ENCLOSURE 2

M180029

Response to Request for Additional Information Regarding Review of Satisfaction of Limitation 10.7 for NEDE-33005P, Revision 0, Licensing Topical Report "TRACG Application for Emergency Core Cooling Systems / Loss-of-Coolant-Accident Analyses for BWR/2-6"

Non-Proprietary Information – Class I (Public)

IMPORTANT NOTICE

This is a non-proprietary version of Enclosure 1, from which the proprietary information has been removed. Portions of the enclosure that have been removed are indicated by an open and closed bracket as shown here [[ ]].

1.0 INTRODUCTION

By letter M170165, dated July 7, 2017, General Electric – Hitachi Nuclear Energy (GEH) submitted information required to satisfy Limitation 10.7 for NEDE-33005P, Revision 0, "Licensing Topical Report TRACG Application for Emergency Core Cooling Systems / Loss-of-Coolant Accident Analyses for BWR/2-6" (Reference 1). Among other things, this information specifically addressed TRACG model sensitivity to changes in noding detail, which had been previously evaluated in Section 4.3 of the U.S. Nuclear Regulatory Commission (NRC) staff safety evaluation (SE) approving NEDE-33005P.

By a letter dated November 6, 2017, the NRC issued a request for additional information (RAI) regarding the review of the satisfaction of Limitation 10.7 for NEDE-33005P, Revision 0, Licensing Topical Report "TRACG Application for Emergency Core Cooling System / Loss-of-Coolant-Accident Analyses for BWR/2-6" (Reference 2). GEH responses to the NRC RAIs in Reference 2 are included herein.

Upon review of Reference 2, GEH determined that the following three items summarize the NRC questions associated with the Reference 1 (M170165) study.

(1) In the additional studies in Reference 1, there are increases in variability associated with the small perturbation analyses compared to the results reported in previous RAIs, which are included in NEDE-33005P-A (Reference 6). The response to this concern is addressed in Section 2.0.

(2) The response to specific questions regarding the analysis in Reference 1 are addressed in Section 3.0.

(3) Provide additional information to justify that the noding uncertainty is an acceptably small contributor to overall model uncertainty as to be neglected when analyses are performed using the standard nodalization, or propose, and justify, an allowance to include for this potential source of discretization error. The noding uncertainty discussion and uncertainty estimation is presented in Section 4.0 and the further justification of using standard nodalization for TRACG loss-of-coolant accident (LOCA) is given in Section 5.0.

A summary and conclusion is provided in Section 6.0.

2.0 COMPARISON OF M170165 RESULTS WITH PREVIOUS NEDE-33005P-A RAI RESPONSE RESULTS

The small perturbation studies in noding sensitivity in M170165 were performed in the same way as the studies in the responses to a few of the RAIs included in NEDE-33005P-A (Reference 6), primarily RAI-6 for BWR/4 (the responses to RAIs 3 and 4 in NEDE-33005P-A are for BWR/2). The analyses in M170165 used the same BWR/4 TRACG basedeck with the updated detailed core modeling (discussed in M170165 Section 2.1). The major difference in the core modeling is [[ ]]. For the nodalization studies in M170165 Table B5.2-1, a [[ ]] was performed for [[ ]]. The [[ ]] are reported in M170165 Table B5.2-1, together with the differences between the base case and each nodalization case.

It should be noted that the magnitude of [[ ]] cited in Reference 2 regarding the previous BWR/4 small perturbation analysis in the response to RAI-6 in NEDE-33005P-A is [[ ]], as shown in Figures R6-11 and R6-12 in NEDE-33005P-A. It is not the [[ ]] for the analyses in M170165 below.

Table 2-1 shows the minimum (Min), maximum (Max), and standard deviation (St. Dev.) of the core PCT for each analysis in M170165 Table B5.2-1. The PCT range for each analysis can be obtained by subtracting the minimum value from the maximum value for each analysis.

For the small break small perturbation analysis calculations, the first and second PCT peaks as shown in Figures B5.2-3, B5.2-6 and B5.2-9 in M170165 are distinguished. The results similar to M170165 Table B5.2-1 and Table 2-1 are shown in Table 2-2 and Table 2-3, respectively, in this enclosure. Note that in these two tables (Table 2-2 and Table 2-3), the small break composite core PCT results in M170165 Table B5.2-1 are retained for direct comparison.

