October 19, 2012

Mr. Jerald G. Head
Senior Vice President, Regulatory Affairs
GE-Hitachi Nuclear Energy Americas, LLC
P.O. Box 780, M/C A-18
Wilmington, NC 28401-0780

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION RE: GE-HITACHI NUCLEAR ENERGY AMERICAS TOPICAL REPORT (TR) NEDE-33005P, REVISION 0, "TRACG APPLICATION FOR EMERGENCY CORE COOLING SYSTEMS / LOSS-OF-COOLANT-ACCIDENT ANALYSES FOR BWR/2-6" (TAC NO. ME5405)

Dear Mr. Head:

By letter dated January 27, 2011 (Agencywide Documents Access and Management System Accession No. ML110280323), GE-Hitachi Nuclear Energy Americas submitted for U.S. Nuclear Regulatory Commission (NRC) staff review TR NEDE-33005P, Revision 0, "TRACG Application for Emergency Core Cooling Systems / Loss-Of-Coolant-Accident Analyses for BWR/2-6." Upon review of the information provided, the NRC staff has determined that additional information is needed to complete the review. On October 1, 2012, James F. Harrison, Vice President - Fuel Licensing and I agreed that the NRC staff will receive your response to the enclosed Request for Additional Information (RAI) questions by March 15, 2013. If you have any questions regarding the enclosed RAI questions, please contact me at 301-415-2365 or Stephen.Philpott@nrc.gov.

Sincerely,

/RA/

Stephen S. Philpott, Project Manager
Licensing Processes Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 710

Enclosures:
1. RAI questions (Non-Proprietary)
2. RAI questions (Proprietary)

cc w/encl 1 only: See next page

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REQUEST FOR ADDITIONAL INFORMATION

BY THE OFFICE OF NUCLEAR REACTOR REGULATION

NEDE-33005P, "TRACG APPLICATION FOR EMERGENCY CORE COOLING SYSTEMS / LOSS-OF-COOLANT-ACCIDENT ANALYSES FOR BWR [BOILING WATER REACTOR]/2-6"

GE-HITACHI NUCLEAR ENERGY AMERICAS, LLC

PROJECT NO. 710

1) The NRC staff requests additional technical basis to justify the adequacy of statistical distributions presented in section 5.1 of the topical report (TR) that are used to determine 95/95 upper tolerance limits for comparison to the criteria of Title 10 of the *Code of Federal Regulations*(10 CFR) Part 50.46. Please address the following issues either generically and/or for specific phenomena and parameters, as necessary:
    a. Due to the strong influence of the data selection process on the resulting statistical distributions, objective rationale should be provided for the selection of test data and, equivalently, the implicit rejection of other potentially applicable data. Although some datasets may be more relevant than others, excessive selectivity could lead to underestimation of the true uncertainty.
    b. Some data populations used in the TR are of limited size, and it is not apparent whether sufficient statistical power exists to justify conclusions regarding normality and other distribution characteristics. Although the probability for Type I error is established by the confidence level, the probability for Type II error can grow quite large as the sample size is reduced.
    c. Please provide additional technical basis to justify the adequacy of statistical uncertainty distributions that are dependent on the data used to develop closure relations in the code (e.g., phenomenon identification and ranking table (PIRT) items A1, C26, F3, etc.). In this case, how does GEH account for the fact that the statistical distribution does not include a bias and/or fully account for the standard deviation that realistically may exist (e.g., due to issues such as those discussed in parts d. and e. below).
    d. Due to the potential for systematic error, the statement in section 5.0 of the TR that measurement error is implicitly included in comparisons of code predictions with test data appears correct based on the NRC staff's understanding only when data from multiple test programs is considered. In light of the discussion above, please clarify GEH's position on how systematic error is accounted for if data from diverse sources is not used in deriving uncertainty distributions.
    e. To avoid underestimating the true uncertainty, what consideration did GEH give to the fact that test conditions are generally idealized, simplified, and well controlled relative to complex plant conditions under which derived correlations and models are applied? For example, simplified geometries and reduced scales may lead to underestimation of

uncertainty, steady state uncertainty may be less than transient uncertainty, and the uncertainty may increase in an extrapolated transition region between the validation ranges of two correlations.

