REQUEST FOR ADDITIONAL INFORMATION

AREVA NP, INC. (AREVA) TOPICAL REPORT ANP-10300P, REVISION 0

"AURORA-B: AN EVALUATION MODEL FOR BOILING WATER REACTORS; APPLICATION TO TRANSIENT AND ACCIDENT SCENARIOS"

The questions below are organized in reference to the documents submitted as part of this review, including the presentations made by AREVA as part of this review.

AREVA Post-Submittal Presentation, August 14, 2013.

RAI-1 The AREVA staff presentation on August 14, 2013, identified several areas that require additional information for the review.

A) A notification of 'errors found' was attached to NRC:11:081 (noted as Attachment B, **[ ]**). A total of 21 errors/deficiencies were reported (these were identified as primarily data extraction and editorial). Please provide a more detailed summary of the errors and resolutions.

B) Internal Condition Report **[ ]** is used to track supplemental information needed to bring the AURORA-B licensing topical report (LTR) consistent with the latest code version. Provide a summary of any areas in the AURORA-B results presented in the current documentation that were not performed with the latest code version and discuss the resolution path to bring the AURORA-B LTR up-to-date with the latest code version and how it will be kept up-to-date with evolving code versions in future.

ANP-10300P, Revision 0, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios," AREVA December 2009.

RAI-2 The basis for the S-RELAP5 Component Calculational Device (CCD) is identified as the realistic large break loss-of-coolant accident (LBLOCA) code version (EMF-2103(P)(A), Revision 0).

How does this relate to EMF-2100(P)? Is there a **[ ]** Model and Correlation Manual that would provide a delta-review for EMF-2100P?

RAI-3 The water properties are identified as lookup tables. Boiling Water Reactor (BWR) steady state and transient operation relies more heavily on the use of the water property tables in the two-phase region.

Identify whether additional uncertainty evaluations have been made in regards to the water property tables for the BWR operating range.

RAI-4 Control system modeling is identified as required for the AURORA-B evaluation model (EM) (e.g., ANP-10300P, Table 5-4). This includes thermal, hydraulic, and neutronic systems.

How are uncertainties addressed relative to the control system modeling identified in Table 5-4?

RAI-5 Phenomena identification and ranking tables (PIRTs) D03, LP01, and G11 are associated with **[ ]** (ANP-2831P). Section 3.4, Table 5.6, and Section 5.2.8 of ANP-10300P identify that "**[**

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A) Address the potential impact from numerical diffusion (e.g., cold water injection slug that is smoothed due to nodal averaging).

B) Identify those scenarios where **[ ]** is expected to occur relative to **[ ]** issues. What validation cases are used to verify the conservatism of **[ ]** for the various transients to be analyzed and is this transient specific?

RAI-6 The 'transient class' that the AURORA-B EM is applicable to is defined explicitly in Section 3.1.2. This section states: "Provided that the licensing basis of the plant does not significantly depart from the standard review plan (SRP) bases, the AURORA-B EM supports the licensing basis of each plant to which it is applied, consistent with the criteria defined in the licensing basis documents for the plant." The LTR does not address the applicability of the EM to a plant with a licensing basis that *does* "significantly depart" from the SRP bases. Elsewhere in the LTR, it is stated that the AURORA-B EM is applicable to "all BWRs equipped with forced recirculation systems." This is potentially a broader class than explicitly defined in Section 3.1.2. Please clarify this issue by addressing the following:

A) What constitutes a "significant departure" from the SRP bases?

B) What procedure or evaluation steps are followed to verify that the AURORA-B EM is applicable to a given plant with respect to the plant's particular licensing basis?

RAI-7 The discussion in Section 3.1.2.7 of the applicability of the AURORA-B EM to SRP 15.8 transients (anticipated transient without scram) and additional discussion in Section 8.3 states that this LTR addresses only two aspects of this subclass of transients. Specifically, the EM is described as applicable to evaluations addressing "protection of the reactor pressure vessel and associated piping from failure due to over-pressurization, and demonstration that fuel integrity is maintained," and further limits the analysis to "only through the time at which boron begins arriving at the core." Section 8.3 notes that without scram, reactor shutdown is accomplished by initiation of the standby liquid control system (SLCS) which injects water containing dissolved boron into the reactor primary coolant. The EM does not include the SLCS in the system model and does not include the effect of boron feedback to the neutronics models.

The LTR asserts that for evaluations of this class of transient it is conservative to neglect the added mass injected into the system from the SLCS and to terminate the evaluation at the time when boron would reach the core. It is not clear that the EM would in all cases conservatively predict the maximum pressurization in this transient or the maximum core power. Please clarify the phenomenological and modeling basis of the assertion of enveloping conservatism for this simplified approach to evaluations of this class of transient using the EM. Specifically address the following issues:

A) What is the basis for determining the amount of time required for boron to reach the core in this transient scenario? What are the possible uncertainties introduced by the assumptions of boron concentration as a function of time in the water entering the core?

B) What is the phenomenological basis of the implicit assumption that maximum over-pressurization will in all cases occur in the time interval before boron reaches the core?

RAI-8 Plant nodalization is dicussed in Section 5.2.8. In several sections it is identified that nodalization of the test facilities are not prototypic of the expected BWR nodalization (e.g., Section 6.6.1.1).

What nodalization sensitivity studies are planned or have been completed to verifiy that guidance provided for the AURORA-B EM nodalization is adequate (with respect to convergence and accuracy) for the different tranisents?

RAI-9 The discussion in Section 5.2.9.1 (Page 5-28) summarizes the process for determining the **[** **]** response in transient calculations, **[**

] in the above relationship does not take into consideration the uncertainty in the CPR correlation and associated methodology used to predict boiling transition in the transient. Rather than **[**
] to account for uncertainties in the CPR correlation and in the general application methodology. **[** **]** in the above relationship has the potential of over-estimating the margin to boiling transition in the transient for the given assembly.

Justify the use of **[** **]** response.

RAI-10 The discussion in Section 5.2.9.1 (Page 5-29) states "**[**

]." As formulated, this statement cannot be objectively assessed by an independent reviewer.

What criteria are used to define a [ ] for the fuel design?

RAI-11 Several references are made to a MICROBURN-B2 core simulator to initialize MB2-K and that models and boundary conditions are made consistent with the core simulator.

Provide additional discussion of the core simulator and its interaction with both MB2-K and S-RELAP5. In particular, discuss how both geometry and initialization data are controlled.

RAI-12 The LTR (Section 6.8.4.4) uses an uncertainty in [ ] a function of gas composition, gas pressure, and clad-fuel surface roughness (if fuel cladding contact is present). Therefore, utilizing [ ]. In addition, significant differences in predicted gap conductance values between different codes have been observed in direct comparisons, even in cases where such codes have been verified against the same Halden measured fuel temperature data. This is due to the fact that gap conductance cannot be measured. It is only inferred from fuel centerline data based on an assumed fuel thermal conductivity and as a result is strongly dependent on model parameters, such as the assumed conductivity.

A) Please provide a prediction of gap conductance uncertainties [ ], identifying all of the parameters and their uncertainty perturbations used to estimate the distribution of gap conductance such that an independent statistical analysis can be performed with the FRAPCON-3.4 code. Code input and output should be provided for the mean gap conductance and the upper and lower (one sided) 95/95 tails of the gap conductance distribution such that 3 independent calculations can be performed with the FRAPCON code. The FRAPCON code will also be used to perform an analysis of gap conductance distribution that accounts for gap width as well as gas composition (fission gas release) uncertainty to determine the effect of the latter on distribution.

B) Also provide a distribution plot of predicted gap conductance.

C) Please provide the rod power and burnup level for the limiting hot channel MCPR for each current fuel design for different plants.

RAI-13 [ ] in ANP-10300Q1P, Revision 0). This appears to be inconsistent with the fact that [ ]. For consistency, it appears that the gap conductance (see RAI-12 above) uncertainty for the hot subchannel should be a [

]. In addition, the gap conductance may be biased such that has not been considered.

Justify using the **[** **]** for determining the gap conductance uncertainty for the hot channel and the possible bias in the calculated gap conductance. Reconcile this assumption with the fact that the **[** **]**.

RAI-14 A correction was made to Section 6.8.4.3 (bottom of Page 6-165) of the submittal in relation to the sensitivity analyses for Feedwater Controller Failure (FWCF) and Main Steam Isolation Valve events. It appears that this correction may alter Table 32-1 of earlier responses to RAIs.

Please explain the effect of the noted correction on the information reported in Table 32-1. If the contents of this table should change as a result of the correction, please provide an updated Table 32-1.

RAI-15 The following is intended to clarify which RODEX4 models are used in AURORA-B.

