REQUEST FOR ADDITIONAL INFORMATION

RELATED TO TOPICAL REPORT ANP-10332P, REVISION 0,

"AURORA-B: AN EVALUATION MODEL FOR BOILING WATER REACTORS;

APPLICATION TO LOSS OF COOLANT ACCIDENT SCENARIOS"

AREVA INC.

(CAC NO. MF3829/EPID: L-2014-TOP-0004)

RAI-66

Figures 7-26 through 7-30 of ANP-10332P show that the heater-rod wall temperatures are both underpredicted and overpredicted. Explain the assessment stated in Section 7.3.8.2 of ANP-10332P that the trend of the predicted wall temperatures shows an overall conservatism.

RAI-67

Explain the criteria used to deduce from the reported void data that the start of the superheated vapor region for Thermal Hydraulic Test Facility (THTF) Test K (see Section 7.3.8.2 of ANP-10332P) was around 6.5 feet. In particular, the basis is not clear because comparing Test K to other high-power tests such as Test N suggests that the start of the superheated vapor region could occur at a higher elevation.

RAI-68

Please describe the natural circulation flowpath for the two loop test apparatus (TLTA) system configuration 5A (referred to in Section 7.3.9 of ANP-10332P in connection with the heated bundle, downcomer, and bypass) and clarify any steps taken to calibrate and initialize the modeling of this flowpath.

RAI-69

Explain the cause of the **[ ]** for the TLTA Boil-off Test 6441-7 (Figure 7-49 of ANP-10332P) between **[ ]**, and clarify why the steady-state initial condition in the simulation was not matched to the test measurement.

RAI-70

Sections 7.3.9.1 and 7.3.9.2 of ANP-10332P discuss TLTA Boil-off Tests 6441-6 and 6441-7.

a. For the comparisons with TLTA Tests 6441-6 and 6441-7, please clarify how large a time-scale shift (as discussed on pages 7-51 and 7-52 of ANP-10332P) was necessary to match the downcomer level at time zero. Please further clarify whether a single, constant timescale offset can provide good agreement between prediction and measurement in Figures 7-49 through 7-60.

b. ANP-10332P states that “the delay in the simulation of [TLTA Test 6441-7] implies a problem with the reported test data and/or assumptions of the conditions.” Clarify the type of problem AREVA believes may have affected the reported data and any potential modifications of the assumed test conditions that could bring the timing of the predicted cladding temperatures closer to the data.

RAI-71

Provide a nodal diagram of the model for the AREVA Fuel Cooling Test Facility (FCTF) described in Section 7.3.12 of ANP-10332P, showing the arrangement of hydraulic components and heat structures, including heated rods, water channel, fuel channel, and bypass channel.

RAI-72

For one axial elevation (e.g., 75 inches) considered in FCTF Test 79 (assessed in Section 7.3.12 of ANP-10332P), please indicate the heat transfer mode in the predictions as a function of time. Please further describe the phenomenon of **[ ]**, its impact, and how it is modeled in the test in a representative manner.

RAI-73

Sections 7.3.13 and 7.3.14 of ANP-10332P discuss assessments against THTF Reflood and Full Length Emergency Cooling Heat Transfer (FLECHT) Reflood and Steam Cooling Tests.

a. Discuss how the assessment calculations shown in Sections 7.3.13 and 7.3.14 address the phenomena identification and ranking table (PIRT) phenomena **[ ]**.

b. Please further explain the statement in Section 6.4.11 of ANP-10332P that acceptable application of the McDonough, Milich, King (MMK) correlation is demonstrated by comparison to the experiments in Sections 7.3.13 and 7.3.14, in light of the observation made by the NRC staff **[ ]**. To what extent is the MMK correlation **[ ]** in the S-RELAP5 simulations of the THTF Reflood and FLECHT Reflood and Steam Cooling Tests?

RAI-74

Please address the following questions concerning the FLECHT Reflood and Steam Cooling Tests assessed in Section 7.3.14 of ANP-10332P:

a. Figures 7-127 and 7-129 show that the AURORA-B loss-of-coolant accident (LOCA) evaluation model (EM) **[ ]** when the test pressure is close to atmospheric (Full Length Emergency Cooling Heat Transfer Separate Effects and Systems Effects Test (FLECHT-SEASET) Test 34209 and FLECHT Skewed Test 13914). Explain the basis for **[ ]**.

b. Although the maximum clad temperatures predicted by S-RELAP5 across all measured elevations appear to show **[** **]** against the corresponding measured values in seven of the tests, for the two tests with skewed axial profiles (Tests 13609 and 13914), there is **[** **]**. Explain the basis for **[** **]** only in the skewed profile tests.

c. Discuss the capability of the AURORA-B LOCA EM to capture the parametric effects of variations in reflood rate, system pressure, and subcooling in the FLECHT-SEASET and FLECHT Skewed Test series.

RAI-75

Discuss how the assessment calculations shown in Section 7.3.15 (Cylindrical Core Test Facility Test) of ANP-10332P address the PIRT phenomena **[** **]**.

RAI-76

Provide a nodal diagram of the model for the Upper Plenum Test Facility (UPTF) tests assessed in Section 7.3.17 of ANP-10332P, and indicate locations of the calculated results shown in Figures 7-169 and 7-173 of ANP-10332P.