2) The NRC staff requests additional technical basis to justify the adequacy of neglecting statistical dependencies between random variable input parameters. The TR generally appears to treat statistical parameters independently, although some parameters would presumably be correlated. Neglect of statistical correlation between input parameters could lead to underestimation of 95/95 upper tolerance limits. Therefore, please describe the approach for identifying and accounting for statistical dependencies between input parameters and justify its adequacy, with emphasis on the issues below.
    a. In a number of cases, random variables used to generate uncertainty for a model or correlation that is used in multiple locations within the computational domain are assumed to be independent. Although part of the uncertainty associated with a correlation may be attributable to uncorrelated differences in local parameters (e.g., flow conditions), generally, GEH's technical basis for presuming that there is no linkage between predictions from the same model in different spatial components could not be discerned from the NRC staff's review of the TR, especially where similar flow regimes exist. The following examples (not all-inclusive) illustrate the issue:
        i. The Lee-Ryley correlation is used to calculate interfacial heat transfer within a variety of spatial components in the computational model, with independent, identically distributed random variable multipliers selected to perturb the heat transfer in each component. However, a significant piece of the model uncertainty is presumably driven by limitations residing in the Lee-Ryley correlation itself (e.g., the assumption of spherical bubbles), which would seemingly distort predictions in multiple spatial locations similarly.
        ii. Similar conclusions apply to statistical distributions for other models used in multiple regions of the computational domain, such as those for interfacial drag, interfacial shear and entrainment, heat transfer (Chen, Dittus-Boelter), etc.
        iii. Internal rod pressures may be correlated within a given assembly or section of core with a higher peaking than predicted.
        iv. The thickness of an oxide or crud layer on fuel rods may depend on conditions common to all rods, and may affect all correlations for heat transfer from the fuel.
    b. Uncertainties associated with predicting some parameters, for example interfacial heat transfer and interfacial drag / shear, are presumably correlated with each other through one or more fundamental input random variables influencing both parameters (e.g., in this case, interfacial area concentration and relative phase velocity). Please clarify how independence is assured in the selection of random parameters, or explain how the potential for correlation between random parameters is accounted for in the methodology.

3) A number of nodalization variations presented in Table 5.2-1 of the TR result in predicted changes to the peak cladding temperature (PCT) for a BWR/4 that approach or exceed the significance threshold of 50°F in 10 CFR 50.46 for changes or errors to a methodology. Estimating the aggregate effect of nodalization variations based on the available data shows that the potential range of cumulative variation is large (i.e., sum of absolute values of ΔPCT

values in Table 5.2-1), particularly for the potentially limiting intermediate break. Further, there appears to be potential for an increase in PCT that could be significant (e.g., sum of ΔPCT values in Table 5.2-1). As such, it is unclear that nodalization error is small relative to the uncertainties determined in the demonstration analysis in Chapter 8 of the TR or on par with time step variations of the magnitude shown in Figure 6.9-5 of NEDE-32177P, Revision 3. Therefore, please address the following requests:

a. Either (1) reduce the uncertainty band associated with nodalization to a level that is small relative to other uncertainties that are explicitly accounted for by the methodology, (2) reasonably estimate the nodalization error and include an allowance for this error in the methodology (e.g., through the analysis resolution), or (3) adequately justify the current approach.
b. Please provide results of similar nodalization and time step studies that are applicable to the expected limiting break for the BWR/2 design and further address the request in Part a. (above) considering the potential for limited margins to regulatory criteria.

4) In a number of places in the TR, the proposed disposition of certain evaluation model parameters (e.g., [

] (e.g., Table 5.2-1, section 8.1.3, section 8.1.4, Table 8.1-12, section 5.1.8.2). In light of the potential for random noise to cause significant variation in figures of merit in certain scenarios, please discuss to what extent single-simulation sensitivity studies genuinely reflect the expected influence of parameter perturbations in future statistical calculations for a similar reactor design, versus being attributable to random, noise-level perturbations. Please discuss measures taken to ensure that the results of sensitivity studies provide useful and representative data (e.g., sensitivity cases are performed with noise-driven phenomena such as the “parallel channel effect” held constant or from multiple simulations with varied noise-level inputs).

5) The TR asserts in section 6.4 that the range of PCT results conservatively accounts for the “parallel channel effect” via either normal distribution statistics or order statistics. However, no evidence is presented that the parallel channel behavior predicted by the TRACG [GEH proprietary version of the Transient Reactor Analysis Code (TRAC)] evaluation model would accurately represent multi-channel behavior in a reactor core. For example, due in part to phenomenological uncertainties as well as the grouping of bundles in the TRACG evaluation model, it is not clear that the probability of the TRACG peak-PCT bundle not being “plugged” with liquid is equivalent to the probability of all bundles in a reactor core containing similarly hot rods being unplugged during a LOCA. Without evidence of equivalence in this and similar comparisons between the evaluation model and an actual reactor core, confidence cannot exist that the parallel channel effect is realistically accounted for through upper tolerance limits derived from either normal distribution statistics or order statistics. In light of the discussion above, please address the following points:

a. Either revise the TRACG evaluation model to account for the uncertainties associated with the parallel channel effect conservatively or (if justifiable) realistically, or provide sufficient evidence to justify that the parallel channel effect is simulated by the existing TRACG evaluation model in a physically and statistically representative manner.

   b. Clarify the reactor types, break size ranges, and break locations for which the parallel channel effect is expected to have a significant impact on statistical predictions of PCT.

6) Please illustrate the impact of phenomenological uncertainties on the PCT range predicted by the TRACG evaluation model with the parallel channel effect isolated. Please provide a summary of descriptive statistics similar to Figure 6.4-2 for the same case (i.e., BWR/4 limiting break) but with the variability due to the parallel channel effect suppressed and the random variables for PIRT multipliers chosen according to baseline uncertainty distributions. Please further explain the technique used to bias toward prediction of hot channel plugging.

