer rate. The results show that the difference between the calculated and measured IC inlet pressures is within [[ ]]. The average bias and standard deviation for the heat transfer rate is [[ ]]. However, these values were determined using a secondary heat transfer modeling strategy different from that used for the ESBWR models. GEH submitted an update to the TRACG qualification with specific information applicable to the ESBWR in Reference 41. The staff reviewed the steady-state PANTHERS/IC calculations using the updated version of TRACG04 submitted in Reference 41. The results of these calculations show that the updated version of TRACG04 gives very similar results and is in general agreement with the PANTHERS data.

3.2.1.6.3.2 Transient Tests

The purpose of the transient tests was to measure the change in IC performance with a known quantity of noncondensable gas present or a change in pool water level. For the transient gas injection tests, noncondensable gas was injected into the condenser. The pressure at which the vent opens was established for each test. Section 4.2.6.2.1 of Reference 40 discusses the results. For the higher steam flow test, the timing of the pressurization as calculated by TRACG did not match the test data. Consequently, the amount of gas injected as calculated by TRACG did not match the test data. TRACG better matched the data for the lower steam flow test. GEH attributed this to the entrainment of the gas within the water in the drainline and stated that the one-dimensional modeling of the lower header using TRACG may undercalculate the gas entrainment.

The staff reviewed the transient gas PANTHERS/IC calculations using the updated version of TRACG04 submitted in Reference 41. The results of these calculations show that the updated version of TRACG04 gives very similar results for the high steam flow test, which do not agree with the data. The comparison for the lower steam flow test was not presented.

In RAI 21.6-55, the staff requested that GEH justify the missed timing of the noncondensable gas transport in the IC in the presence of radiolytic gas generation during an event. In response to this RAI (Reference 42), GEH stated that radiolytic gas is not modeled during an AOO because the IC is vented during normal operations and the transient does not last long enough to generate these gases. The staff agrees with GEH that it is not necessary to model noncondensable gases generated by radiolytic decomposition for ESBWR AOO/ATWS calculations because the IC is vented during normal operation and the duration of these transients is not long enough to generate these gases. Based on the applicant's response, RAI 21.6-55 is resolved.

Subsequently, in a recent design change, the applicant changed the ICS and vent valve operation logic to mitigate the accumulation of radiolytic hydrogen and oxygen. As such, staff reopened RAI 6.2-202 S02 and asked the applicant to explain if TRACG calculations are still applicable to the new design. GEH stated in the response to RAI 6.2-202, S02 that no changes have been made to the design of the ICS condenser in regard to the number, thickness, material, or tube configuration of the tubes. Therefore, the staff concludes that the prototype ICS testing used for TRACG qualification remains applicable. Staff evaluation of the IC hydrogen accumulation is further described in the Chapter 5 of the ESBWR FSER. Therefore, the portion of RAI 6.2-202 regarding TRACG qualification of the ICS is resolved.

With regard to the IC pool water level test a series of steady-state tests at reduced levels were performed. GEH showed by comparison to steady state test results, that TRACG is capable of modeling the pressure needed to condense all of the steam for pool levels ranging from about [[ ]]. As stated in Table 6.2-6 of Revision 3 of the DCD (Reference 16), the nominal pool level is [[ ]]. The staff compared the steady state test results to the TRACG calculated pool level and confirmed that the results provided by GEH concluded that TRACG is capable of modeling this transient.

3.2.1.6.3.3 Heat Transfer Correlations

For the TRACG04 simulations of the PANTHERS facility, TRACG04 uses the [[ ]] correlation for condensation heat transfer inside the condenser tubes and the [[

]] for pool side heat transfer (Section 4.2.4.2 of Reference 40). Because of good agreement with test results the staff finds the [[ ]] correlations to be acceptable as described in “Passive Cooling Containment Cooling Units,” Section 3.2.6.1.5 of NEDC-33083P-A, “TRACG Application for ESBWR,” Reference 1 for modeling the passive containment cooling system condensers based on comparison to experiments (PANTHERS and PANDA). Since this correlation also produces comparable results in PANTHERS IC modeling, the staff finds it acceptable for use in the ESBWR simulations of the IC for AOO/ATWS. In Reference 42 and Section 4.4.1 of Reference 1, GEH indicated that the ATWS/AOO model uses the [[ ]] heat transfer correlation for the secondary-side heat transfer. As a supplement to RAI 21.6-55, the staff requested that GEH explain and justify the differences between the PANTHERS and AOO/ATWS modeling strategy for the pool side. In response, GEH noted that the secondary-side heat transfer is not the limiting resistance to heat transfer in the IC (the conduction through the IC tube walls is limiting). The staff notes that the Chen correlation and the Forster-Zuber correlation differ, as the Forster-Zuber correlation neglects the difference between the lower mean superheat of the fluid and the superheat of the fluid at the wall (maximum superheat). The difference between the lower mean superheat of the fluid and the superheat of the fluid at the wall is small for pool boiling. Therefore, the staff considers it appropriate to use the Forster-Zuber correlation to model secondary side pool heat transfer in the IC. Based on the applicant’s response, RAI 21.6-55 is resolved.