The maximum PCT ranges from the small perturbation analyses are summarized below:

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The following PCT range plots analogous to NEDE-33005P-A, Revision 1, Figure 6.4-9 (which is the same as Figure R6-11 in Reference 6) are provided for some typical nodalization studies shown in M170165 Table B5.2-1.

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Figure 2-3 can be compared to Figure 6.4-9 in NEDE-33005P-A, Revision 1 (both are the limiting break but the Figure 2-3 analysis used the updated detailed core model and increased average channel noding).

In the following section, the response to the following RAI question is provided. The comparisons shown below provide the comparison with the same basis between the M170165 analysis and the analysis in the NEDE-33005P-A RAI responses.

> *Explain why the small perturbation analyses in M170165 exhibit greater PCT range than those previously discussed in the RAI responses for NEDE-33005P-A.*

In the above question, the results associated with "those previously discussed in the RAI responses for NEDE-33005P-A" refer to the results reported in Figures R6-11 and Figure R6-12 in NEDE-33005P-A, which were generated from a [[

]]. To facilitate the discussion in this response, Figures R6-11 and Figure R6-12 in the NEDE-33005P-A RAI-6 response are copied as Figure 2-6 and Figure 2-7, respectively, in this enclosure. From Figure R6-12 in NEDE-33005P-A (or Figure 2-7), the following basic statistical information regarding those runs can be found: [[

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To explain "the small perturbation analyses in M170165" in the above question, the base case small perturbation statistical analysis for the limiting intermediate break (IB) using the updated detailed core model in M170165 is selected. It should be noted that the detailed core model in

Reference 6 is updated in M170165 to be fully compliant with the NRC Safety Evaluation (SE) requirements and resulting Reference 6 commitments, which were detailed in Section 2.1 of M170165. For the updated detailed core model, [[

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Figure 2-8 and Figure 2-9, similar to Figure 2-6 and Figure 2-7, show the core PCT range and distribution from the small perturbation statistical runs for the intermediate break base case in M170165. The basic statistical information regarding those runs can be found in Figure 2-9. Acknowledging that the core PCTs in Figure 2-8 and Figure 2-9 come from CHAN28, the same information for CHAN25 is provided in Figure 2-10 and Figure 2-11 in order to make the direct comparison with the information in Figure 2-6 and Figure 2-7. Comparison of the results in Figure 2-6 from the previous study and the results in Figure 2-10 in M170165 show that the PCT responses as compared between the results in the RAI responses in NEDE-33005P-A and in M170165 are similar.

The basic information regarding statistical parameters for those runs is summarized in Table 2-4. The results in this table show that [[

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Based on the discussion and the additional information and comparisons provided in this section, it is shown that the [[ ]] order of magnitude from the small perturbation still holds true for the analyses in M170165. All noding sensitivity analyses in M170165 have a standard deviation less than [[ ]]

Table 2-1: Maximum, Minimum and Standard Deviation of PCT for the Analyses in M170165
Table B5.2-1

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Table 2-2: Summary of Nodalization Sensitivity Studies for Jet Pump Plants – Small Break

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Table 2-3: Maximum, Minimum and Standard Deviation of PCT for the Analyses in M170165 Table B5.2-1

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Table 2-4: Summary of PCT Statistical Information from Small Perturbation Runs

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Figure 2-1: PCT Range for the Steam Dome Axial Nodalization Large Break (First Peak) Sensitivity

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Figure 2-2: PCT Range for the All Channel Axial Nodalization Large Break (Second Peak) Sensitivity

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Figure 2-3: PCT Range for the Average Channel Axial Nodalization Intermediate Break Sensitivity

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Figure 2-4: PCT Range for the Hot Channel Axial Nodalization Small Break Sensitivity

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Figure 2-5: PCT Range for the Steam Dome Axial Nodalization Small Break Sensitivity

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Figure 2-6: PCT Range for BWR/4 Intermediate Break (Figure R6-11 in NEDE-33005P-A)

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Figure 2-7: PCT Distribution for BWR/4 Intermediate Break (Figure R6-12 in NEDE-33005P-A)

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Figure 2-8: PCT Range for BWR/4 Intermediate Break (Base Case in M170165)

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Figure 2-9: PCT Distribution for BWR/4 Intermediate Break (Base Cases in M170165)

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Figure 2-10: CHAN25 PCT Range for BWR/4 Intermediate Break (Base Cases in M170165)

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Figure 2-11: CHAN25 PCT Distribution for BWR/4 Intermediate Break (Base Cases in M170165)

3.0 GEH RESPONSES TO NRC SPECIFIC QUESTIONS REGARDING M170165 ANALYSES

This section provides additional discussions to specific NRC questions regarding the analyses in M170165.