7) Please address the following issues associated with the concept of analysis resolution that is outlined in section 6.4 of the TR:
   a. The concept of analysis resolution is meaningful when used in the sense of practical limitations in the capability of an evaluation model to simulate known physical processes in a reactor to an arbitrary degree of precision. However, the linkage in section 6.4 between the analysis resolution and the parallel channel effect does not fully conform to this definition because the probability of bundles containing hot rods in the reactor being plugged with liquid appears to be a significant uncertainty that is fundamentally associated with a limitation in physical knowledge rather than the practical capability of an evaluation model. Therefore, please either redefine the analysis resolution in light of the discussion above, or provide adequate justification for the current approach.
   b. The general method for determining the analysis resolution elaborated in section 6.4 of the TR appears to be predicated on the presumption that, for all potentially limiting LOCA scenarios for operating BWRs, variation in the figures of merit due to [ ] that presumably influence the analysis resolution (e.g., nodalization error, time step error, model simplification error). If, however, the limiting LOCA scenario for a given BWR is not [ ] Please either generalize the proposed method for determining the analysis resolution, or provide adequate justification for the general applicability of the current approach to all potentially limiting LOCA scenarios for operating BWR designs.
   c. The NRC staff requests additional technical basis to justify the adequacy of a [ ] Please use an alternate [ ]
   d. Once an appropriate analysis resolution is defined that ensures external factors are bounded, please clarify whether it would be justified to accept a lesser total uncertainty for determining upper tolerance limits (e.g., the standard deviation associated with

calculation results). For example, [

]

8) Please provide clarification regarding the process discussed in section 9.2 for determining whether it is necessary to perform a revised statistical analysis in response to a change or error in the evaluation model. The TR states that a [

] Please clarify the following points:

a. What is the [

]

b. The TR appears to be inconsistent with 10 CFR 50.46, which mandates use of a fixed difference in PCT (50°F) as the criterion for determining whether a cumulation of changes and errors is significant. Given that the 95/95 upper tolerance limit is the regulatory figure of merit, please clarify how the proposed approach complies with 10 CFR 50.46, or revise the approach to ensure compliance.

9) Please illustrate whether [

] the BWR/4 demonstration case. Although general discussion of the topic is provided in section 8.3.2.1 of the TR, based on the information provided in this discussion, the NRC staff could not discern [

]

10) Please provide information similar to that provided in Figure 6.9-5 of NEDE-32177P, Revision 3, for the BWR/4 intermediate and small break time step sensitivity cases presented in Table 5.2-1 of the TR (NEDE-33005P). Please also provide similar information for the BWR/2 discharge Design Basis Accident discussed in section 8.3.2.1 of the TR.

11) Please provide an overview of typical results for the calculated PCT and cladding oxidation from the proposed TRACG evaluation model demonstration analysis as compared to those using the current SAFER evaluation model best-estimate and licensing results for analogous initial conditions.

12) Please clarify what assumptions are made concerning offsite power and the availability of nonsafety systems in the demonstration cases and, likewise, how nonsafety systems would be treated for future plant-specific analysis. For example, the small liquid break scenario in Figure 3.2-1 of the TR suggests that reactor pressure is maintained at a control setpoint prior to main steam isolation valve closure, rather than being controlled through the cycling of safety relief valves (SRVs), as indicated in the text of section 3.2.3. An analogous observation is made regarding Figure 8.1-6 and section 8.1.2.2, both of which cases are

contrasted with Figure 8.3-17, where SRVs appear to cycle. Please discuss how the availability of offsite power affects the figures of merit for compliance with 10 CFR 50.46 and justify that the assumptions made with respect to offsite power and nonsafety systems are consistent with analyzing the most limiting conditions. Please clarify whether these limiting conditions change as a function of break size.

13) [

] addressing the following points:

a. [

b.

c.

]

14) The TR indicates in section 3.4 that medium-ranked parameters have a small effect on primary safety parameters and may be excluded in the overall uncertainty evaluation. This definition and treatment is not consistent with the typical characterization of medium-ranked parameters as those having a moderate effect on figures of merit (i.e., neither dominant nor negligible). The NRC staff further noted that the demonstration analyses presented in section 8.1.3 appear to include several medium-ranked parameters among the most influential for determining PCT.
    a. Please confirm whether medium ranked parameters will be included in statistical analysis and revise the TR (e.g., section 3.4) as necessary to be consistent with the positions taken in this RAI response.
    b. Please confirm whether future plant-specific analyses will be based on the use of the highest overall rank for a given PIRT phenomenon versus design-specific / scenario-specific PIRT rankings. This distinction is important because, while the NRC staff agrees that the design- and scenario-specific PIRT rankings in the TR are largely representative of typical BWRs of a given product line, it is not clear that they fully capture design variations among individual plants (e.g., certain BWR/3s and /4s with elevated PCTs).