3.2.1.6.3.4 Conclusion

The staff finds that TRACG is capable of modeling the IC behavior during AOO/ATWS events for pure steam condensation. The staff agrees with GEH that the time scales seen during AOO/ATWS events are short enough that noncondensable gases generated by radiolytic decomposition will be insignificant and that modeling of pure steam condensation for these events is appropriate.

3.2.2 Element 2—Assessment and Ranging of Parameters

3.2.2.1 Step 7—Establish Assessment Matrix

The capability of TRACG to predict the important thermal-hydraulic phenomena for natural circulation has been assessed through comparisons with separate effects tests, integral systems tests, and full-scale plant data.

The TRACG qualification report (Reference 22) describes the general code assessment that has been performed. Additional qualification has been performed for the ESBWR. Reference 41 documents these assessment cases. In Table 4.3-2 in Reference 1, GEH identified the qualification basis for each of the high-ranked phenomena identified in the AOO PIRT by citing the quantitative assessment performed against separate effects tests, component performance tests, integral system tests, and plant data. The assessment descriptions cover the test facility, where applicable; the test results; TRACG sensitivity studies; and nodalization studies, where applicable. All high-ranked phenomena have been assessed.

The TER (Reference 15) discusses an evaluation of the assessment of TRACG as it relates to ESBWR AOOs. The staff finds that the assessment of TRACG is extensive and demonstrates the capability of TRACG to simulate AOO events in the ESBWR.

In RAI 21.6-75, the staff requested that GEH submit an update to the qualification report (Reference 22) that is consistent with the current version of TRACG used in ESBWR licensing analyses (TRACG04). In response, GEH submitted Revision 3 of the TRACG qualification report in August 2007. Based on the applicant's response, RAI 21.6-75 is resolved. Additional discussion can be found in Reference 10, Sections 3.2 and 19.2.1.

GEH is consistent with this step in the CSAU approach.

3.2.2.2 Step 8—Nuclear Power Plant Nodalization Definition

In response to staff RAI 21.6-65 (Reference 26), GEH provided the nodalization definition for the TRACG input decks used to simulate ESBWR AOOs and IEs. The VESSEL nodalization is similar to that used for modeling ESBWR stability (Reference 20) and was approved by the staff (Reference 9). It has the same number of levels with minor differences in node sizes that will not impact the results of the AOO and IE calculation.

GEH used the same nodalization for the CHAN component as that used for the ESBWR stability analysis (Reference 15). The staff reviewed this in detail. As discussed in Reference 9, the staff finds this nodalization acceptable for use in the ESBWR stability analysis. This is also applicable to, and therefore acceptable for, ESBWR AOO and IE analyses.

Because of code limitations on the maximum number of components, GEH cannot model each channel individually in TRACG. Therefore, GEH combines the channels into groups. GEH states that the channel grouping used for the ESBWR AOO/IE analysis is the same as that described in the topical report NEDE-33083P, Supplement 2, "TRACG Application for ESBWR Anticipated Transient without Scram Analyses," issued January 2006 (Reference 43). The ESBWR AOO/IE input deck contains [[ ]] channel groups. GEH combines the channels, based on similar hydrodynamic characteristics as well as neutron kinetics characteristics. The staff reviewed the GEH channel grouping to verify that it adequately represents the core design as described in NEDC-33239P, Revision 2, "GE14 for ESBWR Nuclear Design Report," issued April 2007 (Reference 44). GEH represents the channels with the highest radial peaking factors as the single channel. In Reference 26, GEH provided a sensitivity study of the channel grouping by [[ ]] for the load rejection with total bypass failure IE. GEH demonstrated that the two cases produce virtually the same results, with the [[ ]] case producing ΔCPR/ICPR results that are more conservative.

The staff requested supplemental information to RAI 21.6-65 on the channel grouping used for ESBWR AOO/IE evaluations. For calculating the ΔCPR/ICPR, the staff asked GEH which channel groups are used. GEH may choose to use only the hot channels. Although this is most conservative in most cases, the staff believes that for cold water injection events, the ΔCPR/ICPR may be underestimated because the largest change in CPR would take place in the peripheral channels.

GEH's response to RAI 21.6-65, Supplement 1, by letter dated April 7, 2008 (Reference 55) notes that the hot channel is always selected for the determination of the operating limit minimum critical power ratio (OLMCPR), because the core MCPR always occurs in the hottest channels. The response in Reference 45 also shows MCPR calculations for the limiting cold water injection event (IICI).

The results for the limiting channel in Ring 3 and the hottest bundle in Ring 2 are shown and compared. Although the decrease in ΔCPR/ICPR is greater in the Ring 3 channel, the MCPR in the hottest bundle is still limiting by a significant amount.

The NRC staff followed with RAI 21.6-65, Supplement 2. This supplemental RAI requested that the GEH response to RAI 21.6-65 be included in the DCD or as a supplement to Topical Report NEDE-33083P. Supplement 2 of the RAI also suggested that GEH consider including the response to RAI 21.6-65, Supplement 1, in the DCD or as a supplement to Topical Report NEDE-33083P. The applicant responded to RAI 21.6-65 S01 & S02 and demonstrated the results were not significantly changed for the detailed TRACG model and subsequently updated NEDE-33083P, Supplement 3 with applicable information. For that reason staff agreed with the applicant's conclusion. Therefore, based on the applicant's response, RAI 21.6-65 is resolved.

