

ANP-10332P, Revision 0, “AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios”: U.S. Nuclear Regulatory Commission (NRC) Staff Post-Acceptance Review Feedback and Questions, AREVA’s Response Approach, and Subsequent NRC Staff Audit Comments

A set of 53 questions was prepared by the NRC staff to support an audit of the AURORA-B loss-of-coolant accident (LOCA) methodology. These questions were initially discussed with AREVA during a teleconference on November 1, 2016. During the AURORA-B LOCA audit on May 16-18, 2017, AREVA provided draft responses to the majority of the questions. Based on a brief review during the audit, the NRC staff provided feedback on AREVA’s draft responses. A summary of the technical interactions on each of the 53 issues is captured below.

Cyan coloring connotes that discussion of highlighted statement did not occur during the audit.

General Questions

1. Highlight major changes in the AURORA-B code since previous reviews, including those for S-RELAP5 and RODEX4.

AREVA Draft Response:

The following major changes were implemented to create S-RELAP5 version []:

- []
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The following major changes are implemented in []:

- []
- []

NRC Staff Audit Comments:

- (1) Issue RAI to document response.

- (2) Additional continuity of assessment documentation appears necessary to support any evaluation model (EM) changes that would affect the information presented in ANP-10332P. Revise question to capture concern.
 - (3) Further explanation necessary regarding significance of BWR LOCA method flag.
 - (4) Response should cover all major changes to the code, whether or not they are intended for BWR LOCA.
 - (5) Provide a detailed description and justification for any changes described in response that are not included in ANP-10332P, Revision 0.
2. Obtain input / output decks for relevant demonstration calculations with capability to plot desired parameters (e.g., BWR/4 limiting small break LOCA (SBLOCA) and large break LOCA (LBLOCA) scenarios, BWR/6 limiting LBLOCA scenario)

AREVA Draft Response:

[

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NRC Staff Audit Comments:

- (1) Because AREVA has implemented a number of EM revisions since submission of ANP-10332P, RAI questions requesting graphics files for revised demonstration cases may be issued.
 - (2) Obtaining break spectra for revised EM and comparing to those in ANP-10332, Revision 0, may help judge the need for additional demonstration-case graphics files.
 - (3) The most up-to-date versions of the user and theory manuals should be provided to the NRC staff. During the audit, staff found that Revision 3 of the user manual, which had been earlier provided by AREVA, was missing information regarding heat transfer regimes that the NRC staff needed to understand the output of the graphics files.
 - (4) If revisions are necessary, the NRC staff to select specific cases – confirm existing cases are sufficient or pick different ones.
3. **Identify the frozen code version associated with the TR.** Further, explain and justify code modeling option selections for each of the analyses performed in the TR. For example, in many cases (e.g., model validation) the analyses appear to use best-estimate code modeling options that are not consistent with the proposed Appendix K EM. Even in cases where demonstration analyses are performed, it appears that the Appendix K EM requirements are not fully activated. Thus, it is not clear in general what relevance the analyses in the TR have to the proposed Appendix K EM.

AREVA Draft Response:

Code validation against test data is performed to assess its capability to predict key phenomena. [

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- [
- [

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[

].

[

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NRC Staff Audit Comments:

- (1) NRC staff to either find evidence that Appendix K EM requirements are not fully activated in demonstration cases or revise the question.
- (2) RAI to document frozen code version for ANP-10332P, Revision 0. Any analyses

performed with a different code version should be identified and called out specifically. For cases where validation is based on earlier code versions, confirmation / basis should be provided that the updated code version would not substantially change the information presented in the TR.

(3) NRC staff to consider the approach of [

].

(4) Provide more details regarding which [

]. If possible, revise question to provide examples of key Appendix K items of interest.

4. Validation for non-impact of code changes on other AURORA-B EM applications.

AREVA Draft Response:

AREVA uses an automated [

]



NRC Staff Audit Comments:

- (1) More detail needed. AREVA should confirm in the response that the continuity assessments for the other methods are not adversely affected by the changes made to the BWR LOCA methodology.
 - (2) AREVA should identify whether any standards exist for determining that, when there is no impact expected from a change on one licensed method to other licensed methods, there is indeed no significant impact on other licensed methods.
 - (3) Discuss how quality assurance is performed on the automated COA calculations to ensure that errors are not introduced, and that if errors are introduced, they can be identified and corrected.
 - (4) Identify which of the validation and demonstration case runs are included in the continuity of assessment set for ANP-10332P, and provide justification.
5. Combined PIRT for SBLOCA and LBLOCA: what is method used to determine ranking in cases of disagreement between ranking for each event? Validation of PIRT results for small or intermediate break range?