3.1 Question 1

Question 1: "Regarding Figure B5.2-5, explain why some cases initiate a cladding heatup earlier than others. Also explain why this behavior isn't exhibited in the small perturbation analyses."

Response:

The comparisons of the mean values of core PCT from M170165 Figure B5.2-5 show that (1) [[

]] Therefore, in the following discussion, the PCT ranges from all small perturbation statistical runs for the limiting channel, CHAN28, in the core are presented.

Figure 3-1, Figure 3-2 and Figure 3-3 present the PCT ranges of CHAN28 for the base, radial and theta nodalization sensitivity analyses, respectively. The comparison between Figure 3-1 and Figure 3-2 shows that [[

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The earlier heatup for some cases in the analysis is attributed to the variation in the system response caused by the small perturbations in TRACG models. The small differences in PCT responses for different cases are not surprising.

3.2 Question 2

Question 2: "Regarding Figure B5.2-7, explain what drives the significantly earlier achievement of stable quench and return to nucleate boiling in the model with increased hot channel axial detail."

Response:

From M170165 Figure B5.2-7, it is observed that [[

]] in M170165 Figures B5.2-8 and B5.2-9. Also, note that [[

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3.3 Question 3

Question 3: "In TR Figures 5.2-10 and 5.2-11, explain similar trends in the BWR/2 overall transient to those noted above in B5.2-7."

GEH Response:

The apparent similarity in trends between the BWR/2 and BWR/4 results is coincidental. First, it should be noted that [[

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The TRACG quench model description and its qualification is provided in Reference 3. The model functionality for top-down and bottom-up quenching is the same with the only difference being the correlation that is used for the heat transfer coefficient in the short region with high heat transfer just behind the quench front. This difference was noted in the response to RAI-49 in NEDE-33005P-A and is also described in Reference 3.

3.4 Question 4

Question 4: "Provide comparisons to other figures of merit that may better explain the model sensitivities. Consider:

- Minimum temperature for stable film boiling (Tmin) at time of quench.
- Time of PCT (for a given peak, if large- or small-break).
- Maximum local oxidation."

Response:

When evaluating the qualification basis, PCT is the most appropriate figure of merit (FOM) to use because it is both a licensing parameter and is the key measured quantity in the experimental data. Other FOMs are suggested for consideration in evaluating the sensitivity studies. However, as discussed in Sections 4.0 and 5.0, the sensitivity studies are not the basis for the nodalization adequacy. The qualification basis of the code (Reference 4) is used to determine the adequacy of the nodalization. Instead of analyzing other FOMs to explain the results of the nodalization sensitivity studies, cases from the qualification basis were reexamined to ensure adequacy. Sections 5.0 provides the evaluation of the qualification cases that were examined.

Plots of Tmin versus time for the limiting CHAN, rod group, and axial node where the PCT occurs reveal only how Tmin changes inversely with the local temperature of the cladding because of how cladding thermal properties change with temperature. There is a downward trend in Tmin with time because Tmin tracks downward with the fluid saturation temperature which is decreasing with system pressure. These responses are as expected and reveal no new behavior. It should be noted that Tmin impacts only the timing for when quench can occur and because quench at the limiting PCT location occurs after the cladding temperature has begun to decrease, Tmin modeling has essentially no impact on the value of PCT.

The PCT timing is relatively insensitive to nodalization. Using the large break as an example, [[

]] There is no clear correlation between the mean times of the PCTs and the mean PCT values.

Maximum local oxidation is usually not measured in separate effects and integral system tests (ISTs) and in most tests the cladding material is not zircaloy. So, examining changes in calculated amounts of oxidation for these tests only provides information about the impact of the nodalization (i.e., nodalization uncertainty and biases) and not adequacy of the nodalization.

Maximum local oxidation values in these jet pump boiling water reactor (BWR) calculations are [[

]] It is for this reason that the focus is placed exclusively on PCT as the interesting FOM when evaluating sensitivity to nodalization.

