SAFETY EVALUATION WITH OPEN ITEMS

BY THE OFFICE OF NEW REACTORS,

APPLICATION OF THE TRACG COMPUTER CODE TO

ANTICIPATED TRANSIENTS

WITHOUT SCRAM FOR THE ESBWR DESIGN,

NEDE-33083P, SUPPLEMENT 2

1 Introduction

General Electric Hitachi Nuclear America, LLC (GEH), submitted NEDE-33083P, Supplement 2, "TRACG Application for ESBWR Anticipated Transient Without Scram Analyses," issued January 2006 (Reference 3), as part of the pre-application review activities with respect to the economic simplified boiling-water reactor (ESBWR) advanced passive design. This safety evaluation report (SER) documents the staff's review of NEDE-33083P, Supplement 2, as it relates to ESBWR anticipated transient without scram (ATWS) analyses. Reference 25 discusses the staff's review of TRACG as applied to ESBWR anticipated operational occurrences (AOOs). This SER builds on that review.

2 Regulatory Basis

Title 10, Section 50.62, "Requirements for Reduction of Risk from Anticipated Transients without Scram (ATWS) Events for Light-Water-Cooled Nuclear Power Plants," of the *Code of Federal Regulations* (10 CFR 50.62), defines an ATWS as the following:

> [A]n anticipated operational occurrence as defined in Appendix A of this part followed by the failure of the reactor trip portion of the protection system specified in General Design Criterion 20 of Appendix A of this part.

Furthermore, the rule requires that each boiling-water reactor (BWR) to have the following:

(1) An alternate rod insertion (ARI) system that is diverse (from the reactor trip system) from sensor output to the final actuation device and is designed to perform its function in a reliable manner and be independent (from the existing reactor trip system) from sensor output to the final actuation device

(2) An automatic standby liquid control system (SLCS) with a minimum capacity equivalent to 5.42×10^{-3} cubic meters per second (86 gallons per minute) of 13 weight-percent sodium pentaborate decahydrate solution at the natural boron-10 isotope abundance into a 251-inch (in.) inside diameter reactor pressure vessel (RPV).

(3) Equipment to trip the reactor coolant recirculating pumps automatically under conditions indicative of an ATWS (i.e., an automatic recirculation pump trip (RPT)).

A design certification applicant must submit information demonstrating how the applicant will comply with these requirements.

The rule in 10 CFR 50.62 prescribes hardware requirements, rather than acceptance criteria. BWR performance with the required hardware had been shown to meet specific acceptance criteria. Since the ESBWR uses natural circulation, there are no recirculation pumps to be tripped. Hence, GEH implements no RPT logic in the ESBWR. GEH performed ESBWR ATWS analyses to demonstrate that the ESBWR mitigation features are adequate with respect to the same criteria used to evaluate the hardware requirements in 10 CFR 50.46, “Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors,” for forced recirculation plants. Those criteria are listed below:

- Fuel Integrity—The long-term core cooling capacity is ensured by meeting the cladding temperature and oxidation criteria of 10 CFR 50.46 (i.e., peak cladding temperature not exceeding 1200 °C (2200 °F), and the local oxidation of the cladding not exceeding 17 percent of the total cladding thickness).

- Primary System—RPV integrity is ensured by limiting the maximum primary stress within the reactor coolant pressure boundary to the emergency limits as defined in the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III.

- Containment Integrity—The long-term containment capability is ensured by limiting the maximum containment pressure to the design pressure of the containment structure and the suppression pool temperature to the wetwell design temperature.

- Long-Term Shutdown Cooling—Subsequent to an ATWS event, the reactor shall be brought to a safe-shutdown condition and be cooled down and maintained in a cold-shutdown condition.

GEH used the TRACG code to ensure that safety limits are met during an ATWS event.

3 Technical Evaluation

In the following sections, the staff addresses the scope of the review; the technical evaluation based on the code scaling, applicability, and uncertainty (CSAU) methodology; and the confirmatory calculations performed in support of this review.

3.1 Scope of Review

The scope of this section of the SER is limited to the capability of the TRACG code to perform ATWS analyses for the ESBWR. The SER on ESBWR design certification discusses the adequacy of the ESBWR ATWS systems (e.g., SLCS) and evaluation of the ATWS event as it pertains to regulatory criteria. This review builds on the evaluation of the ability of TRACG to perform AOO analysis discussed in Reference 25.