AREVA Draft Response:

Small to intermediate breaks are validated by the FIST and TLTA assessments, GE level swell, THTF reflood, and by the range of reflood rates considered in FLECHT-SEASET.

NRC Staff Audit Comments:

Do not plan to issue as RAI question focusing on PIRT validation for small- or intermediate-break range. However, may pursue question to document basis for determining net ranking.

- 6. If parameters passed to a given model or correlation are outside of its qualified and validated range of applicability, is an error messages generated by the code, or does it continue to execute, producing potentially non-physical results?

AREVA Draft Response:

[

]

<u>Parameter</u>	<u>Range</u>
[]
[]
[]
[]
[]

NRC Staff Audit Comments:

- (1) NRC staff to revise question to quote directly from SRP 15.0.2. AREVA should be requested to demonstrate compliance with applicable guidance.
- (2) NRC staff may consider a [

].

- 7. Which phenomena in Table 4-1 are captured by each of the eight processes in Table 6-3? Are there highly ranked phenomena that are not associated with closure relations and are not included in Table 6-3?

AREVA Draft Response:

The highly ranked phenomena from PIRT Table 4-1 are shown below as sub-bullets under each of the eight bulleted processes from Tables 6-3 and 6-4. All highly ranked phenomena are associated with closure relations or included in Tables 6-3 or 6-4.

- []

• [○]]
• [○ []]

• [○]]
• [[]]

• [○]]
• [○ []]]
• [[]]]
• [[]]]

[

o

]

NRC Staff Audit Comments:

- (1) No comments provided during audit. Reviewed further post-audit.
- (2) Ask RAI to document response.
- (3) Looks like [] in the list?
- (4) Revise question to speak about Tables 6-3 and 6-4.

Analysis Implementation

8. Discuss implementation of method for plant-specific analysis:

- a. Determination of limiting initial conditions (e.g., steam dome pressure, core flow, feedwater flow and temperature, downcomer water level).

AREVA Draft Response:

[

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[

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NRC Staff Audit Comments:

- (1) AREVA should add basis for using nominal conditions for the parameters listed above.
- (2) [].
- (3) If further NRC staff review identifies specific questions on any of these particular items, NRC staff may revise the question.
 - b. What plant parameters have to be analyzed specifically to determine the operating conditions envelope described in Section 9.1.3 in the TR, such that the analysis can be considered valid and applicable?

AREVA Draft Response:

[

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NRC Staff Audit Comments:

Consider MELLLA+/EFW SEs – do other limits exist that need to be respected or are there other statepoints that need to be calculated? In certain past applications of this sort, there may be conditions and limitations for completing calculations on at least four statepoints (i.e., permutations of maximum and minimum powers and flows.)

- c. Which break locations must be considered in the analysis and to what extent?

AREVA Draft Response:

[

]. The extent of the break spectrum analysis is discussed in the response for Item g.

NRC Staff Audit Comments:

Response should supply additional details, particularly []. If these breaks should be included in plant submittals, or if they are certain to be bounded is a topic that should be addressed at the TR level if possible.

- d. Which single failures have to be considered for each break? It is likely that the limiting break and single failure have to be determined as a unit.

AREVA Draft Response:

[

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NRC Staff Audit Comments:

Agree. Document response with RAI.

Discuss [

].

AREVA Draft Response:

[

].

NRC Staff Audit Comments:

(1) NRC staff to consider differences [

].

(2) [

].

(3) [

].

- f. Discuss assumptions regarding offsite power, non-safety equipment, and operator actions.

AREVA Draft Response:

Loss of offsite power is assumed. Non-safety equipment and operator action are not credited during the LOCA event.

NRC Staff Audit Comments:

Agree. Document response with RAI.

- g. Discuss overall physical behavior inherent in the demonstration case break spectra and required resolution for plant-specific analysis.