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Figure 3-1: CHAN28 PCT Range for BWR/4 Intermediate Break (Base Cases in M170165)

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Figure 3-2: CHAN28 PCT Range for BWR/4 Intermediate Break (Radial Cases in M170165)

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Figure 3-3: CHAN28 PCT Range for BWR/4 Intermediate Break (Theta Cases in M170165)

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Figure 3-4: CHAN28 Quench Front Locations (Large Break All Channel Axial Nodalization in M170165)

4.0 NODALIZATION ADEQUACY

The main question from Reference 2 is:

> *Provide additional information to justify that the noding uncertainty is an acceptably small contributor to overall model uncertainty as to be neglected when analyses are performed using the standard nodalization, or propose, and justify, an allowance to include for this potential source of discretization error. Such justification could be strengthened by addressing, specifically, any combination of the following points:*

This section first discusses nodalization uncertainty, and is followed by the standard nodalization justification. From this point forward in the enclosure the discussions of the channel axial nodalization are limited to cases where all channels (hot and average) have the same axial nodalization. It is evident from the tables in Section 2.0 that the results from the [[

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4.1 Nodalization Uncertainty

A clarification should be made between nodalization uncertainty and nodalization adequacy. The purpose of the M170165 nodalization sensitivity studies is to establish the adequacy of the nodalization. In addressing each of the points that are proposed in the Reference 2 RAI, the adequacy of the nodalization is supported.

In this response, the uncertainty introduced by the nodalization is analyzed to further support the adequacy of the nodalization. But the basis of the nodalization adequacy ultimately remains the qualification basis. The results presented in M170165 focus on [[

]] (the results are presented in M170165 Table B5.2-1). A distinction must also be made as to the meaning of the standard deviation for each of the nodalization sensitives (shown in Table 2-1 and Table 2-3). This is not nodalization uncertainty, but rather the small perturbation uncertainty which is a measure of the code and modeling uncertainty for each nodalization.

Overall the evaluation model has several sources of uncertainty. These sources are:

- **Code Uncertainty** – The impact of the computational framework of the model, best understood as the impact of a change on the computational model that would have no expected change in reality (for example a change in the time step)
- **Model Uncertainty** – The uncertainty from the individual models, experimental data and other sources and is captured in the phenomena identification and ranking table (PIRT) uncertainties imposed in the analysis
- **Plant Uncertainty** – The uncertainty in the measurements at the plant which are inputs to the evaluation model

- **Nodalization Uncertainty** –The impact of the specific discretization selected. There are multiple ways to represent the physical system which may result in different results.

Thus, the total uncertainty can be understood as the combination of all these uncertainties.

It is stated in NEDE-33005P-A on page 2-22 in Section 2.5.2 under item 8 that:

> *In principle, nodalization can be treated as an individual contributor to code uncertainty; however, quantification of nodalization uncertainty can be very costly. Thus, the preferred path is to establish a standard nodalization based on the assessment against separate and integral effects tests.*

4.2 Nodalization Bias

The adequacy of the base nodalization is established from the qualification basis, not from these nodalization sensitivity studies for LOCA calculations in a jet pump BWR. Additional discussion on the qualification cases is presented in Section 5.0 where sensitivities to specific aspects of the component nodalizations are shown. There are important differences between a multi-channel BWR application and a single-channel or few-channel integral system test (IST). The most obvious difference is that the integral tests have measured values to which the calculated responses can be compared whereas the BWR calculations do not. Also, the controlled boundary conditions associated with the ISTs make these tests more suitable for looking at separate effects due to nodalization of specific components because indirect effects due to feedback to/from the BWR system are minimized in the ISTs. The intent is not to minimize the importance of the BWR system effects for the intended plant LOCA application; instead, the intent is to place component spatial nodalization considerations in the larger context of the overall system and core modeling of the BWR. Subtle changes in plenum-to-plenum pressure drop that occur in the multi-channel BWR applications and impact the response of the PCT in the hot channels, have been incorporated into the BWR modeling [[

]]. The uncertainty of the BWR initial conditions, boundary conditions, and plant parameters are also addressed in the LOCA methodology as discussed in Chapter 6 of NEDE-33005P-A.

For TRACG LOCA application, the qualification basis lays out a standard component nodalization to use for the analysis. The work completed in M170165 looks at [[ ]] different nodalizations for jet pump BWR LOCA applications. The sensitivity studies performed show biases in the calculated mean PCT values relative to the base component nodalization PCT values. This is the bias quantification shown in M170165 Table B5.2-1 that is discussed in the beginning of Section 4.1.

For some of the sensitivities, [[

]]. The interactions in system phenomena change with break area and because of this the uncertainties are also different as has been illustrated for a BWR/4 in Figure 8.1-29 and for a BWR/6 in Figure 8.2-18 of NEDE-33005P-A (Reference 6). It is acknowledged that for different applications the break size associated with the maximum PCT can change; however, what does not change is the balance between phenomena that contribute to the PCT and its uncertainty. The key point is that these different uncertainty responses are already an integral component of how the licensing basis PCT is determined.