3.2 CSAU-Based Technical Evaluation

GEH has chosen to follow the basic CSAU approach outlined 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 4), for evaluating total model and plant parameter uncertainty in ESBWR ATWS calculations. [[ ]]

The CSAU methodology consists of 14 steps contained within 3 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 the specific plant and accident scenario. Code limitations are noted 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 and scale-up capability and to determine 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 ATWS scenarios applicable to the ESBWR that can be analyzed using TRACG and the associated methodology described in Reference 3. These correspond to Standard Review Plan (SRP) Section 15.8.

More detail on the specific events for which this methodology is applicable appears in Section 2.0 of the technical evaluation report (TER) on ESBWR ATWS events (Reference 16, which is also provided as an enclosure to this report).

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 for an event can vary significantly from one nuclear power plant design to another. GEH has specified that the methodology applies to the ESBWR natural circulation, passive design. The staff evaluated the methodology as it applies to the 4500-megawatt thermal (MWt) ESBWR design described in Revision 3 of the ESBWR DCD.

GEH is consistent with this step in the CSAU approach.

3.2.1.3 Step 3—Phenomena Identification and Ranking

All phenomena that occur during an accident or transient do not influence the behavior of a nuclear power plant undergoing the event in an equal manner. A determination must be made to establish those phenomena that are important for each event and various phases within an event. 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 ATWS events in the ESBWR in a PIRT, which is located in Table 3-1 in Reference 3. Reference 10 discusses the parameters. The phenomena are identified as having an effect on three critical safety parameters—(1) suppression pool temperature, (2) vessel pressure, and (3) fuel clad temperature.

In ranking the phenomena, GEH divided the limiting scenarios into five phases, namely (1) short-term pressurization, neutron flux increase, and fuel heatup, (2) feedwater runback and water level reduction, (3) boron injection, mixing, and negative reactivity insertion, (4) post shutdown suppression pool heatup, and (5) depressurization of the reactor.

GEH states that emergency operating procedures (EOPs) may direct an operator to depressurize the reactor during an ATWS, but these procedures have not been established at this time. In Request for Additional Information (RAI) 21.6-4, the staff asked GEH to address depressurization during an ATWS event. In response (Reference 18), GEH described its procedure for developing a PIRT for ATWS depressurization. This procedure was nearly identical to that used when developing the PIRT for loss-of-coolant accident (LOCA) events, with some differences noted by GEH. The staff finds that GEH has addressed the differences between a depressurization resulting from a LOCA and one resulting from a controlled depressurization during an ATWS. However, the staff noted in its supplemental RAI that GEH has not provided demonstration calculations or the procedures for depressurization during an ATWS, and therefore the staff cannot thoroughly review the application of TRACG to depressurization. **RAI 21.6-4 is being tracked as an open item.**

The following PIRT parameters were introduced specifically for ESBWR ATWS evaluation:

- ATW1—boron mixing/entrainment between the jets downstream of the injection nozzle

- ATW2—boron settling in the guide tubes or lower plenum
- ATW3—boron transport and distribution through the vessel, particularly in the core bypass region
- ATW5—boron reactivity

More details of the staff's review of the GEH AOO PIRT appear in Section 3.0 of the TER (Reference 16, or the enclosure).

The PIRT is comprehensive and gives the appropriate rating to ESBWR ATWS phenomena.

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 after an evaluation has been completed, changes to the code do not impact the conclusions 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 for input into TRACG04.

On October 14 through 19, 2006 and October 30 through November 3, 2006, the staff performed an audit of PANAC11 and TGBLA06 as they are applied to the ESBWR. During the audit, the staff reviewed the most current versions of PANAC11 and TGBLA06 codes for their applicability to the ESBWR. GEH makes error correction versions to 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 the conditions and limitations to be specified in its safety evaluation for NEDE-33239P (Reference 26) which is still under staff review.

The methodology (Reference 3) restricts changes to TRACG04. Changes to the models in Reference 6 may not be made 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, "Domestic Licensing of Production and Utilization Facilities." If the calculated TRACG results of the qualification tests (Reference 12 or its successor) used to test the code change by more than the uncertainty in that assessment, the staff requires that GEH 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.

Open items are associated with the review of TRACG for ESBWR AOOs in this area, as documented in Reference 25.