In a letter to the NRC dated June 20, 2007 (Reference 46), GEH provided the nodalization diagrams for the other nonvessel components, including the steamlines and the IC, of the AOO/IE input deck. Section 3.2.2.2.1 discusses the staff's evaluation of the IC nodalization.

3.2.2.2.1 Isolation Condenser System Nodalization

GEH submitted a nodalization diagram of the ICS in Reference 46. The staff reviewed the nodalization of the IC model. In Section 4.2.4.1 of Reference 40, GEH described the PANTHERS model in detail. In response to RAI 21.6-55, GEH identified the differences between the modeling of this test IC and that used in the AOO/ATWS and LOCA modeling for the ESBWR in Table 1 of Reference 42. In a supplemental request to RAI 21.6-55, the staff requested additional information on the nodalization of the IC for AOO/ATWS events in the ESBWR. The staff also requested that GEH justify the nodalization changes from the PANTHERS IC facility and demonstrate that the differences still adequately model the ICS. The staff asked GEH to justify the use of [[ ]] cells in the condenser tube for AOO/ATWS simulations, whereas Section 4.2.4.1.3 of Reference 40 states that sensitivity studies were performed to demonstrate that the use of [[ ]] cells was adequate. In response, GEH provided sensitivity study results between the four and eight cell models for the IICI event. The results show that the four-cell model is conservative and therefore acceptable. Based on the applicant's response, RAI 21.6-55 is resolved.

3.2.2.3 <u>Step 9—Definition of Code and Experimental Accuracy</u>

Simulation of experiments developed from Step 7 (discussed in Section 3.2.2.1) using the nuclear power plant nodalization from Step 8 (discussed in Section 3.2.2.2) provides checks to determine code accuracy. The differences between the code-calculated results and the test data provide bias and deviation information.

Code scaleup capability can also be evaluated from separate effects data, full-scale component test data, plant test data, and plant operating data where available. Overall code capabilities are assessed from integral systems test data and plant operational data. References 22, 41, and 40 document the assessments of TRACG. Since the ESBWR is a new design, operating plant data do not exist. However, the key parameters and phenomena for analyzing AOOs in the ESBWR are not significantly different from those in operating reactors.

GEH uses TRACG to simulate separate effects tests, component performance tests, integral systems tests, and operating BWR plant data. GEH is able to determine an uncertainty between the code-calculated results and the test data. Sections 4.0 and 5.0 of the TER (Reference 15) discuss the uncertainties associated with various qualification tests.

In RAI 21.6-75 (Reference 47), the staff requested that GEH submit the updated qualification report that is consistent with the current version of TRACG used in ESBWR licensing analyses

(TRACG04). In response, GEH submitted Revision 3 of the TRACG qualification report in August 2007. Based on the applicant's response, RAI 21.6-75 is resolved. Reference 10 contains additional discussion.

GEH is consistent with this step in the CSAU approach.

3.2.2.4 Step 10 – Determination of Effect of Scale

Various physical processes may give different results as components or facilities vary in scale from small to full size. The effect of scale must be included in the quantification of bias and deviation to determine the potential for scaleup effects. The key parameters and phenomena for analyzing AOOs in the ESBWR do not have significantly different scales than those in operating reactors. GEH therefore does not need to perform scaling analyses for simulation of ESBWR AOOs. The staff discusses scaling of tests performed to qualify TRAC for ESBWR-specific components in Section 21.5 of this SER.

GEH is consistent with this step in the CSAU approach.

The staff finds each step in Element 2 to be consistent with the CSAU approach and therefore acceptable.

3.2.3 Element 3—Sensitivity and Uncertainty Analysis

3.2.3.1 Step 11—Determination of the Effect of Reactor Input Parameters and State

The purpose of this step is to determine the effect that variations in the plant operating parameters have on the uncertainty analysis. These are inputs into the code. GEH divides code inputs into four categories:

(1) geometry inputs
(2) model selection inputs
(3) initial condition inputs
(4) plant parameters

3.2.3.1.1 Geometry Inputs

Uncertainty in geometry inputs comes from measurement and manufacturing tolerances. In addition, some geometrical uncertainties can be introduced in the spatial nodalization where GEH uses simple components to characterize more complex systems. Examples include using one-dimensional components to simulate three-dimensional structures or combining multiple individual channels into a representative channel component. Uncertainties associated with these modeling strategies are determined as part of the TRACG qualification (Reference 26).

3.2.3.1.2 Model Selection Inputs

Model selection inputs are used to select the features of the model that apply to the intended application. The uncertainty associated with the models is quantified in the TRACG qualification (Reference 22) for each model. These inputs are specified within the application methodology and will not change. The application methodology described in Section 4.1.5.2 in Reference 1 controls changes to the uncertainty values used for the model inputs. New data may become available with which the specific model uncertainties may be reassessed. If the reassessment results in a need to change a specific model uncertainty, the specific model uncertainty may be revised for ESBWR AOO licensing calculations without NRC review and approval as long as the process for determining the uncertainty is unchanged. In all cases, changes made to model uncertainties that are done without review and approval will be transmitted to the NRC for information.