RAI-77

The relevance of the assessment results presented in Section 7.3.17 of ANP-10332P to the boiling water reactor (BWR) LOCA event is not apparent. In particular:

- The geometry and other test conditions associated with modeling counter current flow limitation (CCFL) in the downcomer of a pressurized water reactor (PWR) do not appear relevant to the modeling of CCFL at the upper tie plates, water channel inlets and outlets, side-entry orifices, and control rod guide tubes of a BWR.

- The CCFL input parameters used in the UPTF assessment runs **[** **]**.

- As discussed in Section 5.5.2 of the S-RELAP5 Models and Correlations Code Manual (Theory), "… **[** **]**," and "assessment for UPTF Test 6 and Test 7 …demonstrates … **[** **]**."

Considering these points, please explain how the CCFL input parameters representative of BWRs have been validated by the comparisons presented in Section 7.3.17 of ANP-10332P.

RAI-78

For Steam Sector Test Facility (SSTF) System Test EA3.1 Run 111 (Section 7.7.1.1 of ANP-10332P):

a. In Figure 7-213, why does **[ ]**, fill up faster than the bypass region? Similar behavior was not observed for **[ ]**.

b. Explain the cause of the calculated differential pressures in Figure 7-214 showing **[ ]** (blue and green curves).

c. Please clarify why no data from **[ ]** is shown in Figure 7-214. Is the differential pressure data from **[ ]**?

d. Is there differential pressure data from **[ ]**? If yes, provide comparison between data and prediction.

e. Figures 7-217 and 7-218 show lower plenum liquid temperature. Why is predicted temperature **[ ]**, and what is the impact on the analysis?

f. Please clarify how this test validates code models for the **[ ]** highly ranked PIRT phenomena listed for this test. Identify relevant parts of the code/data comparison that validate each of the PIRT phenomena.

RAI-79

For SSTF System Test SRT-3 Run 26 (Section 7.7.1.2 of ANP-10332P):

a. Figures 7-228 to 7-230 show collapsed levels in various parts of the vessel. Why does the channel in **[ ]**?

b. The transition to **[ ]** is exhibited consistently in the differential pressure data (Figures 7-231 and 7-232) and the liquid temperature data (change in slope in Figure 7-244). Explain the approximately **[ ]**.

c. Discuss the basis for the conjecture expressed on page 7-204 of ANP-10332P that a higher subcooling of the liquid in the upper plenum (UP) led to higher predicted collapsed water level in the UP, and clarify whether this conclusion is supported by calculations. Because of the importance of subcooling relative to the CCFL phenomenon, it is not clear that AREVA's reasoning is correct.

d. Please clarify the time at which the zero in your calculations for SSTF Test SRT-3 Run 26 corresponds to in relation to the timescale used in Figure 28 of NUREG/CR-2566.

RAI-80

For the TLTA Large Break Test 6425-2 (Section 7.7.2.1 of ANP-10332P):

a. The calculation underpredicts bundle mass inventory (Figure 2-261) and overpredicts lower plenum mass inventory (Figure 7-262). ANP-10332P attributes this result to bundle drainage to the lower plenum. Explain which phenomena caused the early bundle drainage and the resulting impact on peak clad temperature (PCT). Discuss the implication of this discrepancy regarding the assessment of the PIRT phenomenon **[ ]**.

b. Figures 7-250 through 7-253 show emergency core cooling system (ECCS) flow rate. The code predicted later ECCS injection **[ ]**. What caused this model discrepancy and what is its impact on prediction of a conservative PCT?

c. Figure 7-264 shows total vessel coolant inventory, which is **[ ]**. What is the reason for the **[ ]** and what would be the impact **[ ]** on PCT?

d. Figures 7-265 and 7-266 show predicted exit flows with **[ ]**. There is no data comparison, and it is not clear whether the S-RELAP5 prediction is realistic. Will this **[ ]** lead to an artificially early prediction of quenching?

e. How does this calculation provide validation for the long list of phenomena associated with this test in Section 7.7.2 of ANP-10332P?

RAI-81

For the TLTA Small Break Test 6432-1 (Section 7.7.2.2 of ANP-10332P):

a. Was the calculated break flow shown in Figure 7-281 of ANP-10332P calibrated against test data and imposed as a boundary condition for the simulation? Please clarify how the break area and discharge coefficient were chosen for simulating this test. Furthermore, since there is no comparison with break flow data provided in ANP-10332P, please explain how this test validates the PIRT phenomenon **[ ]**.

b. Discuss the effect of the breakdown of CCFL at the upper tie plate (UTP) **[ ]** shown in Figure 7-289, and a corresponding reduction in lower plenum mass that occurs at about the same time in Figure 7-288.

c. Please provide a table with timings for different events from TLTA Test 6432-1 and the corresponding S-RELAP5 simulation (e.g., similar to that in Table 7-20 for TLTA Test 6425-2).

d. Figure 7-284 shows low pressure coolant injection (LPCI) flow, which is initiated based on system pressure. LPCI flow apparently began at around 40 seconds in the test and rapidly increased at around 450 seconds. S-RELAP5 predicted initiation of LPCI flow into the vessel at around 450 seconds. Please clarify the difference in predicted-to-measured flow prior to about 450 seconds. Is the measurement prior to 450 seconds recording a minimum recirculation flow that is not injecting into the test vessel?

e. Figure 7-289 shows fluid mass in the upper plenum. There is **[ ]** in the prediction compared to the data. Explain the discrepancy in the prediction.

RAI-82

How was the initial mass and flow distribution in the Full Integral System Test (FIST) vessel established for each test shown in Section 7.7.3 of ANP-10332P?