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 evaluation of the code's applicability to postulated transient or accident scenarios for a specific plant design can be performed through a traceable record. GEH has provided the documentation through the submittal of ESBWR ATWS specific documentation in References 3, 9, and 10 and code documentation in References 6 and 10.

Open items are associated with the review of TRACG for ESBWR AOOs in this area, as documented in Reference 25.

3.2.1.6 Step 6—Determination of Code Applicability

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 in a realistic manner 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. These models should include the following four elements:

(1) field equations—provide code capability to address global processes

(2) closure equation—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 (Reference 1) and the application to AOO and ATWS overpressure events in BWR/2–6 (References 7 and 27). The staff also reviewed TRACG as applied to ESBWR AOO/IE analysis as documented in Reference 25.

Open items are associated with the review of TRACG use for ESBWR AOOs in this area, as documented in Reference 25.

3.2.1.6.1 Thermal-Hydraulic Modeling

Reference 25 contains a review of the TRACG thermal-hydraulic modeling as applied to ESBWR AOOs. Some of the phenomena unique to ATWS events include those related to high heat flux and boron mixing and transport. A review of TRACG thermal-hydraulic modeling as related to ESBWR ATWS events appears in Section 4.0 of the TER (Reference 16 or the enclosure). The following sections discuss other phenomena that are unique to modeling ESBWR ATWS events.

Open items are associated with the review of TRACG use for ESBWR AOOs in this area, as documented in Reference 25.

3.2.1.6.2 Minimum Stable Film Boiling Temperature

For the minimum stable film boiling temperature, GEH uses the Iloeje correlation for ESBWR applications. TRACG has the option of using the Shumway correlation, which, according to GEH, better captures the flow and pressure dependence. The staff has not reviewed the Shumway correlation which was an option provided by GEH and finds the use of the Iloeje correlation acceptable for ESBWR ATWS applications. For ATWS events where the core does go into film boiling, the minimum stable film boiling temperature is used only to determine when the core will quench and has no effect on the value of the maximum PCT.

3.2.1.6.3 SLCS Modeling

GEH modeled the SLCS using a [[ ]] component. In RAI 21.6-12 (Reference 15), the staff asked GEH to justify its selection of the velocity for this component. GEH responded to this RAI in Reference 18. The staff found potential errors in the information submitted by GEH and requested supplemental information. **RAI 21.6-12 is being tracked as an open item.**

3.2.1.6.4 Boron Mixing and Transport

The ESBWR uses the SLCS to shut down the reactor in the event of an ATWS. This system injects soluble boron, a strong neutron absorber, into the peripheral bypass of the core.

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The boron model is simple but has produced good results for a number of applications. However, empirical confirmation is needed at different scales. [[ ]] Section 3.2.1.8 of this report discusses the adequacy of the GEH TRACG nodalization for performing ATWS evaluations. In RAI 21.6-41 (Reference 15), the staff requested that GEH justify its position that the uniform mixing assumption of the boron in the bypass will be conservative. The information requested in RAI 21.6-41 was also listed in RAI 21.6-44 which additionally included a request for GEH to address computational fluid dynamics (CFD) calculations. Therefore, RAI 21.6-

41 was closed and RAI 21.6-44 remains open. **RAI 21.6-44 is being tracked as an open item.**

[[ ]] The ESBWR ATWS analysis does not use this model; therefore, the staff did not review it.

3.2.1.6.5 Boron Settling

Boron may be lost to the system because of settling in the control rod guide tubes and the lower plenum. Since TRACG assumes that boron is uniformly mixed in each cell, TRACG will not be able to calculate the effects of boron settling. Therefore, the effects of potential removal of boron from the system because of settling can be controlled using nodalization and input assumptions. GEH did not adjust the nodalization to account for this settling. In Reference 3 (Section 5.0), GEH concluded that the boron will not settle by calculating a critical velocity based on a critical Froude number. GEH estimated that the critical velocity is much less than the velocity being calculated by TRACG, and thus settling will not occur. In RAIs 21.6-9, 21.6-27, and 21.6-28 (Reference 15), the staff asked GEH to justify the assumptions about the settling of boron. In response to RAI 21.6-27 in Reference 18, [[ ]] During some time periods, the velocity is [[ ]] and in response to RAI 21.6-9 in Reference 20 and 21.6-28 in Reference 18, GEH performed sensitivity studies on the [[ ]]. RAIs 21.6-9, 21.6-27, and 21.6-28 are resolved. Section 4.0 of the TER (Reference 16 or the enclosure) also discusses this issue. The sensitivity studies performed by GEH are based on the main steam isolation valve (MSIV) closure ATWS. These may be different for different ATWS events since the flow field will be different. In a supplement to RAI 21.6-39, the staff asked GEH to address the flow field for ATWS events that may be different than MSIV closure. In addition, the results of the CFD analyses discussed in Section 3.3.2 may provide additional insight into the settling of the boron. **RAI 21.6-39 is being tracked as an open item.**