3.2.3.1.3 Initial Condition Inputs

GEH considers initial conditions to be those inputs that determine the overall steady-state nuclear and hydraulic conditions before the transient. The plant operating procedures and the technical specifications define the range of these input parameters. GEH either sets the initial condition at its most limiting value within the allowable range or considers the entire range when performing reload licensing analyses. GEH lists the following key plant initial conditions and the uncertainties associated with each:

- total core power
- total core flow
- feedwater temperature
- steam dome pressure
- downcomer water level
- core loading pattern and exposure distribution
- axial power distribution
- radial power distribution control rod pattern

The uncertainties of some of these parameters are based on NEDC-32694P, “Power Distribution Uncertainties for Safety Limit MCPR Calculations,” issued August 1999 (Reference 48). The staff does not necessarily find all the uncertainties associated with this topical report to be applicable to the ESBWR. GEH did apply ESBWR uncertainties where necessary, e.g. for core flow measurement. Uncertainties related to the calculation of the OLMCPR are discussed in NEDC-33237P, Revision 1, “GE14 for ESBWR—Critical Power Correlation, Uncertainty, and OLMCPR Development” (Reference 49), and have been reviewed as part of Section 4.4 of the ESBWR DCD (References 16 and 28). Power distribution uncertainties have been reviewed as part of Section 4.3 of the ESBWR DCD (Reference 16).

3.2.3.1.4 Plant Parameters

GEH defines a plant parameter as something that influences the transient response but has no effect on the steady state, such as a protection system setpoint, valve capacity or stroke time, or a scram characteristic. For these parameters, GEH uses the analytical limit, which in many cases is related to a plant technical specification. GEH gave the analytical scram speeds used for ESBWR analyses in Table 4.5-2 in Reference 1. It used different scram times for pressurization and overpressure transients.

These scram times are more conservative than the technical specification scram times listed in the same table. The scram times listed in the ESBWR technical specifications (Chapter 16) of the DCD (Reference 16) differ from those listed in the topical report. In RAI 21.6-63, the staff requested that GEH identify the differences between the analyses performed for Chapter 15 of the DCD and that described in Chapter 4 of Reference 1. In response to RAI 21.6-63, Supplement 1, GEH submitted Reference 4, which describes an updated TRACG application for ESBWR transient analysis. Reference 4 includes updated analytical scram speeds for the

ESBWR AOOs, which correspond to the scram times in the ESBWR technical specifications in Chapter 16 of the DCD.

In RAI 21.6-57 the staff requested additional information on the scram time delays assumed in the analysis. GEH explained in its response that a delay of [[ ]] is assumed from when the scram signal is initiated to when the rods actually begin to move into the core. The staff asked that the control rod scram time requirements criteria be justified (RAI 21.6-57, Supplement 1). In its response (Reference 50), GEH stated that the criteria are based on scram time measurements performed for the advanced boiling-water reactor (ABWR) and that the scram signal instrumentation and hardware are identical to those of the ABWR. To verify that the ABWR testing is applicable to this ESBWR analysis, startup testing for the ESBWR will measure and record the response times for the reactor protection system instrument channel (see Section 14.2.8.1.9 of Reference 16). The scram delay time is important in certain AOOs (load rejection and turbine trip with total turbine bypass failure), that have a large spike in reactor power within 1 second of the transient, and are mitigated almost entirely by the control rod insertion (Figure 21.6-57-1 in Reference 19). Staff considers RAI 21.6-57 to be resolved because the scram time delays utilized in the analyses are based on actual ABWR control rod scram time performance measurements for components and instrumentation identical in design to those of the ESBWR, and because their applicability to ESBWR will be confirmed during startup testing under ESBWR DCD Rev. 7, Section 14.2.8.1.9 (Reference 16).

The staff finds that GEH has adequately addressed the effect of reactor input parameters and state on ESBWR AOO analyses. GEH is consistent with this step in the CSAU approach.

3.2.3.2 Step 12—Performance of Nuclear Power Plant Sensitivity Calculations

Sensitivity calculations are performed to evaluate the sensitivity of a methodology to various operating conditions that arise from uncertainties in the reactor state at the initiation of the transient, in addition to the sensitivity to plant configuration. The safety-related quantities of importance in the AOO analysis are CPR, maximum pressure, and water level. GEH calculated representative transients to demonstrate ESBWR plant behavior using TRACG. The demonstration calculations were provided as Section 4.7 of NEDC-33083P-A, “TRACG Application for ESBWR,” Reference 1.