RAI-83

Regarding FIST Large Break Test 6DBA1-B (Section 7.7.3.1 of ANP-10332P):

a. Was the **[ ]** described in Section 6.4.10 of ANP-10332P used in applying the CHF correlation to the test simulation?

b. Explain the claim that the narrow downcomer in FIST will lead to larger interfacial stress.

c. Comparing Figures 7-300 and 7-306, explain why automatic depressurization system (ADS) flow is **[ ]**.

d. In Figure 7-312, why is predicted liquid inventory in the UP **[ ]**?

RAI-84

Regarding FIST Small Break Test 6SB2C (Section 7.7.3.2 of ANP-10332P):

a. Table 7-24 shows the timings of different events along with times from test. Comparing to the test data, the timing of **[ ]** in the prediction. What caused this **[ ]**?

b. The code predicted **[ ]** that led to a lower PCT prediction. Figure 7-335 shows **[ ]**. The code also predicted **[ ]**. All these discrepancies could have contributed to lower predicted PCTs, as shown in Figures 7-351 through 7-353. Explain which phenomena and models caused these nonconservative predictions of PCT.

c. Provide the S-RELAP5 prediction results for FIST 6SB2C if this case is run with the ADS signal set to open based on a delay from the calculated occurrence of the Level 1 signal, such that the ADS would actuate at **[ ]**.

RAI-85

Regarding FIST LPCI Line Break Test 6LB1 (Section 7.7.3.3 of ANP-10332P):

a. For this test, which ADS delay after Level 1 is correct, 120 seconds (stated on page 7-316 of ANP-10332P) or **[ ]** (suggested by event timing listed in Table 7-26 of ANP-10332P)?

b. Table 7-26 shows the timings of events. As in the previous case, S-RELAP5 predicted a delayed Level 1 signal and delayed opening of ADS. However, S-RELAP5 predicted earlier jet pump discharge uncovery and earlier recovery by 100 seconds. What is the cause of these discrepancies?

c. Figures 7-371, 7-372, and 7-373 show predicted void fraction in the rod bundle at different elevations. Between 30 and 100 seconds, the code underpredicted void fraction, which implies the presence of more liquid. Explain why this is not reflected consistently in the predicted mass in the rod bundle in Figure 7-375.

d. Figures 7-376, 7-377, and 7-378 show predicted void fraction at different elevations in the bypass region. Before **[ ]**, the code predicted lower void and higher liquid fractions at these locations. Figure 7-380 shows the total mass in the bypass region and indicates that the code underpredicted mass. How is this underprediction of mass consistent with lower void fraction at different heights before **[ ]**?

RAI-86

Regarding FIST Large Break Test 4DBA1 (Section 7.7.3.4 of ANP-10332P):

a. Figure 7-396 shows that both measurement and calculation indicate zero void in the vicinity of the jet pump exit beyond 110 seconds. Explain the difference between the measured and predicted mass in the lower plenum below the jet pump exit (Figure 7-405 of ANP-10332P) when there is no void measured or predicted.

b. Table 7-28 summarizes the timings of different events and reports that ECCS injection occurs at 30 seconds in both the test and the S-RELAP5 simulation. However, as in other comparisons, S-RELAP5 predicts the Level 1 water level trip setpoint being reached later than in the test. Hence, the water level signal triggering ECCS actuation may have been predicted later as well. Therefore, please clarify if the S-RELAP5 prediction of ECCS actuation was based on a trip using system water level conditions or a specified time. If a specified time was used, please further provide justification that the simulation provides a representative validation of the predictive capability of S-RELAP5.

c. As reflooding occurs due to upflow from the bottom of the rod bundle, lower plenum conditions are important. S-RELAP5 predicts earlier fill-up of the lower plenum than in the test (e.g., Figure 7-398 shows void fraction at the top of lower plenum and

Figure 7-405 shows the liquid mass in lower plenum). S-RELAP5 also predicts more liquid in the bottom of the rod bundle **[ ]** (Figure 7-399). Please explain the phenomena that lead to the overprediction of liquid in the lower plenum and bottom of rod bundle, and explain the impact of the S-RELAP5 overprediction on the conservativism of calculated peak cladding temperatures and other figures of merit.

d. Figures 7-414 through 7-416 show clad temperature histories at different locations. The highest predicted temperature occurs at the **[ ]** (Figure 7-416). This prediction is fairly close to the measured value, although quenching is predicted somewhat late. At lower elevations, similarly late quenching is predicted, but the PCT is significantly overpredicted. What is the reason for such large overprediction of clad temperature at **[ ]**?

e. Please explain the difference between the calculated and measured void fraction in Figure 7-409 after approximately 110 seconds. It appears that the code prediction is significantly different than the measurement.

RAI-87

The ECCS injection valves have finite stroke times and there is time delay between valve opening and the flow reaching rated value. Diesel generator start times also impact the event significantly. What specific delays are accounted for in the plant-specific analyses?

RAI-88

Why in Table 7-47 of ANP-10332P is the 1.0 DEG discharge break area not twice the discharge pipe flow area? (Discharge pipe area appears incorrect).

RAI-89

For the BWR/6 small break analysis presented in Section 7.7.6 of ANP-10332P, why does the actuation of safety relief valves (SRVs) between 50 and 250 seconds (Figure 7-512 of ANP-10332P) have no apparent effect on the upper plenum pressure (Figure 7-502)? A similar observation was made relative to the cases for the BWR/4 small-break analysis. Please further comment upon the conservatism of selecting a conservatively high SRV setpoint for small-break LOCA analysis.