3.2.1.6.6 Channel Leakage Model

During SLCS activation, the boron will fill the core bypass and enter the channels through the leakage paths. The staff reviewed the channel leakage model in TRACG. The staff needs additional information to complete its review of this item. In RAI 21.6-100 (Reference 5), the staff requested that GEH provide justification for the applicability to ATWS of the TRACG channel leakage correlations. **RAI 21.6-100 is being tracked as an open item.**

3.2.1.6.7 Fuel Thermal Conductivity and Gap Conductance

Reference 25 documents the staff's review of the fuel thermal conductivity and gap conductance models. In RAI 21.6-38, the staff asked GEH to justify the uncertainty value used for pellet thermal conductivity and explain how this covers the uncertainty in [[ ]] in the ATWS evaluations. In response, [[ ]] **RAIs 6.3-54, 6.3-55, and 4.8-16 dealing with additional information on gap conductance and thermal conductivity are being tracked as open items.** The staff has determined that the response to RAI 21.6-38 is adequate. Therefore, RAI 21.6-38 is resolved.

3.2.1.6.8 Hot Rod Model

GEH has implemented a hot rod model in its one-dimensional thermal-hydraulic model of the channel component in TRACG04. GEH calculated a PCT during ATWS events but calculated this for the limiting bundle and did not activate the hot rod model for that application. Therefore, the staff did not review the model for this application.

3.2.1.6.9 Three-Dimensional Neutron Kinetics Modeling

Reference 25 discusses the staff's review of the three-dimensional neutron kinetics in TRACG. Therefore, all open items discussed in that section also apply here. The staff is especially concerned about the [[ ]] since there are higher void fractions in the core during an ATWS event. In addition, ATWS evaluations are performed for a top peaked end-of-cycle (EOC) power shape.

3.2.1.6.10 Xenon Reactivity

[[ ]] In Reference 28, [[ ]] Since the timeframe of concern for ATWS is on the order of seconds or minutes, and xenon concentrations change over the course of hours, the staff finds that the [[ ]] assumption is reasonable.

3.2.1.6.11 Boron Reactivity

[[ ]]

Since the boron is introduced into the core only during the ATWS event, there are no direct exposure effects on the boron or the reactivity. The reactivity worth of the boron can be accurately captured if the absorption cross-section is increased to account for the neutron absorption in boron. This is most accurately done when the thermal cross-section is adjusted. The boron absorption cross-section will depend on the local flux spectrum.
[[ ]]

In RAIs 21.6-34 and 21.6-35 (Reference 15), the staff asked GEH to provide additional information on the boron reactivity model and justify some of the assumptions used in the development of the model. GEH provided these details in Reference 21. [[ ]]

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[[ ]]

[[ ]] the staff asked GEH to justify this model when applying it to other fuel designs not encompassed [[ ]]

The staff believes that GEH stated all of the factors affecting boron reactivity in the development and testing of its empirical model. The staff finds the responses to RAIs 21.6-34 and 21.6-35 acceptable. However, the only validation available for staff review is a code-to-code comparison to PANAC11. The staff plans to perform independent

Monte Carlo N-Particle (MCNP) calculations to compare the efficacy of the empirical cross-section model to account for the spectral shift consistent with MCNP calculations performed for different fuel lattices at a variety of exposure histories to examine the impact of exposure effects on the instantaneous nodal thermal spectrum. In addition, [[ ]]. The staff plans to perform independent calculations regarding the 1-percent uncertainty. **This is an open item.**

Element 2—Assessment and Ranging of Parameters

3.2.1.7 Step 7—Establish Assessment Matrix

The staff's review of the assessment of TRACG as applied to ESBWR AOOs appears in Reference 25. This review is also applicable to ESBWR ATWS events. In Table 4.2 in Reference 3, GEH identified the qualification basis for each of the high-ranked phenomena identified in the ATWS PIRT by citing the quantitative assessment performed for separate effects qualification, component performance qualification, integral system qualification, 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 in Reference 16 (the enclosure) discusses an evaluation of the assessment of TRACG as it relates to ESBWR ATWS scenarios.