In RAI 21.6-62, the staff requested additional clarifying information on the differences in the Critical Power Ratio calculation for the Feedwater Control Valve Failure event provided in Section 4.7 of Reference 1 and in DCD, Tier 2, Revision 1. In the response to RAI 21.6-62, GEH explained that the difference was due to a design change to the turbine bypass capacity, and that the DCD results supersede the results presented in Section 4.7 of NEDC-33083P-A, “TRACG Application for ESBWR,” Reference 1. The staff found this explanation reasonable, but because of other known design changes, requested in RAI 21.6-63 that GEH address all of the differences in the analyses provided in Section 4 of NEDC-33083P-A, “TRACG Application for ESBWR,” Reference 1 and the DCD, Tier 2, Chapter 15, “Transient and Accident Analysis” results. In response to RAI 21.6-63, GEH provided a detailed comparison table addressing all aspects of the analyses, including the cases considered, the core analyzed, the nodalization, the cycle state points, key input parameters, the event sequences, and the results. The staff found this information beneficial in making its safety determination, and requested in Supplement 1 to RAI 21.6-63 that it be incorporated in either the DCD or in a revision to the topical report. In response, GEH submitted Revision 1 to Supplement 3 to NEDE-33083P (Reference 4). Since the requested information has been incorporation in the documentation, RAIs 21.6-62 and 21.6-63 are resolved.

GEH is consistent with this step in the CSAU approach.

3.2.3.3 Step 13—Determination of Combined Bias and Uncertainty

Once the individual biases and uncertainties, such as those resulting from modeling and input variations, are established, a proven technique must be used to combine these biases and uncertainties to establish an overall uncertainty. Various proven methods for determining uncertainty are available.

For the TRACG application to ESBWR AOO analysis described in Reference 1, GEH chose the normal distribution one-sided upper tolerance limit method if the output distribution is normal; otherwise, it used the order statistics method.

This method for determining combined bias and uncertainty is the same as that used in the GEH application of TRACG to BWR/2–6 AOO analysis (Reference 6) and in the application of TRACG to ESBWR stability (Reference 20). The staff reviewed this method in detail during the review of TRACG for BWR/2–6 AOO analysis, and the associated SER documents the staff's review. The staff finds the use of this methodology acceptable for determining the combined uncertainty for TRACG modeling of the ESBWR AOO events.

The difference between the GEH application of this methodology and that in Reference 2 is that GEH included only the highly ranked PIRT phenomena in the application of TRACG to ESBWR AOOs, whereas GEH included high- and medium-ranked phenomena for the other approved applications. In RAI 21.6-64, the staff asked GEH to justify the exclusion of the medium-ranked phenomena. Section 3.2.1.3 of this report discusses the justification provided by GEH. Based on the applicant's response, RAI 21.6-64 is resolved.

GEH is consistent with this step in the CSAU approach.

3.2.3.4 Step 14—Determination of Total Uncertainty

For the ESBWR, GEH uses the same process as that approved for TRACG as applied to AOO analysis for BWR/2–6 in Reference 6 for determining total uncertainty in TRACG-calculated values, such as those used to determine operating design limits in fuel thermal/mechanical performance, peak vessel pressure, and minimum water level. The associated SER (included in Reference 6) describes the staff's review of that methodology. The staff finds the use of this methodology acceptable for calculating total uncertainty for TRACG evaluations of ESBWR AOOs.

The staff finds each step in Element 3 to be consistent with the CSAU approach and therefore acceptable.

3.2.4 Conclusions on Code Scaling, Applicability, and Uncertainty Methodology

GEH followed the CSAU methodology (Reference 14) for determining uncertainty in its TRACG evaluation of ESBWR AOO events, as described in Section 4.0 of Reference 1. The staff finds that GEH addressed all elements of this methodology and deems the GEH approach acceptable.

3.3 Staff Independent Calculations

The staff used TRACE to perform independent calculations of ESBWR steady-state and AOO events. The staff performed these confirmatory calculations to provide reasonable assurance that GEH is adequately and conservatively modeling AOO events for the ESBWR using TRACG.

Given that pressurization transients are typically the limiting events; the staff performed the confirmatory calculations for the turbine trip with total bypass failure (TTNBP) event. The geometry in the staff TRACE ESBWR model was taken from the TRACG input deck supplied by GEH. This did not compromise the independence of the calculation, and it eliminated the possibility of attributing any differences in results to differences in plant geometry.

3.3.1 Steady-State Results

Steady-state cases were first run using TRACE to generate results for comparison to the TRACG predictions. Based on the steady-state results, the staff concluded that TRACE and TRACG were predicting the same initial conditions. The staff calculations, using the TRACE models and correlations, confirm the GEH calculations.

3.3.2 Transient Results

The results of interest for this study are the change in CPR, the peak vessel pressure, and the minimum collapsed water level. The staff cannot incorporate the GEH CPR correlation into TRACE (for proprietary reasons). Therefore, instead of comparing the change in CPR, the staff compared the TRACE-predicted reactor total power, the core inlet flow, and the core inlet subcooling to the TRACG results. The peak vessel pressure and the collapsed water level were directly compared to TRACG results. The staff concludes that the results of these comparisons show, over the range of interest, reasonable assurance that the TRACG predictions for ESBWR AOO analyses are sufficient.