Are there any RODEX4 models used in the AURORA B code, other than the following?

i. **[** **]**
ii. **[** **]**
iii. **[** **]**
iv. **[** **]**

If other models are used but are not documented in BAW-10247P, identify and provide complete descriptions of these models and explain how they are used in the AURORA-B EM.

RAI-16 Gaseous swelling and burst fission gas release have been observed in high burnup fuel during rod power increases.

Please provide data and analyses **[** **]** fuel gaseous swelling and burst fission gas release (due to fracturing of highly pressurized bubbles) for each of the anticipated operational occurrence (AOO) events where fuel temperature increases.

RAI-17 Section 8.1.4 states that some AOOs are limiting at beginning of cycle (BOC), some at end of cycle (EOC), and some are limiting at intermediate times in the cycle.

A) Please provide the methodology used to determine the limiting exposure for those AOOs that are limited by hot channel ΔMCPR.

B) Please provide the methodology used to determine the limiting time for each AOO event that is modeled core-wide in the fuel cycle being analyzed. If a particular event is always more limiting at BOC or EOC, please provide justification explaining why this is always limiting at this time during the cycle for each plant type.

RAI-18 In Section 9.3, criteria are established defining an “insignificant change” in three figure of mertis (FoMs) (specifically, **[** **]**) due to a code change or in a sensitivity analysis. Criteria are also established defining a “small change” in these FoMs when comparing results of “two comparable analyses.” For **[** **]**.” Clarify the use that will be made of these definitions in application of the AURORA-B EM, and address the following specific questions.

A) What specific range of operating conditions are encompassed in the term “**[** **]**?” How is this range extended to transient conditions?

B) What use, if any, might be made of these definitions for conditions outside the range defined as “**[** **]**?”

C) What is the basis for reporting only 2 decimal places for MCPR, when CPR correlations are typically assessed with 3 decimal places in the MCPR?

RAI-19 In Section 9.4, the LTR asserts that AREVA may perform code modifications to elements within the EM without having to seek further NRC approval, if the changes in results fall within the definitions cited in Section 9.3. Examples of such potential modifications specifically listed in Section 9.4 consist of

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The reviewers acknowledge that three of these **[** **]** might reasonably fall within the purview of a quality program that is compliant with Title 10 of the *Code of Federal Regulations* Part 50 Appendix B requirements. Therefore, changes of these three types should not require further NRC approval, provided the effects on relevent FoMs fall within the definitions outlined in Section 9.3.

The remaining two items **[** **]** involve making changes to the basic modeling capabilities of the AURORA-B EM and could potentially alter the technical basis upon which the EM (and component codes) has been reviewed and approved. In most cases, it would be expected that changes of this nature would either expand the range of applicability of the EM or would in some sense improve the predictive capability of a given model or closure relationship and, therefore, NRC review would be required. However, such changes may not fall within the stated definition of ‘significant’ and still be changes that should be submitted for review.

Please address the following concerns for making model and code changes without NRC approval:

A) The potential for compensating errors or model/methodology changes resulting in "no significant change" in results.

B) Individual changes may result in "no significant change" but the cumulative effect of several changes over a period of months/years could be significant. There have been cases in past NRC reviews where each individual model or methodology change was not significant (within the criteria proposed in Section 9.3 of this LTR) but the combined changes were significant (as determined by NRC review).

C) The potential for adverse interactions or incompatibilities with other models in the code.

D) Completeness of verification and validation of the new model and of the EM in general, relative to the results presented in Section 6 of this LTR.

E) If new data are added for verification, how would the applicability and uncertainty in this new data affect overall uncertainty in relation to the code applications.

RAI-20 From the description provided, it appears that MICROBURN-B2 ignores bypass flow void fraction by treating the bypass flow water as if it were mixed with the water within the assembly. It is not clear that pin power reconstruction can be accurately determined using this approach. Rods near the bypass channel will be underpredicted while rods away from bypass overpredicted and this effect this will be greatest at high void fraction, e.g., greater than 90 percent. In addition, it is not clear that the modeling simplification of mixing bypass flow water with assembly water is conservative for all steady-state conditions.

A) From the description provided MICROBURN-B2 appears to assume that the bypass flow and the assembly flow always have the same void fraction. Is this always a conservative assumption, can one flow path void more rapidly than the other flow path? How will this impact the accuracy of pin power reconstruction? If bypass flow is treated separately, please describe how this is done and the data used to confirm void the modeling is satisfactory for the bypass flow.

B) MICROBURN-B2 use a fitting function for cross-sections. Figure A-15 in ANP-10300Q1P, Revison 0, suggests that the fitting function starts to under-predict reactivity after approximately 80 to 85 percent void. Is this conservative for all transients considered under this LTR? If not, please discuss the non-conservatism. Does the code stop the analysis when these fitting functions start extrapolating past where they are valid? How are cross sections determined for greater than 80 percent void for pin power reconstruction?

RAI-21 The calculation of 3-dimensional (3D) assembly power and the expansion to individual pin powers is important because it is used to evaluate fuel design limits (Section 4.3 and Sections 1 and 3.2 of 2A4-MB2K-0). The report states that MB2-K uses the same methods as MICROBURN-B2 to determine assembly and pin powers.

In order to demonstrate that both codes provide the same results, please provide a comparison of steady state MB2-K assembly power, pin power expansion, and decay power with MICROBURN-B2 for the same conditions.

RAI-22 No limitation on application of MICROBURN-B2 for determining assembly to assembly power could be found in the submitted documentation. Similarly no limitation could be found for the methodology used for determining fuel pin to pin rods powers.

A) Is there a limitation on application of MICROBURN-B2 for assembly to assembly power peaking? If so, identify the appropriate data and explain how it was used to make this determination. If not, explain how it can be assured that MICROBURN-B2 and MB2-K will not be applied outside the applicability range of assembly peaking.

B) Similarly, is there a limitation on methodology for pin-to-pin power peaking? If so, how was this determined? The response should identify the appropriate data used. If not, how can it be assured that this methodology will not be applied outside the applicability range for pin peaking?

RAI-23 The void predictions for the 18-inch diameter void fraction tests are **[** **]** on average in Figure 6-7.

Please discuss reasons why the code **[** **]** this particular dataset and the possible impact this **[** **]** may have on each of the AOO events.

RAI-24 Section 6.2.5 states “Since USNRC approval in Reference 5, qualification of the code system has been confirmed for EPU [extended power uprate] conditions.” It is not clear that the modeling simplification of mixing bypass flow water with assembly water is conservative for all transient conditions and that assumed cross sections are accurate at high void fractions. Additional information is needed to justify the accuracy of the neutron kinetics parameters and response in MB2-K given the following observations.

A) From the description provided, MB2-K appears to assume that the bypass flow and the assembly flow always have the same void fraction. Is this always a conservative assumption, can one flow path void more rapidly than the other flow path? If bypass flow is treated separately please describe how this is done and the data used to confirm void the modeling is satisfactory for the bypass flow for transients.

B) MB2-K uses a fitting function for cross-sections. Figure A-15 in ANP-10300QP, Revision 0, suggests that the fitting function starts to under-predict reactivity after approximately 80 or 85 percent void. Is this conservative for all transients considered under this LTR? If not, please discuss the non-conservatism. Does the code stop the analysis when these fitting functions start extrapolating past where they are valid?

C) How are cross sections determined for greater than 80 percent void?

RAI-25 Section 6.4 suggests that AURORA-B provides reasonable predictions for core wide events in Tables 6-4, 6-5, 6-6, 6-7, 6-8, and 6-9. However, no comparisons are made for predicted power distributions for each case. Therefore, no conclusions are possible about the code's ability to predict power distributions.

Provide a comparison of pin to pin power distributions and assembly to assembly distributions for each case documented in Tables 6-4 through 6-9.

RAI-26 Section 6.6.2.1 discusses distortions in local power range monitor (LPRM) measurements and the time to achieve peak power.

How would the difference in the real versus calculated delayed neutron parameters impact the result? How sensitive are the results to changes in delayed neutron fraction?

RAI-27 Table 6-19 provides a **[ ]**. This data appears to be an average of the measured peak powers achieved during the transient. Figures 6-68, 6-74, and 6-80 show the predicted and measured initial (steady-state) axial powers prior to the transient. The **[ ]**.

A) What is the distribution of LPRM measured versus calculated (radial power changes during each of these events)?

B) How are these **[ ]** included in the biases and uncertainties in Table 6-36 and licensing applications?

C) How is the assumption that **[ ]** validated?

D) How is the assumption that transient pin power distribution is proportional to assembly power distribution validated?

RAI-28 Section 6.8.5 has provided a **[ ]**. This uncertainty is also proposed to be applied for AURORA-B AOO analyses.

Please provide data to justify this uncertainty value for each of the events evaluated with AURORA-B.