15) The technical basis for the uncertainty distribution and justification GEH proposed for PIRT item M9 (LPCI/Break Flow Interaction) was not apparent to the NRC staff. In particular, the

discussion in section 5.1.12.5 proposes that [

]
However, other factors would apparently influence this phenomenon, such as local flow conditions, the assumed break orientation and geometry, and nodalization. Therefore, please provide adequate justification to support credit taken for LPCI flow from the broken loop to the core across the spectrum of breaks for which this flow would be split between the break and the vessel. To the extent possible, please include reference to experimental data that can be used to validate the flow splits predicted by the TRACG evaluation model.

16) Please clarify whether TR reference [46] is consistent with the assertions in section 5.1.2.4 that [

]. Because of the significant difference in [

] is unclear.

17) Please clarify the nomenclature regarding lognormal distributions that is used throughout the TR.
    a. Please confirm what is meant by mode and gain when referring to the lognormal distribution. For example, see Figure 5.1-10, where the reported mode does not appear to correspond to the peak of the probability distribution function.
    b. Please confirm whether, in the discussion of PIRT item A1, it is correct that the quoted standard deviation of [ ] belongs to the associated normal distribution, rather than the lognormal distribution being discussed.

18) Please address the following issues with the statistical distribution for PIRT item F1 by revising the statistical distribution or providing adequate justification for the current approach:
    a. Representation of the void deviation using [
    ].
    b. It is unclear that the distribution parameters and imposed cutoff capture data at both the upper and lower extremes of the distribution (Is the minimum of [ ] samples reasonably considered the minimum possible value of the distribution?).
    c. The selection of a [
    ] inflate the expectation value of the multiplier.

19) Please explain and justify the criteria used for selecting test data for the uncertainty derivations for PIRT item A5 (lower plenum void distribution) and related PIRT item F1 (upper plenum void distribution). Different selections of data from some of the same test facilities (9 tests for A5 versus 28 tests for F1) were made to derive the respective uncertainty distributions.

20) In a number of demonstration cases in the TR, the PCT calculated for the limiting bundle [

] (e.g., Figures 8.1-5, 8.1-23, 8.1-24, and 8.1-25).

a. [
]

b. In cases where the maximum PCT occurs in a Ring 2 bundle, it does not appear to [ ] as discussed in section 5.1.6.4, [ ] Please provide an alternate justification that the spray flow distribution uncertainty is bounded in this case.

21) PIRT item F4 in section 5.1.6.4 discusses the spray distribution for an uncovered upper plenum.
   a. Please clarify whether [ ] in section 5.1.6.4 applies to [ ]
   b. Please clarify GEH's position concerning whether the specific information contained in TR section 5.1.6.4 is applicable only to [ ] or all BWR/2s.
   c. Please provide TR references [64] and [61].
   d. Please clarify whether spray degradation is primarily a function of reactor pressure or the differential pressure between the reactor vessel and wetwell. Please identify the wetwell pressure assumed in the calculation.

22) Please provide justification for ranking [ ] The TR notes that choking may occur at the jet pump for large discharge breaks, and this behavior is exhibited in the demonstration calculations in Chapter 8. The demonstration calculations also indicate that discharge breaks may be limiting for some BWRs.

23) The NRC staff was unable to confirm the statistical distributions proposed for certain parameters from either Table 5.1-2 or the text of Chapter 5 (e.g., PIRT items A2, A3 (wall heat transfer), C20 (minimum stable film boiling temperature), Q5, C22, L3, M8, G3). Please explicitly identify the statistical distributions proposed for any parameters if not previously provided.

24) Please confirm that the TRACG LOCA evaluation model will require fuel parameter inputs from the PRIME code, and that code options associated with fuel thermal conductivity degradation will be implemented in a manner that addresses NRC staff concerns expressed in its letter dated March 23, 2012 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML120680571). If approval for inputs from legacy fuel codes (e.g., GESTR is referred to in the TR) or legacy TRACG code options is requested, please provide justification.

25) Please clarify the behavior in Figure 8.1-5, wherein [ ] as stated in section 8.1.2.1. Nor does the difference appear to be primarily associated with the timing of reflood, since the divergence in temperature seems to originate approximately coincidently with the start of low-pressure core spray (LPCS).

26) Comparing Figures 8.1-6 and 8.1-7 (BWR/4 small-break LOCA), cladding temperatures appear to turn around rapidly following initiation of LPCS (even Ring 1 bundles), despite only faint quantities of core spray being injected prior to 300 seconds. Please explain this behavior and contrast it with the scenario analyzed in Figures 8.2-6 and 8.2-7 (BWR/6 small-break LOCA), where larger LPCS flows over approximately 30 seconds are unable to arrest the PCT transient.

27) The demonstration cases in Chapter 8 refer to the MELLLA+ power-flow map to establish limiting conditions for the analysis basis of BWR/4 and BWR/6 reactors. For plants that do not use this map, please clarify how the limiting power and flow conditions will be determined.