4 CONDITIONS AND LIMITATIONS

The staff has reviewed Chapter 4 of NEDC-33083P-A (Reference 1), as well as NEDE-33083P, Supplement 3 (Reference 4), and any approval of Chapter 4 of NEDC-33083P-A and of NEDE-33083P, Supplement 3, would be with the following specific conditions:

(1) The staff evaluated the methodology for analyzing ESBWR AOO and IE events using TRACG described in Chapter 4 of Reference 1 as it applies to the 4,500-MWt ESBWR design as described in the ESBWR DCD. If GEH or an applicant referencing the methodology in Chapter 4 of Reference 1 or in Reference 4 wishes to use this methodology for an ESBWR design not completely consistent with the ESBWR DCD, then GEH or the applicant must provide a summary of the design changes and verify for NRC staff review and approval that the methodology remains applicable. This was identified as a COL information item in DCD Tier 2, Section 4.3.5.

(2) The models described in Reference 5 may not be changed without NRC review and approval. The NRC must review and approve any changes to the method described in Section 4 of Reference 1.

3) Changes in numerical methods to improve code convergence, or code enhancements or error corrections must be tested and auditable records kept in accordance with Appendix B to 10 CFR Part 50. If the calculated TRACG results of the qualification tests (Reference 22) used to test the code change by more than the uncertainty in that assessment, the staff requires GEH to submit the changes for review.

4) New models or features, other than input enhancements that do not affect calculated results, may not be implemented without prior NRC review and approval.

5) The application methodology described in Section 4.1.5.2 in Reference 1 controls changes to the uncertainty values used for the model inputs. New data may become available with which the specific model uncertainties may be reassessed. If the reassessment results in a need to change the specific model uncertainty, the specific model uncertainty may be revised for ESBWR AOO licensing calculations without NRC review and approval as long as the process for determining the uncertainty is unchanged. In all cases, changes made to model uncertainties without the need for review and approval will be transmitted to the NRC for information.

6) Use of TGBLA or PANAC11 codes must be within the conditions and limitations stated in Section 4.3.3.2.5 of Reference 21.

7) The approval of the statistical methodology used to determine an uncertainty in TRACG calculations does not inherently approve an OLMCPR methodology or imply justification for the removal of the safety limit minimum critical power ratio (SLMCPR). The applicant restored the SLMCPR value in the technical specifications. Section 15.1.1 of the ESBWR DCD final SER (Reference 28) discusses details of the staff evaluation.

8) The staff's acceptance of the TRACG decay heat model for simulating ESBWR AOOs does not constitute acceptance of this model for LOCA applications.

9) An additional 0.01 will be added to the limiting OLMCPR, until such time that GEH expands the experimental database supporting the Findlay-Dix void-quality correlation to demonstrate the accuracy and performance of the void-quality correlation based on experimental data representative of the ESBWR fuel design and operating conditions during steady-state, transient, and accident conditions.

10) Future ESBWR TRACG AOO analyses must be performed using the GSTRM model for both gap conductance and thermal conductivity, and the conclusions and limitations (including the 350 psi critical pressure penalty) drawn by the NRC staff evaluation of GEH's Part 21 report (Appendix F to the SE for NEDC-33173P, ML073340722) 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 AOO analyses, the fuel conductivity and gap conductance models must be consistent.

5 CONCLUSIONS

The staff reviewed the information provided by the applicant for the use of TRACG for ESBWR AOO analyses. The staff concludes that the TRACG code and methodology described in Reference 4 and associated RAI responses are applicable to the evaluation of ESBWR AOOs as described in Chapter 15 of the ESBWR DCD, with the conditions and limitations as described in Section 4 of this report.

References

1. NEDC-33083P-A, MFN 05-017, “TRACG Application for ESBWR,” March 2005 (ADAMS Accession Nos. ML051390265, ML051390257).

2. NEDC-33083P, MFN 04-109, Section 4.7, “Demonstration Calculations for ESBWR AOOs,” October 2004 (ADAMS Accession Nos. ML042930020, ML042930018).

3. Letter from J.C. Kinsey (GE) to NRC, MFN 08-124, “Response to Portion of NRC Request for Additional Information Letter No. 116 – Related to ESBWR Design Certification Application – RAI Numbers 21.6-63 S01 and 21.6-65 S02,” February 15, 2008 (ADAMS Accession No. ML080510188).

4. NEDE-33083P, Supplement 3, Rev. 1, “TRACG Application for ESBWR Transient Analysis,” October 2009 (ADAMS Accession Nos. ML092860090, ML092860088, ML092860089).

5. NEDE-32176P, Rev. 3, “TRACG Model Description,” April 2006 (ADAMS Accession Nos. ML061160238, ML061160236).

6. NEDE-32906P-A, MFN 06-046, Rev. 2, “TRACG Application for Anticipated Operational Occurrences (AOO) Transient Analysis,” February 2006 (ADAMS Accession Nos. ML060530571 and ML060530575).

7. NEDE-32906P, Supplement 2-A, “TRACG Application for Anticipated Operational Occurrences Transient Analysis,” March 2006 (ADAMS Accession Nos. ML060800323, ML060800318, ML060800320).

8. NEDE-32906P, Supplement 1-A, “TRACG Application for Anticipated Transient Without Scram Overpressure Transient Analysis,” November 2003 (ADAMS Accession Nos. ML033381102, ML033381077, ML033381096).