RAI-29 The discussion of results of model comparisons with measured void fraction data in Section 6.2.1, Rod Bundle Void Tests, is too limited and condensed for a complete review of void fraction modeling as it relates to the highly ranked PIRTs (i.e., **[ ]** (C06), **[ ]** (C07), and **[ ]** (C13)) identified at the beginning of this subsection. Specifically, the assessment is summarized with three plots (Figures 6-1, 6-2, and 6-3) showing calculated-to-measured predictions of bundle average void fraction from the FRIGG and KATHY databases.

Instrument uncertainties reported in Table 6-1 as plus or minus (±) values are not defined and the error bars shown on the data points in Figures 6-1 through 6-3 are inadequately explained. The LTR also fails to address sources of uncertainty other than instrumentation uncertainty even though the text expressly acknowledges that the instrumentation uncertainty does not capture the total uncertainty in the experimental data (as noted on Page 6-4 of the LTR, "However, the total uncertainty of the measurements (including power and flow uncertainties) is expected to be larger than the indicated values"). In most situations, experimental uncertainty is much larger than instrument uncertainty and using instrument uncertainties alone to assess code prediction performance is likely to result in overly optimistic (non-conservative) conclusions. Even though this is tacitly acknowledged in the LTR, nothing is presented to address this issue or quantify the total uncertainty in measured void fraction values presented in this section.

The information provided in Section 6.2.1 (showing direct comparison of predictions to data and the incomplete quantification of the uncertainty in those predictions) is not sufficient to perform a review assessment of the capabilities of the component models in the EM to appropriately predict these important phenomena. Please provide an expanded discussion of the validation and verification of the two-phase flow models used in the EM, addressing the following specific issues.

A) Please provide calculated-to-measured comparisons of axial distribution of void fraction for specific tests in the database, spanning typical BWR operating ranges of flow rate, pressure, and inlet subcooling, insofar as possible within the range of the experimental databases. The FRIGG databases in particular have an excellent axial resolution of void measurements. The ATRIUM-10A void tests are somewhat more limited in this regard but still provide calculated-to-measurement comparisons for at least three different axial levels within the test section.

B) Discuss the performance of the model predictions relative to the measured data (i.e., biases and random uncertainties) over the axial length of the test section, particularly addressing any local variations in the fit (compared to the overall fit to this data illustrated by the comparisons in Figures 6-1 through 6-3.)

C) Examining the plots in Figures 6-1 through 6-3, it appears that the uncertainty in the void fraction predictions compared to measured data **[ ]** for the ATRIUM-10A void fraction tests (see Figure 6-3), compared to the result shown for the FRIGG tests (see Figures 6-1 and 6-2). Since the ATRIUM-10A assembly geometry is more typical of modern BWRs and therefore of the expected application of the EM, this suggests **[ ]**.

   Discuss the implications of this modeling result, particularly in terms of its effect on the appropriate approach to **[ ]** obtained in applications of the EM to **[ ]**.

D) Explain what the instrument uncertainties represent in Table 6-1 and completely define the uncertainties encompassed by the error bars in Figures 6-1 through 6-3. Provide estimates of the total uncertainties (instrument plus experimental) in measured void fraction values for this data. If replicate tests exist in the data sets, use them to quantify the total uncertainties in measured void fraction values. Otherwise, provide rough estimates of total (instrument plus experimental) uncertainties based on experience or other applicable data sets that contain replicate tests. These estimates of the total uncertainty (measurement plus experimental) should be included in Table 6-1 and in the error bars on figures, not just measurement uncertainty. Revise the discussion in Section 6.2.1 to include the effect of the total uncertainty on the assessment of code predictions for this data.

E) Explain the source and derivation of the **[ ]** in Figures 6-1 through 6-3 and address their relationship to the total uncertainty in the measure void fraction values. Discuss the significance of **[ ]**.

RAI-30 The discussion of results of model comparisons with measured void fraction data in Section 6.2.2, Christensen Void Tests, is also too limited and condensed for a complete review of void fraction modeling as it relates to the highly ranked PIRTs (i.e., **[ ]** (C06), **[ ]** (C07), and **[ ]** (C13)) identified at the head of this subsection. In addition, the same issues noted in RAI 29 related to appropriate presentation and evaluation of the total uncertainty in the data and its effect on the assessment of code performance are applicable to the information presented in Table 6-2 and Figure 6.4.

Because this data is from a rectangular single-channel test section, it is less directly relevant to anticipated applications of the EM but this venerable data set has been used to develop and evaluate the performance of a wide range of two-phase flow models and correlations. As such, the ability to appropriately compare with this data set is a useful verification and partial validation of the models incorporated in the EM. Please provide an expanded discussion of the validation and verification of the two-phase flow models used in the EM, as provided by comparison to this data set, addressing the following specific issues.

A) Please subdivide the presentation of the calculated-to-measured comparisons in Figure 6-4 to differentiate the region of test conditions, including pressure, inlet flow rate, and inlet subcooling. Discuss the significance of any observed variation in the fit of calculated to measured results within these subdivisions of the database, particularly in regard to variation from the average fit to the entire database.

B) Please expand the presentation of comparisons of axial void distribution to include individual tests spanning the region of typical application of the EM to modern BWR operating conditions, insofar as the range of the database allows.

(Figure 6-5 shows three tests with a range of inlet subcooling values, but at 600 pounds per square inch absolute (psia), and does not identify the range of flow rates encompassed by these three tests. Additional profiles should include data from tests at typical operating conditions of 1000 psia and should also identify the associated inlet subcooling and flow rate.) Discuss the significance of any observed variation in the fit of calculated to measured results for axial profiles from different operating ranges, particularly in regard to variation from the average fit to the entire database.

C) Explain what the instrument uncertainties represent in Table 6-2 and what uncertainty is encompassed by the error bars in Figure 6-4. Provide estimates of the total uncertainties (instrument plus experimental) in measured void fraction values for this data. If replicate tests exist in the data sets, use them to quantify the total uncertainties in measured void fraction values. Otherwise, provide rough estimates of total (instrument plus experimental) uncertainties based on experience or other data sets that contain replicate tests. These estimates of the total uncertainty (measurement plus experimental) should be included in Table 6-2 and in the error bars on figures, not just measurement uncertainty. Revise the discussion in Section 6.2.1 to include the effect of these uncertainties on the assessment of code predictions for this data.

D) Explain the source and derivation of the **[ ]** and address their relationship to the total uncertainty in the measured void fraction values. Discuss the significance of **[**

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RAI-31 The Allis-Chalmers large-diameter void tests (References 29, 30, and 31 in the LTR), as discussed in Section 6.2.3, consist mainly of industrial prototyping of bubble rise phenomena in a range of vessel diameters. No data were obtained for annular flow which is the flow regime that most closely approximates the phase-separated flow field in the steam separators, particularly in the later stages of the multi-stage separators. As noted in the LTR, the references do not present information on measurement and experimental uncertainty nor do they discuss the two-phase flow modeling used to convert the measured data, consisting primarily of pressure differential measurements, to local void fraction. The approach used in the LTR is to **[**

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The brief description of this assessment, as presented in the LTR, is insufficient to explain how this indirect evaluation of the code-data comparison was accomplished. Please provide a more detailed description of this assessment, specifically addressing the following points.

A) In what way is comparison with the Allis-Chalmers data relevant to the verification and validation of these models?

B) How is the [ ] of the prediction uncertainty determined? Since the [ ]?

C) In what sense is this a 'bounding' estimate when the primary reference shows a [ ], when evaluated against its own database? The [ ] will only show the uncertainty in predictions of that correlation for the Allis-Chalmers data and not directly provide any information about the uncertainty (experimental plus measured) of void fraction data in the Allis-Chalmers data set itself. If properly calculated statistical prediction intervals (individual or simultaneous) were obtained for the [ ]. Since this is not presented in the LTR, explain how estimates of (or information about) uncertainty in measured void-fraction values for the Allis-Chalmers data could be obtained using (i) [ ] or (ii) [ ] in Figures 6-6, 6-7, and 6-8.

D) How is the measured pressure data used to determine the local void fraction values and void fraction distributions reported for these tests?

RAI-32 The discussion of results of model comparisons with measured two-phase assembly pressure drop data in Section 6.5.1, Rod Bundle Pressure Drop, is too limited and condensed for a complete review of two-phase thermal-hydraulics modeling as it relates to the highly ranked PIRT (i.e., [ ] (C02)) identified at the head of this subsection. The source of the extremely limited assessment information that is included in this section of the LTR has been identified as "[ ]."

Specifically, Table 6-10 and Figures 6-18 through 6-20 are from this uncited reference. This uncited reference provides information on the [ ] databases but additional information is needed to appropriately review the use that is made of these databases in assessing the two-phase pressure drop models in the EM with respect to the highly ranked PIRT C02 ([ ]). The assessment appears to treat the combined [ ] databases as a [ ]. The only [ ], each characterized by an empirically determined drag loss correlation.