An open item in this area of the review was previously mentioned in Reference 25. RAI 21.6-75 (Reference 11) asks GEH to provide an update to the TRACG qualification report (Reference 12) that is consistent with the current version of TRACG used in ESBWR licensing analyses (TRACG04). **RAI 21.6-75 is being tracked as an open item.**

GEH is consistent with this step in the CSAU approach.

3.2.1.8 Step 8—Nuclear Power Plant Nodalization Definition

[[ ]] Reference 25 discusses the adequacy of this nodalization for simulating transient thermal-hydraulic and neutronic behavior in an ESBWR.

In its response to RAI 21.6-42 (Reference 18), GEH provided the staff with the boron concentrations and mass flow rates through the core bypass and channels for the MSIV closure transient. RAI 21.6-42 is resolved.

As stated in Section 3.2.1.6.4 of this report, the [[ ]]. Section 5.1 of Reference 3 presents the [[ ]] The staff requested and received additional information on the preceding analysis (Reference 15, 19) and concluded the responses addressed its concerns.

GEH submitted a partial response to RAI 21.6-40 in Reference 20. Section 4.0 of the TER (Reference 16 or the enclosure) discusses this information. RAI 21.6-40 is resolved.

The staff requested that GEH perform CFD calculations to help justify the selected TRACG nodalization. NRC staff is performing independent confirmatory CFD calculations in addition to the GEH effort discussed in Section 3.3.2 of this report. GEH plans to submit its CFD calculations in response to RAI 21.6-44. **RAI 21.6-44 is being tracked as an open item.**

In addition to the CFD calculations being performed by GEH and the NRC, the staff requested that GEH perform nodalization studies of the vessel to illustrate the sensitivity of the TRACG-calculated safety parameters to nodalization. [[ ]] GEH submitted the results of its radial and azimuthal sensitivity studies in Reference 24. GEH performed a series of sensitivity studies that [[ ]]

GEH showed that, when it injects boron into the [[ ]] the shutdown time [[ ]]. This was because in both cases [[ ]]

GEH repeated this study with the [[ ]]. The results for both [[ ]] [[ ]]

GEH compared the results of just the [[ ]] to demonstrate that the case with [[ ]] [[ ]]

[[

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Despite the more conservative results, GEH proposed to maintain the [[ ]] and inject the boron into this ring size [[ ]]

The staff does not have enough information at this time to support the GEH conclusion. The staff is waiting for the results of both GEH and NRC/RES CFD calculations to show that [[ ]]

In RAI 21.6-83 (Reference 11), the staff requested that GEH perform sensitivity studies for the axial nodalization of the bypass. **RAI 21.6-83 is being tracked as an open item.**

In addition, the nodalization being studied by GEH and the NRC's CFD analyses are for the limiting ATWS event (MSIV closure). In RAI 21.6-39 (Reference 15), the staff requested that GEH evaluate the [[ ]]. Section 4.0 of the TER (Reference 16 or the enclosure) also discusses this open item. **RAI 21.6-39 is being tracked as an open item.**

3.2.1.9 Step 9—Definition of Code and Experimental Accuracy

Simulation of experiments developed from Step 7 (discussed in Section 3.2.1.7) using the nuclear power plant nodalization from Step 8 (discussed in Section 3.2.1.8) 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 tests 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 12, 13, and 14 document the assessments of TRACG. Since the ESBWR is a new design, no operating plant data are available. However, many of the key parameters and phenomena for analyzing ATWS in the ESBWR are not significantly different from those in operating reactors.

GEH used TRACG to simulate separate effects tests, component performance tests, integral systems tests, and operating BWR plant data. GEH was able to determine an uncertainty between the code-calculated results and the test data. Sections 4.0 and 5.0 of the TER (Reference 16 or the enclosure) include discussion of the uncertainties associated with various qualification tests.