28) Based on Figure 8.1-10 in the TR, the limiting condition for axial flux peaking appears to depend on fuel-specific factors, such as the extent to which partial-length rods are present. Please clarify whether differences in fuel and/or plant design would be accounted for in the determination of the limiting axial flux profile used for plant-specific LOCA applications, or whether GEH considers node [ ] to be generically limiting for axial flux peaking. The NRC staff notes that node [ ] was considered to be the limiting axial flux peaking location for all TR demonstration calculations, apparently based on the analysis in section 8.1.4.2.

29) Similar to what has been provided for the BWR/4 in Table 8.1-5, please present results for sensitivity studies for BWR/2 axial peaking for the PCT and maximum local oxidation to confirm that the limiting axial flux profile has been identified. For example, it is unclear to the NRC staff that a [ ]

30) Please explain the [ ] for the BWR/4 case shown in Table 8.1-12. Further, although the upper bound ECCS coolant temperature considered seems relatively high, based on Figure 8.3-15, it is not clear that exceeding the nominal ECCS coolant temperature would not adversely impact cladding oxidation for a BWR/2. Please further discuss the influence of ECCS coolant temperature on oxidation for the BWR/2 (with emphasis on the limiting scenario) and adequately justify the choice of the limiting condition chosen.

31) Please explain further why it is not necessary or desirable to include biases in the break spectrum calculation (section 8.1.6). It is not clear that excluding biases would provide an acceptable method for identifying the limiting break location (discharge and suction breaks

are observed to result in similar PCTs for both BWR/4 and BWR/6 demonstration cases) and size range that is potentially limiting for performing statistical calculations.

32) The loss of an isolation condenser is taken as the limiting failure for the BWR/2 demonstration calculations in section 8.3.2.1. Given the marginal impact expected for the isolation condenser in mitigating a large-break LOCA, the basis for this choice is not clear. Although the TR states that the demonstration case core spray system is single-failure proof, these systems may experience failures (e.g., a booster pump or redundant pump) that degrade the system flow rate and/or discharge pressure. As such, it appears likely that the operational status of components within the core spray system may influence PCT and oxidation more than the isolation condensers. Please demonstrate the sensitivity of the BWR/2 to postulated single failures within the core spray system to identify whether these failures may be more limiting than the demonstration case. Based on the evaluation model proposed in the TR, the net influence of core spray system subcomponents is not clear due to the competing effects of increased spray cooling and the degradation of condensation heat transfer due to infiltration of noncondensible gases.

33) Please provide the following information related to PIRT item C18 (cladding perforation):
    a. A summary of or reference for the tests that includes the number of tests, the type(s) of cladding tested, and the heatup rates used.
    b. The basis for applying the empirical data used to estimate clad rupture stresses to current-generation fuels.
    c. The basis for the assumption of normality for the upper and lower 95 percent groups used to determine the rupture stress.
    d. Explanation of the origin of and justification for the assumed uncertainty of the built-in fuel rod internal pressure curves and the normality of the multiplier on rod pressure.
    e. Relative to the high-temperature phase change of zirconium, please clarify the statement on page 2-11 of the TR that phase change of in-core materials is not modeled.

34) From the discussion of PIRT entry B9 (three-dimensional effects of LPCI injection into the bypass region) in section 5.1.2.9, the basis for disposition of the issue appears to reference a nodalization sensitivity study performed for a BWR/4, for which the effect is presumably not relevant. Please provide adequate basis that increased azimuthal nodalization of the vessel is not necessary for modeling a BWR with LPCI injection into the bypass region, discussing any sensitivity studies that have been performed specifically for this case.

35) Unlike the other BWR demonstration calculations, the boiling transition peak for the BWR/2 case is not fully quenched for the limiting channel/rod. Thus, the temperature increase associated with boiling transition contributes to the eventual PCT. As such, please provide further justification that parameters affecting the boiling transition temperature increase (e.g., void coefficient, Doppler coefficient) do not appreciably influence the ultimate PCT.

36) PIRT item C3 includes phenomena associated with dynamic gap conductance and gap size, mainly focusing on post-scram pellet contraction. Please clarify whether the impact of clad ballooning on gap size is captured in this or another PIRT item, and explain how the assigned uncertainty derived from pellet conductivity applies to or bounds the effect of clad

ballooning. Please further characterize the approximate lower temperature threshold at which GEH considers ballooning important and identify whether the BWR/2 small-break LOCA, for which PIRT item C3 is ranked low, could reach this range.

37) In Table 3.4-1, PIRT entry F3 indicates that the PCT transient is over before the vessel is depressurized to containment pressure. However, this does not appear consistent with Figures 3.2-6 (showing nearly complete depressurization by approximately 100 seconds) and 3.2-9, as well as independent calculations performed by the NRC staff. Therefore, please either clarify the technical basis or revise the statement.

38) PIRT item M3 is ranked medium, even for the BWR/2 case. However, based on the demonstration calculations, M3 appears to have a dominant impact on the PCT. Please clarify whether GEH considers the PIRT to be fundamentally correct (i.e., the influence of this factor in code simulations is primarily due to a conservative assumption regarding the containment boundary condition), or whether an increased ranking should be assigned for the BWR/2 case.