9. Letter from D.B. Matthews (NRC) to R.E. Brown (GEH), “Reissuance of Safety Evaluation Regarding the Application of the GE-Hitachi Nuclear Americas LLC (GEH) Licensing Topical Report, ‘TRACG Application for ESBWR Stability Analysis,’ NEDE-33083P, Supplement 1,” August 29, 2007 (ADAMS Accession Nos. ML072270192, ML072270244, ML072270255, ML072270267, ML072270276).

10. Safety Evaluation for (LTR) NEDC-33083P, “Application of the TRACG Computer Code to the ECCS and Containment LOCA Analysis for the ESBWR Design,” (ADAMS Accession No. ML093450400).

11. NUREG-0737, “Clarification of TMI Action Plan Requirements,” November 1980 (ADAMS Accession No. ML051400209).

12. Regulatory Guide 1.203, “Transient and Accident Analysis Methods,” U.S. Nuclear Regulatory Commission, December 2005 (ADAMS Accession No. ML053500170).

13. NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition,” Section 15.0.2, “Review of Transient and Accident

Analysis Methods," U.S. Nuclear Regulatory Commission, January 2006 (ADAMS Accession No. ML053550265).

14. 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).

15. Spore, J. (ISL), ISL-NSAD-TR-06-16, "Technical Evaluation Review of TRACG Applications to ESBWR AOOs," January 2007 (ADAMS Accession Nos. ML080710175, ML0807702760).

16. Letter from R. Kingston (GEH) to NRC, "General Electric Company—ESBWR Standard Plant Design Certification Application Design Control Document, Revision 7, Tier 1 and Tier 2," MFN 10-126, March 29, 2010. (ADAMS Accession No. ML101340380)

17. NEDC-33079P, Rev. 1, "ESBWR Test and Analysis Program Description," March 2005 (ADAMS Accession Nos. ML051390233, ML051390223).

18. NEDC-33079P, Rev. 1, Supplement 1 (Part 2 of Document), "ESBWR Test and Analysis Program Description, Discussion of PIRT Parameters," March 2005 (ADAMS Accession No. ML051390233).

19. Letter from J.C. Kinsey (GE) to NRC, MFN 07-008, "Response to Portion of NRC Request for Additional Information Letter No. 66 Related to ESBWR Design Certification Application—Safety Analysis—RAI Number 21.6-57 and 21.6-60 through 21.6-62," January 2007 (ADAMS Accession Nos. ML070380569, ML070380572).

20. NEDE-33083P, Supplement 1, "TRACG Application for ESBWR Stability," December 2004 (ADAMS Accession Nos. ML050060160, ML050060161).

21. Safety Evaluation for (LTRs), NEDC- 33239P, Revision 4, "Safety Evaluation for GEH Topical Reports 'GE14 for ESBWR Nuclear Design Report' and NEDE-33197P, Revision 4, 'Gamma Thermometer System for LPRM Calibration and Power Shape Monitoring,'" July 2010. (ADAMS Accession Nos. ML101670068, ML101720671, ML101670050)

22. NEDE-32177P, Revision 2, "TRACG Qualification," January 2000 (ADAMS Accession Nos. ML003683162, ML003682751).

23. Letter from D.H. Hinds (GE) to NRC, MFN 06-487, "General Electric Company—ESBWR Standard Plant Design—Revision 2 to Design Control Document Tier 2, Chapter 6 (Engineered Safety Features)," November 30, 2006 (ADAMS Accession Nos. ML063490096, ML063490100, ML063490102).

24. Letter from D.H. Hinds (GE) to NRC, "General Electric Company—ESBWR Standard Plant Design—Revision 2 to Design Control Document Tier 2, Chapters 2 through 5, 7 through 15, 17, and 18," October 31, 2006 (ADAMS Accession Nos. ML063100233, ML063100232).

25. MFN 07-452 Enclosure 1, NEDE-32177P, Revision 3, “TRACG Qualification,” August 2007 (ADAMS Accession Nos. ML072480013, ML072480029, ML072480083, ML072480089).

26. Letter from J.C. Kinsey (GE) to NRC, MFN 07-347, “Response to Portion of NRC Request for Additional Information Letter No. 66—Related to ESBWR Design Certification Application—RAI Numbers 21.6-65 and 21.6-85,” June 21, 2007 (ADAMS Accession No. ML071930527).

27. GEH Document UM-0136, Rev. 0, “TRACG04A, P User’s Manual,” December 2005 (ADAMS Accession Nos. ML071150375, ML071150376).

28. GE Hitachi Nuclear Energy, Revision 6, “ESBWR Design Control Document,” December 15, 2009 (ADAMS Accession No. ML093434420)

29. Safety Evaluation Report for Licensing Topical Reports NEDC-33237P, “ESBWR Critical Power Correlation” and NEDC-33413P, “Full Scale Critical Power Testing of GE14E and Validation of GEXL14E,” July, 2010 (ADAMS Accession Nos. ML101740168, ML101740299).