An open item in this area of the review was previously mentioned in Reference 25. RAI 21.6-75 (Reference 11) asked GEH to provide an update to the TRACG qualification report (Reference 12) that is consistent with the current version of TRACG used in ESBWR licensing analyses (TRACG04). Other open items are related to the boron reactivity and mixing qualifications as described in Sections 3.2.1.6.11 and 3.2.1.9.1 of this report. **RAI 21.6-75 is being tracked as an open item.**

3.2.1.9.1 Boron Mixing Qualification

To qualify and determine the uncertainty in the boron mixing model, GEH used data from three-dimensional boron mixing tests conducted in a [[ ]] (BWR/5 and BWR/6) RPV using the high-pressure core spray (HPCS) spargers as the primary location for injection of the simulated boron solution. In RAI 21.6-44 (Reference 15), the staff asked GEH to provide additional details of the boron mixing and transport tests used to qualify the TRACG boron model and its applicability to the ESBWR given its unique injection location (in the core bypass). GEH provided additional information about the test used to qualify the boron mixing model in Reference 22. [[ ]]

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[[ ]]
[[ ]]

The staff currently does not accept the GEH application of this test to the ESBWR. The argument by GEH is predicated on knowing the ESBWR boron flowpath and knowing that it is similar to that seen when boron [[ ]]. However, this leads to circular reasoning since the data are supposed to be used to inform the TRACG model that it is adequately calculating the boron mixing and flowpaths in the core. [[ ]] In addition, comparing the [[ ]] to the ESBWR MSIV closure ATWS event seems awkward. GEH should have made comparisons using a TRACG input deck of the same experiment to indicate how the code reproduces experimental behavior and to evaluate how it scales with ESBWR dimensions. The ESBWR MSIV closure ATWS event is so dissimilar to the experiment that a direct comparison is difficult. Based on the staff audit of TRACG as applied to the ESBWR LOCA the staff observed that [[

]]. This is non-conservative and inconsistent with the GEH conclusion in the RAI response. The staff asked for supplemental information for this RAI response. **RAI 21.6-44 is being tracked as an open item.**

Staff will verify GEH is consistent with this step in the CSAU approach upon resolution of applicable open items.

3.2.1.10 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 ATWSs in the ESBWR do not have significantly different scales than in operating reactors. The staff discusses scaling of tests performed to qualify TRACG for ESBWR-specific components in Section 21.5 of the SER for ESBWR design certification. Section 3.2.2.3.1 of this report details the staff's request for additional information in RAI 21.6-44 on the scaling of the qualification performed for the boron mixing model. **RAI 21.6-44 is being tracked as an open item.**

Staff will verify GEH is consistent with this step in the CSAU approach upon resolution of applicable open items.

3.2.2 <u>Element 3—Sensitivity and Uncertainty Analysis</u>

3.2.2.1 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. As discussed in Reference 25, GEH divided code inputs into four categories:

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

For TRACG ATWS analysis, [[ ]]. The application methodology described in [[ ]]. New data with which the specific model uncertainties may be reassessed may become available. If the reassessment results in a need to change specific model uncertainty, the specific model uncertainty may be revised for ESBWR ATWS 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 review and approval will be transmitted to the NRC for information.

The treatment of initial conditions is slightly different for the [[

]]. Since ATWS is a low-probability event, the NRC has accepted this approach in the past for TRACG ATWS analyses as applied to BWR/2–6 (Reference 7). The staff finds this approach acceptable for ESBWR ATWS analyses.

The treatment of [[ ]]. Since ATWS is a low-probability event, the NRC has accepted this approach in the past for TRACG ATWS analyses as applied to BWR/2–6 (Reference 7). The staff finds this approach acceptable for ESBWR ATWS analyses.

GEH is consistent with this step in the CSAU approach.

3.2.2.2 Step 12—Performance of Nuclear Power Plant Sensitivity Calculations

Sensitivity calculations are performed to evaluate methodology sensitivity to various operating conditions that arise from uncertainties in the reactor state at the initiation of the transient, in addition to sensitivity to plant configuration. The safety-related quantities of importance in the ATWS analysis are peak vessel pressure, peak clad temperature, peak suppression pool temperature, and peak power. Using TRACG, GEH performed calculations of representative ATWS events to demonstrate ESBWR plant behavior. [[ ]] RAI 21.6-53 will remain open until the revised topical report is submitted and staff can review the transient cases. **RAI 21.6-53 is an open item.**

GEH is consistent with this step in the CSAU approach.

3.2.2.3 Step 13—Determination of Combined Bias and Uncertainty

GEH chose the [[ ]]

GEH is consistent with this step in the CSAU approach.