Please expand the discussion in Section 6.5.1 to provide a complete description of the assessment performed using this data on the two-phase flow models in the EM. Specifically address the following issues and questions.

A) For each fuel design, provide information tabulating the number of test points for that fuel design, the ranges of operating conditions tested (pressure, flow rate, inlet subcooling, exit quality), the number of specific spacer grid configurations tested, and the number and range of test points for each grid configuration.

B) Separate plots of the **[** **]**. How was it determined that the two datasets could be combined to obtain a meaningful overall relative prediction error?

C) Table 6-10 summarizes means and standard deviations (SDs) of relative errors (REs) in code-calculated (C) pressure drop versus measured (M) values (i.e., [RE=(C-M)/M]. When statistically assessing prediction errors, one must consider the assumptions underlying statistical methods. The relevant assumption for Table 6-10 is whether uncertainties in REs are more stable (i.e., close to being constant) on an absolute basis or a relative basis. The SDs in Table 6-10 seem to **[** **]** which suggests SDs of REs are not approximately constant. Please provide justification for using this assumption in the statistical assessment of this data.

D) The listing of means and SDs in Table 6-10 do not constitute sufficient evidence that the true unknown mean for each subgroup of data is statistically different from zero. Please provide a more statistically defensible basis for assessing whether the code yields biased predictions for subgroups of data by exit flow quality, such as determining the p-values of two-sided t-tests. **[** **]**, it is actually standard errors (SEs) that are used in performing t-tests. Discuss the practical consequences of any statistically significant mean REs.

E) Figure 6-18 shows **[** **]**. A simple homogeneity of variance assessment of the SDs in Table 6-10 that we performed shows that **[** **]**. Hence, it is not appropriate to assess the distribution of all REs nor would it be appropriate to apply any statistical method to all of the REs that makes the assumption of homogeneity of variance. Explain the purpose of the assessment of normality presented in Figure 6-18 and justify its use in the assessment of code predictions for this data.

RAI-33 The description of the process for determining the drag loss correlation coefficients for a given spacer grid configuration in the **[** **]** databases is incomplete in the uncited reference **[** **]**. The coefficients (a through e, where **[**

]) are described as being obtained by adjustment to fit the data.

A) How are these coefficients determined for each grid configuration in the combined database?

B) What is the uncertainty in the fit to data associated with the coefficients of the form loss correlation for each grid configuration?

RAI-34 The process for determining the 'correction factor' of **[** **]**, appears overly simplistic, and possibly inappropriate. In particular, it appears inconsistent with the **[** **]**. With such an approach, it would seem that the effect of the **[** **]** would be captured in the original fit to the data. The **[** **]** and an inappropriate means of capturing the effect of the **[** **]** in this region.

Please justify the correction factor of **[** **]** given the above issues/comments.

RAI-35 The process for determining the 'interfacial friction multiplier' (factor f in the two-phase grid loss coefficient correlation) for ATRIUM-10A/B fuel designs is incompletely explained in the uncited reference (**[** **]**) and does not appear consistent with the approach of **[** **]** to determine the coefficients (a through e) of the grid loss coefficient correlation.

Please justify the use of the 'interfacial friction multiplier' for ATRIUM-10A/B fuel designs, given the above issue/comment.

RAI-36 The recommended approach for extrapolating or interpolating the empirical coefficients (a through e) to obtain an appropriate two-phase grid loss coefficient for grid configurations not included in the combined **[** **]** databases is unclear and appears somewhat arbitrary.

How is it determined that the benchmark statistics in Table 6-10 of the LTR are applicable to the assumed two-phase form loss coefficient for a grid spacer design that has not been tested?

RAI-37 The comparisons with experimental data shown in Section 6.5.4, Critical Power Tests, are presented in the LTR to address four highly ranked PIRT phenomena; three related to core performance and one related to fuel rod modeling capabilities. Specifically , this section addresses C04 (**[** **]**), C07 (**[** **]**), C09 (**[** **]**), and FR11 (**[** **]**). As noted in the assessment description in the LTR, it is a standard practice in the industry to use critical power correlations developed with steady-state data to predict boiling transition in transients. Evaluations of transient data has shown that such correlations typically under-predict the time to boiling transition and may in some cases predict boiling transition for tests where it did not occur in the course of the experiment. This conservatism in the application of CPR correlations to transient conditions is generally accepted as a desirable feature of the modeling capability for transient analysis. It raises questions related to transient core thermal-hydraulic behavior that are not addressed in the LTR, regarding the effect on the uncertainty in the void fraction predictions obtained in transient calculations with the EM, considering both the axial distribution in a given channel and the **[** **]**.

The uncertainty in the void fraction predictions obtained with the EM is assessed in the LTR by comparison to steady-state data. The transient data discussed in Section 6.5.4 does not include void fraction measurements, so direct comparison with transient void fraction data is not possible. However, the cladding temperature predictions, as compared to measured data (see Figures 6-33 through 6-36), suggest that there would be an increasing difference between predicted and experimental (un-measured) void fraction shortly before and shortly after boiling transition is observed in the experimental data.

Please address the effect of this increased uncertainty in the predicted void fraction and void fraction distribution on the overall uncertainty of predictions with the EM in transient applications for all transient application, including those that approach or exceed boiling transition. Specifically discuss the following questions.

A) What effect does the early transition to post-CHF heat transfer conditions, conservatively predicted using a steady-state CPR correlation, have on the predicted local void fraction before boiling transition occurs?

B) What effect does the **[** **]**, as indicated by model predictions compared to the thermocouple traces shown for this data in the LTR (see Figures 6-33 and 6-36)), have on the predicted local void fraction after boiling transition occurs?

C) What is the range of **[** **]**? Discuss the accuracy of the predicted time of boiling transition relative to operating parameters of flow rate, pressure, and inlet subcooling.

D) Discuss the characteristics of the tests where the EM is **[** **]**. What is the inferred reason for the **[** **]** does it have in the overall applicability of the EM to transient conditions in operating BWRs?

RAI-38 Section 6 (Page 6-1) defines four categories of Assessment Criteria to describe agreement between predictions of the EM and experimental data; Excellent, Reasonable, Minimal, and Insufficient. These categories are given only qualitative definitions. In the assessment of data evaluations, the “Excellent Agreement” and “Reasonable Agreement” categories are the only ones actually used. The lack of more specific definitions, without any sort of quantitative guidelines, leads to confusing and in some cases seemingly arbitrary assessment classifications, particularly for the “Reasonable Agreement” category. A wide range of evaluations are classified as “Reasonable Agreement” in subsequent subsections for demonstrably unequal model/code prediction performances. For example, in some cases model/code predictions are generally unbiased but with more random uncertainty than cases classified as “Excellent Agreement,” thus leading to a classification of “Reasonable Agreement.” In other cases, model/code predictions are biased over portions of the range of data or even over the whole range of the data and still are classified as “Reasonable Agreement.” Some cases classified as “Reasonable Agreement” appear to be “stretching” that definition and may actually warrant consideration as “Minimal Agreement.” The range of model/code prediction performances is too wide to classify them all as “Reasonable Agreement” rendering the entire classification system relatively meaningless.

There are several specific examples of inconsistent or conflicting classifications in Sections 6.2 to 6.6. For example, in Section 6.6.2 (Page 6-95 of the LTR), “reasonable to excellent code-data comparisons” are summarized as “the EM makes excellent predictions.” In Section 6.6.2.5, Figures 6-81 to 6-85 show the code predicts **[** **]**. And yet, in all three cases, the results are categorized as “reasonable to excellent.”

Section 6.6.2 also notes (on Page 6-97) that a **[** **]**. There is no explanation of how it affects the assessment of code-data agreement. The response provided to this RAI is of particular importance because the issues raised here also apply to the specific detailed comments and questions raised in specific instances of the application of the Assessment Criteria, in RAIs 44 through 62.

A) Explain the basis for the four categories used to define Assessment Criteria. Provide a complete definition of the quantitative criteria used to determine the categories. If the categories are not based on quantitative assessments, justify the use of heuristic evaluations and the unusual width of the category defined as “Reasonable Agreement.”

B) In Sections 6.2 to 6.6 where the code-data comparisons are categorized, assess whether there are inconsistencies in the application of the categories and explain any cases where you conclude a revised category is appropriate.

C) Explain the use of ‘bias corrections’ applied to the code predictions (e.g., in Section 6.6.2) in evaluations in comparison with experimental data and describe how such corrections affect the reported assessment of code-data agreement.