AREVA Draft Response:

An abbreviated matrix of break sizes, similar those in Table 7-37, are analyzed for each single failure in a plant-specific analysis to determine the limiting single failure.

[

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- [

- [

- [

- [

]

NRC Staff Audit Comments:

(1) [

(2) [

(3) [

(4) [

9. (Page 3-3) Credit for analysis results that do not achieve quenching, versus addressing code runtime issues or errors that prevent completion.

AREVA Draft Response:

[

].

NRC Staff Audit Comments:

[

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10. (Page 3-3) Terminating analysis when hot rod quenches: How is it known, if other rods have not yet quenched, that they could not be the hot rod?

AREVA Draft Response:

[

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NRC Staff Audit Comments:

As noted in discussion above, in general, analyses may be terminated when the hot rod and any other potentially limiting rods have quenched. [

].

11. Where are plant-specific analysis requirements specified? Are modeling practices shown in the demonstration runs optional or required for plant-specific analysis, e.g.,:

- a. No credit for ECCS flow until rated pump speed is achieved.
- b. No credit for high drywell pressure signal with initiating ECCS actuation.
- c. Modeling practices for various components including ECCS and SRVs.

AREVA Draft Response:

[

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NRC Staff Audit Comments:

The NRC staff suggested that AREVA provide the modeling guidelines for information or provide an additional document that summarizes key points from the modeling guidelines. AREVA agreed during the audit to submit the modeling guidelines for information. The NRC staff agreed during the audit that there is no expectation that AREVA maintain all aspects of the modeling guidelines constant in the future. A substantial part of the information described in the modeling guidelines resides at a lower level of detail than is typically specified in TRs that describe the acceptable EMs; hence, revisions to modeling guideline information does not in general require prior NRC approval. [

].

12. For typical BWR/3-4 ECCS design, how much of LPCI flow injected into broken loop can enter the vessel for recirculation system discharge line breaks that are not DEG? If credit is taken, then please describe the modeling used and provide adequate basis.

AREVA Draft Response:

[

]

NRC Staff Audit Comments:

The NRC staff agrees with response as written, noting that [

].

13. What is meant by "Opposite unit false LOCA signal?" What ESF equipment is available in this event and in what situations can this be the limiting single failure?

NRC Staff Audit Comments:

RAI not expected.

14. How are pre-event oxidation values determined, and is this considered to be part of the *AURORA-B methodology*?

NRC Staff Audit Comments:

RAI expected to document response.

15. How are complete axial power profiles generated and verified for plant-specific analysis?
Can two profiles (mid-peaked and upper-peaked) bound all possibilities? Plant-specific sensitivities may be necessary.

AREVA Draft Response:

The axial power profile is modeled [



[

bottom half.

]. Axial offset is the ratio of the power in the top half of the core to the



Two changes will be made to establish power distributions:

- [

].

- [

].

[

].

NRC Staff Audit Comments:

(1) The NRC staff questioned whether two axial profiles [

].

[

].

16. Please clarify the treatment of LHGR, decay heat, and stored energy, and explain why it is conservative in an overall sense.

NRC Staff Audit Comments:

RAI likely to document response.

17. As shown in Figure 6-2, why is it conservative to model non-limiting rods as having maximum stored energy (as opposed to maximum decay heat) or other parameter?

NRC Staff Audit Comments:

Not expected to become an RAI / combine with previous question.

(As discussed during audit, AREVA to correct Figure 6-2 in the revised version of ANP-10332P.)

18. Discussion of potential for changing nodalization and modeling practices (e.g., Page 6-28). These features should be prescribed based on maintaining consistency with the selections used in performing the code validation and in the NRC staff's review thereof.

AREVA Draft Response:

[

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NRC Staff Audit Comments:

The NRC staff agrees with response and notes that it represents a modification to the discussion in Revision 0 of the TR that should be addressed in Revision 1. The modeling guidelines used to generate future plant licensing submittals should be consistent with the modeling guidelines used to generate the validation and benchmarking analyses.

19. Split breaks have been calculated [

].

AREVA Draft Response:

[

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NRC Staff Audit Comments:

(1) The question will be revised to reflect Appendix K position.

(2) There is a significant difference [

].

20. Why are no numerical results presented for some of the break sizes in the break spectra presented? For example consider the [

].