RAI-90

Confirm for the demonstration of Appendix K conservatism presented in Section 7.9.2 of ANP-10332P that all assessments were performed utilizing all Appendix K models and other conservative assumptions implemented in the AURORA-B LOCA EM. In particular, Section 7.9.2 only mentions three changes relative to the assessments in Section 7.7, namely, increasing decay heat power, using the Moody critical flow model, and **[ ]**. Discuss the potential impacts if some Appendix K models and assumptions were not used in the assessment calculations.

RAI-91

Please explain how the **[ ]** in Tables 7-62 through 7-65 have been calculated.

RAI-92

Comparing the two simulation results for TLTA Case 6432-1, as presented in Sections 7.7.2.2 and 7.9.2.1 of ANP-10332P (the latter of which contains additional conservatisms), explain the **[ ]**, shown in Figure 7-531 from Section 7.9.2.1 versus that shown in Figure 7-289 from Section 7.7.2.2. It is noted that for this test the only ECCS activated were the LPCS (at 435 seconds) and LPCI (at 445 seconds). If the difference is attributed to the **[ ]** in the calculation described in Section 7.9.2.1, then please show a comparison of liquid mass flow at the upper tie plate between the two cases.

RAI-93

Please provide a plot similar to Figure 7-349 showing the bundle inlet flow (expanded view) that also includes the simulation results of the FIST Small Break Case presented in Section 7.9.2.2 of ANP-10332P. How does the prediction for the case in Section 7.9.2.2 compare with the data? Is there a similar predicted **[ ]** that does not appear in the measured data?

RAI-94

The AURORA-B LOCA EM **[ ]**. Does the calculation presented in Section 7.9.2.2 of ANP-10332P impose the **[ ]** consistent with these conditions, or did the calculation **[ ]** throughout the entire calculation? Please provide justification for the selected modeling approach.

RAI-95

Of the three modeling practices presented in Section 7.9.2.2 of ANP-10332P as Appendix K assumptions, please discuss their relative significance in terms of impacts on the calculation of PCT and other figures of merit.

RAI-96

For the test for rod bundle pressure drop (Section 7.6.1), Figure 7-181 indicates that the **[ ]**. How does this difference in prediction compare with measurement uncertainty?

RAI-97

Regarding the jet pump tests in Section 7.6.2 of ANP-10332P, the data for BWR/5 and BWR/6 jet pump (Figure 7-185) shows **[ ]**. Please explain whether the flow during the spectrum of postulated LOCAs evaluated by the AURORA-B LOCA EM would typically be in the range of **[ ]**. If so, then please further provide a basis that the models in S-RELAP5 are adequately validated for this regime, despite the evidence of **[ ]**.

RAI-98

Regarding the loss of fluid test jet pump tests with two phase flow (Section 7.6.2.3):

a. For Figures 7-187 and 7-188, why does the code **[ ]** the data? What is the effect of this **[ ]** on the figures of merit (FoMs)?

b. The text of Section 7.6.2.3 of ANP-10332P refers to Figure 8-8 and Section 8.2.2; however, these items do not appear in ANP-10332P. Please clarify.

RAI-99

For the Steam Separator Tests (Section 7.6.3): Explain the effect of **[ ]** of carryunder (in Figures 7- 194, 7-195, 7-199, and 7-200) on break flow and FoMs. In particular, are separator flow rates in the test representative of conditions expected in the LOCA scenario, such as during ADS actuation or a main steam line break? Is this data relevant to the LOCA event?

RAI-100

For the CCFL Mini Loop Test (Section 7.6.5):

a. Legends in Figures 7-202 and 7-203 are not clear. Provide definitions of the terms in the legend and the dimensionless volume fluxes.

b. Since CCFL Mini Loop Tests were **[ ]**, justification regarding the effect of pressure for the Kutateladze correlation is needed to support application to a **[ ]**. Please provide this justification for applying air-water results from the CCFL Mini Loop test (or any other **[ ]** results used in the AURORA-B LOCA EM) to plant **[ ]**.

c. Does the plant model use the standard Kutateladze correlation and parameters that were used in the mini loop CCFL test? Please explain and justify how the specific values and parameters used in S-RELAP5 to model CCFL were derived for each location in S-RELAP5 where CCFL is modeled.

RAI-101

Section 6.4.2 of ANP-10332P cites its Reference 15 (RODEX2 ECCS Comparisons for a BWR dated September 6, 1983) as establishing the basis for the selection of the limiting power history in making a conservative determination of fuel stored heat. However, the basis supporting application of this methodology with the AURORA-B LOCA EM is unclear, particularly in light of the facts that (1) Reference 15 predates the recent reappraisal of the impact of thermal conductivity degradation, (2) the RODEX2 code used in Reference 15 has long been supplanted by enhanced analytical methods, such as the RODEX4 code used in the AURORA-B LOCA EM, (3) core design and operating cycle strategies have significantly changed across the industry since 1983, and (4) fuel designs have also evolved significantly since 1983 (e.g., incorporation of part-length rods, water channels, and burnable absorbers).

Hence, it is not clear that any conclusions regarding the conservatism of power histories drawn from Reference 15 would be relevant to future application of the AURORA-B LOCA methodology. Therefore, in light of the points raised by the NRC staff, please either (1) justify the continued applicability of the Reference 15 methodology for determining a limiting power history for the computation of fuel stored heat or (2) provide a revised determination of the limiting power history along with justification for its conservatism.