RAI-39 In the model validation efforts involving comparison of predictions to experimental data, appropriate sources of uncertainty (i.e., bias/systematic and random) must be discussed and quantified for each such data set. The random sources of uncertainty in measured values include experimental uncertainty as well as measurement uncertainty (since it is generally assumed that the experimental and measurement processes are not biased or that there are insufficient data to detect biases if they existed). Where the code uses "correlations" fitted to data, there will be random uncertainty in code-predicted values which must also be quantified. In the comparisons presented in Sections 6.2 and 6.5, in some cases only bias is addressed and random uncertainty is not addressed. Some comparisons do not address experimental uncertainty at all, and instead address only measurement uncertainty. Random uncertainty in predicted values is not discussed in any of the evaluations presented in the LTR. This leads to the general concern that the validation efforts in subsections of Sections 6.2 and 6.5 result in overly positive (non-conservative) conclusions on how well a model/code performs because the evaluation does not account for all contributions to bias and random uncertainty. Also, some predicted vs. measured plots show bias which are not acknowledged or discussed in the text. This is another indication of evaluations giving an overly positive view of model prediction performance. In a similar manner as noted above in the comment for RAI-38, the response provided to this RAI is of particular importance because the issues raised here also apply to the detailed comments and questions raised in specific instances of the evaluation of biases and uncertainties in code-data comparisons in RAIs 44 through 62.

Provide discussions of model-data comparisons in subsections of Sections 6.2 and 6.5 to address experimental as well as measurement uncertainty in the data. The discussion should address bias and random uncertainty separately. Provide quantitative estimates of bias and random uncertainty. Note that it is not necessary to provide separate estimates of experimental and measurement uncertainty unless there are the data to provide separate estimates. A combined estimate of experimental and measurement uncertainty is sufficient.

RAI-40 The term "prediction uncertainty band" is used in evaluations discussed in Sections 6.2 and 6.5, as well as elsewhere in the report. These bands are **[** **]**, but they are not clearly defined in the text. The term "prediction uncertainty band" is similar to terminology for statistical simultaneous prediction intervals (bands). Statistical methods for calculating prediction intervals (individual or simultaneous) from correlations fitted to data are not generally **[** **]**. Less-commonly used statistical methods that yield **[** **]**. The intention and purpose of these "bands" is unclear and additional information is needed to evaluate whether their use in the LTR is appropriate.

Provide a complete explanation of the "prediction uncertainty band" values, including a description of how they were obtained and how they are interpreted in the assessment of agreement between model predictions and experimental data.

RAI-41 The assessment of the jet pump model with best-estimate coefficients versus measured data (see Section 6.5.2.1 and Figure 6-21) is unclear and does not provide sufficient information to perform a proper review of the evaluation and conclusions presented in the LTR. Additional explanation of the assessment is needed, addressing the following points.

A) Explain how Figure 6-21 constitutes a comparison of 'best estimate model coefficients' vs. measured data. It appears to be merely predicted values versus measured data. If the best-fit coefficients were used, this needs to be documented in a form that can be reviewed; showing the model used and its parameters, the type of regression used to fit the data and what the optimization/fitting criterion was (e.g., ordinary least squares with minimizing the sum of squared errors), the number and nature of data used for the fit, and standard "goodness of fit" statistics.

B) Explain how the "2σ [sigma] data uncertainties for the pressure ratio and mass flow ratio of each data point" were calculated. The discussion for the n-ratio and m-ratio needs to clarify that at least experimental plus measurement/instrument uncertainties are included. Also, since the discussion makes clear that coefficients were fitted using data, then "model prediction uncertainty" should also be quantified and included in the comparisons.

C) Explain why the error bars in Figure 6-21 are generally much larger for the m-ratio than for the n-ratio. Also, the lengths of the error bars for both the m-ratio and n-ratio vary considerably over data points in Figure 6-21. This suggests that homogeneity of variance may not hold which would be an important concern for any parts of the code developed using regression methods. Address whether any methods to develop part of the code rely on homogeneity of variance.

D) Earlier sections in the report summarized the performance of models by indicating what percentage of data points fell within bounding lines. There are no bounding lines in Figures 6-21 and 6-22 but it is still appropriate to report what percentages of predicted values agree with measured values (when accounting for data and model-prediction uncertainties as addressed in previous comments). Please provide this information.

<u>RAI-42</u> In Section 6.5.3 of the LTR, comparisons between experimental data and calculated results obtained with S-RELAP5 modeling are shown in Figures 6-25 through 6-30 for two-stage and three-stage steam separator designs. The discussion of these Figures cites Reference #43 in the LTR. The experimental data shown in Reference #43 is not the data that appears in these figures. In addition, the evaluation of the code-data agreement is **[**

]. This is a further example of the lack of qualitative/quantitative assessment of code-data comparisons noted in RAI-38 and RAI-39. In this particular evaluation, the classification categories claimed do not appear to be consistent with the comparisons to experimental data, as shown in Figures 6-25 through 6-30.

A) Provide the actual source(s) of the data shown in Figures 6-25 through 6-30 and add them to the LTR with a discussion of the test conditions for which these measurements were obtained, including void fraction.

B) Discuss measurement and modeling uncertainties associated with the measured pressures, and carryover and carryunder fractions reported for this data. Specifically address how it is determined that the phase separation predictions obtained in system models of operating BWR plants are yielding appropriate results for carryover and carryunder. What is the uncertainty in such predictions and how is it determined? Justify the reported assessment of agreement in terms of qualitative evaluations of the accuracy of the model predictions and the uncertainty of the experimental data.

RAI-43 The code-data agreement assessment in Section 6.5.4 of the LTR discussing the comparison of S-RELAP5 predictions of the boiling transition (BT) experimental data is confusing, unclear, and at a number of points inconsistent with the actual results presented. As presented, the agreement assessment is unjustified and appears incorrect in a number of particulars.

A) The code predictions presented in Section 6.5.4 are presented as intentionally biased in the conservative direction, yet are assessed as being in “excellent agreement” with the experimental data. Explain the rationale for assessing this as “excellent agreement” when comparison with other data sets is considered “excellent” only when predictions are unbiased.

B) Which **[ ]** and what is the rationale for assessing the code-data comparison for these data?

C) How are the **[ ]** determined for application of the model to the data in Table 6-13? How is the **[ ]** evaluated in this application?

D) Please provide estimates of prediction uncertainties in the code values in Figures 6-31 and 6-32, as was done for previous figures. The concern is that the performance of the code for some data points could be non-conservative when accounting for uncertainty.

E) The portion of Table 6-13 for **[ ]** classifies **[ ]** calculations. However, Figure 6-32 shows at most **[ ]**. Please explain this apparent inconsistency.

RAI-44 In Section 6.6.1.1, discussion of the natural recirculation test states “These tests measured the natural circulation core flow rate as a function of power and water level in the downcomer and bypass.” This suggests that there are two test variables that should be used to assess performance of the code but the assessment is presented for only one variable (downcomer water level.)

Provide a complete discussion of the code-data assessment for this test addressing the effect of core power as well as downcomer water level on the evaluation results. Address specifically the differences between code and data values, as presented in Figures 6-44 and 6-45, notably in the behavior seen in the bottom portion of

Figure 6-45. Explain the rationale for categorizing the **[**

]

RAI-45 The presentations of the results in Section 6.6.2.3 through 6.6.2.5 (which evaluate the comparisons of code predictions with the reactor transients) are overly simplistic and inconsistent in their categorization of the comparison assessments. The discussion in these sections needs to be clarified and expanded, to show a more consistent basis for the assessments.

Discuss the significance of the **[**

].

RAI-46 Section 6.8 (Page 6-152) states "The impact of the EM structure is addressed by applying the EM within a range that assures the FoM experience an insignificant or conservative change in result over the range." The meaning and intention of this statement is unclear, and does not provide useful information on how EM biases and uncertainties are determined.

Define the 'range' that is being referred for application of the EM and explain what is done to assure that the FoM experience an "insignificant or conservative" change over that range. Justify how the 'range' accounts for biases and uncertainties in the EM.

RAI-47 Section 6.8 (Page 6-152) states that sensitivity analyses presented in Section 6.8.3 are provided as " an example of a typical process for determining which plant parameters are important, and how to determine conservative plant parameter values." While this may be a valuable analytical approach for applications of the EM (e.g., by knowing which parameters have the largest impact on results and for which conservative values should be chosen) it is still necessary to assess the impacts of biases and uncertainties in the code predictions and determine if they are acceptable.

Provide a discussion showing how it is determined where the EM yields biased predictions, the directions of the biases, the magnitudes of the biases, and how estimates of "random error" uncertainties are determined. Show how this information is used to assure that the conservative values are "conservative enough" without being "too conservative".

RAI-48 Section 6.8 (Page 153) states **[**

] There is no clear explanation of how such biases and uncertainties are captured or propagated through the model and, in fact, comments and RAIs preceding this one raise substantial questions regarding the adequacy and appropriateness of approaches used to determine and evaluate code biases and uncertainties.