AREVA Draft Response:

[

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NRC Staff Audit Comments:

RAI expected to document response.

21. Please explain and clarify statement on page 6-15, for both low- and high-pressure ECCS pumps:

[

]

AREVA Draft Response:

[

]

NRC Staff Audit Comments:

No RAI expected. The information was clarified in the audit. The reactor pressure is calculated by the code, whereas [

].

22. Please clarify what is meant by statement on page 4-3 of TR that

[

]

How would AREVA determine whether a licensing basis has significantly departed from the SRP bases? Provide relevant examples. What if a departure occurs?

AREVA Draft Response:

[

]

NRC Staff Audit Comments:

Expect RAI to document response.

23. How are the limiting accident scenarios identified for maximum local oxidation and for core-wide oxidation? Is it assumed to be the same scenario as produced the limiting PCT, or are other conditions considered, since the set of limiting conditions for PCT do not necessarily lead to the limiting values for the other parameters?

AREVA Draft Response:

[

]

NRC Staff Audit Comments:

AREVA to add detailed justification concerning why [

]. NRC staff may augment question.

24. Discuss process for determination of converged steady-state initial conditions prior to entering transient calculation, both with respect to RODEX4 and S-RELAP5. Discuss performing calculations over time in life.

AREVA Draft Response:

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]

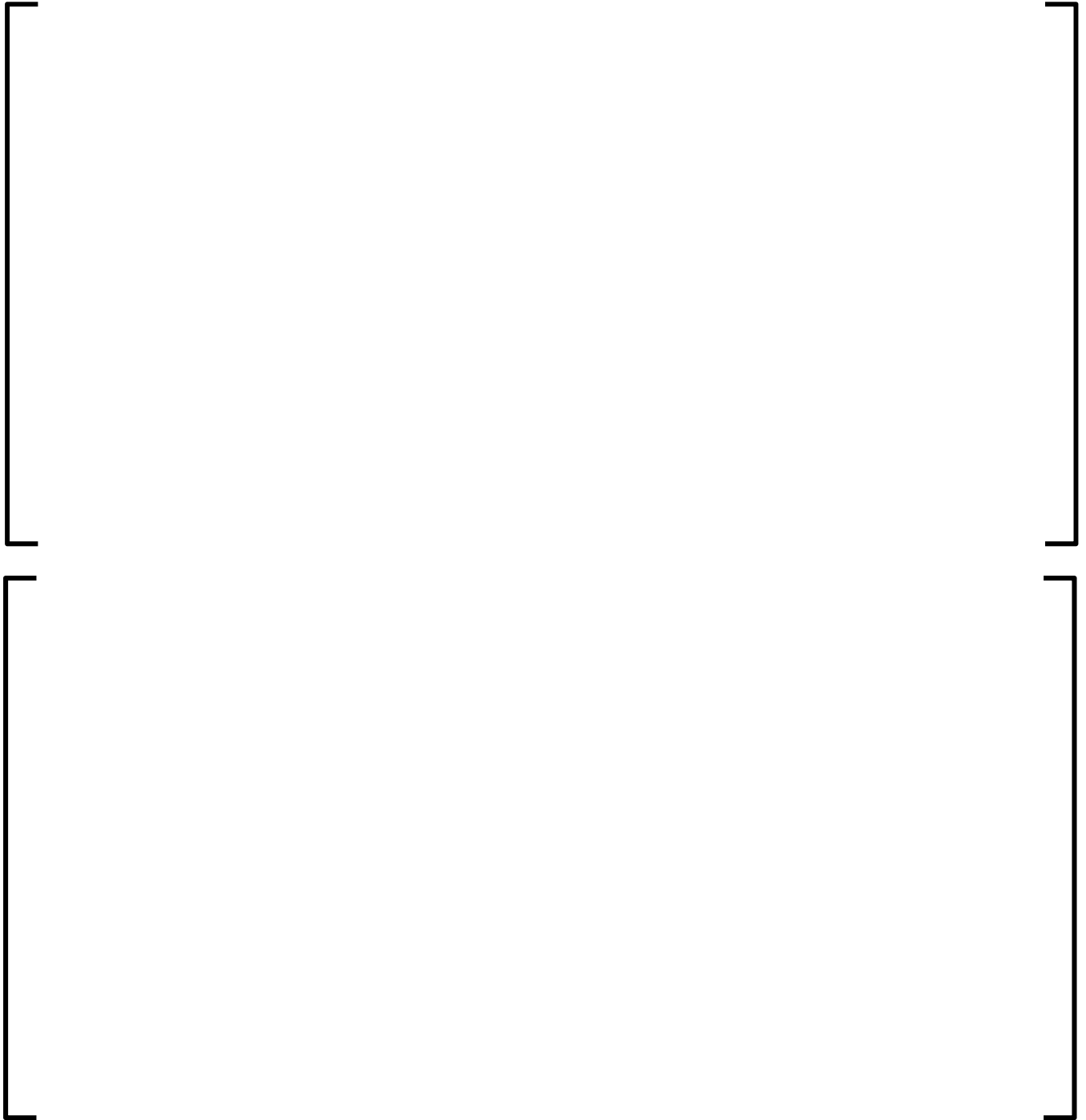
NRC Staff Audit Comments:

(1) Clarify what is meant by “The [] is re-run....” For example, []?
[]
[]
[]

25. Demonstration cases for the BWR/6 ECCS configuration with top-peaked power profile appear important for understanding axial peaking impact for this ECCS configuration.

AREVA Draft Response:

Demonstration cases for the BWR/6 with a top-peaked axial were executed and follow:





NRC Staff Audit Comments:

- (1) RAI expected to document response.
- (2) RAI to explain the [].

26. Is thermal expansion considered in modeling the plant geometry?

NRC Staff Audit Comments:

RAI not expected.

Fuel Channel Grouping / Channel Flow Regime

NRC Staff Audit Comments:

For the questions covering [] behavior (i.e., Questions 27-33), the NRC staff made a number of general comments during the audit, rather than concentrating on each individually:

- (1) NRC will attempt to consolidate this set of questions based on audit discussions.
- (2) AREVA should consider performing additional sensitivity studies, which may be larger in scope than discussed by AREVA during the audit. In particular, the NRC staff wished to confirm that the nodalization selected by AREVA for plant-specific simulations is stable and not subject to user-effects. AREVA concluded based on []

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- []

- []

[]

- []

(3) AREVA suggested that a sensitivity study using a []

(4) []

(5) []
[]

(7) []
(8) []

(9) []

]

27. Fuel channel grouping / nodalization. Discuss why the [] expected during a LOCA.

AREVA Draft Response:

A key consideration is the ability for the nodalization to simulate the []

[]. The results are documented in Section 7.9.6.2.

The core nodalization in the SSTF assessment presented in Section 7.7.1.2 included []

[]. The bundle groupings in these cases were summarized in Table 7-61.

Results of these parametric studies concluded that:

- []
- []

].

- [

].

- [

].

28. Discuss assumptions for core spray distribution and basis for modeling of core spray entering hot bundle (e.g., including maldistribution factors, CCFL, steam upflow / interfacial drag, upper plenum conditions, ECCS configuration) and how this may impact the flow regime that a bundle enters.

AREVA Draft Response:

Section 6.4.7 describes the [

].

29. [

].

AREVA Draft Response:

[

- [
- [
- [

]

]

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- []
- []
- []

[]:

- []
- []

30. Clarify the intent / significance of [] results predicted by the EM.

AREVA Draft Response:

[]

]:

[]

Recent, pre-qualified automation cases were used to assess the impact of the [] for BWR/3, BWR/4 and BWR/6 plants. []

].

[]]. It adds significant conservatism beyond and not required by Appendix K.

31. NRC staff seeks to understand which channels are in different flow modes for one or more demonstration cases.

AREVA Draft Response:

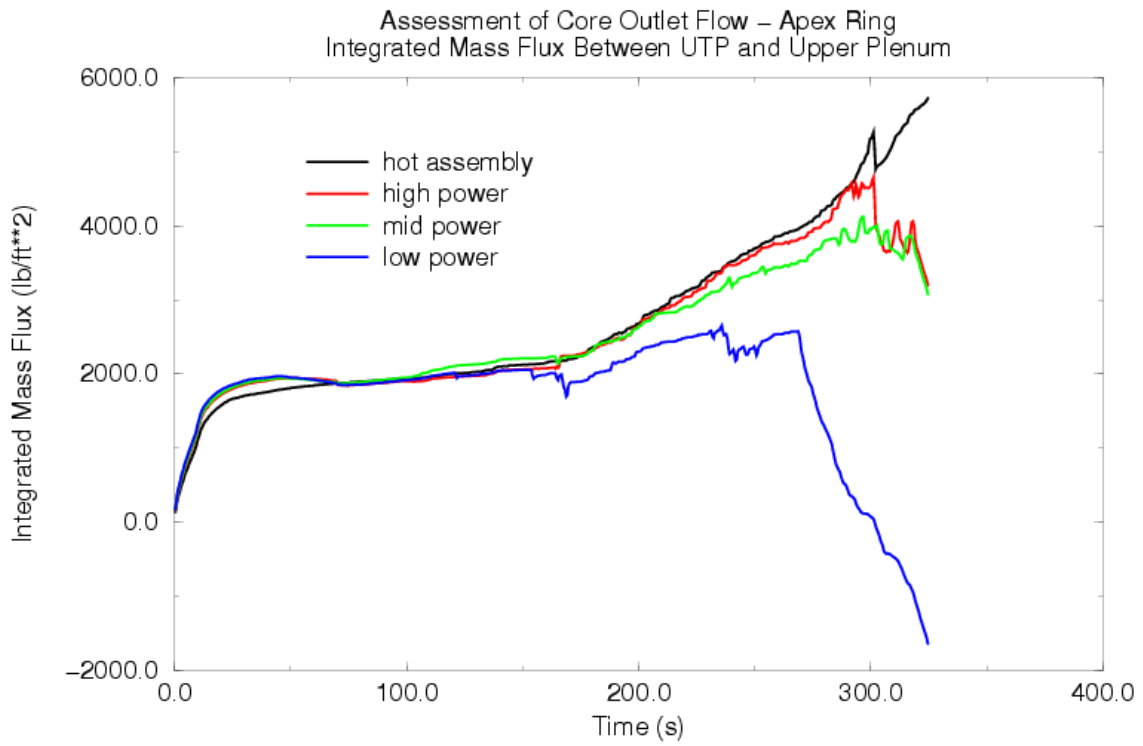
Results from BWR/6 large break demonstration case from Section 7.7.6 (1.0 DEG, Pump Suction, SF-LPCS, mid-peaked) are plotted below showing the integrated mass fluxes at the exit of each core channel. [

]. The first three figures show the integrated total, liquid and vapor mass flux for the [

].

[

].



[

]