RAI-102

Page 6-51 of ANP-10332P states that "At steady state conditions, prior to the initiation of the LOCA event, the **[** **]**." Please clarify whether the intended meaning is that the input for steady-state **[** **]** in the S-RELAP5 code.

RAI-103

Please explain how the void distribution and two-phase level models in AURORA-B have been validated for LOCA conditions where the reactor may be fully depressurized. In particular, the lowest pressure range in ANP-10332P where code predictions are compared to measured data appears to be in the range of **[** **]** pounds per square inch absolute (psia). The NRC staff noted the following observations which should be addressed in the response:

a. It is not clear why additional timestep comparisons against the GE Level Swell Tests were not included in ANP-10332P. The final comparison included in ANP-10332P was at 100 seconds, which appears to involve a pressure of approximately **[** **]** psia. Please provide additional comparisons for further timesteps of the GE Level Swell Test that would better characterize the low end of the pressure range applicable to the LOCA event or explain why these comparisons would not be relevant.

b. Please clarify the apparent inconsistency between the pressure range specified in Table 7-2 for the Christensen tests (400-1000 psia) and the range specified in the accompanying text description in Section 7.3.5 (725-1260 psia).

c. Although **[** **]** is cited as a phenomenon validated by the FCTF and FLECHT tests, the comparisons provided for these tests appear to show only measured PCT, rather than any data that can be directly linked to **[** **]**. Hence, it is not clear that FCTF and FLECHT provide useful information in this regard.

RAI-104

Please clarify how the flow rates and power-to-flow ratios for the hot bundle and other high-powered channels during the reflood phase of a typical BWR compare to the THTF tests used in the validation of the topical report in Section 7.3.8.

RAI-105

The pressure range for the THTF tests in Section 7.3.11 of ANP-10332P used to derive the **[** **]** psia. Please clarify whether **[** **]** has been validated at pressures less than **[** **]** psia and justify why **[**

] should be applied at pressures below this range. In so doing, please address in particular the following points:

a. Was [ ] used in the validation comparisons against FCTF data (ANP-10332P, Section 7.3.12)?

b. Was [ ] used in the validation comparisons against the FLECHT data (ANP-10332P, Section 7.3.14)?

RAI-106

The explanation in ANP-10332P for the delayed quench for TLTA Test 6425 Run 2 (i.e., prediction of lower liquid holdup in the bundle) does not appear to fully explain the behavior exhibited in this test. Following the filling of the bypass at approximately 150 seconds, and the lower plenum by about 210 seconds, it is not clear why quenching within the bundle should not follow within a reasonable timeframe. However, the code does not predict complete quenching until approximately 840 seconds (i.e., 10.5 minutes after the bypass and lower plenum have refilled).

a. Please provide a more fulsome explanation for the extensive delay in prediction of quench for this test, along with additional figures that illustrate the code predictions of fluid inventory for the bundle and other locations within the vessel (i.e., bypass, lower plenum, upper plenum) through 900 seconds. Please further include figures that would establish whether or not misprediction of CCFL (e.g., underprediction at SEO, overprediction at UTP) could have a role in the observed discrepancy in quench time.

b. Please explain why the phenomena that resulted in an extensive delay in the quench prediction for TLTA Test 6425 Run 2 are not operative in the FIST integral tests, which were likewise performed in a single-channel configuration (i.e., FIST being an upgraded version of the TLTA facility). In particular, the FIST large-break tests appear to demonstrate quenching within a reasonable time period, and the FIST small-break test results in Section 7.7.3.2 show reduced heatup and time-at-temperature relative to the test data.

RAI-107

In RAI 61, the NRC staff requested that AREVA address the observation that, in one of the audited demonstration cases, [

] that was reported in ANP-10332P as the PCT for that case. Further review by the NRC staff regarding the three audited demonstration cases has resulted in related observations that should likewise be addressed by AREVA:

For the predicted results of the BWR/4 large-break case (i.e., 1.0 double-ended guillotine break on the pump suction line with the "LOCA" single-failure), the [

] of the core exhibits a PCT and local oxidation in [ ]. The NRC staff found this result unexpected, inasmuch as the models used by AREVA for the [ ] have been described in ANP-10332P as conservative. In light of the discussion above, please explain why the cladding temperature and local oxidation for the [

], and further justify that the modeling of the **[ ]** in the AURORA-B LOCA EM are conservative.

b. For half of the **[ ]** in the cases audited, the PCT and local oxidation predicted for the **[ ]**. The **[ ]**, but they are modeled as being **[ ]**. Please explain why the predicted **[ ]** than that of the **[ ]**, and further justify that the modeling of the **[ ]** is conservative.

c. In light of the above observations, please provide more information to support the conclusion in Section 6.2.1 of ANP-10332P that **[ ]**. Because it is not clear *a priori* which bundles will be limiting, it is not clear to the NRC staff that the same **[ ]**.

d. Please further clarify whether AREVA would exclude calculated results for **[ ]** when reporting calculated values for the figures of merit for cladding temperature and oxidation. If AREVA intends to report only values associated with the **[ ]**, then justification should be provided as to why this practice should be considered acceptable.