A) Provide a detailed discussion of how estimates of biases and random uncertainties (experimental, measurement, model fitting) are propagated through the EM and used to select the changes in variables assessed via sensitivity analyses. Address the potential effect of biases and random uncertainties to be different over different subregions of the whole region of applicability for a given code/model and how they can be summarized as biases and random uncertainties by subregions of input variables. Also address how the sensitivity analysis process accounts for different biases and or uncertainties in different subregions.

B) Propagating biases and uncertainties through a model/code is typically done via **[ ]**. Such methods provide for addressing the combined effects of all biases and uncertainties that affect the code results, as opposed to sensitivity analyses that address only the effect of differences in one variable/component at a time. Explain why **[ ]** (or some other approach that would account for all biases and uncertainties simultaneously) were not used.

C) Explain how biases and uncertainties may be propagated through the EM by modifying the input models. Modifying input models has to be done at the "component level" which makes it difficult to assess the final biases and uncertainties for results that depend on several components. That is, there may be interactive effects of components as well as biases and random uncertainties propagating across different components of the code. Discuss what was done in this evaluation to capture these effects presumably using some alternative means. If these effects were neglected, justify that approach as adequate to capture the propagation of biases and uncertainties in the EM.

<u>RAI-49</u> Sections 6.8.2 and 6.8.3 discuss sensitivity analyses for a number of parameters. While it may be of interest to assess the sensitivity of the code to other parameters, the work in Sections 6.8.2 and 6.8.3 seems disconnected to the work in Sections 6.2, 6.5, and others to assess biases and random uncertainties in model/code predictions as functions of parameters varied in the validation/qualification data sets.

A) Explain the rationale for selecting parameters for sensitivity evaluations and justify why these are not generally the same parameters as were varied in the data sets used for code validation and qualification.

B) The results of sensitivity analyses presented in multiple subsections of these sections are for **[ ]** in parameters. Justify the implicit assumption that **[ ]**.

<u>RAI-50</u> In Section 6.8.4, some subsections focus on choosing adjustments to parameters (for sensitivity analyses) to bound biases. Other subsections focus on selecting adjustments to bound uncertainties. Adjustments should account for both biases and random uncertainties which may differ for different situations and subregions of variables used in code calculations and varied in validations/qualification data sets. It appears from the discussions in subsections of Section 6.8.4 that the approach used considers only biases or only random uncertainties in a given evaluation but does not in any case account for both biases and random uncertainties.

Justify the selection approach used to determine adjustments to parameters and explain why different approaches are used for different subsections of this section of the LTR. Explain how biases and random uncertainties are accounted for in each case and provide justification for not considering biases and sources of random uncertainty in all cases.

<u>RAI-51</u> In Section 6.8.4 (Page 6-159), the LTR states "Where appropriate, **[**

]." It is not clear what is meant by this statement, since in general the analyses presented in the LTR **[**
] of the total random uncertainties in model/code predictions.

A) Provide a detailed description of how the estimates of bias or 2σ limits for random uncertainties were derived, including the data used and include numeric estimates of the values obtained for the specific cases presented in Section 6.8.4.

B) Define what is meant by 'positive and negative responses' in the FoM and explain how such responses are quantified and used in the assessment of model performance.

C) The sentence "**[**
]" is unclear. Taken literally, it suggests the magnitudes of alteration were set to representative values (i.e., allowing for doubling the value). Or, maybe it means that a representative value was used without any accounting for bias or random uncertainty. Explain and justify what is meant by this sentence.

<u>RAI-52</u> In Section 6.8.4, Table 6-36 (Pages 6-160 through 6-163), the LTR asserts that biases and uncertainties are addressed in previous subsections (e.g., Sections 6.2 and 6.5 among others). As noted above in several other comments and RAIs, biases are not addressed in the model/code assessments in any of these subsections **[**

]. As currently documented, it appears that the work summarized in Table 6-36 may be insufficient to ensure that the code outputs will be accurate or conservative after accounting for biases and random uncertainties (which may be different for different subregions of the space of input parameters for the code).

A) Provide a detailed discussion identifying and quantifying model prediction biases and random uncertainties, to justify the assertion in Table 6-36 that these are accounted for in the assessment.

B) Provide a detailed description or case identification system to connect the subsections of Section 6.8.4 to the cases listed in Table 6-36. As currently documented there is no clear connection between Table 6-36 and the results presented in the various subsections of Section 6.8.4.

<u>RAI-53</u> Section 6.8.4.1 (Page 6-164) states "**[**

]." How this was done is not explained, nor is the **[** **]** of confidence defined in a quantitative sense. The LTR further states "**[** **]**." The meaning of this statement is unclear and does not appear to have any relationship to the model assessment. Finally, in Section 6.8.4.2 (Pages 6-164 and 6-165) adjustments up and down of **[** **]** were originally selected, but then the adjustment was changed to **[** **]**. There is no explanation of how the adjustments (up and down) of **[** **]** were selected or what they are expected to account for in terms of bias and uncertainties.

A) Explain in detail the approach used to select the 'adjustment' to bound the bias in assembly void fraction. Define what is meant by "**[** **]**."

B) Clarify what is meant 'a less severe response' and expand the discussion to explain the significance to the assessment of the model.

C) Explain the basis used to select the range of adjustments considered, and show how the selected values account for possible bias and uncertainties in the model.

RAI-54 In Section 6.8.4.3 (Page 6-165), the discussion of bounding values is incomplete, inconsistent, and lacks any quantitative basis for the assertion of **[** **]**.

Clarify what is meant by a 'representative bounding value.' Typically, a 'representative value' is not a 'bounding value' by definition. Justify the implied assumption that **[** **]** to appropriately encompass estimates of bias and the uncertainty. Please provide your response in relation to RAI-12 above.

RAI-55 The discussion in Section 6.8.4.4 (Page 6-166) is unclear and too condensed to provide sufficient information for this review.

A) Explain the rationale for selecting **[** **]**, including its relationship to estimates of bias and the uncertainty in those estimates. Please provide your response in relation to RAI-12 above.

B) Explain what is meant by the phrase "at the approximately 2σ level" and justify its use in this instance, especially since various subsections of Section 6.8 have been choosing adjustment values based on biases. (Generally σ is used to quantify random uncertainty, not bias. Bias is quantified by a magnitude of bias, not a standard deviation.)

RAI-56 In Section 6.8.4.5 (Pages 6-166 and 6-167), adjustments of **[** **]** are assumed for evaluations of Doppler feedback sensitivity in the model, without providing any justification for this value.

Provide a discussion of the basis for selecting adjustments of **[** **]** and show that this is appropriate to account for the estimates of bias and uncertainty for this model.

RAI-57 The discussion relative to the jet pump model in Section 6.8.4.6 (Page 6-167) is unclear and too condensed to provide adequate information for review. In particular, the sentence "**[**

]" is unclear.

Expand the discussion in this section to explain what was done, and show that appropriate adjustments were selected, such that they account for both bias and random uncertainty in the model predictions of jet pump performance.

RAI-58 The discussion in Section 6.8.4.7 (Pages 6-167 and 6-168) relative to steam separator modeling is unclear and does not contain enough information to perform an appropriate review.

Expand the discussion to describe in detail what was done to evaluate the model. In particular, describe and justify the rationale for the **[** **]** described in the LTR. Describe the magnitude of the **[** **]** account for the applicable biases and random uncertainties relevant to this model.

RAI-59 The discussion in Section 6.8.4.8 (Pages 6-167 and 6-168) relative to steam separator pressure drop modeling is unclear and does not contain enough information to perform an appropriate review. Also, the magnitudes of the adjustments applied are not reported (as has been the case for all previous subsections).

Expand the discussion to describe in detail what was done to evaluate the model. In particular, describe and justify the rationale for **[** **]**, as described in the LTR. Describe the magnitude of the adjustments selected and show how the selected adjustments account for the applicable biases and random uncertainties relevant to this model.

RAI-60 Section 6.8.5 presents a discussion describing the determination of "suitably conservative measures" for the EM. This discussion is incomplete and contains insufficient information to perform an appropriate review. In addition, the distinction between 'global effects' and 'local effects' is unclear and does not appear to be meaningful in relation to the evaluation of biases and random uncertainties. There are confusions of terminology that render some parts of the discussion meaningless from the standpoint of statistical evaluations.

A) Provide a complete description of how each of the three kinds of differences (difference in ΔMCPR, difference in peak pressure, and difference in integral power) are **[** **]**. Specifically, describe in detail and justify the **[** **]** approach that appears to be used in this section.

B) Justify the assumption used in the **[** **]** approach that the sensitivities combined are statistically independent. Discuss what is known about the correlations (or covariances) among code predictions from the separate components that were combined via the **[** **]** approach. If some or all of these are expected to be nonzero, discuss the possible consequences on the results of the statistical independence assumption being incorrect.