The PCT sensitivities with nodalization changes can vary for different break sizes. This is expected because the local physics that control the value of PCT are dependent on the LOCA system responses via a complex interaction between competing processes. Ultimately the PCT at a particular location occurs when the heat removal at that location balances the heat generation at that location. Local heat generation depends on the initial local power, decay heat as a function of time, and any additions of energy due to the zirconium-water reaction (generally small for jet pump BWRs). The initial power at the limiting location is fixed by conservatively choosing the bundle radial peaking factor, APS, and rod local peaking factors; thus, the decay heat versus time for this limiting location is determined. Consequently, it is the timing and duration of the poor cooling conditions that is most strongly correlated to the cladding temperature response. The *duration* of the temperature excursion in determining PCT is also important and was discussed in Section 5.3.2.4 of NEDE-33005P-A (Reference 6).

The complications due to system effects enter in via the local heat transfer coefficient. At the location and time of the PCT the local heat transfer mode will always be some form of steam cooling for any case that is producing a high PCT. That is because other heat transfer modes such as quenching, nucleate boiling, or subcooled forced convection are much more efficient and thus will result in a lower calculated temperature. Steam cooling heat transfer depends on steam flow rate and fluid quality. Both of these depend on the flow rate and enthalpy of fluid entering the channel and these two quantities in turn depend on system effects that control the pressure distribution, fluid inventory, and fluid distribution in the reactor vessel. Spatial nodalization for the channels and the vessel play a role but much less of a role than the role played by break location and size, automatic depressurization system (ADS) capacity and timing, and ECCS capacities and timings. The timing of cladding heatup is interrelated to the timing of ADS and ECCS activation and varies with break area as illustrated for a BWR/4 in Figure 8.1-22 and as discussed in Section 8.1.5.1 of Reference 6. The similar interactions and relationship to break area for a BWR/6 are discussed in Section 8.2.4.1 and illustrated in Figure 8.2-15 of Reference 6.

In consideration of the points made in the prior three paragraphs, it is productive to examine in more detail the selective sensitivity studies that show the largest mean PCT sensitivities to changes in nodalization to understand how they can be addressed. For this purpose, the key results from the selected nodalization changes with the highest mean PCT sensitivities are presented in Table 4-1 and Table 4-2. The results reported in Table 4-1 and Table 4-2 were obtained [[ ]] for each of the studied nodalizations.

The last row in Table 4-1 shows how the mean PCT from the [[

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Table B5.2-1 in M170165 (also Table 4-1 in this enclosure) shows that for the base nodalization the highest mean temperature from the small perturbations is [[ ]] for the limiting intermediate break. For the same break size and scenario, the highest mean value increase [[ ]] occurs when the VSSL radial nodalization rings are increased [[ ]]. The observed increase is for CHAN28 [[

]]. For all the nodalization studies, CHAN28 sets the PCT and thus determines the change relative to the base nodalization.

Figure 4-1 compares two power shapes for CHAN28. The light dashed curve shows the unrealistic power shape as modeled in M170165 and the dark solid curve shows a realistic power shape. Both APSs and APFs are conservative because together they [[

]]. Both curves satisfy the commitments [[ ]] in RAI responses 72 and 73 and in the third row of NEDE-33005P-A Table 6.2-2 (also Table R73-1).

The fact that the largest sensitivity occurs in CHAN28 is due to several factors. [[

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The modeling of CHAN28 has an impact on the calculated PCT for different break sizes as shown by the tabulated values in Table 4-1 and Table 4-2. [[

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The licensing basis PCT is calculated for the limiting intermediate break size. The duration of heatup varies substantially for the intermediate break sizes and generally is longest for the intermediate break size that produces the highest PCT. Heatup duration for intermediate break sizes is primarily determined by system interactions such as the timing of lower plenum flashing compared to when ECCS injection becomes effective after depressurization following ADS activation. This is the main reason that the calculated PCT remains relatively insensitive to changes to the channel axial nodalization as shown by the bottom rows in both Table 4-1 and Table 4-2. The mean PCTs for the intermediate break go down insignificantly [[

]].