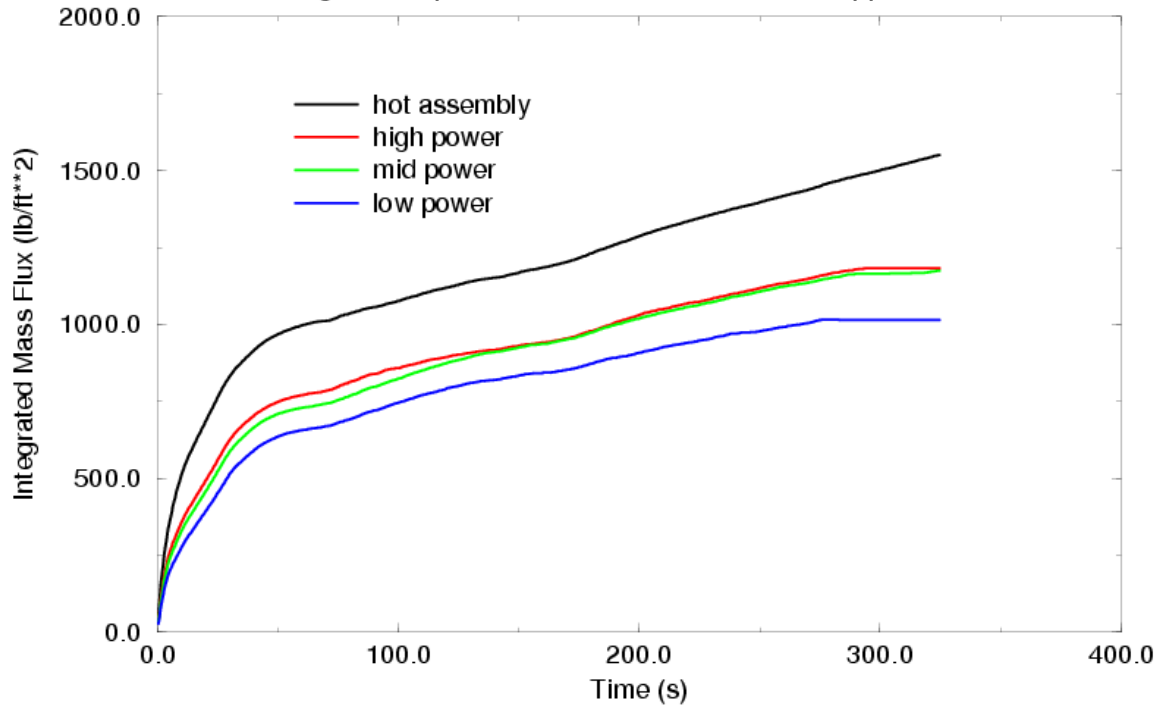
[

]

[]

[]

Assessment of Core Outlet Flow – Middle Ring
Integrated Vapor Mass Flux Between UTP and Upper Plenum



32. In cases where the [], then justification is necessary to demonstrate that this prediction is justified. Sensitivity studies may help define transition boundary between channel flow regimes.

AREVA Draft Response:

[

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33. Page 6-87: Is [] during the demonstration cases and other assessment comparison cases?

AREVA Draft Response:

[

]

Boiling Curve

34. [

]

a. [] Discuss practical importance, use a demonstration case if applicable.

AREVA Draft Response:

[

]

NRC Staff Audit Comments:

(1) [

- a. [
- b. [

]

]

- c. [

]

(2) [

]

(3) [

]

(4) [

]

35. Some correction factors for Groeneveld CHF lookup table data appear to have fuel-design-specific aspects. Is this correct, and how are these factors applied?

NRC Staff Audit Comments:

Likely to become an RAI.

36. Use of MMK correlation, considering its validated pressure range relative to the pressures experienced in BWR LOCA event at the time it would be used.

NRC Staff Audit Comments:

No RAI expected.

37. [

] What is the most applicable for spectrum of BWR LOCA events?

AREVA Draft Response:

[

]

NRC Staff Audit Comments:

RAI may be issued to document response.

38. [

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AREVA Draft Response:

[

]

[

NRC Staff Audit Comments:

RAI expected to document response.

39. Due to the expected importance of the LBLOCA scenario, AREVA should provide an additional, zoomed-in plot to supplement the information in Figure 6-20. Specifically, the additional plot should [] for considering the typical BWR LBLOCA event.

AREVA Draft Response:

The following plot shows Figure 6-20 zoomed-in to a pressure range more typical of a BWR LBLOCA event and the temperature range of the data:



NRC Staff Audit Comments:

RAI expected. Question likely to be modified to request that AREVA address the reason for the different behavior seen in the two datasets. The [], is all below it. Appears non-random. Why?

Various Modeling Questions

40. Basis for determining CCFL based on [] (Page 6-86).

NRC Staff Audit Comments:

Likely an RAI and/or L&C if included in Rev. 1 of TR.

41. One BWR/3 plant, to which this methodology may be applied, has isolation condensers. Please either (1) confirm method will not model isolation condensers or (2) provide appropriate modeling of isolation condenser, including sufficient validation.

AREVA Draft Response:

The method will not model isolation condensers.

NRC Staff Audit Comments:

RAI not expected.

42. Discuss []. Discuss basis and past regulatory history with these assumptions. Is the assumption of []?

AREVA Draft Response:

[

]

[

]

[

]

NRC Staff Audit Comments:

[

] for determining the limiting conditions for 10 CFR 50.46?

43. Many test facilities referenced in validation matrix are associated with PWRs. PWR tests may be less suitable for code validation for BWR LOCA. For instance, BWR-FLECHT tests were run. Other test facilities may be more relevant to BWR LOCA than CCTF. For these and some other tests (both SET and IET), more rationale may be necessary as to why the results scale directly from PWR to BWR condition.

AREVA Draft Response:

[

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NRC Staff Audit Comments:

RAI expected to document response.

44. Which specific bypass leakage paths (e.g., between bypass region, fuel bundle, lower plenum, guide tubes) are explicitly modeled in the AURORA-B model? What are the characteristics of the flowpaths?