RAI-108

Based on observations from the audit of demonstration input decks, the NRC staff understands that swelling and rupture is modeled in AURORA-B **[ ]**. Please justify that this approach is acceptable and conservative, particularly in light of RAIs 107 and 114 that address observations that (1) the **[ ]** may not provide the limiting results for cladding temperature and oxidation, (2) the modeling of rod swelling and rupture may increase core heat generation due to the oxidation reaction (i.e., particularly in high-powered bundles) and hence peak cladding temperatures **[ ]**, and (3) modeling the swelling and rupture **[ ]** may reduce cooling to the **[ ]**.

RAI-109

Regarding AREVA's modeling of fuel swelling, rupture, and blockage described in Section 6.4.5 of ANP-10332P:

a. Many modern cladding designs and materials that AREVA may analyze with the AURORA-B methodology did not exist in the early 1980s when NUREG-0630 and Exxon Nuclear Company, Inc. Topical Report XN-NF-82-07(P)(A), Revision 1, were published. Please provide justification that the models described in these reports are applicable to modern fuel designs currently being produced by AREVA, and, as applicable, other vendors (perhaps with additional bias / uncertainty). Please clarify whether data exists to demonstrate the conservatism of these models to modern fuels.

b. It is not clear to the NRC staff that the models described in ANP-10332P for fuel rod swelling, rupture, and blockage are the same as those previously approved in

XN-NF-82-07(P)(A), Revision 1. Please provide sufficient explanation of what parts of the modeling in ANP-10332P are the same as those used in XN-NF-82-07(P)(A), Revision 1, and which parts of the model (if any) are different from that previously approved and used in EMF-2361(P)(A).

c. The codes used in ANP-10332P are different than those used in XN-NF-82-07(P)(A), Revision 1. Therefore, please clarify how the differences in the codes used in these reports would affect the data comparisons that are provided in XN-NF-82-07(P)(A), Revision 1.

RAI-110

Regarding the flow blockage model described in Section 6.4.5 of ANP-10332P, please clarify the following:

a. ANP-10332P states that a model derived from PWR application described in Section 7.4.6 of Reference 6 to ANP-10332P will be applied in the AURORA-B LOCA EM. This model **[ ]** the blockage region. For BWR application, this model is used to adjust the **[ ]**. Please explain how this equivalent adjustment is implemented and cite the section of the S-RELAP5 theory manual where the relevant information is located. Please clarify whether any other changes are assumed to result due to the flow blockage besides a **[ ]**.

b. Clarify in one of the large-break and one of the small-break demonstration cases audited by the NRC staff to what extent blockage was experienced in the hot channels and estimate the impact on the calculation. Please further characterize the blockage that occurred in the additional demonstration case requested by the NRC staff below in RAI 115 and estimate the impact on the calculation.

c. Please clarify how the flow blockage model for BWR application has been validated.

RAI-111

In light of the observations discussed above in RAI 107, the conservatism of several aspects of the **[ ]** was not apparent to the NRC staff. Please address the following items:

a. Please clarify the impact of the **[ ]** for large break LOCA (LBLOCA) and small break LOCA events. In particular, it appears that the **[ ]** may be conservative for small break cases but may not necessarily have a significant impact on at least some LBLOCA cases for which **[ ]** regardless of the presence of an **[ ]**.

b. Please describe the impacts of modeling the **[ ]** on the LOCA results for the **[ ]**. Presumably, the modeling of the **[ ]** is not associated with many assessment results (e.g., with the exception of FCTF), since **[ ]** did not **[ ]**. Presumably, the impacts of the **[ ]** are largely associated with its capability to serve as a **[ ]**. Please provide a basis for concluding that the modeling of the **[ ]** has been validated to be either conservative, realistic, or not consequential to the predictions of PCT, maximum local oxidation, and core-wide oxidation.

c. Since there is a **[**downflow restriction placed on the hot channel**]**, it is not obvious why the PCT is not always associated with **[ ]**. (In fact, was it not for the demonstration case results shown in Section 7.7.4, the results of Figure 7-543 of ANP-10332P might have resulted in the suggestion that a **[ ]**.) Therefore, please explain why, as illustrated in a number of the large-break demonstration cases, the **[ ]**.

RAI-112

Please clarify why the results of the sensitivity studies in Sections 7.9.3 through 7.9.6.1 of ANP-10332P are acceptable, addressing the specific points raised below:

a. Even if the largest timestep is eliminated (which AREVA concludes is appropriate based upon the sensitivity results for the small-break LOCA scenario), the timestep sensitivity study shows that varying the maximum timestep request between 0.001 and 0.005 seconds may result in a difference of **[ ]** in the predicted peak cladding temperature in some scenarios. However, ANP-10332P concludes that the results show the solution is converged in time by the relatively small impact of the peak cladding temperature figure of merit from reducing the timestep from the nominal value.

b. The sensitivity study associated with changing the number of hydraulic nodes in the core from **[ ]** shows a **[ ]** sensitivity for the large-break case. However, ANP-10332P concludes that the results demonstrate the acceptability of the **[ ]** model by **[ ]** in peak cladding temperature over the range of break size by doubling the hot channel nodes.

c. The sensitivity study associated with the core radial power distribution for the large-break case appears to have a peak cladding temperature sensitivity **[ ]**. However, ANP-10332P concludes that the radial power distribution in the core has **[ ]** on the peak cladding temperature.

d. What is the standard against which the results of the sensitivity studies are judged to determine whether a certain parameter is sensitive? Some of the cases indicate sensitivities on the order of **[ ]**; nevertheless, AREVA concludes in all cases that the sensitivity results are acceptable.

e. Were the validation analysis cases in ANP-10332P simulated in all cases with the nominal timestep and an axial channel nodalization consistent with the nominal value? In any cases where other than the nominal values were used, please identify the values used and provide justification for the applicability of the results in light of the sensitivities demonstrated in ANP-10332P.

f. Please confirm that the sensitivity studies in Sections 7.9.3 through 7.9.6.1 of ANP-10332P fully incorporate all Appendix K modeling requirements and other defined features of the AURORA-B LOCA EM described in ANP-10332P. Please identify and justify any exceptions.