C) Include a discussion of why the **[** **]** approach was chosen over **[** **]**, a more commonly used statistical approach for complex, deterministic computer codes to jointly quantify the effects of biases and random uncertainties. It seems that the **[** **]** could account for some dependence of intermediate code results that the **[** **]** would not.

D) Provide a complete discussion of how steam separator modeling biases and uncertainties are appropriately captured in this evaluation. As part of the discussion, address the 'global and local effects' terminology and justify why local effects for biases and/or random uncertainties are not factored into the analyses performed. Also, specifically explain what was done to address uncertainties "at the 2σ level" in light of RAI-55b. In addition, address what is meant by 'bounding expected behavior' and justify the use of such an approach in the context of evaluating this component of the EM.

E) Further explain and justify the claim that "the measures based on propagating the sensitivity results achieve approximately a 2σ level of confidence in bounding the biases and uncertainties of EM outputs."

<u>RAI-61</u> In Section 6.8.5, under the un-numbered heading "Measures applied to ΔMCPR analyses" (Pages 6-170 to 6-171), the LTR states "**[**

]." The description is incomplete and unclear. There is not sufficient information to perform an appropriate review to confirm the conclusion.

Provide a complete explanation of the **[** **]** as it is used in the evaluation of ΔMCPR analyses. Provide calculations showing how this approach is used for this FoM (and other FoMs that are evaluated in the same manner). Justify the "with a high degree of confidence" claim since other RAIs raise numerous issues such that it is not clear that the results provide high confidence (even in a general, non-statistical sense). This will provide a basis to assess the appropriateness of what was actually done.

<u>RAI-62</u> Section 8.1.4 (Page 8-4) states "EM sensitivity analyses are performed to determine the significant plant operating conditions. For significant plant operating conditions, the AOO safety analyses are performed using the limiting values (relative to the calculated figure of merit) within the operating envelope. Nominal or best estimate values are used for operating conditions that are not significant. Performing analyses simultaneously using the limiting value for each significant plant operating condition compounds the overall conservatism of the calculation." The assumptions and analyses underpinning this paragraph raise the following questions. A similar comment applies to Section 8.1.5.

A) Address whether using a conservative value for each significant parameter in all code calculations would be overly conservative (since it protects against all of the worse cases happening at the same time, which may not even be possible). Also, address the inherent assumption that the conservatism of using the limiting values for significant plant operating conditions is enough to offset the smaller contributions from insignificant conditions that are not accounted for because nominal (or best estimate) values are used. Specifically address how many "insignificant" conditions there are (if less than 20 identify each) and discuss whether or not it is likely that small contributions from a larger number of "insignificant" contributions could total to a significant contribution.

B) Describe how the discussion in this section relates to the **[**
] method discussed previously in the LTR.

<u>RAI-63</u> While the NRC staff recognizes the necessity to couple computer codes to increase efficiency, the NRC staff also recognizes that any coupling raises certain issues which must be addressed to ensure the code coupling itself does not result in increased numerical inaccuracies or instabilities. For example, passing instantaneous rate quantities between codes instead of integral quantities may result in the instantaneous quantities not being conserved which would impact the accuracy of the solution. Similarly, using explicit coupling between codes instead of implicit or semi-implicit could impact the numerical stability of the solution.

For the CCDs discussed in the AURORA-B LTR, as seen by the coupling of **[**
] to S-RELAP5, provide justification that given the explicit nature of their coupling the chosen coupling frequency does not result in code instabilities. Also, provide justification that the passing of any instantaneous rate parameters between the CCDs in the AURORA-B LTR does not result in increased numerical inaccuracies.

ANP-2831P, Revision 0, "Phenomenon Identification and Ranking for BWR Events," AREVA NP, Inc., December, 2009.

<u>RAI-64</u> Guidance in Regulatory Guide 1.203, Section 2, recommends that independent peer reviews be performed at key steps in the EM development process. ANP-2831P, Section 4.1, states that the PIRT development and draft review were performed by an "in-house committee of experts."

Please provide additional details of the committee make-up relative to the independence of the review committee and the development team.

<u>RAI-65</u> LTR EMF-2102(P), Revision 0, is referenced by ANP-2831P. AREVA staff identified that Revision 1 is the current version applicable to the AURORA-B EM.

A) It was identified by AREVA staff that Revision 1 of EMF-2102(P) has not been submitted for approval to the NRC. Is this correct?

B) If EMF-2102(P), Revision 1, has not been approved, has Revision 0 previously been included in a review and approval process by the NRC?

C) If EMF-2102(P), Revision 1, has not been approved, has it been (or will it be) submitted as part of a separate submittal, or is it expected to be included as part of the review within this submittal?

D) Identify the revisions made to EMF-2102P for Revision 1.

EMF-2100P, Revision 14, “S-RELAP5 Models and Correlations Code Manual,” AREVA NP, Inc., December, 2009.

RAI-66 Sections 3.1 through 3.4 address flow regime maps, interphase friction, virtual mass force, and interphase heat transfer.

A) Clarify whether these were developed for the pressurized water reactor (PWR) best estimate LOCA model and that these were not modified for AURORA-B EM. If they were modified for AURORA-B EM, identify the changes made specific to AURORA-B EM.

B) It is assumed these models are used in AURORA-B EM, both in the core model and general piping. If this is correct, briefly summarize the evaluation cases in ANP-10300P that would validate the application of these models for AURORA-B EM.

RAI-67 The text leading to Equations 3.214 and 3.219 identifies that **[**

] using what appears to be the Fanning friction factor.

$$\tau_w = \lambda * \frac{\rho V^2}{2}$$

Clarify the actual formulation of the friction factor that is applied in the **[** **]**, as implemented in the AURORA-B EM.

RAI-68 The **[ ]**. No comparison or statistical evaluation is provided in EMF-2100P or ANP-10300P for the wall friction factor accuracy (**[ ]**).

Please provide a reference verifying applicability of **[ ]** to applicable data.

RAI-69 Section 3.6.1 limits the local form loss correlation to "**[ ]**."

A) Verify that this will be applied only to **[ ]**, as implied by the discussion after Equation 3.242.

B) Clarify where the coefficients a, b, c, d, and e are defined/established and are these already defined for existing fuel bundle types?

C) If coefficients a, b, c, d, and e are already defined, the coefficients should be presented as part of the verification and validation package. If they are not defined, will these be defined when the plant specific data is obtained/evaluated and where/what is the methodology to perform the evaluation?

RAI-70 Equation 3.232 is stated as "assumed to be" but appears to be a variation of the modified **[ ]** (Equation 3.238). The form of Equation 3.238 is '1 + the two-phase modifier.' However, in Equation 3.232, if e = 1, $\lambda_f = \lambda g$, and d = a (which appear to be reasonable possibilities), these equations are not 'fundamentally' identical.

$$[Eq.3.232 = \left[1 + \left(\frac{\rho_f}{\rho_g} - 1\right)x\right][1 + a(1 - x)]$$

$$Eq.3.238 = 1 + \left(\frac{\rho_f}{\rho_g}\frac{\lambda_g}{\lambda_f} - 1\right)x[1 + a(1 - x)]]$$

Also, based on a review of **[ ]** for the local loss term, Equation 2.232 appears to have an additional parenthesis that should not be there. For example, if x = 0, these equations are functionally different. However, the underlying two-phase multipliers (Equations 3.230 and 3.237) are the same form.

What is the reference for Equation 3.232? Verify that it is documented correctly in the report, and implemented correctly in the code.

RAI-71 The **[ ]**, is presented as a separate reference (1.14). The **[ ]** has similar inaccuracy ranges as identified for the RELAP5 Mod2 correlation (Genic et. al. *A Review of Explicit Approximations of Colebrook's Equation*, FME Transactions (20100) 39, 67-71).

Is the **[ ]** specifically part of the **[ ]** methodology? If not, why was the **[ ]** retained instead of applying the **[ ]**?

RAI-72 Section 6.2 presents the single-phase and two-phase pump performance models. It is identified that **[ ]**.

Discuss the potential for two-phase flow in the feedwater pumps for the applicable events identified in ANP-2829P and whether the two-phase degradation model is used in AURORA-B EM. If the model is used, address the applicability to BWR pumps.

RAI-73 Equation 6.19, is defined as **[ ]**.

Justify the use of a **[ ]** within the scope of AURORA-B EM. If this parameter is varied with jet pump design, describe and justify the basis for the design-specific values used with this model in the AURORA-B EM.

RAI-74 Equations for calculating A_{dg} and A_{th} are not shown, and are not described in the text.

Provide the definitions/equations for calculating A_{dg} and $A_{th.}$

RAI-75 In Equation 6.21, what is the reference frame for elevation Z (i.e., is this simply the change (delta) in elevation from P_{su} to P_{dg})? In addition, the text in ANP-10300P (Page 6-3) states that pressure ratio is determined from "**[ ]**." Equations 6.21 and 6.22 include the elevation head.