Even with the more realistic CHAN28 APS and APF inputs, the largest sensitivity due to vessel (VSSL) radial nodalization remains essentially unchanged [[ ]]. Changes in VSSL radial nodalization slightly change the boundary conditions seen by CHAN28 that yields the highest PCT. Phenomenologically such changes are like those observed when the plenum-to-plenum pressure drops are impacted by changes in the number and power levels of the average CHAN groups. In the context of the potential impact on the licensing basis PCT, a bias of [[ ]] is small compared to the full-range uncertainty analysis maximum to mean span [[ ]] documented for the limiting intermediate break size reported in Figure R6-10 of Reference 6.

Now how the [[ ]] mean bias is expected to impact the licensing basis PCT is quantified. Section 9.2 of NEDE-33005P-A stipulates that: [[ ]]. The response to RAI-8 elaborates: "If the ΔPCT exceeds the analysis resolution, then it would be prudent to evaluate the effect on the upper tolerance PCT. This evaluation would be performed on the limiting break by exercising the full range sampling of the uncertainty contributors to obtain a new upper tolerance PCT." The response to RAI-71 makes it clear that [[ ]]. This process guidance has been applied to produce the results shown in Table 4-3 for the limiting intermediate break scenario that would set the licensing basis PCT.

As shown in Table 4-3 from the mean of 124 full-range uncertainty analysis cases, the change in vessel radial nodalization produces a mean PCT change of [[ ]]. As expected, this mean change is in close agreement with the mean change of [[ ]] from Table 4-2 based on the 59 small perturbations. This close agreement shows that the phenomena causing the mean difference is equally well represented by the small and full range uncertainty analyses when quantifying the mean impact [[ ]]. Most importantly, Table 4-3 shows that the change in the licensing basis PCT which is determined from the maximum of the 124 full-perturbation trials is an increase of only [[ ]]. This is an acceptable difference.

Table 4-1: Selected Sensitivity Studies for Jet Pump Plants with APF = [[ ]]

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Table 4-2: Selected Sensitivity Studies for Jet Pump Plants with Realistic APF = [[ ]]

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Table 4-3: PCT Changes from Full-Range Uncertainty Analysis (124 trials) for Limiting Intermediate Break

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Figure 4-1: CHAN28 Axial Power Shape and Axial Peaking Factor

5.0 STANDARD NODALIZATION JUSTIFICATION

In this section, responses are provided regarding "Provide a more academic evaluation of solution independence to nodalization. Use three successively increased levels of detail to demonstrate (or at least evaluate) grid-asymptotic behavior." The predictions compared to the test data for the code qualification studies are used to determine what nodalization should be used. The standard TRACG-LOCA nodalization is based on the assessment of TRACG predictions against separate and integral effects tests, which is discussed in Reference 6 Section 2.5.2 Item 8:

> *"In principle, nodalization can be treated as an individual contributor to code uncertainty; however, quantification of nodalization uncertainty can be very costly. Thus, the preferred path is to establish a standard nodalization based on the assessment against separate and integral effects tests. Nodalization studies have been performed in assessing this test data in order to determine the level of detail necessary to represent the important phenomena and then consistent levels of detail have been applied to establish standard noding schemes for the BWR. The standard BWR nodalization for TRACG for ECCS/LOCA applications is defined based on the qualification and is described in the TRACG Qualification LTR [2]. The standard nodalization shown in the Qualification LTR is a representative and typical of the least-detailed nodalization that is considered acceptable. Minor details may be added or changed from the standard nodalization provided the changes are shown not to invalidate the qualification bases and the effect on modeling biases and uncertainties are assessed."*

Among all the nodalization sensitivity studies presented in Table B5.2-1 of M170165, the sensitivity studies that have significant mean-to-mean differences are (1) vessel radial nodalization and (2) channel axial nodalization studies.

To evaluate the impact of channel axial nodalization, the "TRACG Quench Front Model Validation – LOCA Tests" from MFN 13-085 (Reference 3) are performed with the existing coarse nodalization, and a new, fine nodalization. In particular, the tests are Thermal-Hydraulic Test Facility (THTF) Tests 3.03.6AR, 3.06.6B, and 3.08.6C; Two-Loop Test Apparatus (TLTA) Test 6423; and Rig of Safety Assessment (ROSA)-III Tests 912 and 926. Refer to the TRACG Qualification licensing topical report (LTR) NEDE-32177P (Reference 4) for more information regarding these tests.

To evaluate the impact of vessel radial nodalization, the TRACG qualification Steam Sector Test Facility (SSTF) Test EA3-1 (analyzed in NEDE-33005P-A as well) is re-examined. Refer to the TRACG Qualification LTR NEDE-32177P (Reference 4) for more information regarding this test.