RAI-113

Please address the treatment of mixed core configurations.

RAI-114

Regarding the computation in S-RELAP5 of the **[ ]** affected by oxidation, please provide the following information:

a. Provide a description of the **[ ]** in S-RELAP5 (which affects the USEP12 and UMAR16 code versions, et al.), and clarify how the issue is being resolved with respect to the AURORA-B LOCA EM.

b. Please clarify how AREVA has validated that **[ ]**.

c. Please explain why **[ ]** of the AURORA-B LOCA EM and clarify whether the addition of any further validation or **[ ]** tests is necessary to ensure that **[ ]**.

d. Inasmuch as the limited level of detail in the existing discussion may have been a contributing factor to the **[ ]**, please clarify whether an update to the documentation for the S-RELAP5 code theory manual is appropriate to clearly identify how **[ ]** is addressed when calculating **[ ]**. If an update is made, provide an excerpt of the changes.

e. Please clarify which analysis cases (e.g., validation, demonstration, and sensitivity results) from ANP-10332P, if any, require revision **[ ]**. As applicable, please provide the **[ ]**.

f. Please clarify whether the statement on page 8-2 of ANP-10332P is correct in stating that rupture, swelling, and fuel relocation models were added to RODEX4 (i.e., as opposed to S-RELAP5).

RAI-115

The demonstration case decks audited by the NRC staff do not involve cladding temperatures high enough to result in significant swelling and rupture. Due to the importance of understanding these fuel performance phenomena (e.g., as related to issues described above in RAIs 107, 110, and 114), please provide an additional demonstration case for NRC staff audit that illustrates how S-RELAP5 predicts these behaviors (e.g., the BWR/4 Reduced ECCS Analysis in Section 7.7.5 of ANP-10332P). Please ensure that the **[ ]** in RAI 114 has been resolved and that the graphics file includes parameters relevant to swelling, rupture, and flow blockage phenomena (e.g., ECET, ECBURST, and FGPRES).

RAI-116

Please provide a high-level description and/or graphic outlining the sequence of steps necessary for performing a plant-specific analysis using the AURORA-B LOCA EM.

RAI-117

Please describe in detail how exposure studies will be performed when exercising the AURORA-B LOCA EM for plant-specific safety analyses. In particular, please clarify the following points:

a. ANP-10332P in Section 6.3.8 describes **[ ]** based on the exposure study. Whereas, the modeling guidelines document discuss the exposure study **[ ]**. The modeling guidelines indicate that the **[ ]**, which could appear inconsistent with the iterative process discussed in ANP-10332P. Please clarify and reconcile these interpretations regarding how the exposure study is performed and fits into the overall plant-specific analysis process.

b. Section 6.3.8 of ANP-10332P also observes that **[ ]** predicted during the event and is thus conservative. Please clarify the **[ ]** in the exposure study and justify that the treatment is conservative.

c. Please clarify whether the **[ ]** when the exposure study is done, or whether a **[ ]**, and only the **[ ]** of the model is re-run. If only the **[ ]** is re-run, then please provide justification.

RAI-118

ANP-10332P states that FCTF Test 64 is used to assess the **[ ]** and the capability of the S-RELAP5 code to model **[ ]**.

a. Please explain how FCTF Test 64 validates the **[ ]**. The maximum test temperature is **[ ]**, and if both the average rod model and all rod model **[ ]** both have good agreement with the same set of data, it appears rather to suggest that **[ ]** may not be significant to the outcome of the test.

b. In light of the termination criteria described in Section 7.3.12, please clarify why Test 64 was stopped **[ ]**.

c. In light of the discussion above, please explain in general how **[ ]** has been validated for the BWR LOCA event, where it plays a significant role due to the presence of a channeled core and, in many cases, fuel designs with a water channel.

RAI-119

Please provide Reference 84 to ANP-10332P to support the NRC staff's review of the range of conditions associated with the CE/Columbia steady-state film boiling tests and the measured heat transfer coefficients.

RAI-120

The text of ANP-10332P does not discuss Tables 7-13 and 7-14. Please clarify specifically what these tables represent. For example, presumably Table 7-13 is associated with the **[ ]** for choked flow? For example, is the variable being characterized a **[ ]**? For example, how are the data points used in the comparison selected (e.g., at regular time intervals for each of the tests shown in Table 7-12)?

RAI-121

Please clarify whether the final sentence in Section 7.6.2.2 of ANP-10332P should be deleted because it is inapplicable to the AURORA-B LOCA EM.

RAI-122

Please clarify the apparent discrepancy between the statement in the text on page 7-277 of ANP-10332P that the predicted peak cladding temperature for FIST Test 6DBA1 is 752 °F, whereas from Figures 7-321 and 7-322, it appears that the predicted peak cladding temperature is approximately **[ ]**.