39) Sections 4.3.3.2 and 4.3.3.1 referred to in the component performance qualification column of Table 4.2-1 do not appear to exist in NEDE-32177P, Revision 3. Please clarify whether these section numbers refer to NEDC-32725P, which addresses passive systems of the Simplified Boiling Water Reactor. Please explain the relevance of this testing to operating reactors or remove these references from NEDE-33005P.

40) Regarding PIRT items C2AX, B2, and C23, please justify that random perturbations to the distribution parameter (C_0 - 1) and entrainment coefficient (η) are sufficient to provide the expected variation in void distribution, addressing the specific issues below:
    a. Based on a comparison of Figures 5.1-8 and 5.1-9 to Figure 5.1-17, it is not clear that [ ] Similar limitations in reproducing the deviations in [ ] as well.
    b. Please justify that [ ] in a simplified geometry for different flow regimes (i.e., bubbly/churn, transition, annular) may help to demonstrate adequacy.
    c. Although GEH noted desirable properties of the [ ] and justify that the distortion is either negligible or conservative.
    d. Please compare the range of mass fluxes used in the Toshiba tests (section 5.1.3.3) with the mass fluxes expected for the hot bundles under limiting LOCA conditions and justify that the difference does not impact the assumed uncertainty distribution.

41) In section 5.1.1.9, the TR references NEDE-32177P, Revision 3, as containing a study of increasing the azimuthal sectors in the vessel from [ ] However, the NRC staff only located discussion of sensitivity studies that varied the number of azimuthal sectors from [ ] (Table 6.9-2 of NEDE-32177P, Revision 3, and Table 5.2-1 of NEDE-33005P). Please clarify whether additional sensitivity studies have been performed for azimuthal nodalization of the vessel and provide the results.

42) Please clarify the basis for the [ ] From the references cited in section 5.1.3.6, the justification for the individual uncertainties and their combination (i.e., presumably square root sum of squares) was not clear to the NRC staff.

43) Please clarify the statement in section 5.1.3.10 that an uncertainty of [ ] is sufficient to bound the uncertainty in the side entry orifice (SEO) loss coefficient. Specifically, please identify the source of the available data and the extent to which it is applicable to two-phase flow conditions during a LOCA.

44) With reference to section 5.1.3.19, please clarify whether fuel-specific biases and uncertainties will be used in conjunction with the GEXL correlation, as in NEDE-32906P, unless acceptable statistical analysis demonstrates that data for different fuel types may be pooled.

45) Please provide additional technical basis for the assumption that the uncertainty distribution for the Sun-Gonzalez-Tien correlation is [ ]. Intuitively, the additional degree of freedom (i.e., droplets) implies the potential for greater uncertainty relative to a single-phase correlation. Please clarify whether adequate experimental data exists to estimate the uncertainty specific to the Sun-Gonzalez-Tien correlation. Please further justify the adequacy of the assumed uncertainty distributions in the large region ($0.1<\alpha<0.5$) in which the Sun-Gonzalez-Tien and Bromley correlations are interpolated.

46) Please confirm whether the data that is the basis for the uncertainty distribution for PIRT item C16 is the data shown in Figure 6-33 of NEDE-32176P, Revision 4. Please further justify the adequacy of the proposed uncertainty range given the limited size of the database.

47) Please address the following issues associated with the discussion in section 5.1.3.23:

a. Heat transfer references indicate that the Dittus-Boelter correlation is appropriate for small to moderate temperature differences. The correlation tends to overpredict heat transfer at large temperature differences because it does not account for variations in physical properties due to the temperature gradient at a given cross section. The NRC staff understands that temperature differences of approximately 200-300K (jet-pump BWRs) and 400-600K (non-jet-pump BWRs) or higher can exist between fuel rods and steam during a LOCA. However, based on the results presented in NEDE-13462, the tests appear to be based on temperature differences of approximately [ ]

Please clarify whether allowance is made for the effect of the temperature difference in deriving the uncertainty distribution parameters and provide justification.

b. Please justify that no significant scaling issues arise from applying biases and uncertainties associated with tests using a [ ] bundle to a full-sized bundle. For example, please explain why the [ ] bundle tested would not underpredict the temperature for the interior rods of a full-size bundle based on an underestimation of edge-to-center variation and an overestimation of mixing and heat transfer to peripheral rods and the channel wall. Has subchannel analysis been performed to validate that scaling effects are insignificant?

c. The basis for the [ ] for internal rods appears to be derived from a deviation calculated from a bundle-averaged approach for the [ ] test bundle (i.e., including heat transfer from both interior and peripheral rods). Therefore, if a bias is applied only to heat transferred from interior rods, please clarify why the requisite bias would not need to be scaled up proportionally.

48) The TR indicates in section 5.1.3.25 that the uncertainty in spray cooling heat transfer is covered by uncertainties in other parameters. However, this conclusion is not sufficiently justified. In NEDE-32177P, Revision 3, [ ] Please reconcile the apparent conflict or provide further justification for this conclusion.

49) Please clarify whether the uncertainty distribution discussed in section 5.1.3.27 applies to both rising and falling quench fronts. If the uncertainty distribution applies to both, please clarify whether the uncertainty distribution database includes data from rising quench fronts. If not, please clarify how the uncertainty for rising quench fronts is addressed.