Clarify how the data comparison is made in ANP-10300P (Figures 6-21 through 6-24) and whether elevation is included in the pressure ratio.

RAI-76 The jet pump model uses a simplified approach to define the performance characteristics, **[ ]**. Address the following concerns.

A) Define the operating envelope for the jet pump model.

B) The **[ ]** is stated to be applicable for **[ ]**. The fluid in the jet pump will typically be at saturation or subcooled (due to the feedwater subcooling) but can become two-phase under transient conditions, where the choke velocity of two-phase flow decreases dramatically. Address the potential for two-phase flow and the internal jet pump velocities to approach **[ ]**.

C) The **[ ]**. During heatup and depressurization events, there is the potential for vapor generation within the jet pump. Address the jet pump model capability to simulate transient events that would decrease subcooling in the jet pump (e.g., SRP 15.1.1) or decrease system pressure (e.g., SRP 15.6.2).

D) The **[ ]** model assumes the **[ ]**. As indicated in the text, **[ ]**. Address the potential for laminar flow in the jet pump (e.g., degraded feedwater flow, 1 loop flow, etc.).

E) The **[ ]** in the formulation. How is the fluid enthalpy treated? In addition, how is the jet pump volume treated in S-RELAP5 (is the jet pump internal volume preserved/modeled, is it a pseudo volume, is it treated similar to the 'pump' model, etc.).

RAI-77 The jet pump model cannot be evaluated without the values of the coefficients defined and further discussion of this model.

A) Please provide the reference documentation for the derivation of coefficients in Table 6-10.

B) **[ ]**?

RAI-78 Equation 6.100 has a different form in other RELAP5, Volume 1 references.

Confirm the correct formulation or supply the correct formulation.

$$[Equation\ 6.100 \rightarrow \pi r_h^2 P_o + \int_{r_h}^{r_w} (\rho_{mi} V_{an}^2 + P_n) 2\pi dr = \cdots]$$

versus

$$[RELAP5\ references \rightarrow \pi r_h^2 P_o = \int_{r_h}^{r_w} (\rho_{mi} V_{an}^2 + P_n) 2\pi dr = \cdots]$$

RAI-79 Equation 6.108 appears to be mistyped ('+' versus '=' after the first integral term, and missing addition sign after third term).

$$[Equation\ 6.108 \rightarrow \int_0^{r_w} P 2\pi dr + P_o \pi r_w^2 + \pi C^4 [\ldots] \ ?\ \pi C^4 a [\ldots]\ ]$$

Confirm that this interpretation is correct or supply the correct formulation.

RAI-80 It is not clear how Equation 6.111 is formulated; it is stated to be determined by "carrying out the integration and putting things together."

Identify the specific equations used to create Equation 6.111.

2A4-MB2K, Revision 0, "Theory Manual – A Code for Advanced Neutron Kinetics Method for BWR Transient Analysis," AREVA NP, Inc., October 2009.

RAI-81 Section 2.9 provides the coefficients for the reflector response, however, no discussion is provided on the data used to verify these coefficients for rapid transients.

Provide the data used to verify that the reflector response coefficients are not sensitive to changes in the core conditions during a rapid transient. Are there accidents where the reflector response coefficients change?

RAI-82 Section 5 provides sample problems but no experimental data are presented to verify the calculational results of the MB2-K code.

Provide the experimental data used to verify the calculation and analyses used to determine the uncertainty of 3D assembly transient power and 3D power distributions from MB2-K. Particularly, for events that have little thermal-hydraulic impact, such as low (zero) power reactivity insertion. The Peach Bottom events represent integrated system responses, but not isolated kinetic responses.

RAI-83 Section 4.2 addresses how bundle flux distributions are calculated, however, no data or discussion is provided on the uncertainties of these calculated distributions.

A) How are uncertainties in the pin power reconstruction determined, particularly, when there are significant differences in the nodal surface fluxes and currents on each node face (i.e., with a large power tilts across an assembly)?

B) How do rapid power transients impact the pin power reconstruction?

ANP-2829P, Revision 0, "General BWR Design and Event Descriptions," AREVA NP, Inc., December, 2009.

RAI-84 This report discusses scenarios with one recirculation loop out of service resulting in single loop operation (SLO).

Do any of the AOO events in the submittal include SLO? If yes, please describe those events.

Clarification Questions

RAI-85 Neither EMF-2100P nor ANP-10300P identifies the version of RELAP-5 used as the initial starting version for AURORA-B; however, EMF-2103P indicates that this version was S-RELAP5 **[ ]**.

Is S-RELAP5 **[ ]** the starting version for the development of the version in AURORA-B?

RAI-86 The report indicates that the **[**

].

Clarify whether this is the modification for the **[ ]** or something else.

RAI-87 Table 5.6 identifies that the **[ ]** is used. However it is also stated that the **[ ]** has been implemented.

Clarify where the **[ ]** are used.

RAI-88 Reference 4 is identified as ANP-2830P, "BWR Analysis Requirements for Selected SRP Chapter 15 events", AREVA NP Inc., December 2009. However, copies provided for ANP-2830P are titled "Control System and Reactor Protection System Requirement for Modeling BWR Events", December 2009.

Clarify this discrepancy.

RAI-89 Section 3.6 of EMF-2100 identifies that the **[ ]** for the General Electric adiabatic test data.

Clarify that the **[ ]** is a user-defined 'flag' option specifically for AURORA-B EM. Also, verify that selection of the **[ ]**.

RAI-90 Some of the coefficients in Equation 3.224 are not well defined.

Clarify that the **[ ]**. These need to be modified for clarity in the documentation.

RAI-91 A cursory review of EMF-2102(P), Revision 1, indicates that no BWR specific AURORA-B EM verification and validation information is provided in this report.

Is this correct? If yes, is it the intent of ANP-10300P to act as a supplemental to EMF-2102P for the AURORA-B EM?

RAI-92 From Figure A-19 in ANP-10300Q1P, Revision 0, Appendix A, it appears that the assumed traversing in-core probe axial standard deviation is **[ ]** for D-lattice and **[ ]** for C-lattice.

Is this the assumed standard deviation for axial power for each of these lattices? If not, please provide an example of how this is applied to determining the standard deviation in pin power reconstruction.

RAI-93 For Equation 3.231 of EMF-2100, the Reynolds number is not fully defined.

Clarify whether the reference evaluation of Reynolds number in Equation 3.231 of EMF-2100 is for total mass flux, or if it considers vapor or liquid phase only.

RAI-94 The modes of operation that the AURORA-B EM will be applicable to are not clearly defined.

Please provide a detailed description of modes of operation that will be analyzed with the AURORA-B EM, including anticipated operational occurrences. Specifically address applicability to any conditions that involve single loop operation.

RAI-95 Confirmation of data communication between RODEX4 and the AURORA-B EM is needed.

Please provide a detailed description of the data communication between the RODEX4 code and other modules of the AURORA-B EM. Are there parameters passed from RODEX4 to initialize AURORA-B, other than the following?

I. **[**
].

II. **[**
].

If additional parameters are passed from RODEX4 please provide these and how they are used in AURORA-B.

Issue with Adequate References

RAI-96 All material that is the basis for data presentations (e.g., plots and tables) in the LTR and assertions of capabilities of the EM should be specifically referenced with appropriate call-outs in the LTR. Alternatively, the information from the uncited references could be repeated in the LTR but references cited in this new material would then need to be appropriately cited within the LTR.

For completeness of the documentation of the AURORA-B EM, please add the following references to the formal reference list of the LTR, at the locations noted. Information from these references is used in the LTR but without explicit call-out. These references are required to provide complete documentation of experimental data and model assessments in the LTR.

In Section 6.2.3, ATRIUM-10A Void Tests, cite references

i. **[**
]

ii. **[**
].

In Section 6.5.1 Rod Bundle Pressure Drop, cite references

i. **[**

]

ii. [

]

In Section 6.5.2.1, EGG-LTSF 1/6 Scale Tests (a subsection of Section 6.5.2 Jet Pump Performance Tests), cite references

i. EGG-LOFT-5063. LTR 20-105. Revision 0. H.S. Crapo. November 1979. One-Sixth Scale Model Jet Pump Test. 1979. [filename (as supplied by AREVA): EGG-LOFT-5063_ocr.pdf]

ii. EGG-CAAD-5357. G.E. Wilson. February 1981. INEL One-Sixth Scale Jet Pump Data Analysis. [filename (as supplied by AREVA): EGG-CAAD-5357_ocr.pdf]

In Section 6.5.2.2, Other Jet-pump Tests (a subsection of Section 6.5.2 Jet Pump Performance Tests), cite references

i. [
]

ii. [

]

iii. [

]

In Section 6.5.4, Critical Power Tests, cite reference

[
]