RAI-123

Regarding the sensitivity analysis performed for the SSTF results in Section 7.9.6.2 of ANP-10332P, please clarify the following information:

a. Explain why even the **[ ]** in the last time period of the test for part of the time. Note that the cause does not appear to be a reduction in the total number of channels in **[ ]**, since the total number of bundles determined to be in **[ ]** than during the middle time period.

b. Explain the basis for the statement on page 7-473 of ANP-10332P that **[ ]** has no impact on the **[ ]** between bundles. The NRC staff could not judge the validity of this statement in part because comparable figures are not provided between Sections 7.7.1.2 and 7.9.6.2.1 of ANP-10332P, nor are liquid and vapor mass flows at the UTP provided for **[ ]**.

RAI-124

Regarding use of the Drucker-Dhir correlation for two-phase turbulent heat transfer enhancement in rod bundles that is described in Section 6.4.13.2 of ANP-10332P, please address the following questions:

a. Please confirm whether the Drucker-Dhir correlation was used for the comparisons performed against the THTF tests for steady-state film boiling, which were used to determine the **[ ]**.

b. Please further confirm whether the Drucker-Dhir correlation was used in validating the S-RELAP5 heat transfer predictions against FCTF data (ANP-10332P, Section 7.3.12) and FLECHT data (ANP-10332P, Section 7.3.14).

c. Please clarify why implementation of the Drucker-Dhir correlation **[ ]**. Although the value of the Drucker-Dhir enhancement factor **[ ]**, according to the description in the S-RELAP5 theory manual, it **[ ]**. (Because the McEligot correlation continues to be used by S-RELAP5 for single-phase convective heat transfer to vapor, albeit without application of the Drucker-Dhir correlation and **[ ]**, this implementation appears equivalent to a **[ ]**). Considering both theoretical and code stability standpoints, it is not apparent why there is not a **[ ]**.

RAI-125

Table 7-9 summarizes the THTF high-pressure reflood tests used in the validation of S-RELAP5.

a. Please clarify the predicted reflooding velocity for the BWR small- and large-break LOCA cases that were provided to the NRC staff for audit and compare these values to the values in Table 7-9 against which validation was performed.

b. The NRC staff observed an apparent tendency in the S-RELAP5 predictions of the THTF data, namely, that at higher pressures and reflood rates, **[ ]** appeared more frequent, and at lower pressures and reflood rates, **[ ]** appeared more frequent. Please discuss how this tendency may affect the predictions of S-RELAP5 for plant-specific safety analysis.

RAI-126

The **[ ]** results audited by the NRC staff do not indicate significant differences between the UMAR16 and USEP12 versions of S-RELAP5 for many of the cases considered therein. However, comparing the demonstration case results associated with the UMAR16 code version against those of the USEP12 version did reveal substantive differences. For example, when comparing the results calculated for specific failure scenarios, the calculated peak cladding temperatures were seen to be generally reduced, in some cases by **[ ]**. (During the May 2017 audit, AREVA noted that **[ ]** were also implemented in the UMAR16 calculations, although the specific impact of these changes relative to the code version and evaluation model changes was not determined.) In addition, the integral test comparison presented in the **[ ]** results for FIST Test 6SB2C that was audited by the NRC staff appears less favorable with the

UMAR16 code version. Furthermore, the NRC staff observed that the validation comparisons in ANP-10332P are not directly applicable to the revised AURORA-B LOCA evaluation model AREVA now proposes that would incorporate the UMAR16 version of S-RELAP5 and additional evaluation model changes (e.g., **[ ]**, etc.). Therefore, please provide the following information:

a. Please perform additional integral test comparisons using the UMAR16 version of S-RELAP5 to demonstrate the adequacy of this version of the S-RELAP5 code. In particular please (as necessary) perform and discuss in this response the validation of the UMAR16 code version against the following integral tests that were included in ANP-10332P: SSTF Tests EA3.1, Run 111 and SRT-3, Run 26; TLTA Tests 6425-2 and 6432-1; FIST 6DBA1-B, 6SB2C, 6LB1, and 4DBA1. Please confirm that the input decks used in these simulations are identical to those used for the USEP12 calculations presented in ANP-10332P (with the exception of any intended EM changes and corrections, such as those associated with the **[ ]**, etc.), or justify any deviations. Please justify in particular any cases for which the UMAR16 code version (1) does not conservatively predict the data or (2) results in a significant reduction in conservatism relative to the USEP12 calculation.

b. Please provide results for the demonstration case in Section 7.7.5 of ANP-10332P using the UMAR16 version of the S-RELAP5 code with the EM changes and corrections specified in part a., above.

c. During the audit, the NRC staff understood that a **[ ]** maximum time step of **[ ]** was used in cases run with the UMAR16 code version when **[ ]**. Please clarify the reason for this change, and, in light of the timestep sensitivities of **[ ]** discussed above in RAI 112, please clarify why this change in timestep is acceptable.

d. Please provide timestep sensitivity results (i.e., using the timesteps chosen in Section 7.9.3 of ANP-10332P) for the UMAR16 code version with the EM changes and corrections specified in part a., above.

RAI-127

Please explain the basis for the selection of **[ ]**, specifically addressing the following factors:

a. Are all important phenomena examined in the **[ ]**?

b. Are sufficient sensitivity calculations (e.g., timestep sensitivity) performed to demonstrate that unacceptable perturbations have not been introduced to the predicted results?

c. What is AREVA's basis for concluding that the **[ ]** are sufficient to provide a reasonable confirmation that **[ ]** code changes are acceptable or identify any errors that have been introduced into the code?