AREVA Draft Response:

[

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NRC Staff Audit Comments:

- (1) Describe the method for determining characteristics of all leakage paths (e.g., measurements, calculations, etc.), especially for the fit-up gaps, which are more difficult to determine analytically in an accurate manner.
 - (2) Which of the leakage paths are the most significant? Provide an idea of importance. (e.g., flow area, leakage rate during normal operation).
 - (3) Describe in more detail the [] and how the impact is derived.
45. Figure A-2 of TR shows the BWR/5-6 typical ECCS design with the recirculation pump discharge shutoff valve closed. Is this post-LOCA configuration typical for this reactor design?

NRC Staff Audit Comments:

RAI not expected.

46. Use of new or revised models not described in existing TR is viewed by NRC staff as a change to EM, requiring a revised or supplementary TR review. Discuss intent regarding change process for LOCA EM and planned TR revisions, if any.

AREVA Draft Response:

[

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NRC Staff Audit Comments:

Revise question. Draft response doesn't address the fundamental issue. [

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47. What is the full suite of validation analysis that must be re-performed when updates are made to the AURORA-B code system? Does the validation suite contain suitable analyses for all AURORA-B EM applications? Do AURORA-B test problems exist that verify that RODEX kernel in AURORA-B behaves same as stand-alone code?

AREVA Draft Response:

[

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NRC Staff Audit Comments:

RAI expected to document response. The list provided here is for future updates. For supporting Rev. 1 of the TR, a more complete suite of validation results may be necessary.

48. Understand future directions and plans with possible impact of 50.46(c), should proposed rule be finalized. Not clear it is as simple as discussed on page 4-4. (e.g., consider possible links to other items, including Questions 8, 9, 10, 23.) More justification may be necessary to [

]

AREVA Draft Response:

AREVA plans to only address the portion of the draft 50.46(c) rule that applies to the LOCA calculation. Two items will be implemented in S-RELAP5 using a code option flag to be used when and if those 50.46(c) items are approved:

- []
- []

NRC Staff Audit Comments:

- (1) NRC to discuss internally
- (2) AREVA should provide a more detailed response, since compliance with the new rule does not appear to be as simple as portrayed in the response
- (3) Potential schedule impact of assessing compliance to new regulation

49. For BWR/3 through BWR/6 plants, []

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AREVA Draft Response:

The S-RELAP5 model [] and, if it occurs, its impact on all aspects of the calculation.

NRC Staff Audit Comments:

- (1) Additional description should be provided, for instance, that the []
- (2) Discussion of this phenomenon does not appear to be in PIRT. A statement should be provided as to whether this phenomenon is viewed as being of importance in any of the calculations AREVA has completed to date with the AURORA-B LOCA EM, relative to the []
- (3) A statement should be made concerning whether the non-condensable modeling has been validated or benchmarked (e.g., non-condensable flow / systemwide distribution, impacts on coolant flows, impacts on heat transfer and condensation), or whether such activities are not necessary (with justification).

50. The discussion in Section 5.6 of TR is not sufficiently clear. How is experimental uncertainty handled in general – if not explicitly discussed is it neglected?

AREVA Draft Response:

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[

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- [
- [

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NRC Staff Audit Comments:

Likely to revise question and issue RAI. Need to focus the question more explicitly on models that are not explicitly approved as a part of Appendix K.

51. Discuss practice of [] in code validations simulations, as opposed to defining a process for modeling these phenomena and allowing EM to predict the behavior organically. [] gauging of overall EM accuracy.

AREVA Draft Response:

[

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NRC Staff Audit Comments:

AREVA should describe and justify actual process used for determining the loss coefficients for ADS valves in both benchmarking simulations and future plant-specific calculations.

52. On page 7-340, TR states that [REDACTED]]?

NRC Staff Audit Comments:

RAI expected to document response.

53. How does proposed AURORA-B EM compare to the existing approved EM for BWR LOCA?
Is there a comparison case that exists to show results for same or similar relevant scenario?

AREVA Draft Response:

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NRC Staff Audit Comments:

Add LBLOCA comparison case if available.

Additional NRC Staff Audit Comments

1. []
2. []
3. []
4. []
5. []
6. []
7. []