5.1 THTF

THTF was an experimental loop at Oak Ridge National Laboratory designed to represent typical pressurized water reactor fuel bundles, so the pressures are generally higher than for boiling water reactors. Three LOCA tests (3.03.6AR, 3.06.6B, and 3.08.6C) are simulated with TRACG as part of the quench model qualification. Note that these tests do not utilize spray, so there is no top down quenching. Also, the APS is uniform over the heated section. The coarse TRACG nodalization utilizes [[ ]] cells over the 144 inch heated length. The fine nodalization utilizes [[ ]] cells over the heated length.

The TRACG calculated rod temperature comparisons to data for the three tests are shown in Figure 5-1 through Figure 5-3. The results in those figures show that [[

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5.2 TLTA

TLTA is a 1/624 volume-scaled representation of a 218 inch vessel inner diameter BWR/6 standard plant used for LOCA and ECCS testing. The large break LOCA Test 6423/Run 3 is simulated with TRACG as part of the quench model qualification. The facility utilizes a chopped-cosine APS over the heated section. The coarse TRACG nodalization utilizes [[ ]] cells over the 150-inch heated length. The fine nodalization utilizes [[ ]] cells over the heated length.

The TRACG calculated rod temperature comparisons to data for the Test 6423 simulation are shown in Figure 5-4. [[

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5.3 ROSA

ROSA is a 1/424 volume-scaled representation of a 251 inch vessel ID BWR/6 used for LOCA and ECCS testing. The small break LOCA Test 912 and the large break LOCA Test 926 are simulated with TRACG as part of the quench model qualification. For this facility, the heated bundles are ½ height. The facility utilizes a chopped-cosine APS over the heated section. The coarse TRACG nodalization utilizes [[ ]] cells over the 74 inch heated length. The fine nodalization utilizes [[ ]] cells over the heated length.

The TRACG calculated rod temperature comparisons to data are shown in Figure 5-5 and Figure 5-6.

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5.4 SSTF

The purpose of the SSTF sensitivity study is to justify the adequacy of using the 3-Radial Ring Core Model.

The current 3-Radial Ring Core Model (or 4-Radial Ring Vessel Model) used in the TRACG LOCA application was based on the core radial ring sensitivity study in NUREG/CR-2571 (Reference 5) and in NEDE-32177P for SSTF tests. In NUREG/CR-2571 Section 3.3.7, the parallel channel phenomena were studied using TRACB02 for SSTF SEO CCFL Test SE1-5A. The core was modeled using both 3 rings and 5 rings (Figures 3.3.7-2 and 3.3.7-3 of NUREG/CR-2571). The results for this study are presented in Figures 3.3.7-5 through 3.3.7-8 of NUREG/CR-2571 for the 3-Radial Ring Core Model Case (Case 2) and in Figure 3.3.7-9 for the 5-Radial Ring Core Model case (Case 3). The comparisons of the results with data and with different core models demonstrated that "TRACB02 predicts the observed parallel channel flow modes and handles the multiple bundle hydraulic interactions accurately and the calculation results do not differ significantly between 3-Radial Ring Core Model and the 5-Radial Ring Core Model."

This sufficiency of using a 3-Radial Ring Core Model was further demonstrated in the comparisons of TRACG predictions using a 3-Radial Ring Core Model and a 5-Radial Ring Core Model of SSTF TEST SE3-1A in Figures 4.3-5 through 4.3-8 in the TRACG Qualification Report NEDE-32177P.

To further demonstrate the sufficiency of using a 3-Radial Ring Core Model (or a 4-Radial Ring Vessel Model), a sensitivity study of SSTF Test EA3-1 reported in NEDE-33005P-A (Reference 6) Section 7 is performed by using a 5-Radial Ring Core Model (or 6-Radial Ring Vessel Model). The original SSTF Test EA3-1 reported in NEDE-33005P-A used a 3-Radial Ring Core Model. Because the results for this SSTF test in NEDE-33005P-A were generated using the previous TRACG Level 2 code, a benchmark was made using the current TRACG Level 2 code. The benchmark results (compared against those presented in NEDE-33005P-A Figures 7.4-10 through 7.4-14 and Figures 7.4-16 and 7.4-17) are presented in Figure 5-7 through Figure 5-13. The curves labeled "Average – 6 Rings" are the average values from the 6-radial ring calculations, and they will be discussed later in this section. [[