30. Letter from R. Kingston (GEH) to NRC, MFN 08-713, Response to Portion of NRC Request for Additional Information Letter No. 341 – Related to ESBWR Design Certification Application,” – RAI 6.3-54 S01, September 22, 2008 (ADAMS Accession Nos. ML082680145, ML082680144) and RAI 6.3-54 S02, July 22, 2009 (ADAMS Accession Nos. ML092040623, ML092040622).

31. Final Safety Evaluation for LTR NEDC-33173P, “Applicability of GE Methods to Expanded Operating Domains” (Appendix F), January 17, 2008, (ADAMS Accession Nos. ML073340214, ML073340175, ML073340722)

32. Letter from J.C. Kinsey (GE) to NRC, MFN 07-309, “Response to Portion of NRC Request for Additional Information Letter No. 66—Related to ESBWR Design Certification Application—RAI Numbers 21.6-66 through 68, 21.6-80, 21.6-82, 21.6-84,” June 8, 2007 (ADAMS Accession No. ML071920098).

33. Safety Evaluation Report, NEDC-33083P, “TRACG Application for ESBWR Stability,” July, 2010 (ADAMS Accession No. ML093130591).

34. Letter from R.E. Kingston to NRC, MFN 08-547, “Transmittal of Response to NRC Request for Additional Information – NEDC-32906P, Supplement 3, ‘Migration to TRACG04/PANAC11 from TRACG02/PANAC10 for TRACG AOO and ATWS Overpressure Transients,” June 2008 (ADAMS Accession Nos. ML081840270, ML081840271).

35. NEDE-32906P, Supplement 3, “Migration to TRACG04/PANAC11 from TRACG02/PANAC10 for TRACG AOO and ATWS Overpressure Transients,” May 2006 (ADAMS Accession No. ML070300348).

36. Letter from R.E. Kingston to NRC, MFN 08-598, “Response Portion of NRC Request for Additional Information Letter No. 120 – Related to ESBWR Design Certification Application – RAI Number 21.6-108,” July 2008 (ADAMS Accession No. ML082140628).

37. Final Safety Evaluation by the Office of Nuclear Reactor Regulation – Licensing Topical Report NEDE-32906P, Supplement 3, “Migration to TRACG04/PANAC11 from TRACG02/PANAC10 for TRACG AOO and ATWS Overpressure Transients,” (ADAMS Accession Nos. ML091400057, ML091751102).

38. American National Standard for Decay Heat Power in Light Water Reactors, ANSI/ANS-5.1, 23A6938.

39. Martin, C.L., NEDO-23729, “Nuclear Basics for ECCS (Appendix K) Calculations,” Class 1 GE Report, November 1977.

40. NEDC-32725P, Rev. 1, “TRACG Qualification for SBWR,” August 2002 (ADAMS Accession Nos. ML022560076, ML022560558, ML022560559).

41. MFN 04-059, “Update of ESBWR TRACG Qualification for NEDC-32725P and NEDC-33080P Using the 9-Apr-2004 Program Library Version of TRACG04,” June 2004 (ADAMS Accession Nos. ML041610032, ML041610035, ML041610037).

42. Letter from J.C. Kinsey (GE) to NRC, MFN 07-168, “Response to Portion of NRC Request for Additional Information Letter No. 66 Related to ESBWR Design Certification Application—TRACG Application—RAI Number 21.6-55,” March 2007 (ADAMS Accession Nos. ML071010554, ML071010556).

43. NEDE-33083P, Supplement 2, “TRACG Application for ESBWR Anticipated Transient Without Scram Analyses,” January 2006 (ADAMS Accession Nos. ML060190536, ML060190538, ML060190592).

44. NEDC-33239P, Rev. 2, “GE14 for ESBWR Nuclear Design Report,” April 2007 (ADAMS Accession Nos. ML072841052, ML072841054, ML072841056, ML072841059, ML072841058).

45. Letter from J.C. Kinsey to NRC, MFN 08-340, “Response to Portion of NRC Request for Additional Information Letter No. 106 – Related to ESBWR Design Certification Application – RAI Number 21.6-65 Supplement 1,” April 2008 (ADAMS Accession No. ML081000257).

46. Letter from J.C. Kinsey (GE) to NRC, MFN 07-312, “Response to Portion of NRC Request for Additional Information Letter No. 68—Containment Systems and Emergency Core Cooling Systems—RAI Numbers 6.2-98, 6.3-45, and 6.3-51,” June 20, 2007 (ADAMS Accession No. ML071920093).

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

48. NEDC-32694P-A, “Power Distribution Uncertainties for Safety Limit MCPR Calculations,” General Electric, August 1999 (ADAMS Accession Nos. ML003740119, ML003740145, ML003740159, ML003740151).

49. NEDC-33237P, Rev. 1, “GE14 for ESBWR—Critical Power Correlation, Uncertainty and OLMCPR Development,” March 2006 (ADAMS Accession Nos. ML060750687, ML060750690, ML060750695).

50. Letter from J.C. Kinsey (GE) to NRC, MFN 07-008, Supplement 1, “Response to Portion of NRC Request for Additional Information Letter No. 66 Related to ESBWR Design Certification Application—RAI Number 21.6-57 Supplement 1,” August 11, 2007 (ADAMS Accession No. ML072270105)