3.2.2.4 Step 14—Determination of Total Uncertainty

GEH provides the [[ ]] Following the uncertainty analysis, GEH added another set of conservatisms in the initial condition uncertainties, listed in Table 8.3-1 of Reference 3.

GEH provided the calculated peak RPV pressure, peak power, PCT, and peak suppression pool temperature for the nominal and bounding cases and the uncertainty associated with each in Tables 8.3-2 and 8.3-3 of Reference 3. Section 3.2.2.1 of this report discusses this issue.

The staff finds the GEH total uncertainty analysis acceptable.

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

3.3 Staff Independent Calculations

The staff is using the TRACE/PARCS code package to perform independent calculations of the ESBWR ATWS. In addition, the staff is performing independent CFD calculations using the FLUENT code to verify the GEH boron mixing and transport models and vessel bypass nodalization. The staff is using MCNP to verify boron reactivity models. The following sections discuss each modeled event.

3.3.1 TRACE/PARCS Transient Calculations

The staff is modeling ESBWR ATWS events using the TRACE/PARCS/TRITON code package. The model is currently under development. This section of the SER will be updated when the results of the confirmatory analyses are available. **This is an open item.**

3.3.2 CFD Calculations of Boron Mixing and Transport

The NRC staff is conducting confirmatory CFD calculations to confirm the boron mixing and transport models used by GEH. This section of the SER will be updated when the results of the confirmatory CFD analyses are available. **This is an open item.**

3.3.3 Boron Reactivity Calculations

The staff has developed MCNP input decks representative of the ESBWR lattices in support of steady-state physics calculations. The staff is adding boron to compare the cross-section with that used in TRACG. This section of the SER will be updated when the results of the confirmatory analyses are available. **This is an open item.**

4 Conditions and Limitations

The staff has identified the following specific conditions that will be applied to NEDE-33083P, Supplement 2, if approved:

(1) The staff evaluated the methodology for analyzing ESBWR ATWS events using TRACG, described in Reference 0 as it applies to the 4500-MWt ESBWR design presented in the ESBWR DCD, Revision 3. If GEH or an applicant referencing the methodology in Reference 3 wishes to use this methodology for an ESBWR design not completely consistent with Revision 3, GEH or the applicant must provide a summary of the design changes and justification for NRC staff review and approval of the applicability of the methodology.

(2) Changes to the models as described in Reference 6 may not be made without NRC review and approval. The NRC must review and approve any changes to the method described in Reference 3.

(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 12 or its successor) 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) Use of TGBLA or PANAC11 codes must be within the conditions and limitations stated in Section 4.3.3.2.5 of this SER.

(6) Since [[ ]].

(7) Changes to the uncertainty values used for the model inputs are controlled by the application methodology described in Section 2.7.2 in Reference 3. New data with which the specific model uncertainties may be reassessed may become available. If the reassessment results in a need to change specific model uncertainty, the specific model uncertainty may be revised for ESBWR ATWS 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 performed without review and approval will be transmitted to the NRC for information.

(8) [[ ]] is not qualified and not approved for use in ESBWR ATWS events.

The staff may list other conditions and limitations upon closure of all open items.

5 Conclusions

The staff's conclusions cannot be finalized until the remaining open items are resolved.

6 References

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6. NEDE-32176P, Revision 3, "TRACG Model Description," April 2006. (ADAMS Accession No. ML061160238)

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13. 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 6, 2004. (ADAMS Accession No. ML041610037)

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15. Letter from M.C. Barillas (NRC) to D.H. Hinds (GE), “Request for Additional Information Letter No. 31 Related to ESBWR Design Certification Application,” June 23, 2006. (ADAMS Accession No. ML061740028)

16. J. Spore (ISL), ISL-NSAD-TR-07-02, “Technical Evaluation Review of TRACG Applications to ESBWR ATWS,” January 2007.

17. NEDO-32176, Revision 1, “TRACG Model Description,” March 1996. (ADAMS Legacy No. 9604220045)

18. Letter from D.H. Hinds (GE) to NRC, MFN 06-301, “Response to Portion of NRC Request for Additional Information Letter No. 31 and NRC Letter No. 57 Related to ESBWR Design Certification Application—TRACG Application for ESBWR ATWS—RAI Numbers 21.6-4, 21.6-12, 21.6-27 through 21.6-29, 21.6-36 through 21.6-38, 21.6-42, 21.6-45, 21.6-46, and 21.6-52,” September 6, 2006. (ADAMS Accession No. ML062650237)

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