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In the SSTF sensitivity study, the 3-Radial Ring Core Model (Figure 5.3-6 in NEDE-32177P) is modified to a 5-Radial Ring Core Model (similar to the layout in Figure 3.3.7-2 of NUREG/CR-2571). Except for the changes associated with core radial ring change from 3 to 5, no additional changes are made for this sensitivity study. [[ ]] statistical trials using the same PIRTs as used for the runs in NEDE-33005P-A are made. The sensitivity study results are presented in Figure 5-14 through Figure 5-20, which can be compared directly with the results in Figure 5-7 through Figure 5-13. [[

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To facilitate direct comparisons, the mean values of those parameters from [[ ]] statistical runs using the 5-Radial Ring Core Model (or the 6-Radial Ring Vessel Model) are plotted in Figure 5-7 through Figure 5-13 (those curves are labeled as "Average – 6 Rings"). Again, [[

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Figure 5-1: Rod Temperature Comparison for THTF Test 3.03.6AR

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Figure 5-2: Rod Temperature Comparison for THTF Test 3.06.6B

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Figure 5-3: Rod Temperature Comparison for THTF Test 3.08.6C

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Figure 5-4: Rod Temperature Comparison for TLTA Test 6423

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Figure 5-5: Rod Temperature Comparison for ROSA-III Test 912

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Figure 5-6: Rod Temperature Comparison for ROSA-III Test 926

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Figure 5-7: Comparison of System Pressure for SSTF Test EA3-1

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Figure 5-8: Comparison of Temperature at Pool Periphery at the Bottom for SSTF Test EA3-1

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Figure 5-9: Comparison of Temperature at Pool Periphery at Mid-Depth for SSTF Test EA3-1

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Figure 5-10: Comparison of Temperature at Pool Periphery at the Surface for SSTF Test EA3-1

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Figure 5-11: Comparison of Lower Plenum Fill Fraction for SSTF Test EA3-1

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Figure 5-12: Comparison of Bypass Fill Fraction for SSTF Test EA3-1

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Figure 5-13: Comparison of Upper Plenum Fill Fraction for SSTF Test EA3-1

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Figure 5-14: Comparison of System Pressure for SSTF Test EA3-1 (6-Radial Ring VSSL)

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Figure 5-15: Comparison of Temperature at Pool Periphery at the Bottom for SSTF Test EA3-1 (6-Radial Ring VSSL)

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Figure 5-16: Comparison of Temperature at Pool Periphery at Mid-Depth for SSTF Test EA3-1 (6-Radial Ring VSSL)

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Figure 5-17: Comparison of Temperature at Pool Periphery at the Surface for SSTF Test EA3-1 (6-Radial Ring VSSL)

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Figure 5-18: Comparison of Lower Plenum Fill Fraction for SSTF Test EA3-1 (6-Radial Ring VSSL)

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Figure 5-19: Comparison of Bypass Fill Fraction for SSTF Test EA3-1 (6-Radial Ring VSSL)

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Figure 5-20: Comparison of Upper Plenum Fill Fraction for SSTF Test EA3-1 (6-Radial Ring VSSL)

6.0 SUMMARY AND CONCLUSION

Based on the discussion and the additional information and analyses provided in this enclosure, it can be concluded that:

(1) The order of magnitude of the PCT standard deviation from the previous small perturbation analysis holds true for the analyses in M170165. All noding sensitivity analyses in M170165 have a standard deviation on or below the order of magnitude from the previous small perturbation analysis.

(2) It is found that the contribution of the nodalization uncertainty to overall model uncertainty is small compared to the other uncertainties and thus can be neglected.

(3) TRACG predictions against test data in the TRACG qualification report (Reference 4) are the basis for determining the adequacy of TRACG nodalization. The sensitivity studies for additional qualification tests demonstrated that the current vessel and channel nodalizations for the qualification are adequate.

(4) In view of the sensitivity to channel axial nodalization, GEH shall use [[

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7.0 REFERENCES

1. Letter from James F. Harrison (GEH) to Document Control Desk (NRC), Satisfaction of Limitation 10.7 for NEDE-33005P, Revision 0, "Licensing Topical Report TRACG Application for Emergency Core Cooling Systems / Loss-of-Coolant-Accident Analyses for BWR/2-6," M170165, July 7, 2017.
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6. GE Hitachi Nuclear Energy, "TRACG Application for Emergency Core Cooling Systems / Loss-of-Coolant-Accident Analyses for BWR/2-6," NEDE-33005P-A, Revision 1, February 2017.