50) As shown in Figure 6-27 of NEDE-32176P, Revision 4, for post-LOCA pressures exceeding the range associated with a DEGB, the Iloeje correlation tends to predict values of the minimum stable film boiling temperature (T_{min}) that exceed other available correlations. Break spectrum calculations performed with the TRACG evaluation model suggest the possibility that small or intermediate breaks, with pressures exceeding 0.5 megapascals (MPa) during the PCT transient, could represent a potential limiting condition for some BWRs. Given that the Iloeje correlation is based only on data taken at a pressure of 6.9 MPa, it is not clear that the pressure trend in the post-LOCA range of interest can be considered reliable. It is further unlikely that the pressure-dependent trend is linked primarily to pre-existing oxidation on fuel rod surfaces. Ultimately, it is not clear that the impact of the pressure-dependent trend of the Iloeje correlation can be adequately addressed by application of [ ] Furthermore, the NRC staff observed that the demonstration case input decks use the Shumway correlation, which is recommended in the TRACG04P User’s Manual. Based on the discussion above, please revise the model used to predict rewet and/or its uncertainty distribution, or provide adequate justification for the current approach.

51) As applicable to the TRACG LOCA evaluation model, please specify the circumstances under which rewetting is permitted without satisfying the requirement that the local equilibrium quality is below [ ] of the critical quality. In addition, please provide adequate basis for the [ ] The NRC staff could not locate adequate basis for these values in NEDE-32176P, Revision 4, and NEDE-32177P, Revision 3.

52) In the discussion of PIRT item C22, the [ ] Please clarify whether the intent of the discussion in section 5.1.3.28 is that heat from the channel wall may be transferred to fluid on either the inside or outside of the channel wall. It is the NRC staff's understanding that heat is transferred to fluid inside the bundle essentially only when liquid is in contact with the interior channel wall (i.e., [ ]). Please revise the TR, as necessary. Please provide additional explanation and justification if the NRC staff has misunderstood the quoted statement.

53) Please clarify the source of the data for PIRT item C24, which states that TRACG predicts the spacer component of the core pressure drop with [ ] In contrast, Table 5-3 in NEDE-32906P, Revision 3, reports [ ] Given the potential for increased uncertainty associated with two-phase flow throughout the bundle, please provide adequate justification for [ ]

54) The 1979 American Nuclear Society Standard 5.1 decay heat calculation for an exposure of 15 GWd/MTU with TRACG shown in Figure 5.1-18 appears to predict decay heat power fractions that are significantly less than predictions with the same model for an exposure of 10 GWd/MTU using SAFER in NEDO-23785, Volume 3, Appendix B, Figure 1. Please clarify the different input assumptions or other causes that lead to this difference.

55) For some PIRT items, the uncertainty in future predictions of a regression model is assumed to be represented by the standard deviation associated with the data used to generate the regression model (e.g., [ ]). Please clarify why the uncertainty associated with future predictions (i.e., data not included in the regression model) need not be determined by the prediction interval for a new observation. See, for example, section 18.17 of NUREG-1475, Revision 1.

56) Based on the data plotted in Figure 5.1-19, it is not clear that a normal distribution explains the variation in predictions of the single-parameter model used for pre-accident oxidation. Please provide the Anderson-Darling normality test results for C26I (initial oxide thickness) and justify that the assumption of normality does not result in significant error relative to the criteria of 10 CFR 50.46.

57) The basis for the adequacy of the database used to derive the uncertainty distribution for critical flow is not clear, and the uncertainty proposed by GEH appears substantially lower

than other statistical studies. Please either revise the uncertainty distribution proposed in section 5.1.11.1 in response to the concerns below, or provide adequate justification that the proposed distribution remains appropriate in light of these concerns:

a. A large body of critical flow data exists; however, only nine tests were used to derive the uncertainty parameters for the TRACG LOCA evaluation model. The limited dataset is particularly important because critical flow behavior and uncertainties vary significantly across various flow regimes (e.g., subcooled, saturated liquid, two-phase, steam). Because the chosen tests appear to have been selected to span these flow regimes, the proposed uncertainty distribution resembles an amalgamation of even smaller samples from several distinct populations, rather than a statistical treatment of a single population. (The dependence of uncertainty on the flow regime is alluded to in section 6.3.6 of NEDE-32176P, Revision 4, which references a slightly larger database of eleven tests.) As such, the amalgamated uncertainty distribution proposed by GEH includes single-phase data, which downwardly biases the uncertainty in the critical flow rate for the limiting recirculation breaks where larger two-phase uncertainties dominate.
b. The basis for the selection of the nine tests used to derive the proposed uncertainty distribution (or, equivalently, the rejection of other applicable tests) from the large body of existent critical flow data has not been justified. In particular, some of the test data chosen to derive the uncertainty distribution (e.g., the comparison with GIRAFFE break flow at twenty minutes) does not appear to be among the most applicable with regard to simulating the limiting LOCA scenarios expected for operating BWRs.
c. The basis for choosing specific datapoints from a given test for comparison, as well as the weighting of data during the statistical combination process is not clear. Uncertainty associated with times early in the blowdown (e.g., for a large break) can be higher and further is apparently more influential on PCT than uncertainty at later times.
d. As applicable, please discuss the selection of critical flow discharge coefficients for the statistical database used to derive the uncertainty distribution and to what extent latitude in making this choice influences the statistical results. Please further clarify how discharge coefficients will be chosen for plant-specific analysis.
e. Please clarify the significance of noncondensibles on critical flow and the consequent impact on figures of merit for the LOCA evaluation model. If significant, please further discuss the validation of the models used for noncondensibles and identify whether the influence of noncondensibles is included in any of the tests in the statistical database.

58) The basis for the attribution in section 5.1.6.2 of all uncertainty associated with PIRT item F2 to the uncertainties associated with liquid side interfacial heat transfer and drag is unclear. For example, as discussed in section 7.8.2 and section 7.8.3 of NEDE-32176P, Revision 4, the modeling of injected spray and turbulent mixing both influence upper plenum mixing. Please justify the insignificance of these parameters or include them as factors in the uncertainty analysis for PIRT item F2.

59) Please provide Anderson-Darling normality test descriptive statistics for PIRT item F3. Please further clarify whether the correlation for turbulent films is of importance for the uncertainty analysis for a LOCA and whether this regime was covered by tests used to derive the uncertainty distribution or is otherwise accounted for by the TRACG evaluation model.

60) Please clarify the pressure drop parameter that is varied for PIRT item H4 (pump pressure drop) in the LOCA evaluation model and specify the uncertainty distribution and parameters along with justification. Please further identify the number of tests that were considered in the derivation of the uncertainty assumptions, and summarize the test conditions and the basis for their applicability to LOCA conditions.

61) For PIRT item M8, an effective reduction is proposed for its uncertainty relative to NEDE-32906P. However, under LOCA conditions, a greater uncertainty may actually be expected because (1) the peak mass flow rates during blowdown may exceed flows during normal operation (especially for the BWR/2 design) and (2) the flow is two-phase. Please clarify the extent to which these two factors are accounted for in the database used to derive the proposed uncertainty distribution, and if necessary revise the uncertainty distribution.

62) The TR proposes in section 5.1.13.2 a range for isolation condenser heat transfer [ ] If isolation condensers are credited for the limiting LOCA scenario for a given plant, please commit to validating that this distribution is appropriate on a plant-specific basis for future licensing calculations and revise the TR to state as such.

63) In May 2004, BWR/2 licensees submitted 10 CFR 50.46 notifications that refer to an exothermic hydrogen-oxygen recombination reaction having the potential to increase the calculated PCT and local oxidation. The phenomenon appears to have been dispositioned, in part, based on the conservatism inherent in the Appendix K evaluation model. Please discuss and provide justification if the hydrogen-oxygen recombination phenomenon is deemed insignificant for BWR/2s in the context of the best-estimate TRACG evaluation model.

64) Please clarify the method used to derive the uncertainty bands for the CCFL constant, K, for PIRT items C6 and C7 and provide the following references:
    a. D.D. Jones, "Subcooled CCFL Characteristics of the Upper Region of a BWR Fuel Bundle," NEDG-23549, July 1977.
    b. D.D. Jones, S.S. Dua, "GE Analytical Model for LOCA Analysis in Accordance with 10CFR50 App. K; Amendment 4 – Saturated CCFL Characteristics of a BWR Upper Tieplate," NEDE-20566-4-P, July 1978.

65) Section 7.1.1 of the TR states that continuity in the probability density functions for figures of merit is a requirement for determining non-parametric tolerance limits according to Wilks' Theorem. However, it is not obvious that these probability density functions will, in general, be continuous. In fact, [ ] calls the TR's assumption of continuity into question. Therefore, please demonstrate that the requirement for continuous probability density functions will be satisfied in the application of the evaluation model described in the TR for quantifying a single probabilistic statement of safety for the complete spectrum of break locations and sizes, the complete spectrum of model parameters and their variation, and the nonlinear feedback introduced by the engineered safety features. In other words, please show that there are no disjoint density

functions of the figures of merit, or they can be identified and taken into account in the application of Wilks' Theorem.

66)

(a) Please justify the conclusion made in the TR that 59 code simulations is sufficient to establish joint 95/95 upper tolerance limits for all pertinent criteria of 10 CFR 50.46 (i.e., PCT, local oxidation, and core-wide oxidation) using non-parametric order statistics. For background, please refer to the discussion provided in the NRC staff's review of a similar statistical approach (ADAMS Accession No. ML062150349).

(b) Please justify the conclusion that assessing compliance with the criteria of 10 CFR 50.46 on an individual basis using a combination of parametric and non-parametric statistical approaches is capable of assuring that 95/95 limits are jointly satisfied. Please further justify that choosing between the parametric and non-parametric approaches *a posteriori* does not degrade the intended confidence level.